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2. The classification of mineral and rock specimens. Besides identifying rocks and giving the composition of minerals, the Bureau makes qualitative tests for important elements and answers inquiries concerning the probable market for and economic value of material similar to samples submitted. This service is furnished free of charge providing the specimens originate within the State of Arizona; a charge of $1 per specimen is made for samples submitted from outside the State. When assays, quantitative chemical analysis, spectographic analyses, microscopic or thin sections are desired, they are furnished at rates established by law, a schedule of which will be submitted on request.

(Continued on inside back cover)

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ARIZONA BUREAU OF MINES

MINERALS AND METALS OF INCREASING INTEREST

RARE AND RADIOACTIVE MINERALS

By Richard T. Moore

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INTRODUCTION

ACKNOWLEDGMENTS

This bulletin was prepared to give the prospector a knowledge of the general features of some of the metals and their minerals which have become increasingly important in the past few years. It supersedes Arizona Bureau of Mines Circular No. 13 "RADIOACTIVE URANIUM AND THORIUM" by J. W. Anthony and includes several metals which were not covered in Circular No. 13.

The author wishes to express his appreciation to Dr. Eldred D. Wilson of the Arizona Bureau of Mines for his helpful criticism during the preparation of the manuscript and for his aid in supplying information for the sections on Arizona occurrences. Grateful acknowledgment is also given Mr. George Roseveare of the Arizona Bureau of Mines for his assistance in gathering data on the uses of the various metals described.

GENERAL FEATURES

In the past decade, military and economic pressures have greatly accelerated research in the field of physical metallurgy. As a result, many uses have been found for elements which hitherto were considered laboratory curiosities, and now some of these minor metals are of strategic importance. This newly-created demand has prompted the extractive metallurgist to devise methods of recovering these elements and to determine which raw materials are the best sources. In some cases the prospector finds deposits which, because of size or some other favorable factors, may encourage the chemist and metallurgist to work out new recovery and refining methods, although the usual role of the prospector is to search for deposits of material already in demand. In any event, the prospector should know what substances to seek, some of the important characteristics of those substances, how they occur geologically, and what tests can be used to determine their presence.

The lack of uses developed for the strategic minor metals until recently is a direct reflection of the rarity of known important deposits of these metals. If relatively large, rich deposits of them had been known in the past, there is little doubt that the metals would long since have been put to use. Another factor which delayed the utilization of the strategic minor metals is the difficulty with which many of them are separated from their impurities. The difficulty of separation gives rise to another problem as far as the prospector is concerned; that is, the identification or testing for these metals. With the exception of two or three of them, there are no satisfactory field tests that can be used. Most of the strategic minor metals occur in very minor concentrations and bear marked chemical similarity to other, more abundant elements; hence their detection by chemical methods

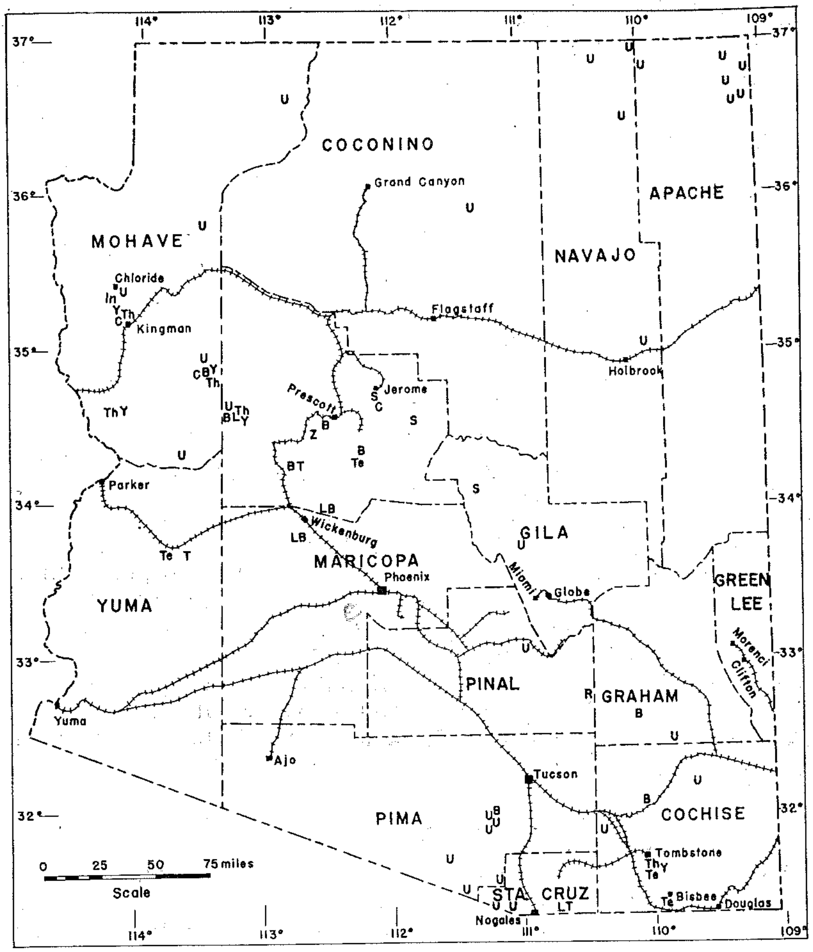

Figure 1.—Index map showing reported occurrences of rare and radioactive ore minerals in Arizona.

B	Beryllium	T	Titanium
C	Columbium and Tantalum	Te	Tellurium
In	Indium	Th	Thorium
L	Lithium	U	Uranium
R	Rhenium	Y	Rare-earths
S	Selenium	Z	Zirconium

necessarily involves the use of elaborate, time-consuming and expensive laboratory procedures.

Considerable work has been done on another laboratory method, spectroscopic examination.

When an element is burned in an electric arc or placed in a high-voltage spark it emits light of various wave lengths characteristic of the particular element. By observing the arc or spark with a spectroscope it is possible to measure the wave length of the various colors emitted and thereby determine the element. The minor metals exhibit this property but to a lesser degree than many other elements. The Arizona Bureau of Mines is at present negotiating for the purchase of the equipment required for this type of identification. Until the equipment can be obtained and put into use, the Arizona Bureau of Mines has no facilities for making a complete qualitative determination of the minor metals that may be present in a sample.

BERYLLIUM

GENERAL FEATURES

Beryllium was discovered in 1797. The metal is dark gray and almost as hard as quartz, but very light in weight, only about 60 per cent as heavy as aluminum. As a conductor of electricity it is very good, better even than copper. Beryllium ranks forty-first in abundance in the earth's crust.

Beryllium finds its most important application as an alloying material with copper and nickel. Alloys containing 98 per cent copper and 2 per cent beryllium, when quick-chilled, are easily worked and can be shaped into many forms. The objects made in this fashion can then be heated to 725 degrees Fahrenheit (400 degrees Centigrade) and cooled slowly under controlled conditions to give them hardness and toughness equivalent to the best steels. Such an alloy is now replacing steel in certain aircraft engine valve springs. In addition to strength and hardness, these alloys have very good corrosion-resisting properties. Copper-beryllium alloys also are used extensively for tools employed in the vicinity of explosive vapor, because they do not throw off sparks of hot metal when struck, as do steel tools.

Another commercial application of beryllium is the use of its oxide in refractory bricks.

BERYLLIUM MINERALS

Beryllium does not occur as a native metal. Only one of its minerals, beryl, is presently considered commercial. Three minerals of potential use are phenacite, gadolinite, and helvite. If large deposits of these three minerals could be found there is little doubt they would have commercial value.

Beryl is a beryllium aluminum silicate containing from 8 to 14 per cent beryllium oxide (BeO). Crystalline or massive; crystals resemble those of quartz. Generally green or blue but also white, gray, yellow, or rose. Streak white, hardness 7.5 to 8, specific gravity 2.6 to 2.8. Luster vitreous to resinous. Fracture uneven to conchoidal, imperfect prismatic cleavage. Emerald and aquamarine are gem varieties of beryl.

Phenacite, a beryllium silicate, contains from 40 to 45 per cent Be0. Generally as rhombohedral crystals. Yellow, rose-red, brown, colorless. Hardness 7.5 to 8.0, specific gravity 2.9 to 3.0. Luster vitreous, fracture conchoidal.

Gadolinite is a beryllium iron rare-earth silicate containing from 6 to 12 per cent Be0. Prismatic crystals, massive. Black, greenish-black, brown. Brittle, hardness 6.5 to 7.0, specific gravity 4.0 to 4.5. Greasy to vitreous luster. Conchoidal fracture, no cleavage.

Helvite, a manganese iron beryllium silicate-manganese sulfide, contains from 2 to 7 per cent Be0. Crystals or round grains. Hardness 6 to 6.5, brittle, specific gravity 3.1 to 3.36. Yellow, yellowish brown, reddish brown. Luster vitreous, streak uncolored.

OCCURRENCE

Beryl, phenacite, gadolinite, and helvite are found principally in the complex granitic pegmatites. Beryl and phenacite are also found in druses[1] in granite associated with topaz, microcline, adularia, and quartz. Beryl has been found in some tin ores. Gadolinite usually occurs associated with allanite and other rare earth minerals and with flourine minerals common to pegmatites. Helvite occurs in quartz veins and in gneisses.

Ninety per cent of the United States' supply of beryl concentrates is imported; South Africa is one of the chief sources. In the United States the important producers of beryl have been Maine, New Hampshire, and Massachusetts in the northeast, South Dakota in the north, and Colorado and New Mexico in the west. Minor production has come from Arizona.

In Arizona, beryl has been reported from deposits in the northwestern part of the Sierrita Mountains, Pima County; Bradshaw Mountains near Crown King, Yavapai County; Eureka District, near Bagdad, Yavapai County; White Picacho Pegmatite District, Yavapai and Maricopa counties; Little Dragoon Mountains, Cochise County, in tungsten veins; Weaver District, Yavapai County asscoiated with mica; and in the western foothills of the Graham or Pinalino Mountains, Graham County.

Gadolinite has been mined for its rare-earth content from pegmatite deposits in the Aquarius Range about 30 miles south of Hackberry, Mohave County.

PRICES AND POSSIBLE BUYERS

Beryllium ores containing 10 to 12 per cent beryllium oxide (Be0) were quoted at $46 per unit[2] of Be0, f.o.b. Colorado mines, at the close of 1953. The General Services Administration (G.S.A.) prices at the depots in New Hampshire, North Carolina and South Dakota, for lots up to 25 tons per year were: 8 to 8.9 per cent Be0, $40 per unit; 9 to 9.9 per cent Be0, $45 per unit; 10 per cent or more, $50 per unit Be0.

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[1] Druses or vugs are crystalline crusts lining the walls of a cavity.

[2] A unit is 1 per cent of a short ton (unless otherwise indicated) and therefore equals 20 pounds. For example if the ore contains 10 per cent BeO and is quoted at $46 per unit, its value exclusive of penalties is 10 multiplied by $46 or $460 per ton.

The following companies have been users of beryllium ores:

American Brass Company, Waterbury, Conn.
Beryllium Products, Co., Temple, Penna.
Brush Beryllium Co., 3714 Chester Ave., Cleveland, Ohio
Champion Spark Plug Co. (Ceramic Division), Detroit, Mich.
Clifton Products, Inc., Painesville, Ohio
E. I. du Pont de Nemours and Co., Inc., 11th and Orange Sts., Wilmington, Del.
Foote Mineral Co., Inc., 1609 Summer St., Philadelphia, Penna.
A. D. Mackay, 198 Broadway, New York City, N. Y.

LITHIUM

GENERAL FEATURES

Lithium is the lightest of metals with a specific gravity of 0.53. Silvery-white. Very soft, ductile. Melting point 354.2 degrees F (179 degrees C). The metal is very easily corroded, even reacting with distilled water, and hence is commonly stored in kerosene for protection from the atmosphere. Lithium ranks thirty-eighth in abundance in the earth's crust.

The highly reactive nature of lithium is the main deterrent to its use as a metal. Its extreme lightness and ease of working would make it very desirable for structural purposes, and it very probably could be alloyed with other metals to give it strength. Until satisfactory methods of surface treating are perfected to protect it from corrosion, however, its use as a structural metal is not possible.

The principal uses of lithium are as compounds. Lithium greases are good lubricants at temperatures down to 60 degrees below zero Fahrenheit and consequently are well adapted for conditions in the Arctic. Lithium chloride serves to control humidity in air-conditioning units, and the oxide is employed in ceramics. Other lithium compounds are used in pharmaceuticals, storage batteries, flares, and helium purification.

LITHIUM MINERALS

The principal lithium minerals of commercial importance are amblygonite, spodumene, and lepidolite. Triphylite and zinnwaldite are of secondary importance.

Amblygonite is a lithium aluminum fluo-phosphate containing 8 to 9 per cent lithium oxide ($Li_2$0). It occurs as crystals ranging from white to pale shades of green, blue, yellow, or brown. Hardness 6, specific gravity 3 to 3.1. White streak. Brittle, uneven to subconchoidal fracture, good cleavage. Some amblygonite, particularly if white or gray, closely resembles plagioclase feldspar, and some varieties display a multiple twinning similar to that found in plagioclase feldspar.

Spodumene is a lithium aluminum silicate containing 4 to 8 per cent lithium oxide. Prismatic crystals or massive. Grayish-white to various shades of yellow, green, and purple. Streak uncolored. Hardness 6.5 to 7, specific gravity 3.1 to 3.2. It has one perfect cleavage, commonly splitting into thin plates, and an uneven to subconchoidal fracture. Kunzite and Hiddenite are clear, colored varieties used as gem stones.

Lepidolite is a potassium lithium aluminum fluo-silicate containing 2 to 4 per cent lithium oxide. It is a true mica very closely resembling muscovite, the common white mica. Violet, yellow, green, rose-red and grayish white. Hardness 2.5 to 4.0, specific gravity 2.8 to 3.3.

Triphylite is a lithium iron phosphate containing 2 to 6 per cent lithium oxide. Commonly massive. Gray, blue, pink, yellow, and brown. Hardness 4.5 to 5, specific gravity 3.4 to 3.6. Fracture uneven to subconchoidal, two good cleavages.

Zinnwaldite, a lithium iron mica, contains 2 to 3 per cent lithium oxide. Dark gray, pale violet, yellow and brown. In appearance similar to lepidolite.

The lithium minerals can be distinguished from feldspar and from other micas, which they most closely resemble, by their fusibility. When small slivers or flakes of the lithium minerals are held in the flame of an alcohol lamp they fuse to a milky-white enamel or glass, whereas feldspar and the non-lithium micas will not fuse at such a low temperature. A second indication of lithium is the purplish-red color imparted to the flame at the instant the lithium mineral fuses. Discretion should be used in the flame test, however, as both calcium and strontium give very similar flame colors.

OCCURRENCE

Lithium minerals, like beryllium minerals, are most commonly found in complex granitic pegmatites.

In the United States, the New England beryl deposits have yielded also lithium minerals. The most important producing areas, however, are the Kings Mountain district in North Carolina and the Black Hills area of South Dakota. In the Etta mine at Keystone, South Dakota, huge crystals of spodumene weighing many tons have been found.

In Arizona lithium minerals have been mined from pegmatites on San Domingo Wash, northeast of Morristown, Maricopa County. These deposits are described in Arizona Bureau of Mines Bulletin No. 162, by R. H. Jahns. Zinnwaldite has been reported from the Duquesne area of Santa Cruz County, and lepidolite occurs in the Bagdad area of Yavapai County.

PRICES AND POSSIBLE BUYERS

Recent prices quoted for lithium mineral concentrates are: spodumene, \$5 to \$8 per unit of contained lithium oxide (Li_20); lepidolite, with about 4 per cent Li_20 \$20 to \$80 per ton; amblygonite, about \$60 per ton.

The following companies have purchased lithium concentrates:

Associated Metals and Minerals Corp., 40 Rector St., New York, N. Y.
Consolidated Feldspar Corp., Trenton, New Jersey
Corning Glass Works, Corning, New York
Foote Mineral Co., 16th and Summer Streets, Philadelphia, Pa.
Harshaw Chemical Co., 1945 E. 97th St., Cleveland, Ohio
Maywood Chemical Co., Maywood, New Jersey
Metalloy Corp. (subsidiary of Lithium Corp. of America), Minneapolis, Minn.
Metal Hydrides, Inc., Beverly, Mass.
R. T. Vanderbilt Co., 230 Park Ave., New York, N. Y.
Varlacoid Chemical Co., 116 Broad St., New York, N. Y.

CESIUM AND RUBIDIUM

GENERAL FEATURES

Cesium and rubidium are silvery-white, light-weight metals, resembling lithium in their physical and chemical properties. Both belong to the family of alkali metals.

Rubidium ranks sixteenth in abundance in the earth's crust. Specific gravity 1.53. Melting point 102.2 degrees F (39.0 degrees C), boiling point 1,254 degrees F (679 degrees C). Hardness about that of beeswax.

Cesium ranks thirty-seventh in abundance in the earth's crust. Density 1.90. Melting point 83.8 degrees F (28.4 degrees C), boiling point 1,274 degrees F (690 degrees C). Softer than beeswax.

Both metals, like lithium, are very reactive and must be kept out of contact with air and water to be preserved.

Although cesium and rubidium are not in great demand, a few applications have been developed for them. Cesium is being used in vapor lamps for infra-red signaling and in vacuum tubes as a "getter" (a substance used to clean up residual gases). Cesium-137, an artificial radioactive isotope[3] shows promise as a source of radiation for medical purposes. Both metals are used as targets in photoelectric cells and both are used as catalysts[4] in certain industrial chemical processes.

CESIUM AND RUBIDIUM MINERALS

Neither cesium nor rubidium occur as native elements, and the only known cesium mineral is pollucite. Although rubidium is more abundant than cesium it is not an essential constituent of any known mineral.

Pollucite is a cesium aluminum silicate containing from 20 to 36 per cent cesium oxide (Cs_2O) and up to 3 per cent rubidium oxide (Rb_20). As cubic crystals or massive. Colorless, hardness 6.5, specific gravity 2.9. Pollucite is the main source of cesium in the United States.

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[3] Isotopes are forms of an element, all identical chemically, but having slight differences in the mass of their atoms. When certain elements, as for example, cobalt and cesium, are exposed to radioactivity, such as by being placed in an atomic reactor (atomic pile), their atoms change slightly in mass, becoming unstable and therefore radioactive. These unstable atoms are called artificial radioactive isotopes.

[4] A catalyst is a substance which affects the rate of a chemical reaction and which may be recovered practically unchanged at the end of the reaction.

Cesium and rubidium occur as minor constituents in some varieties of **lepidolite** (page 10) and may constitute up to several per cent of some of the very white varieties of **beryl** (page 7). Lepidolite is the chief source of rubidium in the United States.

OCCURRENCE

Pollucite is found associated with lepidolite and beryl in the complex granitic pegmatites. The principal production in the United States comes from Maine and the Black Hills area of South Dakota.

PRICES AND PRODUCERS

The chemically pure metals, cesium and rubidium, were quoted in 1951 at $4 to $5 per gram, depending upon quality.

Producers of the metals and their compounds are listed as follows:

DeRewal International Rare Metals Co., Philadelphia, Penna.
Fairmount Chemical Co., Newark, N. J.
Foote Mineral Company, Philadelphia, Penna.
General Electric Company, Scotia, N. Y.
Harshaw Chemical Co., Cleveland, Ohio
A. D. Mackay, Inc., New York, N. Y.
Maywood Chemical Works, Maywood, N. J.

TITANIUM

GENERAL FEATURES

Titanium is a silver-white metal about three-fifths as heavy as iron and having very good strength characteristics. Its light weight and strength make it well adapted to aircraft construction, with the possibility of increasing the payload while decreasing the weight of the plane and yet maintaining the strength necessary for various parts. The military is well aware of the possibilities of titanium and has contributed greatly towards research in titanium production and fabrication. An idea of the intensive research undertaken can be gained by considering that in 1946 only a few pounds of titanium metal were produced, while in 1952 over 1,000 tons of the metal were made available. The aircraft industry, of course, is not the only potential user of titanium; it can be employed wherever light weight and strength are desirable, but the present cost of fabricated metal prohibits its economic use in any other field.

The price of titanium sponge, a refined product, was $5 per pound in 1950. This cost in itself is not prohibitive, but fabrication of the metal into usable shapes is expensive. For example, a particular airframe part made of alloy steel may cost approximately $70 as compared with more than $1,000 for the same part made of titanium alloy.

Although titanium metallurgy has been the subject of extensive research, many problems in that field await solution. Titanium as a metal accounts for only a small part of the total consumption of the raw material. Titanium oxide, for pigment in paints, accounted for 99 per cent of the ilmenite used in 1950.

TITANIUM MINERALS

The principal minerals of titanium are rutile, ilmenite, and sphene.

Rutile, the oxide of titanium, ranges from 41 to 99 per cent in pure $Ti0_2$ content. Occurs as well formed prismatic crystals, long in one dimension and square in cross-section; also massive. Hardness 6.0 to 6.5, specific gravity 4.2. Commonly reddish-brown, also red, blue, violet, black and yellow. Brittle, fracture conchoidal to uneven, one good cleavage. Streak pale brown.

Ilmenite, an iron titanium oxide, contains from 48 to 52 per cent TiO_2. Tabular crystals; also compact, massive. Hardness 5.6, specific gravity 4.5 to 5.0. Luster submetallic, color iron black, streak submetallic. Very slightly magnetic.

Sphene is a calcium titanium silicate containing up to 40 per cent titanium oxide. Flattened to prismatic crystals, also massive. Hardness 5 to 5.5, specific gravity 3.4 to 3.6. Brown, gray, yellow, black. Streak white. Luster resinous to adamantine. Fracture subconchoidal, one fair cleavage.

OCCURRENCE

Ilmenite is a common accessory mineral in many igneous rocks, commonly taking the place of magnetite. It occurs as massive veins and segregations associated with the borders of igneous intrusives. Large deposits are found in the Adirondack Mountains of New York and in the Grenville series in Quebec. Many of the black sands in placer deposits consist largely of magnetite and ilmenite.

Ilmenite reserves in North America are estimated to be sufficient for over one hundred years, even if consumption increases to several million tons per year.

Sphene is a common accessory mineral of igneous rocks of intermediate composition, such as syenite, diorite and hornblende granite. It occurs also in schists and gneisses.

Rutile is an accessory mineral in many igneous rocks and occurs in mica schists and in gneisses as small, well-formed crystals. It also is found as masses and crystals in quartz and feldspar in veins and pegmatites. In the United States, major production is from the New England states and from Virginia.

In Arizona, rutile has been found on the Oliver (Lee) claim, about 500 feet south of the Santo Nino mine. This property is 3 miles southwest of Duquesne, in the Patagonia Mountains, Santa Cruz County. Here the prevailing rock is altered diorite, within which a pegmatite dike, about 3 feet wide where exposed, strikes N. 70 degrees W, and dips 70 degrees SW. Occurring as late hydrothermal minerals in this dike are masses and veinlets of rutile, cupriferous pyrite, and molybdenite.

When visited in October, 1953, the dike had been prospected by a shaft, reported to be 85 feet deep, and a few shallow surface cuts. These workings were several years old.

PRICES AND BUYERS

Ilmenite concentrates assaying 59.5 per cent titanium oxide (TiO_2) sell for prices ranging up to $20 per ton, f.o.b. Atlantic seaboard. When freight rates are considered, it easily can be understood why ilmenite is not a commercial mineral in Arizona; at this writing, no western markets are known for the mineral.

Rutile concentrates assaying 94 per cent or better currently are quoted at 4 to 6 cents per pound, depending upon quality.

Possible buyers of ilmenite and rutile concentrates include:

American Cyanamid Company, West 11th St., Azusa, Calif.
DuPont de Nemours Co., 2260 E. 15th St., Los Angeles, Calif.
National Lead Co., 3113 E. 26th St., Los Angeles, Calif.

GALLIUM, GERMANIUM, INDIUM, AND THALLIUM

GENERAL FEATURES

Gallium, thirty-second in abundance in the earth's crust, is unusual in that it remains liquid through a temperature range of 3,515 degrees F. It melts at 85.5 degrees F (30 degrees C) and boils at 3,601 degrees F (1,985.5 degrees C).

Very few applications for gallium have been developed. Because of its great temperature range in liquid phase, small quantities of the metal have been used in direct-reading, high-temperature thermometers.

Germanium, although discovered in 1886, was not produced commercially in the United States until 1942. It is a member of the silicon family of elements, has a grayish white color, and ranks thirty-sixth in abundance among the elements of the earth's crust. A semi-conductor, its crystals conduct electricity much better in one direction than in the reverse.

Germanium has become very important in electronics. Its properties as a semi-conductor enable it to be used as diode rectifiers to change alternating current to pulsating direct current, as transistors which amplify current changes (similar to triode vacuum tubes), and as photo-electric cells (electric eyes) of very small size.

Indium is a silver-white, ductile, crystalline metal, softer than lead, and resembling aluminum in physical properties. Indium has a specific gravity of 7.31, melting point of 313.2 degrees F (156.4 degrees C) and a boiling point of 2,642 degrees F (1,450 degrees C). It is a very rare element, ranking sixty-fourth in abundance in the earth's crust, but is found in trace amounts widely distributed.

Indium is used in solders and low-fusing alloys and as an alloying agent in high-quality engine bearings.

Thallium, discovered in 1861 and isolated in 1862, is a gray metal, very malleable, and softer than lead. Specific gravity 11.9. Melting point 577 degrees F (303 degrees C), boiling point 2,654 degrees F (1,457 degrees C). A very rare element, ranking sixty-first in abundance in the earth's crust.

The principal use of thallium is in rodenticides; salts of the metal, such as the sulfate, are very toxic and can be mixed with food to kill rats and mice. Some crystalline compounds of thallium are becoming increasingly important in construction of scientific optical equipment.

GALLIUM, GERMANIUM, INDIUM AND THALLIUM MINERALS

Gallium, germanium, indium, and thallium do not occur as native elements and, with the exception of germanite and three very rare minerals of thallium, there are no minerals in which they constitute an essential part.

Germanite is a copper iron zinc germanium gallium arsenic sulfide. It contains from 6 to 10 per cent germanium and up to 2 per cent gallium. Massive, dark-reddish gray. Hardness 4.0, specific gravity 4.4 to 4.6. Metallic luster.

The thallium minerals, lorandite, hutchinsonite, and vrbaite are very similar to one another.

Lorandite, thallium arsenic sulfide, contains 58 to 60 per cent thallium. Prismatic crystals. Carmine-red, dark lead gray. Hardness 2 to 2.5, specific gravity 5.5. Metallic luster, red streak. Excellent cleavage.

Hutchinsonite is a lead thallium copper silver arsenic sulfide containing 18 to 25 per cent thallium; it also contains up to 12 per cent lead and 2 to 9 per cent silver, and if found in quantity would be valuable for these two metals. Prismatic, radiating tufts. Scarlet to deep cherry-red, adamantine luster. Hardness 1.5 to 2, specific gravity 4.6. Streak deep cherry-red, good cleavage.

Vrbaite, a thallium arsenic antimony sulfide, contains from 29 to 32 per cent thallium. Small tabular crystals. Submetallic to metallic luster, good cleavage, uneven to conchoidal fracture. Hardness 3.5, specific gravity 5.3. Dark gray-black, bluish tint. Streak light red.

OCCURRENCE

Germanite has been found in the copper deposits of Tsumeb, South West Africa, associated as an intimate intergrowth with galena, sphalerite, pyrite, tennantite, and enargite.

Lorandite, hutchinsonite, and vrbaite occur associated with realgar and orpiment, the sulfides of arsenic and antimony, and also with other low-temperature vein minerals.

All four of these elements are found as traces in some base metal sulfides, most tin ores, and in some tungsten, aluminum, columbium (niobium), and tantalum minerals. Field tests for gallium, germanium, indium, and thallium are not practical because of the minute quantities in which the elements are present. As example, gallium is recovered from some aluminum ores containing 0.002 to 0.008 per cent and some Bolivian tin ores contain as high as 0.05 per cent gallium. The percentages of the other three metals when present are comparably low.

Induim has been recovered experimentally from the ore of the Twentieth Century Mine, Chloride, Mohave County.

PRICES AND PRODUCERS

Recent quotations for gallium, refined metal, 99.9 per cent pure, were $3. to $4.50 per gram, depending upon quantity desired. Gallium is recovered from bauxite and Tri-State zinc-lead ores by Aluminum Ore Company, East St. Louis, Ill. and Eagle-Picher Company, Joplin, Mo.

Germanium, refined metal, was quoted at $295 per pound at the beginning of 1954. It is recovered primarily from zinc smelter flue dusts by Eagle-Picher Company, Joplin, Mo. and American Steel and Wire Company, Donora, Pa.

Indium, refined metal, 99.9 per cent pure, was quoted at $2.25 per ounce Troy at the beginning of 1954. Indium is recovered primarily from zinc-smelter residues by American Smelting and Refining Company, Denver, Colorado; Anaconda Copper Mining Company, Great Falls, Mont.; and Cerro de Pasco Copper Corp., Brooklyn, N. Y.

Thallium, refined metal, was quoted at $12.50 per pound at the beginning of 1954. It is recovered in the production of cadmium from flue dusts. American Smelting and Refining Company's Globe cadmium refinery is the principal producer in the United States.

In England, gallium and germanium are being produced commercially from coal flue-dust residues, and recent research indicates that some eastern United States coals contain recoverable quantities of these two metals.

RHENIUM

GENERAL FEATURES

Rhenium was discovered in 1925 in Germany. It is a silver white metal somewhat heavier than gold. The melting point of rhenium exceeds 6,612 degrees F (3,100 degrees C), which among the metals is second only to that of tungsten. It alloys with many metals including cobalt, tungsten, platinum, gold, iridium, and rhodium. Although widely distributed in the crust of the earth, rhenium is a very rare element, ranking sixtieth in abundance in the earth's crust.

Rhenium probably has its greatest use in thermocouples.[5] In this application it is used with platinum, iridium, and rhodium. The high melting point of rhenium is of value in high-temperature alloys, and it imparts good corrosion-resistant properties to such alloys.

OCCURRENCE

Rhenium does not occur as a native metal and is not an essential part of any known minerals. No deposits have been found which can be mined solely for it. The most important source of the element is molybdenite, molybdenum sulfide. Some molybdenite assays as high as 0.05 per cent rhenium. The metal is recovered as a by-product by treating the flue dust resulting from the roasting of molybdenite concentrates. As in the case of other by-product elements, field tests for rhenium are inadequate. Controlled laboratory methods are essential to detect rhenium in the trace quantities in which it occurs.

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[5] A device which develops an electrical potential directly proportional to its temperature and therefore useful in measuring temperatures in furnaces.

PRICES AND PRODUCERS

The Chemistry Department of the University of Tennessee is the only producer of rhenium in the United States, and total production has amounted to only a few pounds per year. The price of the refined metal is reported to be $900 per pound in pound lots.

SELENIUM AND TELLURIUM

GENERAL FEATURES

Chemically, selenium and tellurium are not metals. They have been included with the rare metals because in some forms many of their properties are similar to those of metals.

The element selenium can be prepared in several forms of which the three more common are as a red precipitate, a gray metal, and a black powder. Selenium ranks fifty-sixth in abundance in the earth's crust and the metallic form, which is the most useful, melts at 428 degrees F (220 degrees C) and boils at 1,270 degrees F (688 degrees C).

Tellurium also occurs in several forms but does not resemble the metals as much as does selenium. Its physical and chemical properties are more like those of sulfur, to which selenium and tellurium are both related. Two of the more common forms of tellurium are a black amorphous powder and a tin-white crystalline form which is rather brittle and easily powdered.

Selenium is used in electronic equipment, special alloys, and in various phases of the chemical industry. Much of the selenium produced is utilized in rectifiers which change alternating-current electricity to direct current. This application makes it of great importance to the electronics industry where it is used in television receivers and many other forms of communications equipment. Selenium resembles other of the semi-metals in its property of photosensitivity; a sheet of selenium placed between two metal plates will have an electrical conductivity directly proportional to the intensity of the light to which it is exposed. A familiar application of this is the "electric eye".

Selenium is employed in the glass and pigment industry as a decolorizer. Selenium oxide is utilized as a catalyst in the preparation of some chemicals and drugs.

Tellurium is used primarily as an alloying agent with lead and copper. It imparts to these alloys high strength, hardness, ease of machinability and a high resistance to corrosion.

SELENIUM AND TELLURIUM MINERALS

Selenium and tellurium are found both as native elemnts and as essential constituents of several minerals. The demand for these two elements has been met chiefly by metal recovered as a by-product in copper smelting. Until recently this source was adequate, and consequently no deposits have been mined solely for selenium or tellurium. If demand continues to increase, and there is no reason to assume otherwise, deposits of the more common selenium and tellurium minerals may eventually assume economic importance as sources of these two metals. Several tellurides and some selenides are important for their precious metal content; for example, the gold silver tellurides, sylvanite and calaverite, have been the principal ore minerals at Cripple Creek, Colorado.

Some of the more common minerals are as follows:

Tetradymite, a bismuth tellurium sulfide containing 33 to 36 per cent tellurium. Massive, indistinct pyramidal crystals. Color steel-gray, luster metallic. Hardness 1.5 to 2, slightly sectile. Specific gravity 7.3. Perfect cleavage.

Hessite, a silver telluride containing 35 to 38 per cent tellurium Complex crystals, also massive. Color lead-gray to steel-gray, luster metallic. Hardness 2 to 3, slightly sectile. Specific gravity 8.2 to 8.4. One poor cleavage, fracture even.

Rickardite, a copper telluride, contains approximately 60 per cent tellurium. Massive. Color on fresh surface purple-red, luster metallic. Hardness 3.5; brittle. Specific gravity 7.5. Fracture even.

Emmonsite, an iron telluride, contains approximately 59 per cent tellurium. Fibrous crusts, masses of thin scales. Color yellowish-green, luster vitreous. Hardness near 5. Specific gravity 4.5. One perfect cleavage.

Aguilarite, a silver selenium sulfide, contains about 14 per cent selenium. Skeletal crystals, massive. Color iron black, luster metallic. Hardness 2.5, sectile. Specific gravity 7.6. Fracture hackly, no cleavage.

Naumannite, silver selenide, contains 22 to 29 per cent selenium. Cubic crystals, thin plates, massive. Color and streak iron black, luster metallic. Hardness 2.5, sectile and malleable. Specific gravity 7 to 8. One perfect cleavage.

OCCURRENCE

Selenium and tellurium occur sparingly as native elements in hydrothermal veins associated with base-metal sulfides and with gold and silver tellurides and selenides. At Jerome, Yavapai County, Arizona, crystals of selenium nearly an inch long have been found in the fire zone of the United Verde mine. According to A. O. Beath,[6] of the University of Wyoming, soils in the vicinity of Camp Verde and also in upper Tonto Valley are known to contain selenium, but no figures regarding the percentages present are available.

Native tellurium samples were submitted to the Arizona Bureau of Mines from a locality near Vicksburg, Yuma County by Mr. E. W. Mills in 1938.

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[6] Written communications, 1938.

Tetradymite and hessite are fairly common in gold-quartz veins associated with other tellurides and native tellurium. In Arizona tetradymite has been reported[7] from the Montgomery mine, Bradshaw Mountains, Yavapai County, Arizona, with pyrite near Bradshaw City, and from near Vicksburg, Yuma County. Hessite, one of the commonest of tellurides, has been found[8] as bands and disseminations in quartz with cerargyrite and gold at the West Side mine, Tombstone, Cochise County. Several unidentified tellurium minerals also were reported from Tombstone.

Rickardite occurs in hydrothermal veins associated with pyrite, native tellurium, and other tellurides and also in some copper deposits. Small amounts of the mineral have been found in the Junction mine, Bisbee district, Cochise County.

PRICES AND PRODUCERS

Inasmuch as selenium and tellurium are byproduct metals, no prices or procedures have been established for the purchase of ores of these metals. At the beginning of 1954, refined tellurium metal was quoted at $1.75 per pound. Selenium was quoted at $6 per pound in 100-pound lots and $5 per pound in wholesale lots.

Producers of the metals are:

American Smelting and Refining Company, Baltimore, Maryland.
International Smelting and Refining Co., Perth Amboy, New Jersey.
United States Smelting, Refining and Mining Co., East Chicago, Ind.
Kennecott Copper Corp., Garfield, Utah.

ZIRCONIUM AND HAFNIUM

GENERAL FEATURES

Zirconium, the twentieth element in abundance in the earth's crust, is widely distributed, but rarely as deposits of commercial grade. The refined metal exists in two forms, a white crystalline metal and a bluish-black amorphous powder. It has a density of 6.4 and a melting point of 3,506 degrees F (1,930 degrees C).

Hafnium, forty-seventh in abundance in the earth's crust, was not discovered until 1922. It is very similar to zirconium chemically and always occurs in minor amounts with zirconium. It has a density of 12.1 and a melting point of 3,092 degrees F (1,700 degrees C).

Zirconium and hafnium, because of their marked chemical similarity, are extremely difficult to separate completely; just recently have methods been devised to extract completely the minor hafnium content of zirconium ores on other than a laboratory scale. Hence very few uses have been developed for hafnium.

For many years zirconium has been used as a getter (a substance used to clean up residual gases in electronic vacuum tubes). This use, however, consumes a very small amount of the total produc-

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[7] Galbraith, F. W., *Minerals of Arizona,* Univ. of Ariz., Ariz. Bur. of Mines Bull. No. 153 (1948).

[8] Butler, B. S., Wilson, E. D., and Rasor, C. A., *Geology and Ore Deposits of the Tombstone District:* Univ. of Ariz., Ariz. Bureau of Mines Bull. No. 143 (1938).

tion. The greatest demand for zirconium is as a structural metal in nuclear-energy plants. In this application it has adequate strength characteristics and good corrosion resistance; also it has a very low absorption power for slow neutrons, which is essential to the maintenance of a chain reaction.

Minor quantities of zirconium are used by the chemical industry in connection with the handling of corrosive materials.

ZIRCONIUM AND HAFNIUM MINERALS

Zirconium and hafnium are found in small quantities in several minerals, but only zircon and baddeleyite are commercial sources.

Zircon, a zirconium silicate, contains 67 per cent zirconium oxide and up to 4 per cent hafnium oxide. Prismatic crystals with square cross-section. Colorless, reddish-brown, hyacinth. Streak uncolored, luster adamantine. Hardness 7.5, brittle. Specific gravity 4.7. Transparent varieties common, but some varieties opaque. No cleavage; conchoidal fracture.

Baddeleyite, a zirconium oxide, contains 96 to 99 per cent zirconium oxide and up to 3 per cent hafnium oxide. Crystals flat tabular, also prismatic. Colorless, red yellow, brown, black. Streak white to brownish white. Luster greasy to vitreous, submetallic in dark varieties. Hardness 6.5, brittle. Specific gravity 5.5 to 6. One good cleavage; fracture subconchoidal to uneven.

A deposit of **allanite** (page 25) has been discovered in Tanganyika, Africa which is reported to contain up to 8 per cent hafnium.

OCCURRENCE

Zircon is found as an accessory mineral in many granites and related igneous rocks and as a constituent of placer sands resulting from the erosion of such rocks. As an accessory mineral it commonly occurs as small, well-formed crystals sparingly disseminated throughout the rock. Zircon may form rather large crystals in the pegmatitic phases of numerous granitic rocks.

Zircon is found in minor amounts at many localities in Arizona. Black-sand placers of the Kirkland or Copper Basin District, Yavapai County, are reported to contain it in potentially commercial quantities.

Baddeleyite occurs as an accessory mineral associated with magnetite, ilmenite, corundum, and columbium-tantalum and rare-earth minerals, in some of the dark-colored or basic igneous rocks. It is a rather hard, resistant mineral and lends itself well to concentration in placer deposits derived from these rocks. Baddeleyite has been reported in placers in Brazil associated with an augite-syenite rock similar to the shonkinite at Mountain Pass, California (page 26). No Arizona occurrences have been reported.

PRICES AND POSSIBLE BUYERS

Refined zirconium metal in the amorphous powder form currently sells for $7 per pound. Ores of zirconium, in the form of zircon sand, were quoted in January, 1954, at $42 per long ton (2,240 pounds) delivered on the Atlantic seaboard.

No prices are quoted for hafnium metal or ores.

Possible buyers of zirconium concentrates include:

W. F. Berk & Company, Wood-Ridge, New Jersey.
Beryllium Corporation, Tuckerton Road, Reading, Pennsylvania.
Electro Metallurgical Company, Sheffield, Alabama.
Foote Mineral Company, 18 West Chelton Ave., Philadelphia, Pa.
International Titanium Corporation, Carteret, New Jersey
Metal Hydrides, Inc., 12-14 Congress St., Beverly, Mass.
Orefraction, Inc., 7425 Thomas, Pittsburgh, Pennsylvania
Titanium Alloy Manufacturing Co., 1940 Sugar St., Niagara Falls, N. Y.

COLUMBIUM (NIOBIUM) AND TANTALUM

GENERAL FEATURES

Columbium and tantalum, two very closely related metals, are very similar both chemically and physically and always occur together.

Columbium, the thirty-third element in abundance in the earth's crust, is so named because its first ore came from the United States (Columbia-America). The name Niobium, which is used by many chemists, is derived from Greek mythology and alludes to the constant association of columbium with tantalum (in Greek mythology Niobe was the daughter of Tantalus). Columbium is a steel-gray metal, with a bright metallic luster. Density 8.4. Melting point 3,542 degrees F (1,950 degrees C), boiling point 5,972 degrees F (3,300 degrees C).

Tantalum is the fifty-fourth element in abundance in the earth's crust. It is a grayish white metal, hard, malleable and very ductile. Tantalum has excellent corrosion-resisting properties, not affected by any one acid and only slightly by aqua regia. It has a melting point of 5,162 degrees F (2,850 degrees C) and a boiling point higher than 7,232 degrees F (4,000 degrees C).

Columbium and tantalum are used extensively in high-temperature alloys such as those used for rotors and turbines in jet engines. In amounts of 1 to 5 per cent, they impart great resistance to the deformation and corrosion which normally affect rapidly revolving parts at high temperatures. Columbium added to steels makes them more amenable to welding and reduces intergranular corrosion. Tantalum finds many applications where resistance to corrosion by acids and by many other chemicals is desired. It is used also in electronics in vacuum tubes as electrical conductors and for structural purposes.

COLUMBIUM AND TANTALUM MINERALS

As previously indicated, columbium and tantalum always occur together, even to the point of substituting for one another in their minerals. For this reason the minerals of these two metals are described in groups (all the members of which have similar physical properties) designated by the names of the two end members of the group, that is, with the nearly pure columbium form as one end member and the nearly pure tantalum form as the other.

Pyrochlore-Microlite: Pyrochlore is a complex oxide of calcium, sodium, and columbium with flourine; microlite is a complex oxide of calcium, sodium, and tantalum with hydroxyl and fluorine. Columbium oxide content varies from 73 per cent for pyrochlore to trace amounts in microlite, and tantalum oxide content ranges from 82 per cent in microlite to trace amounts for pyrochlore. Octahedral crystals, irregular masses. Color brown to black for pyrochlore shading into paler brown, red and yellow for microlite. Streak light brown to yellow. Hardness 5 to 5.5, brittle. Specific gravity 4.2 to 6.4. Luster vitreous. Octahedral cleavage; subconchoidal to uneven fracture.

Fergusonite - Formanite: Fergusonite is a complex oxide of columbium, titanium and rare-earths; formanite is a complex oxide of tantalum, titanium and rare-earths. Columbium oxide content varies from about 54 per cent in fergusonite to traces in formanite and tantalum oxide content varies from about 60 per cent in formanite to traces in fergusonite. Prismatic crystals to irregular grains and masses. Color gray, yellow, brown, black. Luster externally dull, vitreous to submetallic on fresh surface. Streak brown to yellow. Hardness 5.5 to 6.5, brittle. Specific gravity 5.6 to 5.8. Poor cleavage; subconchoidal fracture.

Columbite - Tantalite: Columbite is an oxide of iron, manganese and columbium; tantalite is an oxide of iron, manganese, and tantalum. Columbium oxide content varies from near 75 per cent in columbite to traces in tantalite and tantalum content varies from near 85 per cent in tantalite to traces in columbite. Prismatic, tabular, massive. Color iron-black, brown, reddish-brown. Streak dark red to black, luster submetallic to brilliant. Hardness 6 to 6.5, brittle. Specific gravity 5.2 to 8. Good cleavage; subconchoidal to uneven fracture.

Euxenite, a complex oxide of calcium, columbium, tantalum, titanium and rare-earths, contains from 3 to 41 per cent columbium oxide and from one to 47 per cent tantalum oxide. Prismatic crystals, massive. Color black to brownish black, streak yellowish brown to reddish brown. Luster submetallic to brilliant. Hardness 5.5 to 6.5, brittle. Specific gravity 5 to 5.9. Subconchoidal to conchoidal fracture; no cleavage.

Samarskite, an oxide of calcium, iron, uranium, thorium, rare-earths, columbium and tantalum, contains 27 to 46 per cent columbium oxide and from one to 27 per cent tantalum oxide. Prismatic crystals, massive. Color velvet black, altered surface brown to yellowish brown. Streak reddish brown to black, luster vitreous, submetallic, brilliant. Hardness 5 to 6, brittle. Specific gravity 5.7. Poor cleavage; fracture conchoidal.

OCCURRENCES

The columbium-tantalum minerals occur primarily in the pegmatitic phases of granitic rocks associated with magnetite, monazite, allanite, biotite, beryl, lithium minerals, and rare-earth minerals.

In Arizona samarskite has been found in pegmatites in the Aquarius Range, Mohave County, associated with allanite, and has been reported as occurring in the Black Hills near Jerome, Yavapai County. Masses of euxinite weighing up to 50 pounds have been found in the Kingman Feldspar mine, Cerbat Range, Mohave County.

A small quantity of fergusonite has been produced by L. L. Edgerton from a group of two claims in the Aquarius Range, Mohave County. In October, 1951 Eldred D. Wilson of the Arizona Bureau of Mines, visited the claims with Mr. Edgerton and reported as follows:

> These claims are accessible by 9 miles of unimproved road which crosses Big Sandy Wash at a point on the Kingman-Congress Junction Highway approximately 50 miles from Kingman.
>
> Edgerton stated that he has held the claims for several years and has been working them intermittently for the past two years. He stated that his production has amounted to approximately 3 tons of fergusonite concentrates; 5¼ tons of beryl; some oxidized bismuth minerals and a little monazite.
>
> In this vicinity the prevailing rock is pink aplitic granite which forms dikes a few feet to several tens of feet thick as well as larger masses of undetermined extent.
>
> The aplitic granite shows a pronounced lineation which trends approximately east-west. At the mine workings, this lineation dips northward at medium to low angles; about 500 feet further south, its dip rolls southward, suggestive of an anticlinal structure. Irregular dike-like bodies of pegmatite and quartz trend subparallel to the prevailing structure of the aplite.
>
> The mine workings consist of a bench cut about 200 feet long on the north side of a sharp gulch and connecting with a northwesterly open cut about 50 feet long. These are all in a pegmatite dike which dips 15 to 20 degrees northward. It shows a maximum thickness of approximately 100 feet but thins within a few hundred feet east and west.
>
> According to Mr. Edgerton, the northwesterly cut was productive mainly of beryl, although it yielded also one body of fergusonite. Most of his fergusonite production came from the bench cut.
>
> The fergusonite occurs as irregular, isolated bodies, principally associated with altered coarse grayish-black mica and local films of specularite. Commonly these bodies are surrounded by crumbly pinkish-white feldspar, in contact with or near veins of glassy bluish-gray quartz.
>
> Although the physical features which determined the localization of the fergusonite are not readily apparent, the mineral is radio-active. Mr. Edgerton states that his prospecting is guided by a Geiger Counter. He drilled and blasted two holes while we were there, and these holes provided us with samples of the ore.

PRICES AND PRODUCERS

Special domestic purchase prices have been established by the Defense Materials Procurement Agency for columbium-tantalum ores delivered f.o.b. depots in North Carolina, New Hampshire, and South Dakota. In January, 1954, the price was \$1.70 (plus a 100 per cent bonus) per pound of contained columbium oxide-tantalum oxide (Cb_20_5-Ta_20_5) for material containing

50 per cent or more combined oxides (equivalent to $3.40 per pound of combined oxides).

The following companies are producers of columbium-tantalum alloys:

Union Carbide and Carbon Company (Electro-Metallurgical Division) Niagara Falls, New York.
Fansteel Metallurgical Corp., North Chicago, Ill.
Kennametal Inc., Latrobe, Pennsylvania.

RARE-EARTH METALS

GENERAL FEATURES

The rare-earth group of metals is composed of sixteen elements: Lanthanum, Cerium, Praeseodymium, Neodymium, Illinium, Samarium, Europium, Gadolinium, Terbium, Dysprosium, Holmium, Yttrium, Erbium, Thullium, Ytterbium, and Lutecium.

The elements of the rare-earth group have very similar chemical properties and for this reason can be separated only with considerable difficulty, rather elaborate equipment, and the expenditure of considerable time. Commercial laboratories require anywhere from three to six months or more to perform a complete qualitative and an approximate quantitative determination of a rare earth sample, and the process requires a large quantity of material in the sample. Obviously, therefore, the individual can do little to test for the presence of rare-earth elements by simple field methods.

As cerium is commercially the most important of the rare-earth metals, the term "cerium metals" is often used to include the whole group.

The rare-earth metals are used extensively in the glass industry and particularly in glass for specialized optical equipment. Some cerium compounds are used as glass decolorizers and others are used to impart distinctive colors to glass. Cerium oxide is used as an abrasive in polishing optical glass. Lanthanum oxide of high purity is used in silica-free glass for expensive camera lenses because of its high index of refraction and low dispersion. Cerium oxides and fluorides are used in the cores of arc carbons to produce high-intensity white light for such things as search lights, moving-picture projectors, and motion-picture stage lighting.

Cerium metal and alloys account for approximately one-quarter of the rare-earths produced. Misch metal (mixed metal) is an alloy containing 45 to 50 per cent cerium, 22 to 25 per cent lanthanum, 15 to 17 per cent neodymium, 8 to 10 per cent other rare earths, and smaller amounts of iron, silicon, calcium, carbon, and aluminum. Misch metal is used as a base material when alloying the rare earths. Iron-cerium alloys are used as flints in such items as cigarette lighters and miners' lamps.

RARE-EARTH MINERALS

There are approximately seventy minerals containing rare-earth elements of which only a few are presently commercial or show potential commercial possibilities. The others are found in only minor amounts in widely scattered deposits. Physical characteristics of the important minerals are given as follows:

Monazite, a cerium lanthanum yttrium thorium phosphate, contains from 55 to 74 per cent combined rare earth oxides. Wedge-shaped, prismatic and rounded crystals. Hardness 5 to 5.5, brittle. Specific gravity 4.6 to 5.4. Luster resinous to adamantine. Color brown, reddish brown, yellow, green, white. Transparent to translucent. Fracture uneven to conchoidal; some varieties exhibit a fair cleavage.

Allanite is a calcium iron aluminum rare-earth silicate. As crystals resembling epidote; also massive. Color brown to black, luster resinous to submetallic. Hardness 5.5 to 6, brittle. Specific gravity 3 to 4.2. Fracture uneven to subconchoidal.

Bastnaesite, a cerium lanthanum fluo-carbonate, contains 70 to 76 per cent rare earth oxides. As tabular crystals and masses resembling feldspar. Reddish brown to yellow. Hardness 4 to 4.5, brittle. Specific gravity 4.9 to 5.2. Luster vitreous, greasy, pearly. Fracture uneven; some varieties display a good parting. Transparent to translucent; streak white.

Cerite is a rare earth silicate. Massive, granular. Hardness 5.5. Specific gravity 4.8. Color clove-brown, cherry-red to gray.

Zenotime, an yttrium phosphate, contains approximately 60 per cent rare-earth oxides. As prismatic crystals resembling rutile and zircon in shape; also as rounded grains. Various shades of brown, red, yellow, and gray; streak pale brown, red or yellow. Hardness 4 to 5, brittle. Specific gravity 4.4 to 4.54. Luster vitreous to resinous, opaque. Fracture uneven; perfect cleavage.

Gadolinite, which may contain considerable rare-earth oxides is discussed under beryllium (page 7). **Fergusonite, euxenite, samarskite,** and various other rare-earth tantalates and niobates are discussed under columbium and tantalum (pages 21-22).

Euxenite, fergusonite, and samarskite always contain uranium, most monazite and some xenotime contain thorium, and varieties of many of the other rare-earth minerals contain small amounts of uranium and thorium as impurities. In addition, many of the rare-earth minerals which do not contain uranium or thorium are commonly associated with minerals which are radioactive, therefore, when prospecting with radiation detectors, such as Geiger counters and scintillometers, the possible presence of rare-earth minerals should be kept in mind.

OCCURRENCE

The geologic occurrence of most of the rare-earth minerals is very similar. They are found as accessory minerals in pegmatites, granitic and dioritic rocks, and in gneisses resulting from metamorphism of these rocks. In some pegmatites, crystals and masses of the minerals are very abundant and attain considerable size. Crystals and masses of samarskite weighing 20 pounds have been found in the mica mines of South Carolina, and masses of gadolinite weighing 40 to 60 pounds have been mined in Llano County, Texas.

Zenotime is found as small crystals in granites and gneisses and is commonly associated with zircon which it closely resembles. The large commercial deposits of monazite are in placer sands and beach gravels derived from erosion of igneous masses containing the mineral as an accessory. Its high specific gravity and fair hardness make it well adapted to natural concentration.

Notable exceptions to the general mode of occurrence are the bastnaesite deposit of Mountain Pass, California, and the fluorite-bastnaesite veins of New Mexico. At Mountain Pass the bastnaesite occurs associated with barite and carbonites in veins and masses in shonkinite-syenite bodies.[9]

Arizona occurrences of rare-earth minerals have been reported[10] as follows: Monazite: in stream gravels in the Mohave Mountains, 20 miles southeast of Topock.[11] Allanite: Tombstone district as microscopic crystals in granodiorite; in pegmatites at the Kingman Feldspar mine in the Cerbat Range, Mohave County; in pegmatites in the Aquarius Range, Mohave County; in pegmatites in the Eureka district, near Bagdad, Yavapai County.

PRICES AND PRODUCERS

Most of the United States production of rare-earth minerals is coming from the Long Valley monazite field in Idaho, which was discovered in 1950 by the United States Bureau of Mines. This production is not sufficient for current needs, however, and considerable rare-earth minerals and alloys are imported from foreign sources. Considerable research was carried on in 1953 to solve benefication problems associated with bastnaesite in the light of deposits known to occur in California and New Mexico.

In January, 1954, monazite concentrates were quoted at 22 cents per pound of rare-earth oxides for material containing 69 per cent oxides, 19 cents per pound for 66 per cent material, and 16.5 cents per pound of rare-earth oxides in concentrates assaying 55 per cent rare-earth oxides.

The principal monazite processors and rare-earth metal producers are:

Cerium Metals Corp., New York, N. Y.
General Cerium Corp., Edgewater, New Jersey
Kent Metal and Chemical Co., Edgewater, New Jersey
Lindsay Light and Chemical Co. ,West Chicago, Illinois
Maywood Chemical Works, Maywood, New Jersey
New Process Metals Corp., Newark, New Jersey
Rare Earths, Inc., Paterson, New Jersey

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[9] Syenite is a variety of igneous rock similar to granite but which contains no quartz; shonkinite is a variety of syenite containing considerable of the dark colored silicate "augite" in place of biotite.

[10] Galbraith, F. W., *Minerals of Arizona:* University of Arizona, Arizona Bureau of Mines Bull. No. 153 (1948).

[11] Heineman, R. E. S., *American Mineralogist,* vol. 15, pp. 536-37 (1930).

URANIUM AND THORIUM

GENERAL FEATURES

Uranium, the forty-sixth element in abundance in the earth's crust, was discovered in 1789. It is a malleable, white metal, capable of taking a high polish. Density, 18.7. It has a melting point of 2,552 degrees F (1,400 degrees C) and a boiling point of 6,332 degrees F (3,500 degrees C).

For many years uranium was considered a nuisance in certain vanadium and radium ores and had only a very small demand as an alloying agent in specialized steels and as a glass-coloring agent. During the closing months of World War II the United States exploded an atomic bomb, and uranium became one of the most sought-for metals. It is doubtful that any metal has had such a rapid climb to importance.

Thorium is somewhat more abundant than uranium, ranking thirty-fifth in abundance in the earth's crust. It is a tin-white metal with a density of 11.2 and a melting point of 3,353 degrees F (1,845 degrees C).

Thorium has only limited uses and was recently removed from the list of critical elements, although research is still being carried out to determine its possibilities as a source of atomic energy. The most important application of thorium is in gas-lamp mantles. In this application a mixture of thorium and cerium nitrates are used; the thorium is a good absorber of heat, and the cerium is an excellent emitter of light.

URANIUM AND THORIUM MINERALS

There are approximately ninety minerals in which uranium and thorium are essential constituents, and over twice that number in which uranium and thorium have been reported as present. A large proportion of these minerals are very rare, occurring as only minor constituents at a few localities; many more, although of commercial importance, have not been found in Arizona. In the following descriptions only uranium and thorium minerals which have been found in Arizona are included.

Uraninite (pitchblende), uranium dioxide; the natural material includes a mixture of uranium oxides and up to several per cent impurities, including lead, rare-earths, and thorium. It contains 56 to 83 per cent uranium and up to several per cent thorium. Cubic crystals, massive, and as colloform (rounded, globular) crusts and masses. Color black, gray, brown. Luster glassy to submetallic. Hardness 5 to 6. Specific gravity 8 to 10. Fracture uneven to subconchoidal.

Schroeckingerite, complex sodium calcium uranium carbonate-sulfate, contains 26.8 per cent uranium. Small masses of flaky crystals. Color greenish yellow, luster vitreous to pearly. Hardness 2.5. Specific gravity 2.5. Perfect cleavage. Fluoresces strong yellowish-green under ultraviolet light.

Swartzite, complex calcium magnesium uranium carbonate, contains 32.6 per cent uranium. Clusters of minute crystals. Color green. Specific gravity 2.3. Fluoresces bright green under ultraviolet light.

Andersonite, complex sodium calcium uranium carbonate, contains 39.2 per cent uranium. Clusters of minute crystals. Color bright green. Specific gravity 2.8. Fluoresces bright green under ultraviolet light.

Bayleyite, magnesium uranium carbonate, contains 28.9 per cent uranium. Minute, prismatic crystals. Color yellow. Specific gravity 2.0. Green fluorescence under ultraviolet light.

Carnotite, potassium uranium vanadate, contains 52 to 55 per cent uranium. Earthy, aggregates of minute crystals. Lemon yellow, greenish yellow, luster dull, also pearly or silky when crystalline. Hardness 2 to 3. Specific gravity near 4. Perfect cleavage.

Tyuyamunite, calcium uranium vanadate, contains 48 to 51 per cent uranium. Earthy and masses of minute crystals. Canary yellow, greenish yellow, adamantine luster when crystalline. Hardness near 2. Specific gravity 3.7 to 4.4. Perfect micaceous cleavage.

Zippeite, uranium sulfate, contains 64 per cent uranium. Earthy, also as crusts of minute crystals. Orange-yellow, luster vitreous to earthy. Hardness 2 to 3. Specific gravity near 3.5. Perfect cleavage. Fluoresces brilliant green under ultraviolet light.

Johannite, copper uranium sulfate, contains 51 per cent uranium. Prismatic and tabular crystals, also as crusts of minute crystals. Emerald-green to apple-green, light green streak. Luster vitreous. Hardness 2 to 2.5. Specific gravity 3.3. One good cleavage.

Torbernite, copper uranium phosphate, contains 47 to 50 per cent uranium. Square, tabular crystals, also as micaceous masses. Color emerald to grass-green, streak pale green, luster vitreous to sub-adamantine. Hardness 2 to 2.5, brittle. Specific gravity 3.2. Perfect cleavage.

Autunite, calcium uranium phosphate, contains 45 to 48 per cent uranium. Thin, tabular crystals. Color lemon-yellow to greenish-yellow, streak yellowish, luster vitreous to pearly. Hardness 2 to 2.5. Specific gravity 3.1. Perfect cleavage. Fluoresces strong yellowish-green under ultraviolet light.

Becquerelite, hydrated uranium oxide, contains 76 per cent uranium. Tabular crystals, also massive. Color amber to brownish yellow; streak yellow, luster adamantine to greasy. Hardness 2 to 3. Specific gravity 5.2. Perfect cleavage.

Schoepite, hydrous uranium oxide, contains 74 per cent uranium. Crystals tabular, also short prismatic. Color sulfur-yellow; streak yellow, luster adamantine. Hardness 2 to 3. Specific gravity 4.8. Perfect cleavage. Some specimens reported to fluoresce yellowish-green under ultraviolet light.

Gummite, a mixture of hydrous uranium oxides usually containing lead, thorium, and other elements; indefinite composition. Massive. Color yellow, orange, reddish brown, black; streak yellow, luster brilliant to dull, waxey to vitreous. Hardness 2.5 to 5; brittle. Specific gravity 4 to 6.4. Fracture conchoidal to uneven; no cleavage.

Kasolite, lead uranium silicate, contains 40 per cent uranium. Minute, prismatic crystals. Color yellow to brown; luster resinous to greasy. Hardness 4 to 5. Specific gravity near 6. Perfect cleavage.

Uranophane, calcium uranium silicate, contains 57 per cent uranium. Massive, also as radiating fibrous crystals. Color yellow, luster vitreous to pearly. Hardness 2 to 3. Specific gravity 3.8 to 3.9. Good cleavage.

Varying amounts of uranium and thorium occur in several minerals which are currently of more importance for their columbium, tantalum and rare-earth content. Eventually, however, they possibly may be of value for their uranium and thorium content. The following are among this group:

Fergusonite - Formanite (page 22) contains up to 8 per cent uranium and up to 2.5 per cent thorium.

Samarskite (page 22) contains up to 16 per cent uranium and up to 3.7 per cent thorium.

Euxinite-Polycrase (page 22) contains up to 12 per cent uranium and up to 4.7 per cent thorium.

Pyrochlore-microlite (page 22) contains up to 5 per cent uranium and up to 4 per cent thorium.

Monazite (page 25) contains up to 10 per cent or more thorium.

Allanite (page 25) contains up to 3 per cent thorium.

Xenotime (page 25) contains up to 3.6 per cent uranium and up to 2.2 per cent thorium.

Uranium and thorium are unstable elements, having atomic nuclei which are slowly but continuously splitting apart. This atomic deterioration is accompanied by discharge of sub-atomic particles and Gamma radiation similar to X-rays. Devices such as the Geiger-Muller radiation counter and the scintillation counter are capable of detecting and measuring these radiations and therefore afford a simple and rapid method of testing samples for uranium and thorium. Small, light-weight counters have been developed which are very useful in prospecting for radioactive materials.

The following statements regarding the use of counters has been abstracted with little change from a U.S. Atomic Energy Commission news release dated May, 1950.

> The Geiger counter is a simple instrument to operate, but it is not always easy to interpret correctly the readings shown by the instrument. Assuming that the counter is in good mechanical order, a rise in the reading may be caused not only by the presence of uranium or thorium but also by other factors, of which the most important are: (1) the background count and (2) the "mass effect"
>
> (1) *The background count* is the count that is always registered by the instrument, even at a distance from radioactive ores, because of cosmic rays and random gamma radiation. The most important thing for the prospector to remember is to record the background count. The

reading in any specific location, or for any sample, is not significant until the background count has been established and subtracted from the total count.

The background count is not always the same. It varies for different models of the counter, and it may also vary temporarily for the same instrument, for other reasons—especially the type of rocks that the prospector is crossing. Most rocks, even though they do not represent commercially valuable uranium deposits, have some degree of radioactivity, and some have more than others. Therefore, the background will be higher above or near granite or rhyolite, for example, than above or near limestone or dolomite.

The background will rise if the counter becomes contaminated by radioactive dust and dirt entering the carrying case. Samples and specimens should never be carried with the instrument.

The background may also change when the counter is taken into a mine (or when entering a sharp depression). The background usually increases with altitude above sea level. It may vary at different times of the day and in different weather.

(2) The *"mass effect"* means simply that a large mass of weakly radioactive rock may have, *as a whole,* enough radioactivity to affect the counter—even to affect it strongly—although the radioactivity of a small piece of the rock is slight or negligible. When this is the case, the prospector may find that his counter shows a noticeable reaction near the large rock mass, yet a sample removed from the mass and tested elsewhere has little or no effect on the counter.

For these two principal reasons, an increase in the total count registered by the Geiger counter does not necessarily mean the definite presence of uranium.

Generally speaking, however, if the total recorded count is two or three times the background count, the prospector should study the region more closely. In particular, he should attempt to determine the precise source of the radioactivity, in order to distinguish between a counter reading caused by a large low-grade deposit and a reading caused by a small amount of high-grade ore.

Certain factors may prevent existing radioactive ores from registering on the counter. If the rate of survey is too rapid, narrow veins of radioactive material will be missed. Overburden (a covering layer of earth or rocks) above a radioactive deposit may cut off most or all of the radiation, depending on the thickness of the covering layer; even high-grade ores can rarely be detected under more than two feet of overburden.

There is no instrument that will readily indicate the depth and richness of a radioactive deposit. Recordings on the Geiger counter must be supplemented by visual observation, by sampling, and by chemical assaying, to determine the size of a deposit, its grade, and other factors affecting its commercial possibilities.

Counters for use in the field are usually built to stand a certain amount of rough handling, but the counter is a precision instrument and should be protected as much as possible from abuse. It should be carried in a waterproof canvas case. When on an extended trip it is advisable to carry an extra set of batteries.

The counter must not be allowed to register so rapidly that the individual clicks cannot be distinguished, or that the meter hand swings off the dial. This is harmful to the counting mechanism. If possible adjust the instrument to a lower sensitivity; otherwise, increase the distance between the instrument and the material producing the radioactivity.

A simple chemical test for uranium is desirable for confirming the readings of the Geiger counter or to check the presence of uranium when no other methods are available. Such a test is the sodium fluoride bead test.

A loop, ¼ inch in diameter or less, is bent in the end of a thin piece of wire (platinum is generally used although iron will do). A bead of sodium fluoride is fused on the end by dipping the hot loop into powdered dry sodium fluoride and holding in a hot flame. The bead is then touched to the powdered sample and again held in the flame until the powder is thoroughly melted into the bead. When cool, the bead is observed in darkness under an ultraviolet lamp. If uranium is present the bead will fluoresce a deep yellow. The bead should be checked for fluorescence before the mineral to be tested for uranium is introduced to be sure it is not contaminated (the bead may assume a pale blue color, but this is reflection from the light source and will not affect the test). Some elements interfere with this test. Columbium and tantalum will cause the bead to fluoresce weakly, and thorium and cerium tend to prevent the test from working, but only if present in large quantities. For this reason uranium in minerals such as monazite and allanite cannot usually be detected by this test.

OCCURRENCE

The occurrence of monazite, the principal mineral from which thorium is extracted, has been discussed in the section on rare-earths (page 24).

Uranium minerals occur in four principal types of deposits: hydrothermal veins; pegmatite deposits; secondary concentrations in sedimentary rocks; and as placer concentrations derived from the other three types. In Arizona production has been primarily from the secondary sedimentary deposits. These deposits occur in the Colorado plateau region as concentrations of secondary uranium minerals such as carnotite and tyuyamunite. The usual host rock is sandstone. The deposits are generally well defined but vary greatly in size and grade, some occurring as small, irregular masses and others as large, tabular bodies that roughly parallel the bedding of the sandstone. Copper-uranium deposits containing torbernite and powdery black pitchblende have also been discovered in sandstone in the Colorado Plateau region. Although individual copper-uranium deposits have thus far proven spotty, it is hoped that further exploration will lead to the discovery of better deposits of this type.

The minerals containing uranium and thorium common to the pegmatites are the columbium-tantalum minerals. The uranium content of these deposits is generally small, and their importance is dependent upon the presence of other commercial minerals.

The common hydrothermal vein mineral of uranium is uraninite (pitchblende). Typical associated minerals are cassiterite, pyrite, chalcopyrite, galena, and various sulfides of bismuth, silver, and arsenic. Gangue minerals include barite, fluorite, and various carbonates.

Several deposits of the vein type have been discovered in western and southern Arizona as indicated on Figure 1. Descriptions of individual deposits are contained in Circulars of the U.S. Atomic Energy Commission and U.S. Geological Survey. These are listed under "Selected References" in the Appendix of this Bulletin.

INCENTIVE PROGRAM AND BUYING SCHEDULE

In April, 1948, the United States Atomic Energy Commission announced a three-point program designed to stimulate discovery and production of domestic uranium by private competitive enterprise. This program included[12] Government guaranteed ten-year minimum prices for domestic refined uranium, high-grade uranium ores, and mechanical concentrates; a bonus of $10,000 for the discovery of a new deposit and production therefrom of the first 20 short tons of uranium ore or mechanical concentrate assaying 20 per cent or more uranium oxide; and Government guaranteed three-year minimum prices for the low-grade carnotite-roscoelite type uranium-vanadium ores of the Colorado Plateau area and Government operation of two vanadium-uranium plants in that area.

Subsequently the United States Atomic Energy Commission acted to provide a new bonus for domestic uranium ore production and a price increase for Colorado Plateau ores as substantial additional incentives for uranium mining in the United States.

1. Effective March 1, 1951 to March 1, 1954, the Commission will pay a new graduated bonus of up to $35,000, depending upon the quantity and grade of ore, for initial production and delivery of acceptable uranium ore from new and certain existing mining properties.
2. Effective March 1, 1951 to April 1, 1958 the Commission will increase its guaranteed minimum base prices for the uranium oxide content of carnotite-roscoelite type ores of the Colorado Plateau from its former range of 50c-$2 per pound to $1.50-$3.50, depending upon the grade of the ore.

The new bonus, which is described in AEC Domestic Uranium Program Circular No. 6, "Bonus for Initial Production of Uranium Ore from Domestic Mining Properties," provides for the following:

1. For new mining properties, bonus payments will be made on each pound of uranium oxide in acceptable ore delivered to qualified mills or Commission ore-buying stations up to and including the first 10,000 pounds.
2. For mining properties which have produced less than 10,000 pounds of uranium oxide during the period April 9, 1948, to March 1, 1951, bonus payments will be made on the difference between what the mining property has delivered between April 9, 1948, and March 1, 1951 and 10,000 pounds. For example, the owner of a mine that has produced 4,000 pounds of uranium oxide between April 9, 1948, and March 1, 1951, may be eligible to receive a bonus on each new pound produced up to and including the next 6,000 pounds.
3. Bonus payments per pound of uranium oxide in acceptable ores produced from qualified mining properties will range from $1.50 for those ores assaying 0.10 per cent uranium oxide to $3.50 for ores assaying 0.20 per cent or more. Thus the maximum bonus which may be obtained for production from new mines will range from $15,000 to $35,000, depending upon the grade of ore delivered.

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[12] United States Atomic Energy Commission Circulars 1, 2, and 3, April, 1948.

Payments under the new bonus plan will be made for all eligible ores purchased after March 1, 1951. Payments will be made directly by the Commission and not by the receiving station or mill, and will be in addition to purchase payments made pursuant to ore buying schedules. Before bonus payments will be made, the producer must make application to the Commission and the Commission must certify that the mine is eligible for the bonus.

The new bonus is in addition to and does not supersede the old one. The new bonus differs from the old one in several important respects:

1. Whereas the old bonus applied only to ores or mechanical concentrates assaying 20 per cent or more uranium oxide (very high grade), the new bonus provides for payments for ores containing as low as 1/10 of 1 per cent uranium oxide, and for maximum payments for ores assaying as low as 2/10 of 1 per cent.
2. Whereas the old bonus was to be paid only after 20 short tons of ore are delivered to a qualified mill or ore-buying station, the new bonus will be paid on each pound of uranium oxide sold in acceptable ores up to and including the first 10,000 pounds.
3. Whereas the old bonus does not apply to carnotite-roscoelite type ores of the Colorado Plateau, the new bonus does apply.

The new schedule of guaranteed minimum prices for the carnotite-roscoelite type ores of the Colorado Plateau increased the base price paid for uranium ores containing as little as 0.10 per cent uranium oxide from 50c per pound to $1.50 per pound, and for ores containing 0.20 per cent uranium oxide or more from $2 per pound to $3.50. In addition, the premium paid on ores containing more than 4 pounds of uranium oxide to the ton was increased from 25c to 75c per pound.

The new price schedule is as follows:

Uranium Oxide U_30_8 Assay	Bonus Payment per pound of U_30_3
Less than 0.10 per cent	No payment
0.10 per cent	$1.50
0.11 ” ”	1.70
0.12 ” ”	1.90
0.13 ” ”	2.10
0.14 ” ”	2.30
0.15 ” ”	2.50
0.16 ” ”	2.70
0.17 ” ”	2.90
0.18 ” ”	3.10
0.19 ” ”	3.30
0.20 ” ” and more	3.50

APPENDIX

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GLOSSARY

Adamantine. Like a diamond in luster.

Alkali metal family. The group of metals lithium, sodium, potassium, rubidium, and cesium.

Alloy. A compound of two or more metals, usually produced by fusion.

Amorphous. Without form: applied to rocks and minerals having no definite crystalline structure.

Base metal. Any metal as iron, lead, zinc, copper, etc., which is altered by exposure to the air, in contrast with the noble or precious metals.

Catalyst. A substance which affects the rate of a chemical reaction and which may be recovered practically unchanged at the end of the reaction.

Cleavage. The property possessed by many crystalline substances of being rather easily split parallel to one or more of the crystallographic planes peculiar to the substance.

Conchoidal. Shell-shaped, a break or fracture with concave and convex surfaces.

Critical. As applied to metals and minerals, those for which the Government has great demand and, because of limited supplies, regulates their use and sale.

Density. The mass of the unit volume, the ratio of the weight of a body to that of an equal volume of some standard substance, water in the case of solids and liquids.

Dike. A long and relatively thin body of igneous rock, which, while in a state of fusion, has entered a fissure in older rocks and has there chilled and solidified.

Diorite. A granular rock composed essentially of hornblende and feldspar which is mostly or wholly plagioclase.

Dispersion. The relationship of the various indices of refraction a substance has for different colors of light.

Fluorescence. The emission of light from within a substance while it is being exposed to direct radiation.

Fracture. The character or appearance of a freshly broken surface of a rock or mineral.

Gneiss. A layered crystalline rock with a more or less well developed cleavage.

Granite. A granular igneous rock composed essentially of quartz, orthoclase or microcline, and mica. Commonly a minor part of the feldspar is plagioclase. The mica may be either biotite or muscovite or both.

Hardness. The degree of resistance to abrasion or scratching. The standard generally used with minerals is the Mohs scale: 1. Talc; 2. Gypsum; 3. Calcite; 4. Fluorite; 5. Apatite; 6. Orthoclase; 7. Quartz; 8. Topaz; 9. Sapphire; 10. Diamond.

Hydrothermal. Pertaining to hot water, especially with respect to its action in dissolving, re-depositing, and otherwise producing mineral changes within the crust of the earth.

Index of refraction. A number which expresses the amount a substance will bend a ray of light which is passed through it.

Malleable. When slices may be cut off with a knife, and these slices flattened out under a hammer.

Metallic luster. A luster characteristic of metals in a compact state, and shown also by some other substances.

Native elements. Elements that occur in nature uncombined, as nugget gold, metallic copper, etc.

Parting. The tendency of crystals to separate along certain planes that are not true cleavage planes.

Pearly. Applied to minerals having a luster like a pearl, as talc, brucite, stilbite

Pegmatite. An igneous rock, generally coarse grained but usually irregular in texture and composition, composed mainly of silicate minerals of large size, including quartz, feldspar, muscovite, biotite, tourmaline, beryl, lithia minerals, zircon, etc.

Placer. An alluvial or glacial deposit, as of sand or gravel, containing particles of gold or other valuable mineral.

Precious metals. The uncommon and highly valuable metals, especially gold and silver but also platinum and associated metals.

Prismatic. In crystallography, having the form of a prism, being elongated in one direction and of equal dimensions in the other two.

Rare. Widely separated, not occurring massed. Although many of the rare metals are more abundant than, for instance lead, they do not occur in large concentrated deposits.

Resinous. Resembling resin, as opal, and some yellow varieties of sphalerite.

Sectile. When pieces may be cut off with a knife without falling to powder, but still the mineral pulverizes under a hammer.

Silky. Having the luster of silk, like fiberous calcite, fiberous gypsum.

Specific gravity. The ratio of the density of a body to that of water. The ratio of the weight of a body to that of an equal volume of water.

Splendent. Applied to the degree of luster of a mineral, reflecting with brilliancy and giving well-defined images, as hematite, cassiterite.

Strategic. Important to the well-being or defense of the nation and in demand for that reason.

Streak. The color of the powder of a mineral as obtained by scratching the surface of the mineral with a knife or file or, if not too hard, by rubbing it on an unpolished porcelain surface

Sub-atomic. Smaller than atoms, refers to particles such as electrons, protons, etc.

Trace. A very small quantity of a constituent, especially when not quantitatively determined, owing to its minuteness.

Vein. The filling of a fissure or fault in rock, particularly if deposited by aqueous solutions; an occurence of ore, usually disseminated through a gangue, and having a more or less regular development in length, width, and depth.

Vitreous. Having the luster of broken glass, quartz, calcite.

SERVICES OFFERED BY THE ARIZONA BUREAU OF MINES

(Continued from inside front cover)

3. Geologic investigations of mining districts and counties and the making of topographic and geologic maps and reports. In cooperation with the United States Geological Survey a large-scale base map, a reconnaissance geologic map, and a topographic map (100-meter contours) of the entire State have been published. Geologic reports on various mineral resources of the State are prepared.

4. The Bureau provides an ore-testing service for ores originating within the State of Arizona. Full details will be furnished on request.

5. Semitechnical meetings with miners and prospectors are held throughout the State.

6. The collection and dissemination of statistics relating to the mineral industries of the State.

7. The collecting and filing of all items relating to Arizona mines and minerals that appear in Arizona newspapers and in many technical periodicals.

MAPS OF ARIZONA

The Arizona Bureau of Mines now has available for distribution the following maps of the State:

A. Base map of Arizona on a scale of about 17 miles to the inch. This map is strictly geographic, indicating the positions of towns, railroads, rivers, surveyed lands, national forests, national parks and monuments, etc., revised to 1939. It is printed in black on one sheet 22x36 inches and sells for 30c unmounted.

C. Geologic map of Arizona in one sheet of many colors. It was issued in 1924 on the same scale as the topography map, but it is now out of print, and its lithographic plates are worn beyond repair.

The Bureau is now prepared to supply sets of 44 kodachrome slides, 2x2 inches in size, covering the entire map. The slides may be used with either a low-cost pocket viewer or a projector. The price of the set is $9.00 which includes mailing charges.

D. Metallic Mineral Map of Arizona, 25x27 inches. This map consists of a red overprint made on Map A, and shows the principal known localities of metallic minerals by means of representative symbols. Roads are indicated. This map was revised in May, 1953, and sells for 30c when delivered without tube in the offices of the Bureau of Mines. If mailed the cost, including mailing tube, is 45 cents.

E. Nonmetallic Mineral Map of Arizona, 25x27 inches, similar to Map D but devoted to nonmetallic minerals. This map sells for 30c when delivered without tube in the offices of the Bureau of Mines. If mailed, the cost including mailing tube, is 45 cents.

F. Map of Arizona Mining Districts, 25x27 inches. This map consists of a red overprint made on Map A and shows the principal mining districts of mining localities by means of numerals and index. Roads are also indicated. This map is sold for 30c when delivered without tube in the offices of the Bureau of Mines. If mailed the cost, including mailing tube is 45 cents.

All communications should be addressed and remittances made payable to the Arizona Bureau of Mines, University of Arizona, Tucson, Arizona.