Minerals of the world

volume1

By Anna farahmand and Micheal Webber

2010

First published 2010

get in touch with us at **http://www.dead-phoenix-press.com/**

Michael Webber: dead-phoenix-press@xemaps.com
anna farahmand: annafarahmand@yahoo.com

preface

A **mineral** is any naturally-occurring, homogeneous solid that has a definite chemical composition and a distinctive internal crystal structure. Minerals are usually formed by inorganic processes. Synthetic equivalents of some minerals, such as emeralds and diamonds, are often produced in the laboratory for experimental or commercial purposes.

Although most minerals are chemical compounds, a small number (e.g., sulfur, copper, gold) are elements. The composition of a mineral can be defined by its chemical formula. The identity of its anionic group determines the group into which the mineral is classified. For example, the mineral halite ($NaCl$) is composed of two elements, sodium (Na) and chlorine (Cl), in a 1:1 ratio; its anionic group is chloride (Cl^-)--a halide--so halite is classified as a halide. Minerals can thus be classified into the following major groups: native elements, sulfides, sulfosalts, oxides and hydroxides, halides, carbonates, nitrates, borates, sulfates, phosphates, and silicates. Silicates are the most commonly occurring minerals because silica is the most abundant constituent of the Earth's crust (about 59 percent).

A mineral crystallizes in an orderly, three-dimensional geometric form, so that it is considered to be a crystalline material. Along with its chemical composition, the crystalline structure of a mineral helps determine such physical properties as hardness, color, and cleavage.

Minerals combine with each other to form rocks. For example, granite consists of the minerals feldspar, quartz, mica, and amphibole in varying ratios. Rocks are thus distinguished from minerals by their heterogeneous composition. A mere 100 of the several thousand known types of minerals constitute the main components of rocks. you will know more about minerals here.

Aluminum & Bauxite

Aluminum: Is the most abundant metal element in the Earth's crust. Bauxite is the main source of aluminum. Aluminum is used in the United States in packaging, transportation, and building. Guinea and Australia have about one-half of the world's reserves. Other countries with major reserves include Brazil, Jamaica, and India. 	*Bauxite*: A general term for a rock composed of hydrated aluminum oxides. It is the main ore of alumina to make aluminum. Also used in the production of synthetic corundum and aluminous refractories.  **MII Photo**

Background

Aluminum is a silver-white metal, very light in weight (less than three times as dense as water), yet relatively strong. In addition, aluminum is ductile, that is, it can be drawn into wires or pressed into sheets or foil. It is the most abundant metallic element, and the third most abundant of all elements in the Earth's crust, making up 8% of the crust by weight. Only silicon and oxygen are more plentiful.

Aluminum has numerous applications in the home and industry, and is a familiar metal to nearly everyone.

Name

Aluminum is a reactive metal, and does not occur in the metallic state in nature. Therefore, it was unknown as a separate element until the 1820's, although its existence was predicted by several scientists who had studied aluminum compounds. It was produced in metallic form independently by the Danish chemist and physicist, Hans Christian Oersted, and the German chemist, Frederich Wohler, in the mid-1820's.

The name *aluminum* was derived from *alume*n, the Latin name for alum (an aluminum sulfate mineral). The metal was called *aluminium* with the *-ium* ending being the accepted ending for most elements at this time. This usage persists in most of the world except the United States, where the last *i* has been dropped from the name.

Aluminum and Bauxite

Because aluminum metal reacts with water and air to form powdery oxides and hydroxides, aluminum metal is never found in nature. Many common minerals, including feldspars, contain aluminum, but extracting the metal from most minerals is very energy-intensive, and therefore expensive.

The main ore of aluminum is *bauxite,* the source of over 99% of metallic aluminum. Bauxite is the name for a mixture of similar minerals that contain hydrated aluminum oxides. These minerals are gibbsite ($Al(OH)_3$), diaspore ($AlO(OH)$), and boehmite ($AlO(OH)$). Because it is a mixture of minerals, bauxite itself is a rock, not a mineral. Bauxite is reddish-brown, white, tan, and tan-yellow. It is dull to earthy in luster and can look like clay or soil. Bauxite forms when silica in aluminum-bearing rocks (that is, rocks with a high content of the mineral feldspar) is washed away (leached). This weathering process occurs in tropical and subtropical weathering climates.

Alternative sources of aluminum might someday include kaolin clay, oil shales, the mineral anorthosite, and even coal waste. However, as long as bauxite reserves remain plentiful and production costs are low, the technologies to process these alternative sources into alumina or metallic aluminum will likely not progress beyond the experimental stage.

Sources

Australia has huge reserves of bauxite, and produces over 40% of the world’s ore. Brazil, Guinea, and Jamaica are important producers, with lesser production from about 20 other countries. The United States’ production, which was important 100 years ago, is now negligible.

Most bauxite is first processed to make alumina, or aluminum oxide, a white granular material. Sometimes, raw bauxite is shipped overseas for processing to alumina, while in other cases it is processed near the mine. Alumina is lighter than bauxite because the water has been removed, and it flows readily in processing plants, unlike bauxite which has a sticky, muddy consistency. Australia, the United States, and China are the largest producers of alumina. All the U.S. alumina being made is from imported bauxite.

Aluminum metal is refined from alumina, usually in industrialized countries having abundant supplies of cheap hydroelectric power. The refining process is the *Hall-Heroult Process*, named after Charles Hall of the U.S. and Paul L.T. Heroult of France, who each independently invented the process in 1866. In this process, alumina (aluminum oxide) is dissolved in molten cryolite (cryolite is an aluminum fluoride mineral, Na_3AlF_6). The alumina is then separated into its elements by electrolysis. Though attempts have been made to replace this process, it is to this day the only method used to isolate aluminum on a commercial scale.

The largest producers of aluminum metal are Russia, China, the United States, and Canada, countries which have abundant hydroelectric power. More than 40 other countries also produce aluminum, including Norway, Iceland, Switzerland, Tajikistan, and New Zealand, which are small but mountainous, and have many rivers to provide hydroelectric power. Other areas of the world with access to abundant and cheap electricity, such as the Middle East, are also expanding their metal production capacities.

Recycling of aluminum by melting cans and other products is an important source of metal in many developed countries.

Uses

About 85% of all the bauxite mined worldwide is used to produce alumina for refining into aluminum metal. Another 10% produces alumina which is used in chemical, abrasive, and refractory products. The remaining 5% of bauxite is used to make abrasives, refractory materials, and aluminum compounds.

The lightness, strength, and corrosion resistance of aluminum are important considerations in its application. Metallic aluminum is used in transportation, packaging such as beverage cans, building construction, electrical applications, and other products.

Aluminum, the third most abundant element at the Earth's surface, is apparently harmless to plant and animal life.

Alternative Sources

Though aluminum is very important in industry and daily-life applications, it can be replaced by other commodities if necessary. For instance, copper can replace aluminum in electrical applications. Paper, plastics and glass make good packaging alternatives. Magnesium, titanium and steel can be used in vehicles and other forms of ground and air transportation.

Unless energy costs should rise steeply, the use of aluminum in most of these applications is not likely to be seriously threatened. Worldwide sources of bauxite are large enough to supply the demand for aluminum for some time to come.

BARITE

MII Photos

Barite on Fluorite

Barium: Used as a heavy additive in oil-well-drilling mud, in the paper and rubber industries, as a filler or extender in cloth, ink, and plastics products, in radiography (“barium milkshake”), as getter (scavenger) alloys in vacuum tubes, deoxidizer for copper, lubricant for anode rotors in X-ray tubes, spark-plug alloys. Also used to make an expensive white pigment.

Background

Barite is a mineral composed of barium sulfate, $BaSO_4$. It is usually colorless or milky white, but can be almost any color, depending on the impurities trapped in the crystals during their formation. Barite is relatively soft, measuring 3-3.5 on Mohs' scale of hardness. It is unusually heavy for a non-metallic mineral. The high density is responsible for its value in many applications. Barite is chemically inert and insoluble.

Name

Barite (spelled *baryte* in British publications) was named from the Greek word *baros* which means *weighty*, a reference to its unusually high specific gravity. (Specific gravity is a mineralogist's measure of the density of a mineral; this is done by comparing the weight of the mineral to the weight of an equal volume of water.)

Sources

Most barite is mined from layers of sedimentary rock which formed when barite precipitated onto the bottom of the ocean. Some smaller mines utilize barite from veins, which formed when barium sulfate was precipitated from hot subterranean waters. In some cases, barite is a by-product of mining lead, zinc, silver, or other metal ores.

There are nine barite mines in the United States; in Nevada, Georgia, Tennessee, and Missouri. China produces nearly ten times as much barite as the U.S., and India also produces more. About 40 other countries are also producers.

Many barite deposits are known worldwide, but some are uneconomic because barite can be mined more cheaply in China.

Uses

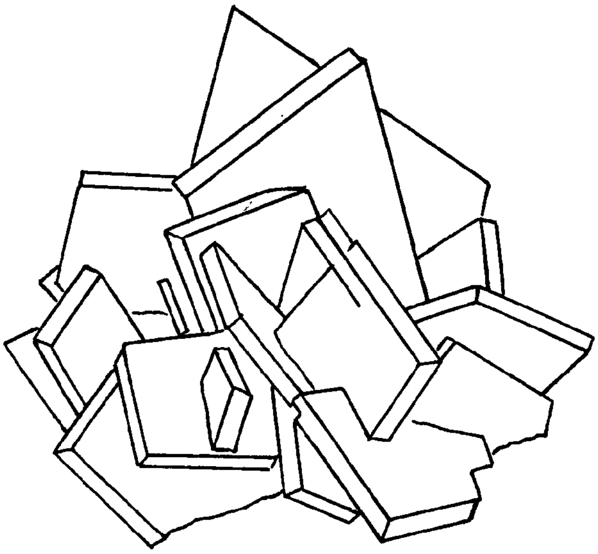
By far, the principal use for barite is as a "weighting agent" in oil and natural gas drilling. In this process, barite is crushed and mixed with water and other materials. It is then pumped into the drill hole. The weight of this mixture counteracts the force of the oil and gas when it is released from the ground. This allows the oil and gas rig operators to prevent the explosive release of the oil and gas from the ground. Currently, the majority of barite consumption in the United States is for this drilling application. However, the consumption in drilling "mud" fluctuates from year to year, as it is dependent on the amount of exploration drilling for oil and gas, which in turn depends on oil and gas prices.

Beyond this, barite is used as an additive to paints, enamels, and plastics, in the production of so-called "lead" crystal or "leaded" glass, stops radiation from computer monitors and television tubes, and as the source of barium chemicals.

Barite has the unique ability to strongly absorb X-rays and gamma rays. Consequently, it is used in medical science for special X-ray tests on the intestines and colon. It is also mixed with cement to make special containers used to store radioactive materials. A more recent application of barite is in the production of brake pads and clutches for cars and trucks.

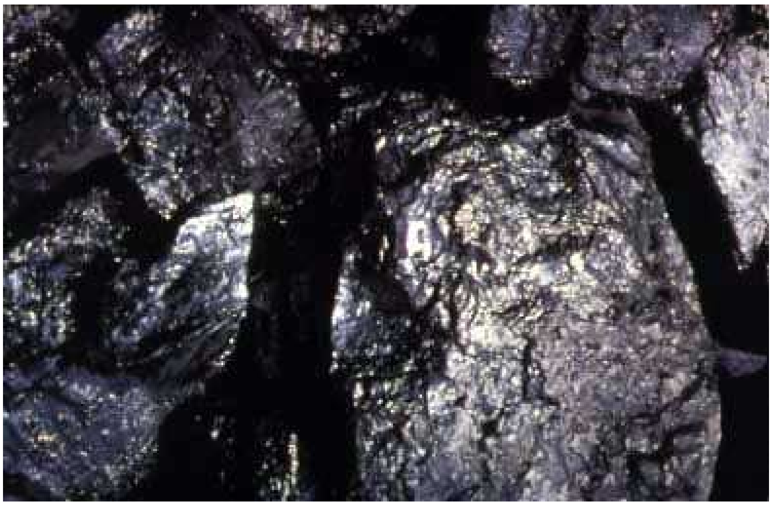
Substitutes and Alternative Sources

Possible substitutes for barite, especially in the oil drilling industry, include other similar minerals, such as *celestite* (strontium sulfate, $SrSO_4$) and iron ore. A German company is producing synthetic iron ore (*hematite*) which is proving a good substitute for barite. However, these alternatives have yet to be widely used in the oil industry, and barite continues to be the preferred commodity for this application as long as barite production remains strong.



Barite crystal drawings by
Darryl Powell
© 1999 Darryl Powell
Used with permission.

COAL



Coal: One of the world’s major sources of energy. In the United States, coal provides approximately 23% of all the energy consumed. Coal is used to produce more than half of all the electrical energy that is generated and used in the United States. Coal is a very complex and diverse energy resource that can vary greatly, even within the same deposit. In general, there are four basic varieties of coal, which are the result of geologic forces having altered plant material in different ways. These varieties descended from the first stage in the formation of coal: the creation of peat or partially decomposed plant material.

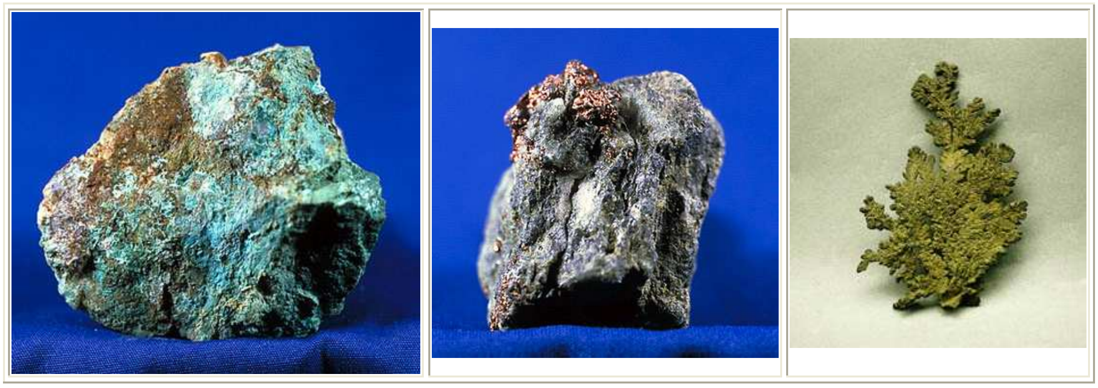
MII Photos

Lignite: Increased pressures and heat from overlying strata causes buried peat to dry and harden into lignite. Lignite is a brownish-black coal with generally high moisture and ash content and lower heating value. However, it is an important form of energy for generating electricity. Significant lignite mining operations are located in Texas, North Dakota, Louisiana, and Montana.

Subbituminous Coal: Under still more pressure, some lignite was changed into the next rank of coal subbituminous. This is a dull black coal with a higher heating value than lignite that is used primarily for generating electricity and for space heating. Most subbituminous reserves are located in Montana, Wyoming, Colorado, New Mexico, Washington and Alaska.

Bituminous Coal: Even greater pressure results in the creation of bituminous, or “soft” coal. This is the type most commonly used for electric power generation in the U.S. It has a higher heating value than either lignite or subbituminous, but less than that of anthracite. Bituminous coal is mined chiefly in Appalachia and the Midwest. Also used to make coke.	
Anthracite: Sometimes also called “hard coal,” anthracite forms from bituminous coal when great pressures developed in folded rock strata during the creation of mountain ranges. This occurs only in limited geographic areas - primarily the Appalachian region of Pennsylvania. Anthracite has the highest energy content of all coals and is used for space heating and generating electricity.	

COPPER



Copper: Used in electric cables and wires, switches, plumbing, heating, roofing and building construction, chemical and pharmaceutical machinery, alloys (brass, bronze, and a new alloy with 3% beryllium that is particularly vibration resistant), alloy castings, electroplated protective coatings and undercoats for nickel, chromium, zinc, etc., and cooking utensils. The leading producer is Chile, followed by the U.S., and Indonesia

Background

It is believed the Egyptians (as early as 3900 B.C.E.) were the first people to create bronze, a mixture of copper and tin. This marked the beginning of the Bronze Age.

Modern culture and life is heavily dependent on copper and copper products. It is a metal that has the desirable physical properties of being *malleable* and *ductile*. *Malleable* means it can be hammered and molded into shapes; *ductile* means it can be drawn into wire. As a result, copper pipes are used to bring water to and through our buildings. Because it is such a good conductor of electricity, millions of miles of copper wire crisscross the landscape and run through our buildings. Copper alloys (such as brass) are important components in many household products and machines. It has been said that the amount of copper a society consumes is a direct indicator of the advancement of that society. In other words, those societies that consume larger amounts of copper are considered more technologically developed.

Copper ore may be found in large deposits, relatively close to the surface, and amenable to relatively low cost bulk mining methods. The combination of its physical properties, abundance, and low cost make it a valuable commodity.

Copper is a mineral. As a mineral, natural copper (also called *native copper*) is relatively rare. Most copper in nature is found in minerals associated with sulfur, or in the oxidized products of these minerals.

Copper also easily combines with a number of other elements and ions to form a wide variety of copper minerals and ores. Copper minerals occurring in deposits large enough to mine include azurite ($Cu3(CO3)2(OH)2$), malachite ($Cu2CO3(OH)2$), tennantite ($(Cu,Fe)12As4S13$), chalcopyrite ($CuFeS2$), and bornite ($Cu5FeS4$).

Name

Copper was named from the Greek word *kyprios*, that is, the Island of Cyprus, where copper deposits were mined by the ancients. The chemical symbol for copper is Cu which is derived from the Latin name for copper, *cuprium*.

Sources

The amount of copper believed to be accessible for mining on the Earth's land is 1.6 billion tons. In addition, it is estimated that 0.7 billion tons of copper is available in deep-sea nodules. Mineral-rich nodules of magnesium, copper and other metals are known to form as a product of deep-sea volcanic activity. Retrieving these nodules from the sea floor is as yet too expensive to allow this to be a major source of copper.

Of the copper ore mined in the United States, the majority is produced in three western states: Arizona, Utah, and New Mexico.

Other major copper producing nations include Australia, Canada, Chile, China, Mexico, Russia, Peru, and Indonesia.

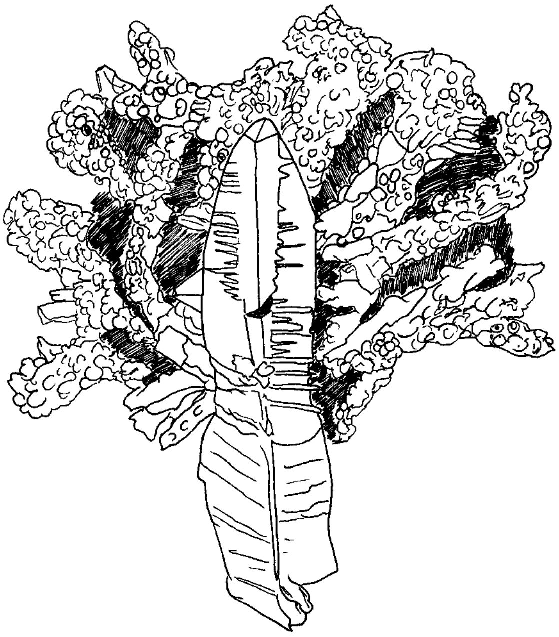
Recycled copper, predominantly from scrap metal, supplies approximately one-third of the United States' annual copper needs.

Uses

In pure form, copper is drawn into wires or cables for power transmission, building wiring, motor and transformer wiring, wiring in commercial and consumer electronics and equipment; telecommunication cables; electronic circuitry; plumbing, heating and air conditioning tubing; roofing, flashing and other construction applications; electroplated coatings and undercoats for nickel, chrome, zinc, etc.; and miscellaneous applications. As an alloy with tin, zinc, lead, etc. (brass and bronze), it is used in extruded, rolled or cast forms in plumbing fixtures, commercial tubing, electrical contacts, automotive and machine parts, decorative hardware, coinage, ammunition, and miscellaneous consumer and commercial uses. Copper is an essential micronutrient used in animal feeds and fertilizers.

Substitutes and Alternative Sources

A number of plastic products are used now instead of copper pipes. The telecommunications industry is using fiber optic cables in place of copper wires, and the invention of cellular and satellite telephone technology allows many areas of the world to have communications without the need to install “copper telephone wires.” Aluminum can be used instead of copper for wires, refrigeration tubing, and electrical equipment.



Copper crystal from Tsumeb, Namibia.

Drawing by Darryl Powell

IRON ORE
Hematite, Magnetite & Taconite

Iron Ore: About 98% of iron ore is used to make steel - one of the greatest inventions and most useful materials ever created. While the other uses for iron ore and iron are only a very small amount of the consumption, they provide excellent examples of the ingenuity and the multitude of uses that man can create from our natural resources. Powdered iron: used in metallurgy products, magnets, high-frequency cores, auto parts, catalyst. Radioactive iron (iron 59): in medicine, tracer element in biochemical and metallurgical research. Iron blue: in paints, printing inks, plastics, cosmetics (eye shadow), artist colors, laundry blue, paper dyeing, fertilizer ingredient, baked enamel finishes for autos and appliances, industrial finishes. Black iron oxide: as pigment, in polishing compounds, metallurgy, medicine, magnetic inks, in ferrites for electronics industry. Major producers of iron ore include Australia, Brazil, China, Russia, and India.

Magnetite

Hematite

Goethite

Limonite

MII Photos

Background

Iron (Fe) is a metallic element and composes about 5% of the Earth's crust. When pure it is a dark, silvery-gray metal. It is a very reactive element and oxidizes (rusts) very easily. The reds, oranges and yellows seen in some soils and on rocks are probably iron oxides. The inner core of the Earth is believed to be a solid iron-nickel alloy. Iron-nickel meteorites are believed to represent the earliest material formed at the beginning of the universe. Studies show that there is considerable iron in the stars and terrestrial planets: Mars, the "Red Planet," is red due to the iron oxides in its crust.

Iron is one of the three naturally magnetic elements; the others are cobalt and nickel. Iron is the most magnetic of the three. The mineral *magnetite* (Fe_3O_4) is a naturally occurring metallic mineral that is occasionally found in sufficient quantities to be an ore of iron.

The principle ores of iron are Hematite, (70% iron) and Magnetite, (72 % iron). Taconite is a low-grade iron ore, containing up to 30% Magnetite and Hematite.

Hematite is iron oxide (Fe_2O_3). The amount of hematite needed in any deposit to make it profitable to mine must be in the tens of millions of tons. Hematite deposits are mostly sedimentary in origin, such as the banded iron formations (BIFs). BIFs consist of alternating layers of chert (a variety of the mineral quartz), hematite and magnetite. They are found throughout the world and are the most important iron ore in the world today. Their formation is not fully understood, though it is known that they formed by the chemical precipitation of iron from shallow seas about 1.8-1.6 billion years ago, during the Proterozoic Eon.

Taconite is a silica-rich iron ore that is considered to be a low-grade deposit. However, the iron-rich components of such deposits can be processed to produce a concentrate that is about 65% iron, which means that some of the most important iron ore deposits around the world were derived from taconite. Taconite is mined in the United States, Canada, and China.

Iron is essential to animal life and necessary for the health of plants. The human body is 0.006% iron, the majority of which is in the blood. Blood cells rich in iron carry oxygen from the lungs to all parts of the body. Lack of iron also lowers a person's resistance to infection.

Name

The name *iron* is from an Old English word *isaern* which itself can be traced back to a Celtic word, *isarnon*. In time, the "s" was dropped from usage.

Sources

It is estimated that worldwide there are 800 billion tons of iron ore resources, containing more than 230 billion tons of iron. It is estimated that the United States has 110 billion tons of iron ore representing 27 billion tons of iron. Among the largest iron ore producing nations are Russia, Brazil, China, Australia, India and the USA. In the United States, great deposits are found in the Lake Superior region. Worldwide, 50 countries produce iron ore, but 96% of this ore is produced by only 15 of those countries.

Iron ore is the raw material used to make pig iron, which is one of the main raw materials to make steel. Due to the lower cost of foreign-made steel and steel products, the steel industry in the United States has had difficult economic times in recent years as more and more steel is imported. Canada provides about half of the U.S. imports, Brazil about 30%, and lesser amounts from Venezuela and Australia. 99% of steel exported from the USA was sent to Canada.

Uses

In the United States, almost all of the iron ore that is mined is used for making steel. The same is true throughout the world. Raw iron by itself is not as strong and hard as needed for construction and other purposes. So, the raw iron is alloyed with a variety of elements (such as tungsten, manganese, nickel, vanadium, chromium) to strengthen and harden it, making useful steel for construction, automobiles, and other forms of transportation such as trucks, trains and train tracks.

While the other uses for iron ore and iron are only a very small amount of the consumption, they provide excellent examples of the ingenuity and the multitude of uses that man can create from our natural resources.

Powdered iron: used in metallurgy products, magnets, high-frequency cores, auto parts, catalyst. Radioactive iron (iron 59): in medicine, tracer element in biochemical and metallurgical research. Iron blue: in paints, printing inks, plastics, cosmetics (eye shadow), artist colors, laundry blue, paper dyeing, fertilizer ingredient, baked enamel finishes for autos and appliances, industrial finishes. Black iron oxide: as pigment, in polishing compounds, metallurgy, medicine, magnetic inks, in ferrites for electronics industry.

Substitutes and Alternative Sources

Though there is no substitute for iron, iron ores are not the only materials from which iron and steel products are made. Very little scrap iron is recycled, but large quantities of scrap steel are recycled. Steel's overall recycling rate of more than 67% is far higher than that of any other recycled material, capturing more than 1-1/4 times as much tonnage as all other materials combined.

Some steel is produced from the recycling of scrap iron, though the total amount is considered to be insignificant now. If the economy of steel production and consumption changes, it may become more cost-effective to recycle iron than to produce new from raw ore.

Iron and steel face continual competition with lighter materials in the motor vehicle industry; from aluminum, concrete, and wood in construction uses; and from aluminum, glass, paper, and plastics for containers.

LITHIUM

Lithium: Lithium compounds are used in ceramics and glass, in primary aluminum production, in the manufacture of lubricants and greases, rocket propellants, vitamin A synthesis, silver solders, underwater buoyancy devices, batteries.

Spodumene Photo from MII, courtesy of the Smithsonian Institution

Lithic Sandstone
MII Photo

Background

Lithium, the lightest metal, is in a group of elements called i>alkali metals or *Group I elements*, it has the atomic number of 3. This group includes lithium (Li), potassium (K), and sodium (Na). The three alkali metals are highly reactive with oxygen and water, so they are stored in oil. Although lithium will react dramatically when put in water, it is the least reactive alkali metal. When it reacts with water it bounces on the top of the water because it is lighter than water.

The metal lithium is a silvery-white; petalite is found in the minerals spodumene, lepidolite mica, and amblygonite.

Johan A. Arfvedson, of Stockholm, Sweden, first discovered lithium in 1817. It was first isolated by W.T. Brande and Humphrey Davy in the 19th century, but it was not commercially produced until 1923.

Name

The name *lithium* comes from the Greek word *lithos* which means *stone* because lithium was first discovered in rocks and other two alkali metals were first discovered in plants. Lithium was first found in the mineral called petalite

($LiAl(Si_2O_5)_2$, lithium aluminum silicate).

Sources

Some lithium is recovered from the mineral spodumene. Commercial quantities of spodumene are in a special igneous rock deposit that geologists call a *pegmatite*.. In pegmatites, the liquid rock (magma) cools so slowly that crystals have time to grow very large. The largest spodumene crystal ever found was found in a pegmatite in South Dakota.

Most lithium is recovered from *brine*, or water with a high concentration of lithium carbonate. Brines trapped in the Earth's crust (called subsurface brines) are the major source material for lithium carbonate. These sources are less expensive to mine than from rock such as spodumene, petalite, and other lithium-bearing minerals.

It is estimated that the United States has approximately 760,000 tons of lithium. The resources in the rest of the world are estimated to be 12 million tons. The United States is the world's leading consumer of lithium and lithium compounds. The leading producers and exporters of lithium ore materials are Chile and Argentina. China and Russia have lithium ore resources, but it is presently cheaper for these countries to import this material from Chile than to mine their own.

Uses

More than one-half of the lithium compounds consumed are used in the manufacture of glass, ceramics, and aluminum. Lithium is also used in making synthetic rubber, greases and other lubricants.

Lithium batteries are proving to be an effective and affordable alternative to traditional batteries, and also in new battery applications.

Lithium is mixed with other light metals such as aluminum and magnesium to form strong, light-weight alloys (an *alloy* is a mixture of metals).

Some lithium, in the form of lithium carbonate or lithium citrate, is used as medicine to treat gout (an inflammation of joints) and to treat serious mental illness.

Substitutes and Alternative Sources

Potassium compounds can be used in glass and ceramic production. Greases can be made using calcium soaps, for example, in place of lithium compounds. In some cases, glass, polymers and resins can be used in place of aluminum-lithium alloys. Zinc, magnesium, nickel and cadmium, and even mercury, can be used to make batteries in place of lithium. (It must be noted that mercury is being phased out of use due to the fact it is so poisonous.)

MOLYBDENUM

Molybdenum: The two largest uses of molybdenum are as an alloy in stainless steels and in alloy steels- these two uses consume about 60% of the molybdenum needs in the United States. Stainless steels include the strength and corrosion-resistant requirements for water distribution systems, food handling equipment, chemical processing equipment, home, hospital, and laboratory requirements. Alloy steels include the stronger and tougher steels needed to make automotive parts, construction equipment, gas transmission pipes. Other major uses as an alloy include tool steels, for things like bearings, dies, machining components, cast irons, for steel mill rolls, auto parts, crusher parts, super alloys for use in furnace parts, gas turbine parts, chemical processing equipment. Molybdenum also is an important material for the chemicals and lubricant industries. Moly has uses as catalysts, paint pigments, corrosion inhibitors, smoke and flame retardants, dry lubricant (molybdenum disulfide) on space vehicles and resistant to high loads and temperatures. As a pure metal, molybdenum is used because of its high melting temperatures (4,730 F) as filament supports in light bulbs, metal-working dies and furnace parts. Major producing countries are China, Chile, and the U.S.

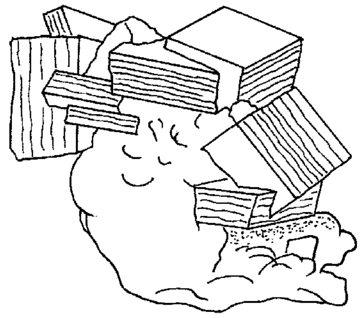
 Molybdenite	 Wulfenite - Lead Molybdate	 Molybdenite Photo from MII, courtesy of the Smithsonian Institution

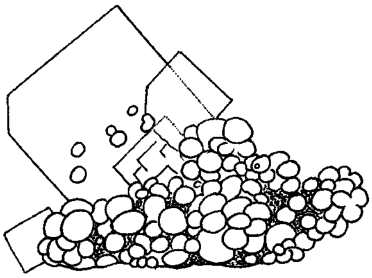
MII Photos

Background

Molybdenum is a metallic, silvery-white element, with an atomic number of 42. Its chemical symbol is Mo. Chemically, it is very stable, but it will react with acids. The physical characteristic that makes molybdenum unique is that it has a very high melting point, 4,730 degrees Fahrenheit. This is 2,000 degrees higher than the melting point of steel. It is 1,000 degrees higher than the melting temperature of most rocks. It has the fifth highest melting point of all of the elements.

Molybdenite (MoS_2, molybdenum sulfide) is the major ore mineral for molybdenum (sometimes called *moly* for short). It is rarely found as crystals, but is commonly found as what mineralogists describe as foliated masses. This means the mineral forms *folia* or layers, like the mineral mica. It is metallic gray, has a greasy feel, and is very soft at only 1 on Mohs' hardness scale. Its softness, metallic luster and gray color led scientists to mistakenly believe it was a lead mineral. Geologically, molybdenite forms in high-temperature environments such as in igneous rocks. Some molybdenite forms when igneous bodies contact rock and metamorphose, or change, the rock. This is called *contact metamorphism*.





Molybdenum is also found in the mineral *wulfenite* (Pb(MoO$_4$), lead molybdate). Wulfenite forms colorful, bright orange, red, and yellow crystals. They can be blocky or so thin that they are transparent. The two drawings here illustrate these two mineral *habits*. (*Habit* is a description of the form in which a particular mineral has grown.)

Molybdenum is a needed element in plants and animals. In plants, for example, the presence of molybdenum in certain enzymes allows the plant to absorb nitrogen. Soil that has no molybdenum at all cannot support plant life.

Molybdenum was discovered by the Swedish scientist, Peter Hjelm in 1781, three years after Carl Scheele proposed that a previously unknown element could be found in the mineral molybdenite.

Name

In 1778, Swedish chemist Carl William Scheele was studying, what he thought was lead, in the mineral *molybdenite*. Molybdenite was named after the Greek word *molybdos*, which means *lead*. Sheele's studies led him to the conclusion that this mineral did not contain lead, but some other element. He named this new element *molybdenum* after the mineral molybdenite. (As an aside, the mineral *scheelite* (Ca(WO$_4$,MoO$_4$), calcium tungstate-molybdate) was named after Scheele in honor of his discovery of molybdenum.)

Sources

The most important ore source of molybdenum is the mineral molybdenite. A minor amount is recovered from the mineral wulfenite. Some molybdenum is also recovered as a by-product or co-product from copper mining.

The United States produces significant quantities of molybdenite from mines in Colorado, New Mexico, and Idaho. Other mines in Arizona, New Mexico, Montana, and Utah produce molybdenum as a by-product. The largest molybdenum resource in the U.S. is in Climax, Colorado. It is estimated that there are 5.5 million metric tons of molybdenum in the United States. It is probable there are more molybdenum resources in the U.S. yet to be discovered.

There are significant molybdenum resources around the world. The leading producers are Canada, China, Chile, Mexico, Peru, Russia and Mongolia. It is estimated that there are 12 million metric tons of molybdenum in the world. Other ore deposits may be discovered.

Uses

Molybdenum is alloyed with steel making it stronger and more highly resistant to heat because molybdenum has such a high melting temperature. The alloys are used to make such things as rifle barrels and filaments for light bulbs. The iron and steel industries account for more than 75% of molybdenum consumption.

The two largest uses of molybdenum are as an alloy in stainless steels and in alloy steels- these two uses consume about 60% of the molybdenum needs in the United States. Stainless steels include the strength and corrosion-resistant requirements for water distribution systems, food handling equipment, chemical processing equipment, home, hospital, and laboratory requirements. Alloy steels include the stronger and tougher steels needed to make automotive parts, construction equipment, gas transmission pipes.

Other major uses as an alloy include: Tool steels, for things like bearings, dies, machining components; cast irons, for steel mill rolls, auto parts, crusher parts; super alloys for use in furnace parts, gas turbine parts, chemical processing equipment.

Molybdenum also is an important material for the chemicals and lubricant industries. Molybdenum has uses as catalysts, paint pigments, corrosion inhibitors, smoke and flame retardants, dry lubricant (molybdenum disulfide) on space vehicles and resistant to high loads and temperatures. As a pure metal, molybdenum is used because of its high melting temperatures (4,730 F.) as filament supports in light bulbs, metal-working dies and furnace parts. Molybdenum cathodes are used in special electrical applications. It can also be used as a catalyst in some chemical applications.

General uses for molybdenum are in machinery (35%), for electrical applications (15%), in transportation (15%), in chemicals (10%), in the oil and gas industry (10%), and assorted others (15%).

Substitutes and Alternative Sources

Possible substitutes for molybdenum as a strengthening alloy in steel include vanadium, chromium, columbium, and boron. However, such substitution is not presently practiced since molybdenum is plentiful, affordable, and effective.

Wulfenite drawings used with permission.

POTASH

Potash: Usually chloride of potassium. Used as a fertilizer, in medicine, in the chemical industry, and is used to produce decorative color effects on brass, bronze, and nickel. Can also be potassium sulfate, potassium-magnesium sulfate, and potassium nitrate. Is an essential mineral for vegetable and animal life.

Potash Feldspar -- *MII Photo*

SILICON or SILICA

Silica (chemical name for the mineral quartz and a synonym for silicon dioxide): Used in manufacture of special steels and cast iron, aluminum alloys, glass and refractory materials, ceramics, abrasives, water filtration, component of hydraulic cements, filler in cosmetics, pharmaceuticals, paper, insecticides, rubber reinforcing agent - especially for high adhesion to textiles, anti-caking agent in foods, flatting agent in paints, thermal insulator. Fused silica is used as an ablative material in rocket engines, spacecraft, silica fibers used in reinforced plastics.

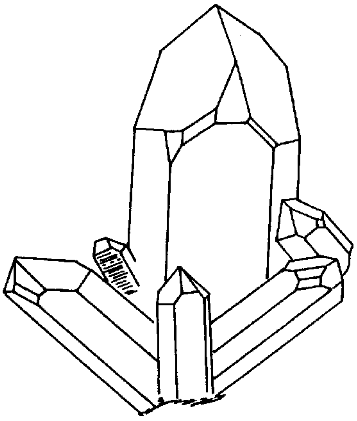
Quartz Crystal Photo from MII, courtesy of the Smithsonian Institution

Background

Silicon is the second most common element in the Earth's crust, comprising 25.7% of the Earth’s crust by weight. It was discovered in 1824 by the Swedish chemist Jons Jakob Berzelius. It is shiny, dark gray with a tint of blue. Silicon, atomic number of 14, is a semi-metallic or metalloid, because it has several of the metallic characteristics. Silicon is never found in its natural state, but rather in combination with oxygen as a silicate ion (SiO_4) in silica-rich rocks such as obsidian, granite, diorite, and sandstone. Feldspar and quartz are the most significant silicate minerals. Silicon alloys with a variety of metals, including iron, aluminum, copper, nickel, manganese and ferrochromium.

Silica is processed into two intermediate products- silicon and ferrosilicon. Silicon is known in the ferroalloy and chemical industries as “silicon metal.” The ultra pure form of silicon (>99.99% Si) is distinguished from silicon metal by the term “semiconductor-grade silicon.” The terms “silicon metal” and “silicon” are used interchangeably.

Silicon is used in ceramics and in making glass. Ferrosilicon is crushed into a variety of forms and sold as bulk metal. Depending on its intended use, it can be mixed with aluminum and calcium. It is a very heavy alloy. When it comes into contact with moist air or water, an explosive chemical reaction occurs in which hydrogen is released. Consequently there are very strict laws about the shipping of ferrosilicon it must be kept perfectly clean and dry.



<= A quartz crystal from Arkansas. Used with permission. © 1999 Darryl Powell.

Silicon is considered a semiconductor. This means that it conducts electricity, but not as well as a metal such as copper or silver. This physical property makes silicon an important commodity in the computer manufacturing business.

Ferrosilicon accounts for 53% of the annual silicon consumption in the United States; pure silicon accounts for the remaining 47%.

Silica is in human connective tissues, bones, teeth, skin, eyes, glands and organs. It is a major constituent of collagen which helps keep our skin elastic, and it helps calcium in maintaining bone strength. Silica dust in mines has caused silicosis or a lung disease in miners. Wetting the area being mined and application of good ventilation has reduced the danger of lung disease. Some organisms like sponges and some plants use silicon to create structural support.

Name

The name *silicon* comes from the Latin word *silicis* which means *flint*.

Sources

Silicon compounds are the most significant component of the Earth's crust. Silicon is recovered from an abundant resource: sand. Most pure sand is quartz, silicon dioxide (SiO_2). Since sand is plentiful, easy to mine and relatively easy to process, it is the primary ore source of silicon. Some silicon is also retrieved from two other silicate minerals, talc and mica. The metamorphic rock, quartzite, is another source (quartzite is metamorphosed sandstone). All combined, world resources of silicon are plentiful and will supply demand for many decades to come.

The United States has plentiful sand, quartzite, talc and mica resources. The majority of the silica produced in the U.S. is produced East of the Mississippi River and in the Northwest. The U.S. also imports silicon from Norway, Russia, Brazil, Canada, and from a number of other countries.

Uses

Ferrosilicon alloys are used to improve the strength and quality of iron and steel products. Tools, for instance, are made of steel and ferrosilicon.

In addition to tool steels, an example of "alloy steels," ferrosilicon is used in the manufacture of stainless steels, carbon steels, and other alloy steels (e.g., high-strength, low-alloy steels, electrical steels, and full-alloy steels).

An alloy steel refers to all finished steels other than stainless and carbon steels. Stainless steels are used when superior corrosion resistance, hygiene, aesthetic, and wear-resistance qualities are needed.

Carbon steels are used extensively in suspension bridges and other structural support material, and in automotive bodies, to name a few. Silicon is also added to aluminum to create a stronger alloy. The largest consumers of silicon metal are the aluminum and chemical industries.

Silicon is used in the aluminum industry to improve castability and weldability, not to add strength as noted in the text. Silicon-aluminum alloys tend to have relatively low strength and ductility, so other metals, especially magnesium and copper, are often added to improve strength.

In the chemicals industry, silicon metal is the starting point for the production of silianes, silicones, fumed silica, and semiconductor-grade silicon. Silanes are the used to make silicone resins, lubricants, anti-foaming agents, and water-repellent compounds. Silicones are used as lubricants, hydraulic fluids, electrical insulators, and moisture-proof treatments.

Semiconductor-grade silicon is used in the manufacture of silicon chips and solar cells. Fumed silica is used as a filler in the cement and refractory materials industries, as well as in heat insulation and filling material for synthetic rubbers, polymers and grouts.

Other silicon materials are used in the production of advanced ceramic materials, including silicon carbide, silicon nitride, and sialons. Silicon carbide is also used as an abrasive material, a refractory agent, and in steel manufacturing.

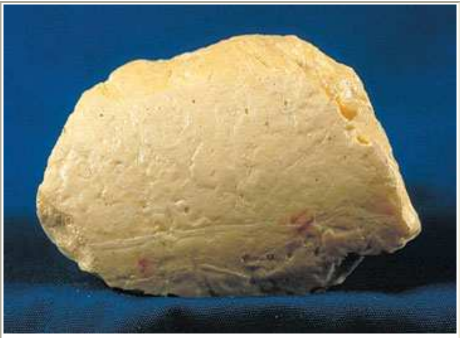
Substitutes and Alternative Sources

There are relatively few options to replace silicon in its applications. Germanium and gallium arsenide can be used as semiconductors in place of silicon. In some applications, a small number of metal alloys, such as silicomanganese and aluminum, can substitute for ferrosilicon.

SULFUR

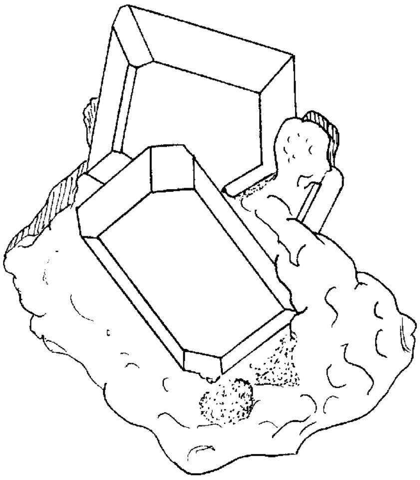
Sulfur: Used in the manufacture of sulfuric acid, fertilizers, chemicals, explosives, dyestuffs, petroleum refining, vulcanization of rubber, fungicides.

Sulfur Photo from MII, courtesy of the Smithsonian Institution



Sulfur Crystal

MII Photo



Background

The bright, lemon yellow, non-metallic element, sulfur, is a very soft mineral. It is only 2 on Mohs' scale of hardness. Sulfur was determined to be an element in 1809. Sulfur has a very low thermal conductivity meaning it cannot transfer heat very well. The touch of a hand will cause a sulfur crystal to crack because the crystal’s surface warms faster than the interior. Sulfur melts at 108 degrees Celsius, and burns easily with a blue flame. Even the flame of a match is enough to set sulfur on fire. When sulfur is burned it combines with oxygen producing sulfur dioxide, SO_2, which smells like rotten eggs.

Sulfur attaches to metal ions, creating a number of significant sulfide ore minerals such as galena (lead sulfide), pyrite (iron sulfide), chalcocite (copper sulfide), and sphalerite (zinc sulfide).

Sulfur easily attaches to oxygen, creating the sulfate ion (SO_4). Sulfates are another significant group of minerals, some of which are important commodities. Gypsum (hydrous calcium sulfate) and barite (barium sulfate) are two commodities that include sulfur.

In the late 1800's, Herman Frasch developed a process for removing sulfur from underground deposits. This is still known as the Frasch process. In this process, hot water is forced into the sulfur deposit. The sulfur melts and is pushed to the surface where it is collected and allowed to cool and solidify, or shipped in molten form.

Name

Sulfur (also spelled *sulphur*) is derived from the Latin name for this element, *sulphurium*. It means "burning stone" in reference to its source from volcanoes and that it burns so easily.

Sources

Mined sulfur is mostly from salt domes or bedded deposits. The vast majority is produced as a by-product of oil refining and natural gas processing.

Uses

The majority of the sulfur produced in the United States is used to make sulfuric acid. Sulfuric acid has multiple uses in the production of chemicals, petroleum products and a wide range of other industrial applications. Sulfur's main use is in making chemicals for agriculture, mostly for fertilizers. Other uses of sulfur include refining petroleum, metal mining, and the production of organic and inorganic chemicals. A multitude of products (such as the production of rubber for automobile tires) require sulfur in one form or another during some stage of their manufacture.

Substitutes and Alternative Sources

There are no good alternatives for sulfur. Fortunately, the variety of sulfur resources in different fossil fuel deposits, as well as the large amount of sulfur contained in sedimentary gypsum, guarantees massive sulfur resources for future use. It is estimated that there are 600 billion tons of sulfur contained in oil shale, coal, and other sediments rich in organic matter but a cost-effective method of retrieving the sulfur has not yet been developed. The sulfur available in gypsum and anhydrite is described as being "limitless."

Sulfur crystal drawing used with permission.
©1999 Darryl Powell

RUTILE

Rutile: Titanium dioxide. Used in alloys, for electrodes in arc lights, to give a yellow color to porcelain and false teeth.

Rutile/Goethite Photo from MII, courtesy of the Smithsonian Institution


Goethite -- *MII Photo*

ANTIMONY


MII Photos


Stibnite Photo from MII,
courtesy of the Smithsonian Institution

Antimony: A native element, antimony metal is extracted from stibnite and other minerals. Antimony is used as a hardening alloy for lead, especially storage batteries and cable sheaths, also used in bearing metal, type metal, solder, collapsible tubes and foil, sheet and pipes, and semiconductor technology.

Stibnite: The sample in the photo contains 71.8 percent antimony and 28.2 percent sulfur. It is the most important ore for antimony. Stibnite is used for metal antifriction alloys, metal type, shot, batteries, in the manufacture of fireworks. Antimony salts are used in the rubber and textile industries, in medicine, and glassmaking.

Background

Antimony is a silvery-gray, brittle semi-metal with atomic number 51. It rarely occurs in nature as a native element, but is found in a number of different minerals, the most important of which is *stibnite* (SbS_3). Antimony is often called a semi-metal, because in pure form it is not shiny and malleable like true metals.

Antimony is not an element which most people see daily in a recognizable form. However, it is present in many products in everyday use. Antimony's moderate price allows it to be used in a wide variety of applications.

Antimony minerals, particularly stibnite, have been known and used since ancient times. Because it is so soft, stibnite was used in ancient times as black eye makeup. The Roman historian, Pliny, wrote about its use as a medicine. Artists used finely-ground stibnite in the Middle Ages as a black pigment. Ancient “scientists” were interested in antimony because of their belief that it may be useful in the process of changing common metals into gold. This field was known as *alchemy.*

Name

The ancients may have occasionally produced pure antimony from its ore stibnite, and medieval alchemists have left recipes for preparation of the pure metal. However, it was not actually recognized as a separate element until the mid-1400's, when chemistry as a science began to take shape. The French chemist, Nicolas Lemery, is known to have performed some of the earliest studies on antimony.

The name *antimony* is derived from the Greek words *anti* and *monos,* which together mean *not alone,* because it rarely occurs naturally in pure form. Its chemical symbol, Sb, is derived from the Latin word *stibium,* which was the name of the most common antimony mineral, stibnite.

Sources

Antimony rarely occurs in its native metallic form in nature. It easily combines with other elements, usually including sulfur, to form over 100 different minerals. Of these minerals, only stibnite (SbS_3) is mined commercially as a source for metallic antimony. Antimony is found in trace (that is, very minor) amounts in silver, copper and lead ores, and it is usually economically possible, as well as environmentally desirable, to extract the antimony from these ores when they are smelted.

Most of the antimony mined each year comes from China, which supplies over three-quarters of the world total. The remainder is from Russia, South Africa, Tajikistan, Bolivia, and a few other countries. Some antimony is produced as a by-product of smelting ores of other metals, mainly gold, copper and silver, in countries such as the United States, Canada, and Australia.

No mines are currently producing antimony ore in the U.S., but important amounts are yielded as a by-product of copper and silver mining. Numerous stibnite deposits occur in Idaho, Montana and Nevada, but most are worked out. Recycling of old lead-acid batteries (such as automobile batteries) contributes to U.S. antimony production.

Uses

The most important use of antimony in the United States is in chemicals used to impregnate plastics, textiles, rubber, and other materials as a flame retardant – that is, a form of fireproofing. This is required by federal law for certain childrens' clothing. Over half the annual U.S. antimony consumption is for the manufacture of flame retardants.

A portion of U.S. consumption is in antimony alloys. Antimony is mixed (that is, alloyed) with other metals, such as lead, to make the lead harder and stronger for use in lead-acid batteries. On the other hand, some alloys such as Babbitt Metal (an alloy of antimony, tin, copper, and sometimes lead) are useful as machine bearings because they are soft and slippery. Antimony is also alloyed with tin to make pewter items such as plates, pitchers and cups, used mostly for decoration. One use of antimony, which is declining, is to make type metal for printing newspapers and magazines. Antimony is one of very few substances (bismuth and water are two others) which expands when it cools and freezes. Antimony-bearing type metal thus fills every corner of a mold used to prepare sharp type for printing. With the advent of computer printing, this use has greatly decreased.

Antimony is also used for pigments in plastics, paints, rubber, and for a wide variety of minor uses, including medicines, fireworks, and others. Antimony oxide is a brilliant yellow color, accounting for much of the pigment use.

A tiny amount of highly purified antimony metal is used in the computer industry to make semiconductors. To be useful in this application, antimony has to be 99.999% pure!

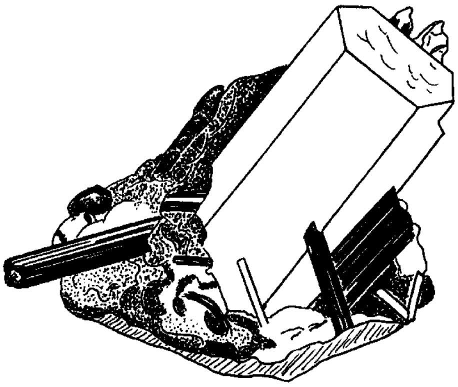
Substitutes

Antimony could be replaced by chromium, tin, zinc, and titanium compounds in the paint industry. Cadmium, sulfur, copper, and calcium can be used to harden lead. A number of organic compounds can be used as fire retardants. Recycling, mining, and smelter production will meet the demand for antimony and antimony compounds for many decades to come.

BERYL/BERYLLIUM

Beryllium: beryllium alloys are used mostly in applications in aerospace, automobiles, computers, oil and gas drilling equipment, and telecommunications. Beryllium salts are used in fluorescent lamps, in X-ray tubes and as a deoxidizer in bronze metallurgy. Beryl is the source of the gem stones emerald and aquamarine. Sample in photo contains 14 percent beryllium oxide.

MII Photo



Background

Beryllium is a metallic element, with atomic number 4 and atomic weight 9. The metal is hard, silvery-white in color, and very light – less than twice as dense as water, and only two-thirds as dense as aluminum, which it somewhat resembles. Beryllium has a very high melting point at 2349° F (1287° C). The combination of its light weight and high melting point make it valuable for making metal alloys.

Because of the toxic nature of beryllium, careful control over the quantity of dust and fumes in the workplace must be maintained.

A beryl crystal from Africa.
(Beryl crystal drawing © 2002 Darryl Powell. Used with permission.)

Name

Beryllium was not known to ancient or medieval civilizations, and was first recognized by the French scientist, Nicholas Louis Vauquelin in 1798. He discovered it as a component of the mineral *beryl*, and named it *beryllium*. Metallic beryllium was not isolated until 1828, by Friederich W˜hler in Germany.

Sources

The most common mineral containing beryllium is beryl, a silicate mineral with the chemical formula $Be_3Al_2Si_6O_{18}$. Beryl forms distinctive hexagonal prisms, and is found in the igneous rock granite and special igneous rocks, derived from granites, known as pegmatites. Colored, transparent varieties of beryl may be gems, such as emerald (green), aquamarine (blue-green), heliodor (yellow), and morganite (pink). In addition to being found in beryl, beryllium is found in the mineral *bertrandite* Be4Si2O7(OH)2, which in recent years has become a major ore of this element, in addition to beryl. Bertrandite is found in certain volcanic rocks derived from granite.

Bertrandite ore mined in Utah makes up nearly all of U.S. production, which is about two-thirds of the world supply. Russia produces most of the rest, from beryl ores. Five to ten other countries mine small amounts of beryl. The United States produces and exports large amounts of beryllium alloys and compounds, and thus is a net importer of ores, but a net exporter of finished beryllium products.

Small amounts of beryllium become available from recycling of beryllium-containing scrap.

Uses

Most beryllium is used in metal alloys, which account for more than 70% of world consumption.

Because beryllium is very light and has a high melting temperature, it is an ideal metal for use in the aerospace and defense industry, almost always alloyed with other metals. Beryllium metal also has the interesting characteristic of being elastic. Consequently, it is used in the manufacture of springs, gears and other machine components that need a degree of elasticity. Another everyday application is in the manufacture of gasoline pumps, because an alloy of copper and beryllium (beryllium bronze) does not spark when hit against other metals, nor emit sparks from static electricity.

Rods made of beryllium metal and oxide are used to control nuclear reactions, because beryllium absorbs neutrons better than any other metal.

Most organisms do not depend on beryllium for growth. In fact, beryllium dust and fumes can be dangerous to human health when inhaled. Consequently, the Clean Ar Act demands very careful handling of beryllium dust and fumes to minimize or eliminate its danger to humans.

Substitutes and Alternative Sources

In some applications, graphite, steel and titanium can be used in place of beryllium. However, it is a critical component of many military and aerospace applications, and even though it is expensive to produce (costing more than silver), it is not often replaced by other materials.

COBALT

 Cobaltite Photo from MII, Courtesy of Smithsonian Institution	**Cobalt**: Used in superalloys for jet engines, chemicals (paint driers, catalysts, magnetic coatings, pigments, rechargeable batteries), magnets, and cemented carbides for cutting tools. Principal cobalt producing countries include Democratic Republic of the Congo, Zambia, Canada, Cuba, Australia, and Russia. The United States uses about one-third of total world consumption. Cobalt resources in the United States are low grade and production from these deposits is usually not economically feasible.

Background

Cobalt is a bluish-gray, shiny, brittle metallic element. Its atomic number is 27 and its symbol is Co. It belongs to a group of elements called the *transition metals*. It has magnetic properties like iron.

Ancient civilizations in Egypt and Mesopotamia used a substance to color glass a beautiful deep blue. In 1735, the Swedish scientist Georg Brandt set out to prove that this color was due not to the element bismuth, as people believed, but to a new and unidentified element. He is credited with the discovery of this new element, which he named *cobalt*.

Cobalt is one of the elements that is very important to life, including human life and health. Vitamin B-12 contains cobalt. In areas where there is little cobalt in the soil, farmers have to provide salt blocks containing cobalt for their animals to lick in order to provide enough cobalt in their diet.

Cobalt is also found in iron-nickel meteorites.

Name

Cobalt was named after the German word *kobald* which means *goblin* or *evil spirit* believed to cause health problems for silver and copper miners.

Sources

It is estimated that there are about 1 million tons of cobalt in the United States. Minnesota has the largest resources, but other ore resources are found in Alaska, California, Idaho, Missouri, Montana and Oregon. The identified cobalt resources in the world total about 15 million tons. Most are found in Australia, Canada, Congo, Russia, and Zambia.

The ocean floor has nodules of metals that form when hot water from deep in the Earth comes into contact with the cold ocean water. These nodules are mostly manganese and so are called *manganese nodules*. It is estimated that there are millions of tons of cobalt in these nodules. Presently, we do not have the technology to retrieve these nodules at a reasonable cost.

All of the primary cobalt used in the U.S. is imported. Cobalt is imported into the United States in the form of cobalt metal, cobalt salts, and cobalt oxide. The imports come from Norway, Finland, Canada, Russia, and other nations.

Uses

Cobalt has been used by civilizations for centuries to create beautiful deep blue glass, ceramics, pottery and tiles. In a similar way, it is being used to make paint pigments.

In addition to these traditional uses, cobalt is used in a number of industrial applications. When cobalt is alloyed with other metals, very strong magnets are created. Superalloys containing cobalt are used in the production of jet engines and gas turbine engines for energy generation. These superalloys account for nearly half of the cobalt used each year. Some cobalt is used to make cutting and wear-resistant materials.

A manmade isotope of cobalt, cobalt-60, produces gamma rays. This is used for sterilization of medical supplies and foods, for industrial testing, and to fight cancer.

Substitutes and Alternative Sources

At times, cobalt prices rise significantly and there is concern about the amount of cobalt easily available around the world. As a result, industries have tried to conserve cobalt consumption. There are some replacements for cobalt, but they don't always work as well as cobalt. For example, nickel-iron or neodymium-iron-boron alloys can be used to make strong magnets. Nickel and special ceramics can be used to make cutting and wear-resistant materials. Nickel-base alloys containing little or no cobalt can be used in jet engines. Manganese, iron, cerium, or zirconium can be used in paint driers.

GYPSUM

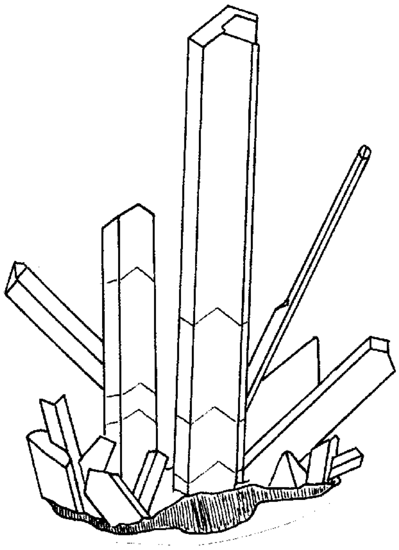
Gypsum: Processed and used as prefabricated wallboard or as industrial or building plaster, used in cement manufacture, agriculture and other uses.

Selenite
MII Photos


Rock Gypsum


Satin Spar Gypsum


Gypsum Photo from MII, courtesy of the Smithsonian Institution



Background

Gypsum is found in nature in mineral and rock form. As a mineral, it can form very pretty, and sometimes extremely large, crystals. As a rock, gypsum is a sedimentary rock, typically found in thick beds or layers. It forms in lagoons where ocean waters high in calcium and sulfate content can slowly evaporate and be regularly replenished with new sources of water. The result is the accumulation of large beds of sedimentary gypsum. Because it is deposited in this environment, it is common for gypsum to be associated with rock salt and sulfur deposits.

Gypsum belongs to a group of minerals called the sulfates, and is the most common of the approximately 150 sulfate minerals. Sulfates are compounds of one or more metals with oxygen and sulfur. The oxygen and sulfur join together to form the sulfate ion, SO_4^{-2}. Technically, gypsum is *hydrous calcium sulfate* because it has water in its crystal structure, $CaSO_4.2H_2O$.

A secondary, and minor source, of raw calcium sulfate is the mineral *anhydrite*. Anhydrite is chemically very much like gypsum, but lacks the water molecule in its crystal structure. Its chemical formula is $CaSO_4$.

Gypsum is very soft at 2 on Mohs' hardness scale. It is so soft that a fingernail can easily scratch it. Gypsum crystals can be a number of attractive colors, ranging from completely colorless to tan and even green. Sedimentary gypsum is nearly always white or gray in color.

Sedimentary gypsum is the gypsum that is mined as a commodity.

Name

The mineral name *gypsum* is so old that it is not known who originated its use. It was derived from the Greek word *gypsos* which means *plaster*. Originally it referred to the form of gypsum which has been heated to a high temperature to drive off the water in its crystal structure; this is called *calcined* gypsum. This is called *Plaster of Paris*.

Sources

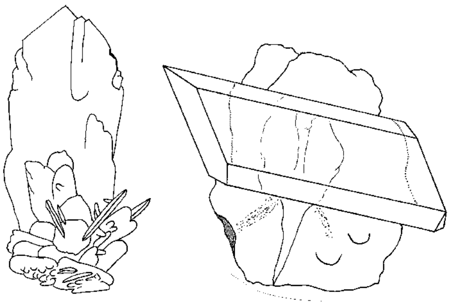
In the United States, gypsum is mined in about 19 states. The states producing the most gypsum are Oklahoma, Iowa, Nevada, Texas, and California. Together, these states account for about two-thirds of the United States' annual production of gypsum. Over 30 million tons of gypsum is consumed in the United States annually. Canada, Mexico and Spain are other significant producers of raw gypsum. In all, more than 90 countries produce gypsum.

Uses

The most significant use for gypsum is for wallboard and plaster products. All modern homes in North America and other developed countries use a great deal of wallboard for interior walls. The United States is the world's leading consumer of wallboard at over 30 billion square feet per year. Some gypsum is used to make Portland cement, and some is used in agricultural applications. A small amount of very pure gypsum is used in glass making and other specialized industrial applications.

Substitutes and Alternative Sources

Gypsum is a by-product of some industrial processes. Although mined gypsum will remain the primary source of this commodity for decades to come, about one-fourth of current gypsum production is provided as a by-product of some industrial processes. There is presently no substitute for gypsum in the production of Portland cement.



Drawings © 1999 Darryl Powell
Used with permission

KAOLIN

Kaolin: Also known as "china clay" is a white, aluminosilicate widely used in paints, refractories, plastics, sanitary wares, fiberglass, adhesives, ceramics, and rubber products.

MII Photos

Background

The term *clay* refers to a number of earthy materials that are composed of minerals rich in alumina, silica and water. Clay is not a single mineral, but a number of minerals. When most clays are wet, they become "plastic" meaning they can be formed and molded into shapes. When they are "fired" (exposed to very high temperatures), the water is driven off and they become as hard as stone. Clay is easily found all over the world. As a result, nearly all civilizations have used some form of clay for everything from bricks to pottery to tablets for recording business transactions.

The minerals that make up clay are so fine that until the invention of X-ray diffraction analysis, these minerals were not specifically known. Under extremely high magnification, one can see that clay minerals can be shaped like flakes, fibers, and even hollow tubes. Clays can also contain other materials such as iron oxide (rust), silica, and rock fragments. These impurities can change the characteristics of the clay. For example, iron oxide colors clay red. The presence of silica increases the plasticity of the clay (that is, makes it easier to mold and form into shapes).

Clays are categorized into six categories in industry. These categories are ball clay, bentonite, common clay, fire clay, fuller’s earth, and kaolin.

Name

Sources

Clays are common all over the world. Some regions, as might be expected, produce large quantities of specific types of clay. It is estimated that the state of Georgia has kaolin clay reserves of 5 to 10 billion tons. The United States is self-sufficient so it imports only small amounts of clay from Mexico, Brazil, United Kingdom, Canada, and assorted other nations. The United States exports nearly half of its production worldwide.

The nations producing the most significant amounts of the various clays are as follows:

- **Kaolin:** Brazil, United Kingdom, and the United States are the dominant producers of high quality kaolin.
- **Ball clays:** Major producers of ball clays are Germany, the United States, United Kingdom, the Czech Republic, China, and France.
- **Fire clays:** Major fire clay producing countries are Germany, and the United States.
- **Bentonite:** Major producers of bentonite are the United States, Germany, Turkey, and Greece.
- **Fuller's earth:** Major producers of fuller's earth are the United States (attapulgite, smectite), Spain (attapulgite, sepiolite), and Senegal (attapulgite).

Uses

The United States both imports and exports clays and clay products. It is estimated that the United States consumes about 37.6 million tons of clays each year.

Ball clays are good quality clays used mostly in pottery but are also added to other clays to improve their plasticity. Ball clays are not as common as other clay varieties. One third of the ball clay used annually is used to make floor and wall tiles. It is also used to make sanitary ware, pottery, and other uses.

Bentonite is formed from the alteration of volcanic ash. Bentonite is used in pet litter to absorb liquids. It is used as a mud in drilling applications. It is also used in other industrial applications such as the "pelletizing" of iron ore.

Common clay is used to make construction materials such as bricks, cement, and lightweight aggregates.

Fire clays are all clays (excluding bentonite and ball clays) that are used to make items resistant to extreme heat. These products are called *refractory* products. Nearly all (81%) of fire clays are used to make refractory products.

Fuller's earth is composed of the mineral palygorskite (at one time this mineral was called "attapulgite"). Fuller's earth is used mostly as an absorbent material (74%), but also for pesticides and pesticide-related products (6%).

Kaolinite is a clay composed of the mineral *kaolin*. It is an essential ingredient in the production of high quality paper and some refractory porcelains.

Substitutes and Alternative Sources

When necessary, calcium carbonate and talc can be used in place of clay as filler in some applications. However, clay is so abundant in all its forms that such substitutions may only be necessary if the alternative materials are less expensive than clay (which is not very likely).

MANGANESE

Manganese: essential to iron and steel production. The U.S., Japan, and Western Europe are all nearly deficient in economically mineable manganese. South Africa and the Ukraine have over 80% of the world's reserves.

Manganite Photo from MII,
courtesy of the Smithsonian Institution

Manganite - *MII Photo*

Background

Manganese is gray-white metal with a pinkish tinge, and a very brittle but hard metallic element. Its atomic number 25. In 1774, while heating the mineral pyrolusite (MnO_2, manganese dioxide) in a charcoal fire, the Swedish scientist Johann Gahn discovered manganese. The heat and carbon in the charcoal separated oxygen from the pyrolusite, leaving a metallic manganese residue. This chemical reaction is called a reduction reaction.

Manganese is a reactive element that easily combines with ions in water and air. In the Earth, manganese is found in a number of minerals of different chemical and physical properties, but is never found as a free metal in nature. The most important mineral is pyrolusite, because it is the main ore mineral for manganese. When manganese is alloyed with other metals like aluminum, copper and antimony, the end product is magnetic.

Trace amounts of manganese are very important to good health. It makes bones strong yet flexible, and it aids the body in absorbing Vitamin B1. It also is an important activator for the body to use enzymes. As little as 0.00002% Mn in the human body is essential. Studies have shown that a lack of manganese leads to infertility in animals.

Name

The word *manganese* comes from the Latin word *magnes* which means *magnet.*

Sources

Over 80% of the known world manganese resources are found in South Africa and Ukraine. Other important manganese deposits are in China, Australia, Brazil, Gabon, India, and Mexico. The United States imports manganese ore because the manganese resources in the U.S. are relatively low in manganese content per ton of ore. Importing these ores is presently more economic than mining them locally.

Most manganese ore imported to the United States is used to manufacture intermediate manganese ferroalloy products and electrolytic manganese for use in dry-cell batteries. Only a small amount of the ore is directly used in the steel making process.

Some manganese is recovered through the reprocessing of scrap metals and steel slag, or the materials left over from the steel-making process. Though considered waste in terms of its steel content, slag often contains significant amounts of other elements that can be recovered.

Deep-sea nodules of manganese and other metals are scattered on the ocean floor. They form when the hot waters from hot springs (called black smokers) on the ocean bottom meet the cold, deep ocean water. The elements in the hot volcanic waters precipitate as nodules. Though rich in manganese (nearly 25% manganese) they are very deep in the ocean and it would cost too much to make them worth retrieving. This may prove to be an important source of manganese in the future should reserves in the Earth’s crust be depleted and cost-effective deep-sea mining methods are discovered.

Uses

Steel becomes harder when it is alloyed with manganese. It has similar applications when alloyed with aluminum and copper. Hardened steel is important in the manufacture of construction materials like I-beams (24% of manganese consumption), machinery (14% of manganese consumption), and transportation (13% of manganese consumption).

Manganese dioxide is used to: manufacture ferroalloys; manufacture dry cell batteries (it's a depolarizer); to "decolorize" glass; to prepare some chemicals, like oxygen and chlorine; and to dry black paints. Manganese sulfate ($MnSO_4$) is used as a chemical intermediate and as a micronutrient in animal feeds and plant fertilizers. Manganese metal is used as a brick and ceramic colorant, in copper and aluminum alloys, and as a chemical oxidizer and catalyst. Potassium permanganate ($KMnO_4$) is used as a bactericide and algicide in water and wastewater treatment, and as an oxidant in organic chemical synthesis.

Substitutes and Alternative Sources

There are presently no adequate substitutes for manganese in its varied applications.

NICKEL

Nickel: Vital as an alloying constituent of stainless steel, plays key role in the chemical and aerospace industries. Leading producers include Australia, Canada, Norway and Russia. Large reserves are found in Australia, Cuba, New Caledonia, Canada, Indonesia, the Philippines, and Russia.

Nickeline photo from MII, courtesy of Smithsonian Institution

Background

Nickel, with a symbol of Ni, is a silvery shiny, metallic element with an atomic number of 28. It can be hammered into thin sheets, which means it is malleable. Nickel, iron and cobalt are the only three elements known to be *ferro-magnetic*. Of the three, nickel is the least magnetic. When all three ferro-magnetic metals are alloyed together, an unusually strong magnet is created. This alloy conducts heat and electricity fairly well, but is not as good a conductor as pure silver or copper.

In 1751, Axel Fredrik Cronstedt of Sweden attempted to extract copper from the mineral niccolite and to his surprise got a silvery-white metal, instead of the copper. He named the new metal *nickel* after the mineral name of *niccolite*. This was the first discovery of nickel in the western world, but an alloy of copper, nickel and zinc - paitung or paktong - was used in China as far back as 235 B.C.E. for utensils and other metal ware.

The presence of elemental nickel in iron-nickel meteorites distinguishes them from rocks or minerals produced in the Earth. The amount of nickel in these meteorites ranges from 5% to almost 20%. When they are sliced and etched with acid, a pattern of intergrown crystals is revealed. This is called a *widmanstatten pattern*. This texture of the iron-nickel meteorites suggests they cooled and crystallized very, very slowly deep inside asteroids.

Trace amounts of nickel are important to a number of species of animals. It plays a role, along with iron, in the transport of oxygen in the blood. Nickel deficiency has been shown to reduce iron uptake in young pigs.

Nickel is also important to the proper function of some enzymes in both plants and animals. Experiments on rats have shown that insufficient nickel leads to liver damage. Nickel is involved in the transmission of genetic code - DNA, RNA, etc. it is also present in certain enzymes that metabolize sugar. Oats and other whole grains are an excellent source of nickel.

Scientists who study seismic waves from earthquakes, have determined that the core of the Earth consists of a liquid outer core and a solid inner core composed of an iron-nickel mixture.

Name

From very early times nickel-bearing minerals, such as niccolite, were mixed with glass to create green glass. This was called *kupfernickel* which means *Devil’s Copper*. When nickel was extracted from niccolite, the mineral name was a logical source of the name for the element, nickel.

Sources

Although today it is not profitable to mine nickel in the U.S., small amounts of by-product nickel are being recovered from copper and palladium-platinum ores in the Western United States.

Approximately 87,000 tons of nickel is recovered annually by recycling stainless steel and other nickel-iron alloys. This represents about 39% of the nickel used each year.

It is estimated that there is about 140 million tons of nickel available in identified deposits. Eighty-four million tons, or 60 percent of the total available nickel is in *laterite deposits*. A deposit in which rain and surface water leached nickel-rich rock and concentrated the nickel at or near the surface of the Earth is a laterite deposit. Nickel sulfide deposits contain the remaining forty percent (56 million tons).

Demand for nickel in the United States is much higher than what recycled nickel can provide, so nickel is imported into the country. Most of the imported nickel comes from Canada (40%), while the rest is imported from Norway (13%), Russia (12%), Australia (10%), and various other nations (25%).

Uses

In the United States, large amounts of nickel (42% of consumption in 2001) are used in the specialty steel industry for stainless steel and related alloys. In 1913, Harry Brearly, an English scientist, was the first to produced stainless steel, when he accidentally discovered that the addition of chromium to steel makes the steel resistant to staining. Today, stainless steel also contains some molybdenum, titanium and nickel, to increase its resistance to corrosion.

Thirty-eight percent of annual nickel use is in *nonferrous alloys* (or mixed with metals other than steel) and s*uperalloys* (metal mixtures designed to withstand extremely high temperatures and/or pressures, or to have high electrical conductivity). Nickel is used as a coating on other metals to slow down corrosion. Nickel coatings accounts for 14% of nickel use.

The remaining 6% of the annual nickel use is for a variety of purposes including the production of coins, nickel-cadmium and nickel-metal hydride batteries; as a catalyst for certain chemical reactions; and, as a colorant, nickel is added to glass to give it a green color. The U.S. 5-cent piece is called a "nickel" because it only contains 25% nickel. The other 75% is copper.

Rechargeable nickel-hydride batteries are widely used for cellular phones, video cameras, and other electronic devices. Nickel-cadmium batteries are used primarily to power cordless tools and appliances.

Substitutes and Alternative Sources

Manganese crusts and nodules on the ocean floor could be a valuable source of nickel someday. These deposits contain manganese and other metal ions, such as nickel. Some deposits appear to have formed when superhot liquids from deep sea volcanoes came in contact with the very cold deep ocean water causing the metals to precipitate and collect on the ocean floor. Other deposits far from subduction zones may have formed when microorganisms in the sea water accelerated the precipitation of dissolved iron and manganese. Today, it is too expensive to mine the deposits, but as the surface nickel deposits are used up, the value of nickel may increase and make it profitable to retrieve these manganese nodules.

There are a number of materials that could be used in place of nickel, but generally, these substitutes are more expensive than nickel and/or less effective. Aluminum, plastics or coated steel could be used in place of stainless steel in some situations. Titanium can be used in place of nickel to make some superalloys.

PYRITE

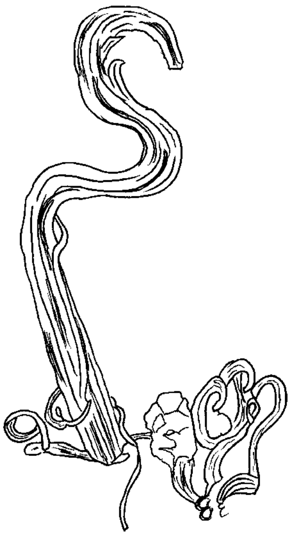
Pyrite: used in the manufacture of sulfuric acid and sulfur dioxide; pellets of pressed pyrite dust have been used to recover iron, gold, copper, cobalt, nickel, etc.; used to make inexpensive jewelry.

SILVER

: Used in
graphy,
ry, in
onics because
very high
ctivity, as
ncy - generally
ne form of an
in lining vats
ther equipment
emical
on vessels,
distillation,
atalyst in
facture of
ne, mirrors, electric conductors, batteries, silver plating, table cutlery, dental, medical, and scientific equipment, electrical contacts, bearing metal, magnet windings, brazing alloys, solder. Silver is mined in approximately 56 countries. Nevada produces over one-third of the U.S. silver. Largest silver reserves are found in the U.S., Canada, Mexico, Peru, and China.

MII Photo

Background



Silver has been known and used since ancient times. Evidence in Asia Minor suggests that people were separating silver from lead as long ago as 3000 B.C.E. Like gold, it is a prized metal, both for its beauty and usefulness.

Silver (atomic number 47) is sometimes found in the Earth as the mineral *native silver*. Its chemical symbol is Ag, after the Latin word Argentum. Silver has a bright, metallic luster, and when untarnished, has a white color. Silver is found combined with a number of different elements to form a variety of minerals and ores. It is also found in very small amounts (called *trace* amounts) in gold, lead, zinc, and copper ores.

As a mineral, silver crystallizes in the cubic (*isometric*) system. In rare cases it forms crystals. Usually it is found in thin sheets or as long wires and bundles of wires, as in these drawings of native silver from Colorado. Silver is rather soft at 2 to 3 on Mohs' hardness scale. Like gold, it is malleable which means it can be hammered into thin sheets. It is also ductile, meaning it can be drawn into wire.

Name

Silver was named from the Old English (Anglo-Saxon) word *seolfer*. This name is related to the German word *silber* and the Dutch word *zilfer*.

An early Latin name for this mineral was *Luna* which means *moon,* an allusion to its striking, bright luster.

Sources

Silver is found in lead, zinc, and copper ore deposits. A full two-thirds of the silver resources in the world are found in association with these other metal ores. The remaining third is found in association with deposits of gold.

The most important ore mineral of silver is argentite (Ag_2S, silver sulfide).

In the United States, Nevada is the leading producer of silver where it is a by-product of gold mining. Other significant world producers of silver are Mexico, Peru, Chile, and Canada. A number of other countries produce smaller amounts of silver.

Uses

Silver has been used for thousands of years for jewelry and decorative items of all types. Likewise, it has been used for silverware. Of all the metals, untarnished silver is the best reflector of light. As a result, it was used in ancient times to make mirrors. Unfortunately, silver tarnishes very easily and quickly, and its use as a mirror could be frustrating. Sterling silver is silver alloyed with another metal, usually copper. For such an alloy to be called "Sterling" it has to have 92.5% silver content. Silver is also used as a currency and at one time, along with gold, was the standard for the currency of the United States of America. Silver bromide and silver nitrate are used in photography. It is estimated that about one-third of the silver used in the United States is used in various photographic materials and processes. It is also used in electrical products because it conducts electricity so well (silver actually conducts electricity more efficiently than copper). It is used by dentists in amalgam fillings. Silver is also used in the production of bearings.

Substitutes and Alternative Sources

There are a number of materials and technologies that can be used in place of silver. Stainless steel is used to make tableware. Film with a lower silver content might be used in photography. Digital photography can conceivably significantly reduce the demand for silver-based films. Digital imaging will also reduce the consumption of silver-based films in the printing industry. Rhodium and aluminum can be substituted for silver in making mirrors.

< = Sheet silver from Colorado

All drawings used with permission

© 2000 Darryl Powell

TANTALUM

Tantalum: a refractory metal with unique electrical, chemical, and physical properties that is used mostly as tantalum metal powder in the production of electronic components, mainly tantalum capacitors. Alloyed with other metals, tantalum is also used in making cemented carbide tools for metal working equipment, and in the production of superalloys for jet engine components. Australia, Brazil, Canada, Congo (Kinshasa), Ethiopia, and Rwanda are leading tantalum ore producers. There is no tantalum mine production in the United States. The sample photograph is tantalite, a source for tantalum.

Tantalite Photo from MII, courtesy of the Smithsonian Institution

Background

Tantalum is a hard, grayish-blue, metallic element. Its atomic number is 73 and its symbol is Ta. It has a very high melting point (2996°C). This melting point is exceeded only by that of carbon, tungsten, and rhenium. Tantalum is remarkably resistant to attack by air, water and most acids.

Tantalum was discovered in 1802 by the Swedish scientist Anders Ekeberg. Commercial use of tantalum began in 1903 with the production of tantalum wire.

Name

Tantalum is mostly found with the element niobium. The two elements are so similar that they are very difficult to isolate from one another. Tantalum was named after the Greek god, Tantalus. Niobium, discovered before tantalum (1801), was named after the daughter of Tantalus, Niobe.

Sources

Tantalum is recovered from ore minerals such as columbite and tantalite. The United States has no high-grade tantalum ores. In fact, no significant tantalum ores have been mined in the U.S. since 1959.

About 20% of the tantalum used in the United States comes from recycling. The rest must be imported. Recent major sources for tantalum imports were Australia, Kazakhstan, Canada, China, Thailand, and others.

Uses

The electronics industry uses most of the tantalum consumed to make electronic components (tantalum capacitors). Since tantalum is so resistant to corrosion, it is used to make surgical instruments and medical equipment such as rods to attach to broken bones, skull plates, and wire meshes to help repair nerves and muscles.

Because it has such a very high melting point, it is alloyed (that is, mixed with) other metals to create alloys that are needed for very high temperature applications. Tantalum is also used in camera lenses.

Substitutes and Alternative Sources

Columbium can be used in place of tantalum to make carbides. Columbium, hafnium, iridium, molybdenum, rhenium and tungsten can be used for high-temperature situations. Aluminum and ceramics can be used in place of tantalum in electronic capacitors. The problem is, however, that most of these substitutes are not as effective as tantalum in some of these applications.

VANADIUM

Vanadium: Used in metal alloys, important in the production of aerospace titanium alloys, as a catalyst for production of maleic anhydride and sulfuric acid, in dyes and mordants, as target material for X-rays. Russia and South Africa are the world's largest producers of vanadium. Large reserves are also found in the U.S., Canada, and China. The sample photo is vanadinite, an ore of vanadium and lead.

Photo from MII, courtesy of the Smithsonian Institution

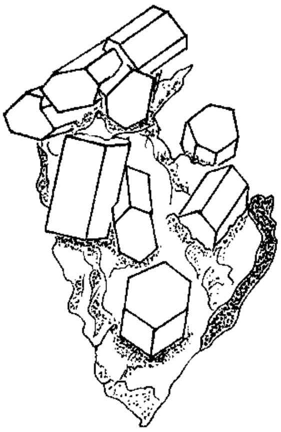
Vanadinite -- *MII Photo*

Background

Vanadium is a soft, silver-gray metallic element. Its atomic number is 23 and symbol is V. Two scientists discovered it. However, they were not working together and even lived across the globe from one another. In 1803, Andres Manuel del Rio, a Spanish mineralogist working in Mexico City, first discovered a material he called "brown lead". He later renamed this compound *erythronium* meaning *red*, a reference that this material turned red when heated. In 1831, a Swedish chemist named Nils Gabriel Sefstrom isolated a new material that he named *vanadium* in honor of the goddess of beauty and fertility, Vanadis. Ultimately, the name vanadium was chosen.

Henry Roscoe isolated metallic vanadium in 1867. He took vanadium chloride (VCl_3) and reduced it with hydrogen to form vanadium metal and hydrochloric acid (HCl). Henry Roscoe isolated metallic vanadium in 1867. He took vanadium chloride

There is a very minor amount of vanadium in the human body, however it does not serve any biological purpose. It is an interesting fact that vanadium is an essential element to *ascidians*, also known as sea squirts. They concentrate vanadium in their bodies to a level one million times higher than the concentration of vanadium in seawater.



Name

Vanadium was named after *Vanadis,* the goddess of beauty in Scandinavian mythology. The name was given by Nils Gabriel Sefstrom. A very beautiful, deep red mineral, vanadinite, contains vanadium and was named after its vanadium content.

Deep red vanadinite crystals. Drawing © 2000 Darryl Powell. Used with permission.

Sources

It is estimated that the presently known world resources of vanadium total 63 million tons. There is no single mineral ore from which vanadium is recovered. However, it is found as a trace element in a number of different rock materials and is a by-product of other mining operations. Vanadium is found in magnetite (iron oxide) deposits that are also very rich in the element titanium. It is also found in bauxite (aluminum ore), rocks with high concentrations of phosphorous-containing minerals, and sandstones that have high uranium content. Vanadium is also recovered from carbon-rich deposits such as coal, oil shale, crude oil, and tar sands.

Vanadium resources in the United States, where it is usually associated with uranium ores in sandstones, are large enough to supply U.S. vanadium needs. However, it is often cheaper to import vanadium and ferrovanadium products. The ferrovanadium that is imported is purchased from Canada, China, the Czech Republic, South Africa, and other nations. The majority of vanadium pentoxide used in glass manufacturing is imported from South Africa.

Uses

Vanadium itself may be soft in its pure form, but when it is alloyed (that is, mixed) with other metals like iron, it hardens and strengthens them dramatically. Consequently, vanadium is used extensively to make alloys (mostly steel alloys) for tools and construction purposes. Most of the vanadium consumed is used for these applications. Specifically, vanadium is alloyed with iron to make carbon steel, high-strength low-alloy steel, full alloy steel, and tool steel. These hard, strong ferrovanadium alloys are used to make armor plating for military vehicles and other protective vehicles. It is also used to make car engine parts that must be very strong, such as piston rods and crank shafts. The steel “skeleton” or frames of high-rise buildings and oil drilling platforms must be very strong to support the weight of the building and its contents; vanadium steel has the strength to support such massive weight.

Some vanadium is used in other industrial applications. For example, vanadium pentoxide (V_2O_5) is used production of glass and ceramics and as a chemical catalyst. (A *catalyst* is a substance that assists in and often speeds up chemical reactions but is not consumed in the chemical reaction.) Compounds of vanadium are used to dye fabrics.

Scientists have discovered that a mixture of the elements vanadium and gallium are useful in making superconductive magnets.

Substitutes and Alternative Sources

A number of other elements can be substituted for vanadium in the production of high-strength steel. These include columbium, molybdenum, titanium, and tungsten. Other metals can be used in place of vanadium as a chemical catalyst, including platinum and nickel.

ASBESTOS

MII Photos

Asbestos: because this group of silicate minerals can be readily separated into thin, strong fibers that are flexible, heat resistant, and chemically inert, asbestos minerals are suitable for use in fireproof fabrics, yarn, cloth, paper, paint filler, gaskets, roofing composition, reinforcing agent in rubber and plastics, brake linings, tiles, electrical and heat insulation, cement, and chemical filters.

Background

"Asbestos" refers to a small number of minerals that are formed of flexible fibers, and have the useful physical property of being very heat resistant. Because asbestos forms as flexible fibers, it is woven to make fabrics for heat-resistant and insulating materials.

Chrysotile asbestos, the fibrous variety of the mineral *serpentine,* is by far the most important type of asbestos. It forms in metamorphic rock, that is, rock that has been altered by intense heat and pressure. Another asbestos mineral is called *crocidolite. Crocidolite* is a dark blue variety of the mineral *riebeckite*. Crocidolite occurs in metamorphic rock. Only about 4% of the asbestos consumed is crocidolite. Other, less important asbestos minerals in occasional use are amosite, anthophyllite asbestos, tremolite asbestos, and actinolite asbestos.

Asbestos has a very high melting point. This, together with the flexible nature of the fibers, helps to determine its usefulness.

Since the discovery in the mid-Twentieth Century that asbestos can cause a fatal lung condition, the mining and use of asbestos has decreased, and has become closely regulated in all countries.

Name

The name *asbestos* came from ancient times from a Greek word meaning *unquenchable* in reference to its resistance to fire and heat. For many centuries, small cloths woven from asbestos were a luxury item, for handling of hot items in kitchens and foundries.

Sources

Most of the asbestos consumed annually is chrysotile asbestos. Asbestos is no longer mined in the United States. Imports from Canada account for most of the U.S. consumption. Russia, Canada, China, and Kazakhstan are major producers of asbestos, with lesser production from a dozen other countries.

The tonnage of asbestos used worldwide is in a slow decline, as, for health reasons, many countries have restricted or altogether banned the use of asbestos. The decline is expected to continue.

Uses

Asbestos is used to make heat resistant products. Long asbestos fibers are preferred, and short fibers are worth only a fraction of the price. The former uses of asbestos in building construction (fireproof ceiling panels in schools, for example) have largely disappeared, although asbestos is still used in making asbestos-cement products, automobile and truck brakes, roof castings, and applications where the fibers are encased in other materials and are unlikely to become free-floating.

Roofing products containing asbestos (asphalt coatings) account for more than half of U.S. consumption. Friction products such as brake pads, and gaskets account for about another 20%. Asbestos is also used for some specialized concrete products.

Substitutes

No better material has been found, or manufactured, that is as versatile as asbestos. However, due to the serious health issues involved in asbestos use, a number of substitute materials are utilized. A variety of different manufactured fibers have replaced asbestos in many applications. These include carbon fiber, cellulose fiber, ceramic fiber, glass fiber and steel fiber. Other minerals, such as wollastonite, are used for some applications.

CHROMIUM

 MII Photo	 Photo Courtesy of Simon Williams,

Chromite (chromium): some 99 percent of the world's chromite is found in southern Africa and Zimbabwe. Chemical and metallurgical industries use about 85% of the chromite consumed in the United States.

Background

Chromium is a hard, bluish metallic element (Cr) with an atomic number of 24. In the mid-1700's, chemical analysis of a mineral from Siberia showed that it contained lead. This mineral, crocoite ($PbCrO_4$, lead chromate), was known as "red lead" because of the beautiful orange-red color of its crystals. It also contained another, then-unknown material. This material was identified as chromium oxide (CrO_3) by Louis-Nicholas Vauquelin. In 1797, he heated this oxide with charcoal to remove the oxygen (chemists call this reaction a *reducing process*) which left the metal *chromium*.

Shortly after Vauquelin's discovery, a German chemist name Tassaert discovered chromium in an ore that geologists now call *chromite* ($FeCr_2O_4$, ferrous chromic oxide). Chromite forms in an igneous environment.

Name

The name *chromium* was derived from the Greek word *chroma* which means *color*, in reference to the fact that chromium is known to cause a number of colors in a variety of materials. For example, the green color of emerald is caused by the presence of very small amounts of chromium in the crystal.

Sources

The only ore of chromium is the mineral *chromite*. United States chromium consumption is equivalent to about 14% of all the chromite ore mined each year. In the western hemisphere, chromite ore is produced only in Brazil and Cuba; the United States, Mexico and Canada do not produce chromite. (The Stillwater Complex in Montana is the biggest chromium deposit in the United States, however it is not producing chromite ore at this time.) By comparison, about 80% of world production of chromite comes from India, Kazakhstan, Turkey and southern Africa. Southern Africa itself produces about half of this.

Geologists estimate that there are about 11 billion tons of chromium ore (chromite) in the world that could be mined. Most of these resources are found in southern Africa. This is enough chromium ore to meet world demand for hundreds of years into the future.

Uses

Chromium is alloyed (that is, mixed) with steel to make it corrosion resistant or harder. An example is its use in the production of stainless steel, a bright, shiny steel that is strong and resistant to oxidation (rust). Stainless steel production consumes most of the chromium produced annually. Chromium is also used to make heat-resisting steel. So-called "superalloys" use chromium and have strategic military applications.

Chromium also has some use in the manufacture of certain chemicals. For example, chromium-bearing chemicals are used in the process of tanning leather. Chromium compounds are also used in the textiles industries to produce a yellow color.

Substitutes and Alternative Sources

There is no good alternative for chromium in the manufacture of steel or chromium chemicals. Scrap metal that contains chromium can be recycled as an alternative source. The natural abundance of chromite in the Earth’s crust makes alternative sources unnecessary at this time.

COLUMBITE

Columbite-tantalite group (columbium is another name for niobium): Columbite is a natural oxide of niobium, tantalum, ferrous iron, and manganese. Some tin and tungsten may be present in the mineral. Columbium, in the form of ferrocolumbium, is used mostly as an additive in steel making and in superalloys for such applications as heat-resisting and combustion equipment, jet engine components, and rocket subassemblies, in cemented carbides, and in superconductors. Brazil and Canada are the world’s leading producers.

Columbite photo from MII, courtesy of Smithsonian Institution

FLUORSPAR - Fluorite

Florite Photo from MII,
Courtesy of Smithsonian Institute

MII Photos

Fluorite (fluorspar): Used in production of hydrofluoric acid, which is used in the electroplating, stainless steel, refrigerant, and plastics industries, in production of aluminum fluoride, which is used in aluminum smelting, as a flux in ceramics and glass, in steel furnaces, and in emery wheels, optics, and welding rods.

Background

When found in nature, fluorspar is known by the mineral name *fluorite*. Fluorspar (fluorite) is calcium fluoride (CaF_2). It is found in a variety of geologic environments. Fluorspar is found in granite (igneous rock), it fills cracks and holes in sandstone, and it is found in large deposits in limestone (sedimentary rock). The term fluorspar, when used as a commodity name, also refers to calcium fluoride formed as a by-product of industrial processes.

Fluorspar is relatively soft, number 4 on Mohs' scale of hardness. Pure fluorspar is colorless, but a variety of impurities give fluorite a rainbow of different colors, including green, purple, blue, yellow, pink, brown, and black. It has a pronounced cleavage, which means it breaks on flat planes. Fluorite crystals can be well formed, beautiful and highly prized by collectors.

Despite its beauty and physical properties, fluorspar is primarily valuable for its fluorine content.

Name

Even though fluorite contains the element fluorine, its name is not derived from its chemical composition. The name was given by Georg Agricola in 1546 and was derived from the Latin verb *fluere* which means *to flow* because it melts easily.

Spar is a generic name used by mineralogists to refer to any non-metallic mineral that breaks easily to produce flat surfaces and which has a glassy luster.

A miner’s name used long ago for fluorite was *Blue John*.

Sources

The United States once produced large quantities of mineral fluorspar. However, the great fluorspar mines of the Illinois-Kentucky fluorite district are now closed. Today, the United States imports fluorspar from China, South Africa, Mexico, and other countries.

A small percentage of the fluorspar consumed in the United States is derived as a by-product of industrial processes. For instance, an estimated 5,000 to 8,000 tons of synthetic fluorspar is produced each year in the uranium enrichment process, the refining of petroleum, and in treating stainless steel. Hydrofluoric acid (HF) and other fluorides are recovered during the production of aluminum.

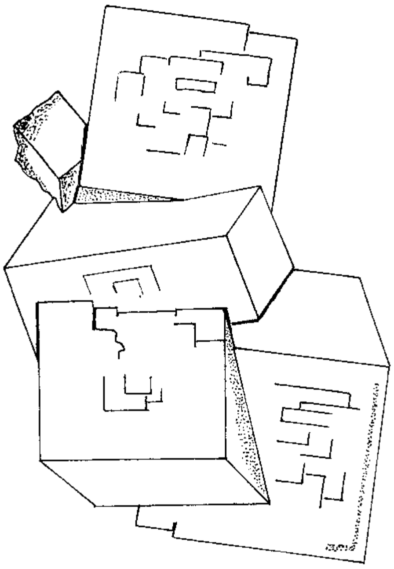
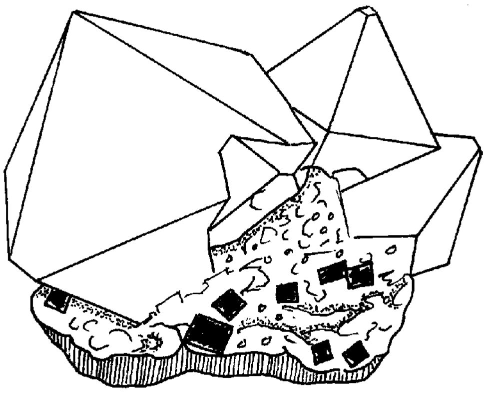
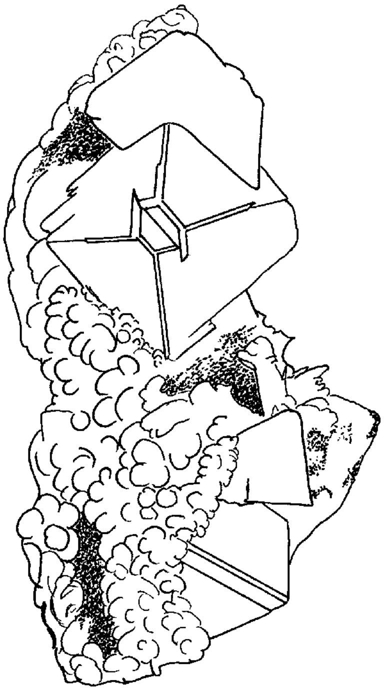
Uses

The majority of the United States’ annual consumption of fluorspar is for the production of hydrofluoric acid (HF) and aluminum fluoride (AlF_3). HF is a key ingredient for the production of all organic and non-organic chemicals that contain the element fluorine. It is also used in the manufacture of uranium. AlF_3 is used in the production of aluminum.

The remainder of fluorspar consumption is as a flux in making steel, glass, enamel, and other products. A flux is a substance that lowers the melting temperature of a material.

Substitutes and Alternative Sources

Phosphoric acid plants, which process phosphate rock into phosphoric acid, produce a by-product chemical called fluorosilicic acid. This is used to fluoridate public water supplies or to produce AlF3. Phosphate-rich rocks are a minor alternative source for elemental fluorine.

 Yellow fluorite from Illinois	 Pink fluorite from Peru
 Green fluorite from Colorado	*Fluorite crystal drawings by Darryl Powell* *© 1999 Darryl Powell* *Used with permission.*

SALT

MII Photos

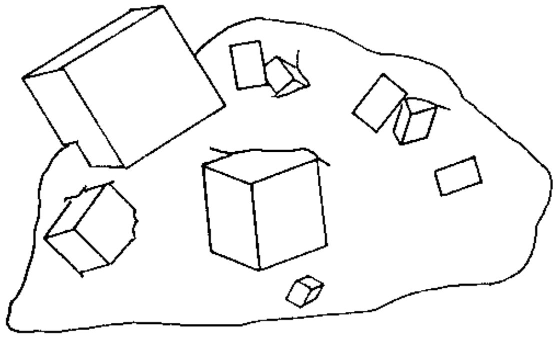
Halite (Sodium chloride--Salt): Used in human and animal diet, food seasoning and food preservation, used to prepare sodium hydroxide, soda ash, caustic soda, hydrochloric acid, chlorine, metallic sodium, used in ceramic glazes, metallurgy, curing of hides, mineral waters, soap manufacture, home water softeners, highway de-icing, photography, herbicide, fire extinguishing, nuclear reactors, mouthwash, medicine (heat exhaustion), in scientific equipment for optical parts. Single crystals used for spectroscopy, ultraviolet and infrared transmission.

Halite Photo from MII, courtesy of the Smithsonian Institution

Background

Salt, composed of sodium chloride (NaCl), is one of the necessities of life for man and animals. Even in earliest times, man valued salt licks, springs, and marshes, and would go to great effort to visit them and carry salt away. In addition to the natural craving for salt which develops when it is absent from the diet, salt is valuable for preserving meats in hot climates.

In Roman society, salt was used as currency, and soldiers were paid in salt. The Latin word *sal* is the root for the English word *salary*. Based on this, we have the familiar phrase that a person is "worth their salt", meaning worth the wages they receive.



Halite crystal drawing used with permission. © 1998 Darryl Powell

Salt that is mined from solid layers in the ground is called *rock salt*. When produced along with other, usually powdery, salt-like compounds by evaporation from seawater, it is called *sea salt* or *solar salt*. Brine is the term for salty water from which salt can be produced. Geologically, salt is also known by its mineral name *halite.*

Pure halite is colorless, though it is often colored by impurities. It is soft and breaks (cleaves) into cubes. Halite crystallizes in the isometric (also called *cubic*) crystal system and when it forms crystals, it generally forms cubes. Its most noticeable and important physical feature is that halite is readily soluble in water. This allows halite to be useful in such varied applications as cooking, food preservation, and chemical production.

Name

The term *salt* is an ancient word, occurring in various forms in earliest English and in related languages. The formal mineral name for crystalline sodium chloride is *halite*, derived from the Greek word *hals* meaning *salt*. The mineral name was given by E.F. Glocker in 1847.

In chemical usage, *salt* may refer to any compound of a metal and non-metal; thus terms such as "copper salts" or "magnesium salts" refer to the chlorides, carbonates, sulfates, etc., of copper or magnesium. "Epsom salts" refers to a specific hydrous magnesium sulfate mineral, made famous by its occurrence at a spring in southern England. Sodium chloride is sometimes referred to as "common salt" or "table salt", to distinguish it from other salts.

Sources

Sodium chloride occurs dissolved in seawater, along with other salts of sodium, calcium, magnesium, and other light metals. When seawater evaporates in a closed lagoon, halite and other minerals precipitate out and sink to the bottom as crystals. In this way, great beds of rock salt have been formed.

When sediments containing rock salt are folded and uplifted, the beds of rock salt are exposed, and in time they dissolve away, forming brines which either percolate into the ground or the ocean, or collect in salt lakes.

Salt can be mined from rock salt either by traditional mining practices using heavy equipment underground, or by pumping hot water in pipes into the salt deposit, where the hot water dissolves the halite. The resulting salt water is then pumped to surface and evaporated to yield salt. This is called “solution mining”. In some modern dry salt lakes, a crust of halite can be recovered by simply scraping the salt crust off the lake bottom with bulldozers or scrapers. Ancient rock salt is mined in Michigan, New York, Kansas, and other states. Solution mining is used to recover salt from underground “salt domes” in Louisiana and Texas. Recovery of salt from dry lakes takes place in the deserts of California, Nevada, and Utah.

Much salt is produced by controlled evaporation of seawater or of brines in salt lakes. In this technique, the water is pumped or drained into shallow ponds. Solar evaporation will eventually (in an arid climate) concentrate the salt to the point where it crystallizes on the floor of the pond. This process is used around San Francisco Bay, at the Great Salt Lake in Utah, and elsewhere.

In the United States, rock salt accounts for one-third of the salt produced, while solution mining yields one-half the total. The remainder comes from evaporation of seawater and lake brines, and a small amount from salt crusts on dry lakes. The United States produces about one-fifth of the world’s salt. However, the United States also imports about one-fifth of its needs from other countries, mostly from Canada and Chile.

Salt is produced in most of the countries on Earth. After the United States, the largest producers of salt are China, Germany, India, and Canada. In most other countries having a seacoast, salt for local use is produced by evaporation of seawater.

Uses

In every country, salt is used in food preparation. In some poor, non-industrialized countries, this is the principal use. However, in a heavily industrialized country such as the United States, the consumption pattern is quite different.

In the United States, over 40% of salt is used in the chemical industry (mainly for the production of chlorine and caustic soda), and another 40% as a de-icer on roads in winter. The remaining is consumed in several sectors, including manufacture of rubber and other goods, agriculture, and food processing including as table salt. Table salt accounts for only about 1% of U.S. salt.

Substitutes

Some other salts, such as calcium chloride and potassium chloride, can be used to de-ice roads and walkways. These options, however, are more expensive than salt. Due to the limitless, inexpensive quantities available, salt is not likely to be replaced in most of its industrial and domestic uses.

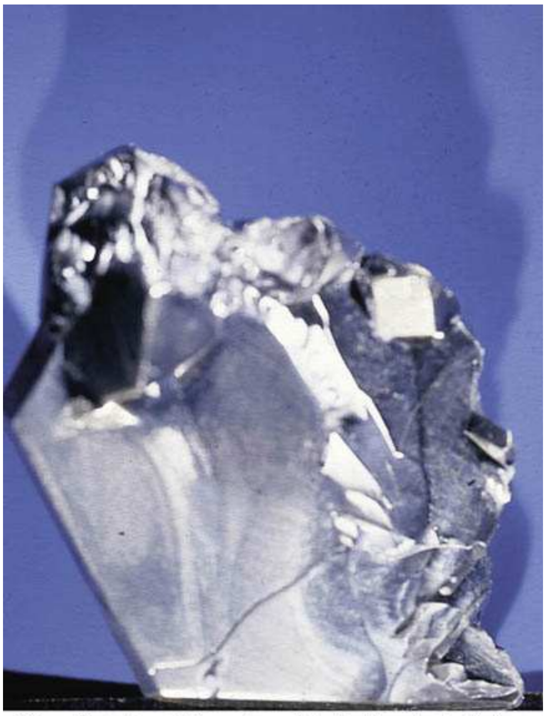
LEAD

Lead: Used in lead batteries, gasoline tanks, and solders, seals or bearings, used in electrical and electronic applications, TV tubes, TV glass, construction, communications, and protective coatings, in ballast or weights, ceramics or crystal glass, tubes or containers, type metal, foil or wire, X-ray and gamma radiation shielding, soundproofing material in construction industry, and ammunition. The U.S. is the world's largest producer and consumer of refined lead metal. Major mine producers other than the U.S. include Australia, Canada, China, Peru, and Kazakhstan.

Galena

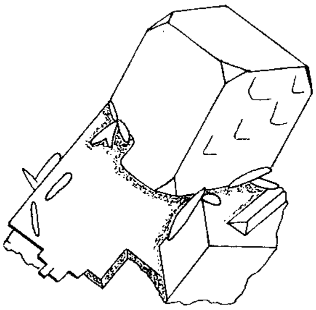
MII Photos

Galena: A lead sulfide, the commonest ore of lead. Sample in photo below contains 86.6 percent lead.



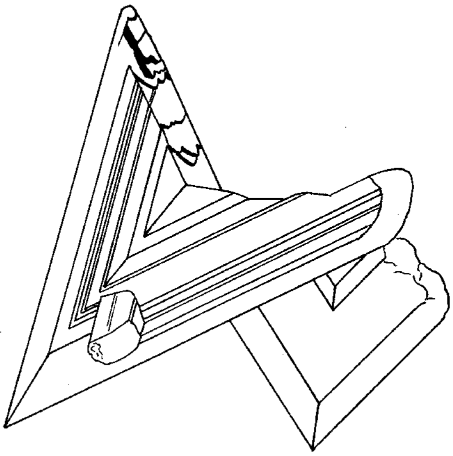
Galena Photo from MII, courtesy of the Smithsonian Institution

Background



Lead, atomic number of 82, is very soft, blue-gray, metallic element and has been used since antiquity. Because it is so soft, lead is usually alloyed with other elements. Water pipes in ancient Rome, some of which still carry water, were made of lead. The English words *plumber* and *plumbing* are derived from the Latin word for lead, *plumbum*. Plumbum is also the source of the chemical symbol for lead, Pb.

Lead is a very heavy element. Native lead was found in Sweden, but it is rare to have the element alone in nature. Combined with other elements, it forms a variety of interesting and beautiful minerals, all of which are heavy due to their lead content. The most significant lead mineral is *galena* (PbS, lead sulfide). Galena deposits have been worked worldwide for their lead. During the Civil War, the Union Army made bullets from lead derived from a galena mine at Balmat, New York. Anglesite and cerussite (($PbSO_4$, lead sulfate and $PbCO_3$, lead carbonate respectively) are two other lead-based minerals.



All major radioactive elements (such as uranium) break down and create lead as one of their end products. Interestingly, lead is used to safely store radioactive materials because it absorbs radiation from the radioactive isotopes.

Lead is toxic. It can cause damage to the digestive and nervous systems, so its use in some applications has been discontinued. Lead poisoning is monitored in children to prevent any permanent damage. At one time lead was added to gasoline to eliminate “knock” in car engines. It was also in paint, but the lead-based paints have a sweet taste, and some children were eating the paint and getting serious lead poisoning.

(Above left: Galena crystals on fluorite from Illinois. Above right: cerussite crystals from Morocco. Drawings used with permission. ©2000, 2001 Darryl Powell)

Name

Although it is believed that it comes from an Anglo-Saxon background, the exact origins of the name *lead* are unknown.

Sources

It is estimated that the identified lead resources worldwide exceed 1.5 billion tons. Much lead is recovered as the primary metal from galena deposits. Significant amounts of lead are being recovered as a by-product or co-product from zinc mines, and silver-copper deposits.

In the United States, mines in Missouri, Alaska, Idaho and Montana produced the majority of lead. Lead is also imported into the United States from a number of countries, both as ore concentrates and as metallic lead.

Canada is the most important importer, followed by Mexico, Australia, and Peru.

More than 1 million tons of lead is recovered in recycling annually, the majority of which is from the recycling of batteries.

Uses

The majority of the lead consumed annually is used to make batteries for cars, trucks and other vehicles, as well as wheel weights, solder, bearings and other parts. Lead is used in electronics and communications (emergency power batteries, for example), ammunition, television glass, construction, and protective coatings. A small amount is used to make protective aprons for patients having x-rays to shield the body from excess radiation exposure, for crystal glass production, weights and ballast, and specialized chemicals.

Substitutes and Alternative Sources

Plastics, aluminum, tin, and iron are replacing the use of lead in construction materials, containers, packaging, etc. Tin and other metals are being used to replace lead as a solder in some applications where lead could poison people, such as in drinking water systems.

PLATINUM GROUP

Platinum Group Metals (includes platinum, palladium, rhodium, iridium, osmium, and ruthenium): They commonly occur together in nature and are among the most scarce of the metallic elements. Platinum is used principally as catalysts for the control of automobile and industrial plant emissions, as catalysts to produce acids, organic chemicals, and pharmaceuticals. PGMs are used in bushings for making glass fibers used in fiber-reinforced plastic and other advanced materials, in electrical contacts, in capacitors, in conductive and resistive films used in electronic circuits, in dental alloys used for making crowns and bridges. in jewelry. Russia and South Africa have nearly all the world’s reserves. The sample in the photo is Sperrylite; it is of very rare occurrence but of interest as the only native compound of platinum.

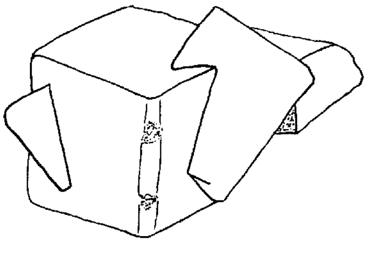
Sperrylite Photo from MII, courtesy of the Smithsonian Institution

Background

The name *platinum* refers to a mineral, an element and a group of elements. As an element, platinum (chemical symbol Pt) is a silvery-gray metal with an atomic number of 78. It belongs to a group of elements that are in the second and third triads of Group VIII of the Periodic Table of the Elements.

The platinum group of elements consists of metals with similar physical properties. They are among the rarest elements in the Earth's crust. They have high melting points, are dense or heavy (mineralogists say they have a high *specific gravity*), and are very non-reactive to other elements and ions. The platinum group elements include: ruthenium (44), rhodium (45), palladium (46), osmium (76), iridium (77) and platinum (78). Of these elements, only platinum and palladium are found in a pure form in nature. The others occur in nature as natural alloys with platinum and gold, for example. In industry people refer to this group of elements as the *platinum group metals,* or simply as PGM.

As a mineral, platinum occurs in dark silicate rocks with minerals containing iron and magnesium. It is usually found as fine grains or flakes scattered throughout the rock and rarely as large nuggets. It crystallizes in the cubic crystal system, but rarely forms actual crystals. The crystal drawings here are of very rare platinum alloy crystals from Russia. Platinum is metallic and, like gold and silver, is malleable (it can be hammered into sheets) and ductile (it can be drawn into wire). Most naturally occurring platinum is actually a mixture of platinum and iridium



Name

Platinum has been known and used since antiquity in South America, where the use of platinum by the natives was discovered by Antonio de Ulloa of Spain in 1735. Because it is silver-gray in color, it was named after the Spanish word for silver, *plata*.

Sources

Geologically, platinum is found in thin layers of metal ores called sulfides. These sulfide ores are found in *mafic* igneous rocks (that is, dark igneous rocks with high iron and magnesium content).

In the United States, the only mines producing platinum group metals (PGM) are in what geologists call the Stillwater Complex of Montana. In recent years, old mines have been enlarged and a new mine has been established in this complex. Small amounts of PGM are recovered from copper processing in Texas and Utah.

In 1822 large amounts of platinum were discovered in the Ural Mountains in Russia. Russia continues to be an important world source of PGM to this day. The most productive PGM mines are in South Africa in a geologic region known as the Bushveld Complex. Canada, Zimbabwe, and Australia also produce PGM.

Significant amounts of platinum are recovered annually through recycling. In 1999, for example, 70 metric tons was recovered through recycling. This will continue to be an important part of PGM supplies in the future.

Uses

Most platinum is used to produce catalytic converters in automobile exhaust systems. The goal is to limit the smog-producing chemicals that come from burning gasoline. When an internal combustion engine burns gasoline, nitrogen oxides (NO_x) are produced. The exhaust passes through the catalytic converter that contains platinum and iridium. The gases are in the converter for 0.1 to 0.4 seconds and in that very short time, 75% of the nitrogen oxide is converted into nitrogen and oxygen. In addition, more than 95% of carbon monoxide and other hydrocarbons in the exhaust are oxidized. The platinum works by lowering the energy needed to cause these chemical changes. The result is a dramatic reduction in pollution.

Although about one-third of all platinum is used by the automotive industry, there are various other uses. It is alloyed with gold, silver and copper for dental uses. PGM is used in chemotherapy, particularly to fight leukemia. Platinum-iridium compounds are used to make biomedical devices. An alloy of platinum and osmium is used in pacemakers to regulate heart function and in heart replacement valves.

Substitutes and Alternative Sources

Some manufacturers are using less expensive palladium in place of platinum in catalytic converters. As a catalytic converter component in diesel engines, palladium is proving to be a better than platinum.

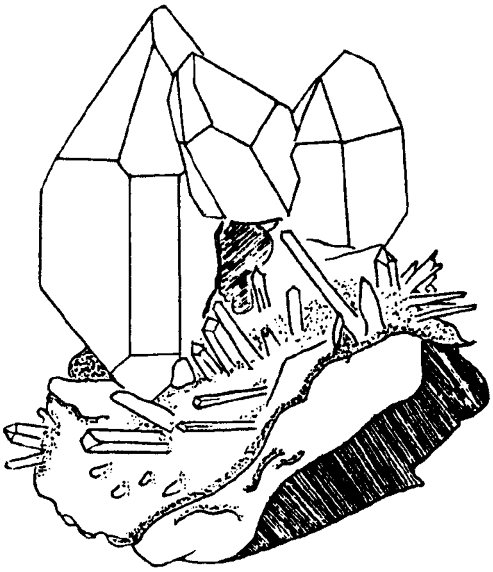
Platinum crystal drawings used with permission.
©2000 Darryl Powell

QUARTZ

Quartz (Silica): as a crystal, quartz is used as a semiprecious gem stone. Cryptocrystalline forms may also be gem stones: agate, jasper, onyx, carnelian, chalcedony, etc. Crystalline gem varieties include amethyst, citrine, rose quartz, smoky quartz, etc. Because of its piezoelectric properties quartz is used for pressure gauges, oscillators, resonators, and wave stabilizers; because of its ability to rotate the plane of polarization of light and its transparency in ultraviolet rays it is used in heat-ray lamps, prism, and spectrographic lenses. Used in the manufacture of glass, paints, abrasives, refractories, and precision instruments.

Rose Quartz Photo from MII, courtesy of the Smithsonian Institution

Background



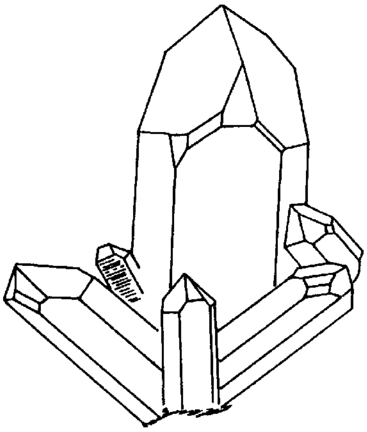
Quartz is a very common mineral in the Earth's crust. Chemically, quartz is *silica,* or silicon dioxide, SiO_2. It is found in most types of rocks: igneous, metamorphic and sedimentary.

Quartz is rather hard, 7 on the Moh's hardness scale, and has a glassy (vitreous) luster. When a crystal is broken, the fracture surface is curved, like a shell. This is referred to as *conchoidal* fracture; glass fractures in the same way.

When crystallized in an open cavity in rocks, quartz forms easily-identifiable 6-sided (hexagonal) prismatic crystals. When formed without open spaces, deep within the earth, quartz crystallizes in small, roundish masses.

Quartz is physically and chemically resistant to weathering. When quartz-bearing rocks become weathered and eroded, the grains of resistant quartz are concentrated in the soil, in rivers, and on beaches. The white sands typically found in river beds and on beaches are usually composed mainly of quartz, with some white or pink feldspar as well.

Name



Because of its abundance and distinctive crystal shape, *quartz* has been recognized as a mineral for thousands of years. The name has an uncertain origin, possibly derived from the German word *quarz*, a word of ancient and uncertain origins.

When water-clear, quartz is known as *rock crystal* or *mountain crystal*. However, quartz can contain a number of different impurities, which create different color varieties. Purple quartz is known as *amethyst*; white is *milky quartz*; black is *smoky quartz*; pink is *rose quartz,* and yellow or orange is *citrine*.

SODA ASH or TRONA

Sodium Carbonate (Soda Ash or Trona): Used in glass container manufacture, in fiberglass and specialty glass, also used in production of flat glass, in powdered detergents, in medicine, as a food additive, photography, cleaning and boiler compounds, pH control of water.

Background

The commodity called "soda ash" is anhydrous sodium carbonate (that is, sodium carbonate without water, Na_2CO_3). It is made both by the processing of the minerals trona ($Na_3H(CO_3)_2.2H_2O$)and nahcolite ($NaHCO_3$), and by processing sodium carbonate-rich waters (called *brines*). Sodium carbonate is one of the most important compounds in the chemical industry. The production of these chemicals and their compounds is known as the “alkali” industry.

Natural sodium deposits are formed by a long geologic process of the erosion of igneous rocks, the transportation of sodium from these rocks, and chemical reactions. First, the sodium is released from igneous rocks when they weather and break down. In the right situation, the sodium is carried by water in rivers, streams, and as runoff and collects in basins. Then, when it comes in contact with carbon dioxide, it precipitates out as sodium carbonate.

When companies process and produce soda ash, a number of other sodium compounds are made as co-products, including sodium bicarbonate (also known as baking soda), sodium sulfite, sodium tripolyphosphate, and chemical caustic soda.

Soda ash is one of the most widely used and important commodities in the United States. Because so much soda ash is used by so many industries, monthly soda ash production information is one of the pieces of information used to determine the condition of the United States economy.

Name

Sources

Deposits of sodium carbonate are found in large quantities in the United States, China, Botswana, Uganda, Kenya, Mexico, Peru, India, Egypt, South Africa and Turkey. It is found both as extensive beds of sodium minerals and as sodium-rich waters (brines).

Six companies in the United States (four in Wyoming, one in California, and one in Colorado) produce over 14 million tons of soda ash annually. The largest trona deposit in the world is in the Green River Basin of Wyoming. It is estimated that this deposit alone could produce as much as 47 billion tons of soda ash. This deposit consists of thick, extensive beds of trona and thin trona beds interbedded with salt (halite). In California, Searles Lake and Owens Lake are soda brine lakes that are estimated to contain 815 million tons of soda ash.

Worldwide, more than 60 natural sodium carbonate deposits have been identified.

Uses

By far, the majority of soda ash is used to make glass. The next largest use is to make a variety of chemicals, followed by soaps and detergents, distributors, the removal of sulfur from smokestack emissions, paper and paper pulp production, water treatment, and other assorted uses. These other uses include oil refining, making synthetic rubber, and explosives.

Substitutes and Alternative Sources

Soda ash can be made synthetically using limestone, salt and ammonia. This is known as the Solvay process, and was the main source of soda ash until the Wyoming trona deposits were discovered. However, it is more expensive than mining natural sodium carbonate deposits. In addition, the waste products of this process are harmful to the environment and could cause serious waste management problems. The enormous natural deposits will not be exhausted for decades to come. If ever soda ash must be synthesized using the Solvay process, nearly limitless sources of limestone and salt are available.

TITANIUM

Titanium: Titanium is a strong lightweight metal often used in airplanes. When titanium combines with oxygen, it forms titanium dioxide (TiO_2), a brilliant white pigment used in paint, paper, and plastics. Major deposits of titanium minerals are found in Australia, Canada, India, Norway, South Africa, Ukraine, and the United States. The sample in the photo is a mineral collector's specimen of titanite (or sphene). However, it is not typical of the black sands often used to produce titanium metal or TiO_2 pigment.

Titanite Photo from MII, courtesy of the Smithsonian Institution

Background

In 1791, the Reverend William Gregor, an English clergyman and mineralogist, reported that he had discovered a magnetic black sand near the beaches of Cornwall, England. The mineral was named menachanite after the local parish of Menaccan. A few years after Gregor's discovery, M.H. Klaproth, a German chemist, separated TiO_2 from the mineral rutile. Klaproth named the new element titanium after the giants of Greek mythology. In 1825, J.J. Berzelius, a Swedish chemist, performed a crude separation of titanium metal. However, it was not until 1910 that M.A. Hunter, an American chemist, produced pure titanium. W.J. Kroll patented his method for producing titanium metal in 1938. Coincidently, commercial production of titanium metal and TiO_2 pigment began in the 1940s.

Titanium is a hard, silvery-gray metallic element. Its atomic number is 22 and its symbol is Ti. It is the 9th most common element in the Earth's crust. It also is found in meteorites, the moon, and the sun.

Titanium metal has a number of useful physical properties. It is very resistant to corrosion. It is hard, has a high melting temperature, and is lightweight. Its strength is similar to steel, but is 45% lighter. Titanium alloys can be twice as strong as aluminum alloys.

Titanium has no known nutritional benefit for animals. It does, however, have some slight benefits for plant health. Titanium has been found to be very compatible with the human body and is often used in surgical instruments and medical implants. Titanium is the only element that will burn in a pure nitrogen atmosphere.

Name

Titanium was named by M.H. Klaproth after *Titans*. The Titans were the giant sons of Uranus and Gaea. They set out to rule heaven, but were defeated by Zeus. Although the name seems quite appropriate, it was not meant to impart any particular meaning.

Sources

Titanium is found in many minerals. *Ilmenite* ($FeTiO_3$) and *rutile* (TiO_2) are the most important sources of titanium. Ilmenite provides about 90% of the titanium used every year. It is estimated that the resources of ilmenite in the world contain 1 billion tons of titanium dioxide. The estimated resources of rutile in the world contain about 230 million tons of titanium dioxide.

Rutile and ilmenite are extracted from sands that may contain only a few percent by weight of these minerals. After the valuable minerals are separated, the remaining sands are returned to the deposit and the land recultivated. In the United States, titanium-rich sands are mined in Florida and Virginia.

Even though the United States mines and processes titanium and titanium dioxide, it still imports significant amounts of both. Metallic titanium is imported from Russia (36%), Japan (36%), Kazakhstan (25%), and other nations (3%). TiO_2 pigment for paint is imported from Canada (33%), Germany (12%), France (8%), Spain (6%), and other nations (36%).

Uses

Most titanium is used in its oxide form. TiO_2 is a white pigment used in paint, varnishes and lacquers (49%), plastics (25%), paper (16%), and other products such as fabrics, printing inks, roofing granules, and special coated fabrics.

Titanium is lighter than steel but still is very strong. It also has a very high melting temperature. These physical properties make titanium and titanium alloys (an alloy is a mixture of metals) very useful in the aerospace industry where it is mostly used to make engines and structural components for airplanes, satellites, and spacecraft. An estimated 60% of metallic titanium is used in the aerospace industry. The remaining 40% is used in a number of other areas that require titanium’s unique properties.

For example, one physical property of titanium is that it is very resistant to corrosion. Since it is very resistant to corrosion by seawater, it is used to make propeller shafts and other ship parts that will be exposed to ocean water. For medial uses, titanium is considered to be bio-compatible and often is used to make joint replacement parts such as hip joints. Because of its strength, it is also used to make armor plated vehicles for the military. Titanium is also used to produce silvery-white sparks in some fireworks.

Substitutes and Alternative Sources

There are few good substitutes for titanium for its aerospace uses. Substituting other metals for titanium usually results in alloys that are not as lightweight or as strong as titanium alloys. For applications that require corrosion resistance, titanium alloys compete with nickel, stainless steel, and zirconium alloys.

As a white pigment, TiO_2’s brightness and opacity are nearly unsurpassed. However, a number of less expensive compounds can be used to substitute or reduce the amount of titanium dioxide needed. These alternative materials include calcium carbonate, the mineral talc, and the clay kaolin.

ZINC

Zinc: Used as protective coating on steel, as die casting, as an alloying metal with copper to make brass, and as chemical compounds in rubber and paints, used as sheet zinc and for galvanizing iron, electroplating, metal spraying, automotive parts, electrical fuses, anodes, dry cell batteries, fungicides, nutrition (essential growth element), chemicals, roof gutters, engravers' plates, cable wrappings, organ pipes, in pennies, as sacrificial anodes used to protect ship hulls from galvanic action, in catalysts, in fluxes, in phosphors, and in additives to lubricating oils and greases. Zinc oxide: in medicine, in paints, as an activator and accelerator in vulcanizing rubber, as an electrostatic and photoconductive agent in photocopying. Zinc dust: for primers, paints, sherardizing, precipitation of noble metals, removal of impurities from solution in zinc electrowinning. Zinc is mined in about 40 countries with China the leading producer, followed by Australia, Peru, Canada, and the United States. In the U.S. mine production mostly comes from Alaska, Tennessee, and Missouri. The sample photo shows sphalerite, a zinc sulfide.

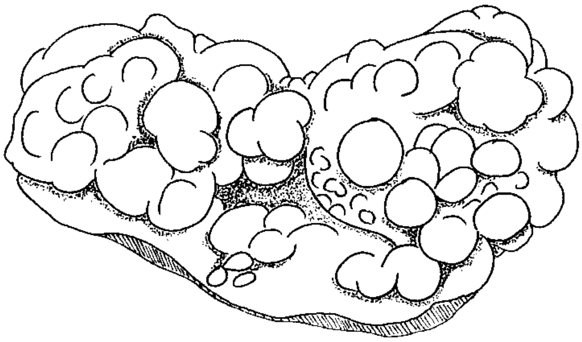
Sphalerite Photo from MII, Courtesy of Smithsonian Institute

Sphalerite -- ***MII Photos***

Background

In the 1200's, India produced zinc metal by burning organic materials with *smithsonite* ($ZnCO_3$, zinc carbonate). Zinc was used long before it was known to be a distinct element. Brass items (brass is an alloy, that is, a mixture, of copper and zinc) have been discovered dating back to as early as 1000 B.C. Zinc was isolated and identified as a distinct element in 1746 by the German, Andreas Marggraf.

Zinc is a blue-gray, metallic element, with the atomic number 30. At room temperature, zinc is brittle, but it becomes malleable at 100 C. Malleable means it can be bent and shaped without breaking. Zinc is a moderately good conductor of electricity. It is relatively resistant to corrosion in air or water, and therefore is used as a protective layer on iron products to protect them from rusting.



Zinc is recovered from a number of different zinc minerals. The most significant of these is sphalerite (ZnS, zinc sulfide). Other minerals, such as smithsonite ($ZnCO_3$, zinc carbonate), and zincite (ZnO, zinc oxide) are also zinc ores.

Adequate amounts of zinc are essential to a healthy life in all humans and animals. It is necessary for the function of a number of different enzymes. It has also been proved necessary for skin and bone growth as well as sexual maturation. The body uses zinc to process food and nutrients. When animals do not have enough zinc in their systems, they need to consume 50% more food to match the weight gain of an animal with enough zinc in its body. About 0.003% zinc is needed for proper health.

Zinc alloys (mixes) well with other metals resulting in stronger, harder metals. Brass, for example, is a mixture of copper and 20%-45% zinc.

Above: Smithsonite (zinc carbonate) from Mexico. This bubbly form is described as "botryoidal." Drawing used with permission. ©2000 Darryl Powell.

Name

The derivation of zinc is unknown but it comes from the similar German word *zinker* that is used for the element zink.

Sources

The identified zinc resources worldwide are estimated to total over 1.9 billion tons. In the United States, zinc is mined in several states. Alaska produces the most, followed by Tennessee, and Missouri. Together, these states account for nearly all of the U.S. zinc production. In earlier years zincite deposits in Ogdensburg, New Jersey produced significant quantities of zinc. These mines are now closed but the zinc production of this area is famous among mineralogists.

The United States imports zinc from a number of countries. Of total U.S. zinc imports, the majority comes from Canada, followed by Mexico, from Peru, other countries. Australia is also a significant zinc-producing nation.

Recycling of new scrap, old scrap and other zinc-using products produces about 400,000 tons of zinc in the United States.

Uses

Zinc is relatively non-reactive in air or water. Consequently, it is applied in thin layers to iron and steel products that need to be protected from rusting. This process is called *galvanizing*. Galvanizing is done in a number of ways. Generally, the metal is dipped in molten zinc. It can also be done by electroplating or by painting on a layer of zinc compound. More than half of the zinc consumed is used for galvanizing.

The second largest use of zinc is as an alloy (other than brass or bronze). Making brass and bronze accounts for another portion of zinc consumption. The remaining zinc consumption is for making paint, chemicals, agricultural applications, in the rubber industry, in TV screens, fluorescent lights and for dry cell batteries. The pennies in your piggy bank are made of zinc - with a thin coating of copper on top.

Substitutes and Alternative Sources

There are a number of alternative materials that are used in place of zinc. For example, aluminum and plastics can be used in place of galvanized steel (plastic trash cans are rapidly replacing the old galvanized cans of earlier generations). A number of elements can replace zinc in its electronics and paint applications. Cadmium and aluminum alloy coatings can be used in place of zinc to protect steel from corrosion.

QUARTZ

MII Photos

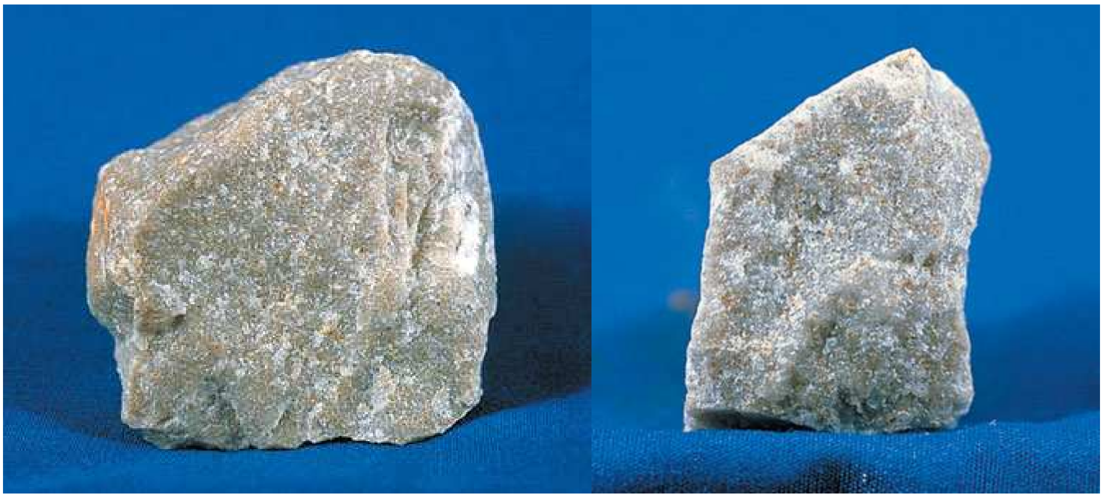
Quartz Crystals

Quartz Crystals

Quartz Sandstone


Quartz Amethyst

Quartz



Quartzite

Quartzite

Background

Quartzite is a nonfoliated metamorphic rock that formed by the metamorphism of pure quartz sandstone. The intense heat and pressure of metamorphism causes the quartz grains to compact and become tightly intergrown with each other, resulting in very hard and dense quartzite. Quartzite is usually white or gray, but can be other light colors depending on the impurities in the parent sandstone. It has a glassy luster, as would be expected considering the quartz in sandstone has a vitreous or glassy luster. When quartzite weathers it can have a granular appearance, but freshly broken surfaces break in even surfaces because the break goes through the intergrown quartz grains. (By comparison, sandstone breaks around the quartz grains and therefore shows a granular appearance on a freshly broken surface.) They can form anywhere heat and pressure change pre-existing sandstone deposits, so quartzite is found both in geologic settings of regional metamorphism (where metamorphism occurs more from pressure than heat) and contact metamorphism (where metamorphism occurs more from heat than pressure). However, quartzite most typically forms during mountain-building events where continents collide with each other. Because it is so dense and tough, quartzite is extremely resistant to weathering and erosion.

Name

Sources

Geologically speaking quartzite occurs in regions of regional, high-pressure metamorphism. In the United States quartzite quarries are found in Idaho, New York, Wisconsin, Pennsylvania, Minnesota, Montana, Arizona and South Dakota. Because it is so dense and resistant to both physical and chemical weathering, it is poor bedrock on which to form soil. As a result, typically-quarried quartzite is very near the surface. Because it is so hard and dense, quartzite has not been quarried as extensively as other softer dimension stone (such as limestone, sandstone and granite), although construction industry experts estimate that present demand exceeds annual production.

A total of 1.3 billion tons of crushed rock is produced in the United States annually. Of this, less than 6% is quartzite. In fact, sandstone, marble, scoria, volcanic cinder and miscellaneous stone - all together - account for less than 6% of the total crushed stone production in the U.S.

Uses

Quartzite is becoming more popular as a dimension stone in the construction industry. The use of quartzite as decorative stone in building construction is growing annually. As noted above, quartzite breaks into flat surfaces. Consequently, quartzite slabs are used to cover walls, as roofing tiles, as flooring, and stair steps to name just a few applications. Quartzite is also used, to a small degree, as crushed stone. The vast majority of crushed stone - about 85% - is used in road construction and repair. In the United States, most crushed stone produced is limestone, granite, and trap rock. Limestone represents 70% of all the crushed rock produced.

Substitutes and Alternative Sources

Other hard, durable rock types are used in road construction and repair. Since they are extremely plentiful and easier to quarry than quartzite, it is not likely that quartzite will be utilized in greater amounts as a crushed rock. On occasion, quartzite is the alternative to other crushed rock simply because it is locally available.
The popularity of quartzite as dimension stone in construction is growing dramatically each year . It is an interesting rock with great durability and a unique texture. More and more contractors and homeowners are using quartzite to finish and decorate their buildings. Natural alternative materials include sandstone, granite, and marble. Created materials include bricks, ceramic tiles, concrete, plastics, and resin-agglomerated stone. (“Resin-agglomerated stone” is a material composed of crushed pieces of stone held together by resin, then cut to the dimensions and shapes needed for each application) There are other materials readily available that have very different physical characteristics. Two examples are aluminum and steel.

By Darryl Powell

Darryl Powell is a 1984 graduate of the University of Rochester, Rochester, New York with a B.S. in Geological Sciences. For six years Mr. Powell was an Adjunct Professor at Finger Lakes Community College in Canandaigua, New York, where he taught “Introduction to Physical and Historical Geology.” He creates Earth Science educational kits for NeoSCI, Inc., a science education resource company based in Rochester, New York. He also writes Earth Science materials for NewPath Learning, Inc.

based in Victor, New York. Mr. Powell is the founder of Diamond Dan Publications, a small company focused on creative activity books and activity-based learning games about rocks and minerals, based in Manchester, New York.

Amphibole

(Amphibolite - Hornblende)

Background

Amphibolite is a dark, heavy, metamorphic rock composed mostly of the mineral amphibole. Amphibolites have very little to no quartz. “Amphibole” refers not to a single mineral, but to a group of minerals. Most belong to the monoclinic crystal system, but some belong to the orthorhombic crystal system. They are silicate minerals containing SiO4 molecules. The SiO4 groups are connected to each other in double chains.

Rocks that are composed mainly of amphibole minerals are found in both metamorphic and igneous environments. Geologists restrict the term amphibolite to metamorphic rocks composed of amphibole. In most instances the specific amphibole mineral is hornblende. By contrast, geologists often refer to igneous rock with amphibole as hornblendite. However, those who work with rock as a construction material usually refer to all rock types composed of amphibole as “amphibolite.” Based on this industrial application of the term “amphibolite” as both metamorphic and igneous in origin, the textures of amphibolite can be either roughly laminated if metamorphic or granular if igneous.

The original rock that is metamorphosed (called the protolith) into amphibolite is often igneous basalt or gabbro. However, the sedimentary rock called marl can also be metamorphosed into amphibolite. “Marl” is mudstone that has a certain amount of calcium carbonate (lime) mixed in it. Geologists have also discovered that some sediments derived from volcanic rock can also be metamorphosed into amphibolite.

The name amphibolite comes from the Greek word amphibolos which means ambiguous, a reference to the fact that the amphibole minerals are easily mistaken for other dark-colored minerals (especially the group of minerals called the pyroxenes).

Name

Sources

Amphibolite is relatively common. It is found in regions that have been affected by regional metamorphism. Amphibolite is found throughout the Appalachian Mountain chain. For example, significant quantities of amphibolite are found in the Gore Mountain region of the Adirondack Mountains in New York State. This is a particularly interesting deposit because the amphibolite contains large nodules of deep red garnet that has been mined for use in sand papers and other abrasives applications. They are also found in the Great Smoky Mountains National Park on the Tennessee-North Carolina border. Other states along the Appalachian Mountains producing amphibolite are Maine, Connecticut, Pennsylvania and North Carolina.

Uses

Amphibolite is very hard and takes a high polish. The combination of its ability to be polished, its dark color and its texture have made amphibolite a popular dimension stone in construction. It is used as paving stones and as a veneer or facing on buildings (both for interior and exterior use).

It is also used as crushed stone for the usual crushed stone applications such as road and railroad bed construction. In this application it is used locally, near the source of the amphibolite. This reduces the cost of transporting non-native stone in from other sources.
Gemologists and lapidary workers have discovered that some amphibolite

rock produces a shimmer effect when it is polished. They use rounded and polished pieces of amphibolite for various pieces of jewelry.

Substitutes andAlternative Sources

There are nearly limitless alternatives for the various crushed stone applications for which amphibolite is occasionally used. Any type of rock, local or imported, that can be readily quarried, crushed and transported can replace amphibolite. In the United States, limestone and granite together represent over 80% of all the crushed rock consumed annually. As noted above, amphibolite is used locally where it is easily quarried, reducing the costs of transporting rock in from other regions.

There are many options to amphibolite as dimension stone. Marble, granite, and quartzite, for instance, can all be polished and used as facing on the interior and exterior of buildings. In some environments even sandstone can be used for building construction. In the end, amphibolite is chosen for the particular color, texture and overall look it gives to a building. Substitutes that provide a similar look include plastics and some varieties of other dark rock like dark granite.

By Darryl Powell

Darryl Powell is a 1984 graduate of the University of Rochester, Rochester, New York with a B.S. in Geological Sciences. For six years Mr. Powell was an Adjunct Professor at Finger Lakes Community College in Canandaigua, New York, where he taught "Introduction to Physical and Historical Geology." He creates Earth Science educational kits for NeoSCI, Inc., a science education resource company based in Rochester, New York. He also writes Earth Science materials for NewPath Learning, Inc. based in Victor, New York. Mr. Powell is the founder of Diamond Dan Publications, a small company focused on creative activity books and activity-based learning games about rocks and minerals, based in Manchester, New York.

Andesite

MII Photo

Aragonite

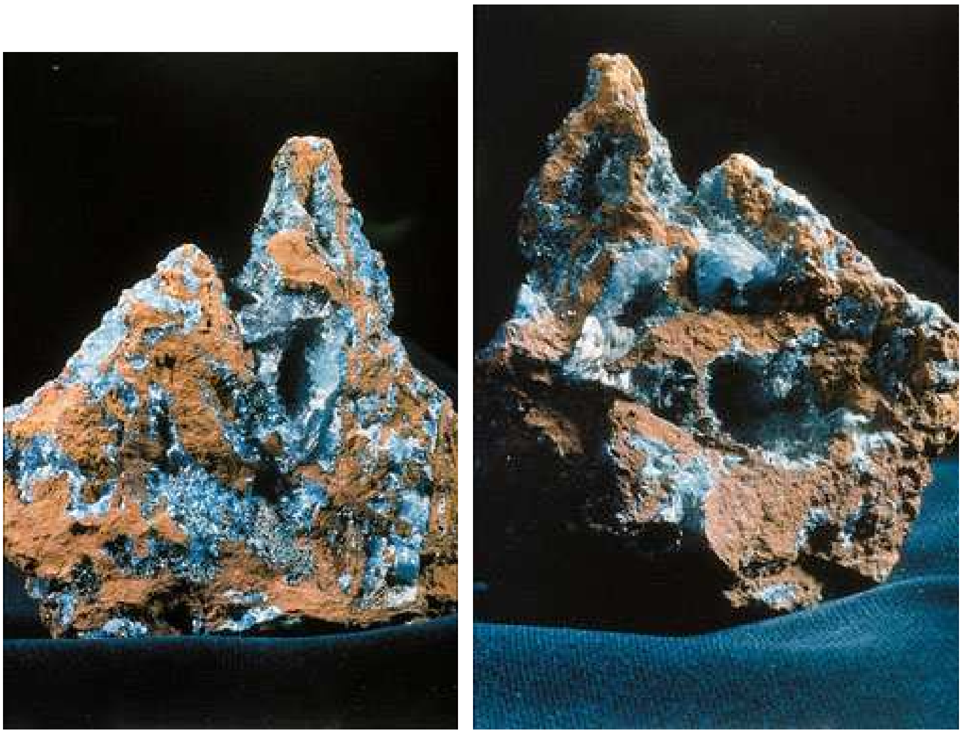
MII Photos

Aragonite is a carbonate mineral, one of the two common, naturally occurring polymorphs of calcium carbonate, $CaCO_3$. The other polymorph is the mineral calcite. Aragonite's crystal lattice differs from that of calcite, resulting in a different crystal shape, an orthorhombic system with acicular crystals. Repeated twinning results in pseudo-hexagonal forms.

Augite

MII Photos

Gold Mineral - Aurichalcite



MII Photos

Autunite

MII Photos

Copper Minerals

Azurite

Azurite with Malachite


Malachite


Malachite


Chalcopyrite


Chalcopyrite


Chalcopyrite


Cuprite


Chalcocite


Bornite


Dipotase


Tennantite

Copper: Used in electric cables and wires, switches, plumbing, heating, roofing and building construction, chemical and pharmaceutical machinery, alloys (brass, bronze, and a new alloy with 3% beryllium that is particularly vibration resistant), alloy castings, electroplated protective coatings and undercoats for nickel, chromium, zinc, etc., and cooking utensils. The leading producer is Chile, followed by the U.S., and Indonesia

Background

It is believed the Egyptians (as early as 3900 B.C.E.) were the first people to create bronze, a mixture of copper and tin. This marked the beginning of the Bronze Age.

Modern culture and life is heavily dependent on copper and copper products. It is a metal that has the desirable physical properties of being *malleable* and *ductile*. *Malleable* means it can be hammered and molded into shapes; *ductile* means it can be drawn into wire. As a result, copper pipes are used to bring water to and through our buildings. Because it is such a good conductor of electricity, millions of miles of copper wire crisscross the landscape and run through our buildings. Copper alloys (such as brass) are important components in many household products and machines. It has been said that the amount of copper a society consumes is a direct indicator of the advancement of that society. In other words, those societies that consume larger amounts of copper are considered more technologically developed.

Copper ore may be found in large deposits, relatively close to the surface, and amenable to relatively low cost bulk mining methods. The combination of its physical properties, abundance, and low cost make it a valuable commodity.

Copper is a mineral. As a mineral, natural copper (also called *native copper*) is relatively rare. Most copper in nature is found in minerals associated with sulfur, or in the oxidized products of these minerals.

Copper also easily combines with a number of other elements and ions to form a wide variety of copper minerals and ores. Copper minerals occurring in deposits large enough to mine include azurite (Cu3(CO3)2(OH)2), malachite (Cu2CO3(OH)2), tennantite ((Cu,Fe)12As4S13), chalcopyrite (CuFeS2), and bornite (Cu5FeS4).

Name

Copper was named from the Greek word *kyprios*, that is, the Island of Cyprus, where copper deposits were mined by the ancients. The chemical symbol for copper is Cu which is derived from the Latin name for copper, *cuprium*.

Sources

The amount of copper believed to be accessible for mining on the Earth’s land is 1.6 billion tons. In addition, it is estimated that 0.7 billion tons of copper is available in deep-sea nodules. Mineral-rich nodules of magnesium, copper and other metals are known to form as a product of deep-sea volcanic activity. Retrieving these nodules from the sea floor is as yet too expensive to allow this to be a major source of copper.

Of the copper ore mined in the United States, the majority is produced in three western states: Arizona, Utah, and New Mexico.

Other major copper producing nations include Australia, Canada, Chile, China, Mexico, Russia, Peru, and Indonesia.

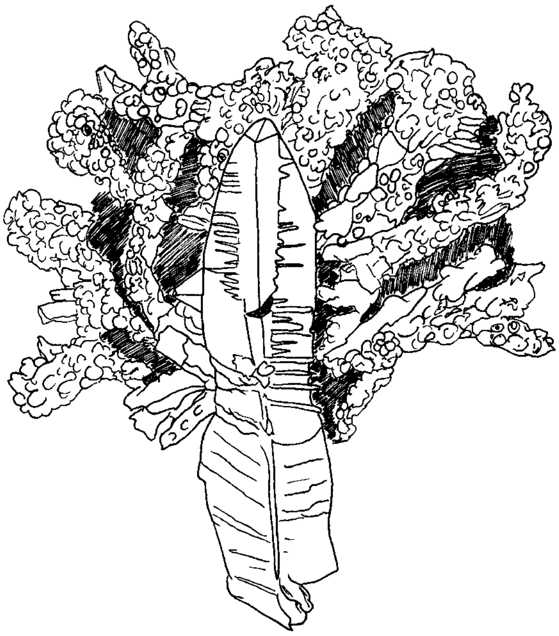
Recycled copper, predominantly from scrap metal, supplies approximately one-third of the United States' annual copper needs.

Uses

In pure form, copper is drawn into wires or cables for power transmission, building wiring, motor and transformer wiring, wiring in commercial and consumer electronics and equipment; telecommunication cables; electronic circuitry; plumbing, heating and air conditioning tubing; roofing, flashing and other construction applications; electroplated coatings and undercoats for nickel, chrome, zinc, etc.; and miscellaneous applications. As an alloy with tin, zinc, lead, etc. (brass and bronze), it is used in extruded, rolled or cast forms in plumbing fixtures, commercial tubing, electrical contacts, automotive and machine parts, decorative hardware, coinage, ammunition, and miscellaneous consumer and commercial uses. Copper is an essential micronutrient used in animal feeds and fertilizers.

Substitutes and Alternative Sources

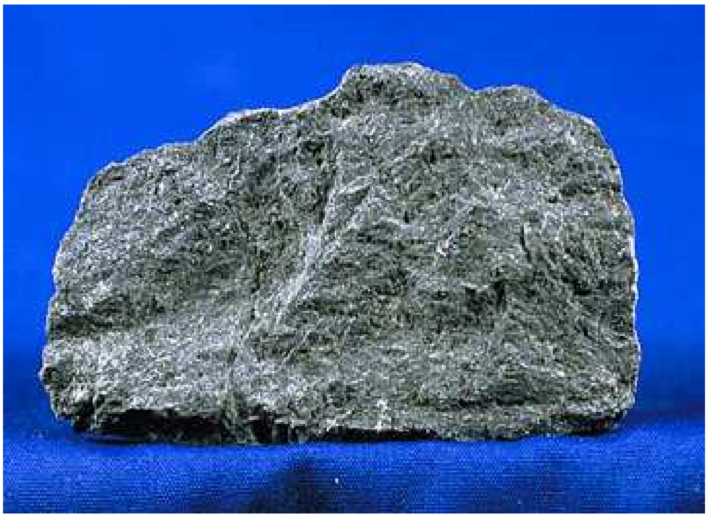
A number of plastic products are used now instead of copper pipes. The telecommunications industry is using fiber optic cables in place of copper wires, and the invention of cellular and satellite telephone technology allows many areas of the world to have communications without the need to install "copper telephone wires." Aluminum can be used instead of copper for wires, refrigeration tubing, and electrical equipment.



Copper crystal from Tsumeb, Namibia.

Drawing by Darryl Powell

Basalt



MII Photos

Biotite

MII Photos

Calcium-rich Plagioclase

MII Photos

Calcite

MII Photos

TIN

Cassiterite

Background

Tin has been known from ancient times. Ancient peoples found that heating the tin mineral cassiterite (sometimes found in streams as nuggets) in a charcoal fire, they could produce the silvery, soft metal we know as tin.

Tin is a silvery-white metallic element with atomic number 50. Tin is malleable, meaning it is easily shaped by hammering. Pure tin also has a relatively low melting point, easily attainable in a wood fire, and is therefore easy to melt and cast in a clay mold. Tin is stable in air and water, meaning it does not oxidize or react easily . When pure tin is bent rapidly, it makes a peculiar squealing noise: this is called the "tin cry."

The ancients found tin to be too soft to be of much use for other than decorative objects, and the use of pure tin in ancient times was restricted to mirrors, clasps, and decorative items. Some coins have been minted of tin, but the coins wear and bend rapidly. However, when mixed (alloyed) with copper, another metal which could be found in a nearly pure state in nature, then a new and much harder alloy resulted: bronze. This discovery marked the beginning of the historical period known as *The Bronze Age*. The advent of the Bronze Age, with the use of bronze spears, arrowheads, knives, sickles, and scythes, greatly enhanced the efficiency of hunters and farmers.

The most important ore mineral of tin, cassiterite (tin dioxide, SnO2) forms in high-temperature veins, usually related to igneous rocks such as granites and rhyolites. It is often found in association with tungsten minerals. When rocks containing cassiterite are weathered (decomposed by the action of surficial waters and oxidation), the cassiterite tends to remain intact, and eventually is concentrated in streams to form "placer" deposits, in a manner similar to gold nuggets in "placer" deposits. Ancient peoples recovered cassiterite from streams by panning, and even today panning or - more importantly - large-scale mechanical dredging of stream deposits and decomposed rock are a major means of producing cassiterite. Veins with a high enough cassiterite content to mine underground occur in China, Bolivia, Peru, and a few other countries.

Name

The name *tin* is an ancient Anglo-Saxon word. Tin in the form of cassiterite was mined in ancient Britain and was a major trade item between Britain and the Greeks and Phoenicians of the Mediterranean region. The chemical symbol for tin, Sn, comes from the Latin word for tin, *stannum*. Tin was one of only seven chemical elements known in pure form, and named by ancient peoples. The mineral cassiterite is named for the ancient Greek word for tin.

Sources

As noted earlier, the primary mineral source for tin is cassiterite. The most tin resources in the United States are in Alaska, but these are relatively insignificant, and the U.S. has long imported its tin from other countries.

World resources to meet the demand for tin are sufficient for many decades to come. The primary producers of tin are China, Indonesia, and Peru, with lesser amounts from Brazil, Bolivia, Australia, and about a dozen other countries.

Uses

Much tin is used to coat so-called “tin” cans. Since tin does not oxidize (rust) in air or water, it is applied to the surface of flat-rolled steel to make tin plate, which is then fabricated to produce “tin” cans. This use accounts for about one-fourth of the tin consumed annually. Alloys such as bronze and pewter are also a major use of tin. Tin is useful in electrical applications, mainly low-melting-point solders, that account for one-fourth of tin consumption. It is also used in construction, transportation (mainly in bearings requiring soft metal alloys) and other various industrial applications. For example, window glass is made by pouring molten glass onto molten tin; this process results in flat sheets of glass. An alloy of tin and niobium has proven to be a “superconducting” compound at very low temperatures.

Substitutes and Alternative Sources

A number of materials can replace tin in its various applications. In the food packaging industry, plastics, paper, aluminum and glass can be used in place of metal “tin cans.” Tin can be used as a non-toxic substitute for lead in solders, pewter, and shotgun pellets. On balance, the world production and consumption of tin have not grown during the past 20 years, due mainly to the substitution of tin by plastic in the manufacture of cans and other containers, such as tubes for toothpaste and ointments.

Chert

Chertjas

MII Photos

Chlorite

MII Photos

MERCURY

Cinnabar - Mercury mineral

Background

Mercury, known since ancient times, is a heavy, silvery, metallic mineral. Its atomic number is 80. It is liquid at room temperature. Only two other elements (cesium and gallium) are liquid at room temperature. Mercury becomes solid at -40° F (-40° C). It is dense and heavy, with a specific gravity of 13.6. For comparison, iron has a specific gravity of 7.5.

Name

The term "native mercury" is used for natural mercury found associated with the mineral cinnebar. Mercury was named after the planet *Mercury* that was named after the Roman god of travel. Mercury is also known by the popular name of *quicksilver*, derived from the Greek words, *hydros* meaning *water*, and *argyros* meaning *silver*, because this silvery mineral occurs at room temperature as a liquid. The symbol for mercury, Hg, was derived from the name, *hydrargyrum*.

Sources

Native mercury is found in association with its ore mineral, cinnabar. In the United States, mercury was mined in California, Arkansas, Oregon, Nevada, Idaho, and Texas, but these deposits are no longer mined. Major world producers of mercury are Algeria, Kyrgyzstan, Spain and China. The United States imports much of the mercury it needs each year.

Mercury vapor has been found to be extremely toxic. New laws, in the United States, call for reductions in mercury emissions from smokestacks and carefully controlled disposal of waste mercury and mercury compounds.

The demand for mercury has declined in the past years because of new technologies and environmental laws. Some of the demand has been met by the recycling of mercury from obsolete or worn out machines, scientific apparatus, and batteries. It is also recovered as a by-product from gold mining operations in California, Nevada, and Utah. Historically, mercury was used to obtain gold from placer gold deposits but this process is no longer used in the United States and many other countries. This process is still used by some operators in a few other countries, but the practice is disappearing.

Uses

Mercury is used to manufacture chlorine and caustic soda (35%). Because it is a metal, mercury conducts electricity making it useful in electronics and electrical applications (30%). Mercury, for example, is necessary in fluorescent light tubes. Mercury was an important ingredient in batteries, but newer types of batteries use other metals. The remaining 35% of mercury usage is in scientific measuring instruments such as thermometers and barometers, and is combined with other metals and used for in fillings for teeth (called *amalgams* by dentists).

Biological Interactions

Mercury vapor is a neurotoxin, which means it affects the nervous system. Once mercury is in the body, it causes nervousness, trembling, personality changes, and in extreme cases, even dementia. Fish that ingest mercury compounds that may occur in streams and lakes can become a source of mercury poisoning in humans. Consequently, the United States has enacted many strict laws to guarantee the proper and safe disposal of all mercury and mercury compounds.

Substitutes and Alternative Sources

Mercury is being used less in batteries as new types of batteries are developed, such as zinc-air, lithium and nickel-cadmium (also called Ni-Cad) batteries. Ceramics have lately been used in dental work instead of the mercury amalgams. Electronic digital instruments are used more frequently in place of mercury thermometers and barometers.

CLAYS

MII Photos

Claystone

Kaolinite

Kaolinite

Background

The term *clay* refers to a number of earthy materials that are composed of minerals rich in alumina, silica and water. Clay is not a single mineral, but a number of minerals. When most clays are wet, they become "plastic" meaning they can be formed and molded into shapes. When they are "fired" (exposed to very high temperatures), the water is driven off and they become as hard as stone. Clay is easily found all over the world. As a result, nearly all civilizations have used some form of clay for everything from bricks to pottery to tablets for recording business transactions.

The minerals that make up clay are so fine that until the invention of X-ray diffraction analysis, these minerals were not specifically known. Under extremely high magnification, one can see that clay minerals can be shaped like flakes, fibers, and even hollow tubes. Clays can also contain other materials such as iron oxide (rust), silica, and rock fragments. These impurities can change the characteristics of the clay. For example, iron oxide colors clay red. The presence of silica increases the plasticity of the clay (that is, makes it easier to mold and form into shapes).

Clays are categorized into six categories in industry. These categories are ball clay, bentonite, common clay, fire clay, fuller's earth, and kaolin.

Name

Sources

Clays are common all over the world. Some regions, as might be expected, produce large quantities of specific types of clay. It is estimated that the state of Georgia has kaolin clay reserves of 5 to 10 billion tons. The United States is self-sufficient so it imports only small amounts of clay from Mexico, Brazil, United Kingdom, Canada, and assorted other nations. The United States exports nearly half of its production worldwide.

The nations producing the most significant amounts of the various clays are as follows:

- **Kaolin:** Brazil, United Kingdom, and the United States are the dominant producers of high quality kaolin.
- **Ball clays:** Major producers of ball clays are Germany, the United States, United Kingdom, the Czech Republic, China, and France.
- **Fire clays:** Major fire clay producing countries are Germany, and the United States.
- **Bentonite:** Major producers of bentonite are the United States, Germany, Turkey, and Greece.
- **Fuller's earth:** Major producers of fuller's earth are the United States (attapulgite, smectite), Spain (attapulgite, sepiolite), and Senegal (attapulgite).

Uses

The United States both imports and exports clays and clay products. It is estimated that the United States consumes about 37.6 million tons of clays each year.

Ball clays are good quality clays used mostly in pottery but are also added to other clays to improve their plasticity. Ball clays are not as common as other clay varieties. One third of the ball clay used annually is used to make floor and wall tiles. It is also used to make sanitary ware, pottery, and other uses.

Bentonite is formed from the alteration of volcanic ash. Bentonite is used in pet litter to absorb liquids. It is used as a mud in drilling applications. It is also used in other industrial applications such as the "pelletizing" of iron ore.

Common clay is used to make construction materials such as bricks, cement, and lightweight aggregates.

Fire clays are all clays (excluding bentonite and ball clays) that are used to make items resistant to extreme heat. These products are called *refractory* products. Nearly all (81%) of fire clays are used to make refractory products.

Fuller's earth is composed of the mineral palygorskite (at one time this mineral was called "attapulgite"). Fuller's earth is used mostly as an absorbent material (74%), but also for pesticides and pesticide-related products (6%).

Kaolinite is a clay composed of the mineral *kaolin*. It is an essential ingredient in the production of high quality paper and some refractory porcelains.

Substitutes and Alternative Sources

When necessary, calcium carbonate and talc can be used in place of clay as filler in some applications. However, clay is so abundant in all its forms that such substitutions may only be necessary if the alternative materials are less expensive than clay (which is not very likely).

Colemanite

(Source of Borax)

MII Photos

Conglomerate

MII Photos

Corundum

MII Photos

Creeoite

MII Photos

Diorite

MII Photos

Dolomite

MII Photos

LIME - Limestone

Limestone

Fossils in Limestone

MII Photos

Background

Lime is a general term used for various forms of a basic chemical produced from calcium carbonate rocks such as limestone ($CaCO_3$) and dolomite ($CaCO_3 * MgCO_3$) More specifically, “quicklime” is calcium oxide (CaO) or calcium-magnesium oxide (Ca)*MgO). “Hydrated lime” (also called slaked lime) is produced by mixing the oxide forms with water. “Hydraulic lime” is an impure form of lime that will harden under water. “Dead-burned dolomite” is a special form of dolomitic lime used in refractories. Most lime is produced by calcining (burning) limestone or dolomite. For example, if limestone is burned at 1010 to 1345 degrees C, the carbon dioxide is driven off and leaves calcium oxide or quicklime. In its purest form and under laboratory conditions, 100 kilograms of limestone will produce 56 kilograms of quicklime. Lime has been used for thousands of years for construction. Archeological discoveries in Turkey indicate lime was used as a mortar as far back as 7,000 years ago. Ancient Egyptian civilization used lime to make plaster and mortar. In the United States, lime use has changed dramatically. In 1900, more than 80% of the lime used in the U.S. was for construction uses. Today, nearly 90% is used for chemical and industrial uses.

Name

Sources

In the United States, lime is produced in a number of states. Companies in Texas, Alabama, Kentucky, Missouri, Ohio and Pennsylvania account for more than one-half of U.S. production annually. In addition, lime is imported from Canada and Mexico. Other nations producing lime include Belgium, Brazil, China, France, Germany, Italy, Japan, Poland, Romania, and the United Kingdom.

Significant amounts of lime are recycled. Paper companies recycle large volumes of the lime they use. Some water treatment facilities recycle lime as well.

Uses

The largest use of lime is in steel manufacturing where lime is used as a flux to remove impurities such as phosphorus and sulfur. Lime is used in power plant smokestacks to remove sulfur from the emissions. Lime is also used in mining, paper and paper pulp production, water treatment and purification, and in wastewater treatment. It is used in road construction and traditional building construction.

Substitutes and Alternative Sources

Limestone can be used in place of lime for some industrial applications such as agriculture, as a flux in steel making, and in sulfur removal. Limestone is much less expensive than lime; however, it is not as reactive as lime, so it may not be the best substitute in all cases. Magnesium hydroxide can be used for pH control. Lime resources are plentiful worldwide for the near and distant future, and substitutes may not be necessary for a long time to come.

Gabbro

MII Photos

GARNET (Industrial)

Garnet Schist

Background

"Garnet" is the name given to a group of chemically and physically similar minerals. A very small number of garnets are pure and flawless enough to be cut as gemstones. The majority of garnet mining is for massive garnet that is crushed and used to make abrasives. Garnet is a silica mineral; in other words, garnet's complex chemical formula includes the silicate molecule (SiO_4). The different varieties of garnet have different metal ions, such as iron, aluminum, magnesium and chromium. Some varieties also have calcium. Garnets all crystallize in the isometric (meaning equality in dimension. For example, a cube, octahedron, or dodecahedron.) crystal system. Garnets all are quite hard, ranging between 6 and 7.5 on the Mohs' hardness scale. They also lack cleavage, so when they break, they fracture into sharp, irregular pieces. The combination of the hardness and fracture make garnet a valuable abrasive material.

Name

The name *garnet* has been used since ancient times. It was derived from the Latin word *granatium* which means *a pomegranate* because small, red garnet crystals were thought to resemble pomegranate seeds. The original name given this mineral group was *granat*. In time the "r" and "a" were transposed giving us *garnet*. The name was officially proposed to mineralogists by the German theologian and philosopher, Albertus Magnus.

Sources

In the United States, only a few companies in three states (Idaho, New York, and Montana) produce garnet for industrial use.

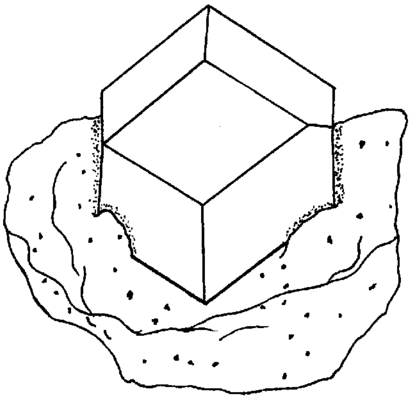
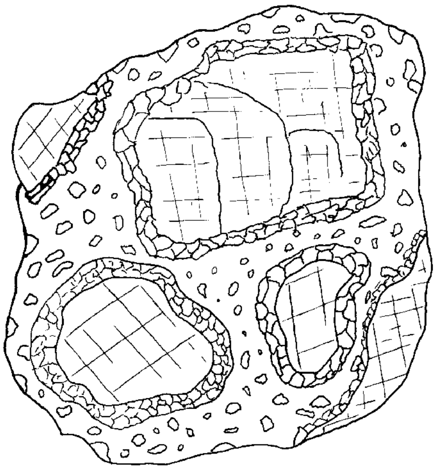
There are many significant garnet-producing countries. Noteworthy among them are Australia, China, and India, all of which export significant amounts of garnet. Russia and Turkey also produce large amounts of industrial garnet, but they are not yet exporting much of this material.

Uses

Garnet is ground to a variety of sizes to be used as an abrasive. Garnet sandpaper was the original application of this mineral. It is also used to make a number of similar products, including sanding belts, discs, and strips. Today, the vast majority of garnet is used as an abrasive blasting material, for water filtration, in a process called water jet cutting, and to make abrasive powders.

Substitutes and Alternative Sources

A number of natural and synthetic materials could be used in place of garnet for abrasive purposes. The natural materials include the minerals staurolite, quartz, diamond and corundum. The synthetic materials include fused aluminum oxide and silicon carbide.

A typical garnet crystal From  Mexico	Typical massive garnet from New York State. Irregular masses of garnet in metamorphic rock. 

Garnet crystal drawings by Darryl Powell
© 1999 Darryl Powell
Used with permission.

Garnierite

(Nickel Ore)

MII Photos

Geaoksutite

MII Photos

Sandstone

 Image Source: USGS	 Image: Source: USGS, Cross Bedding.

Background

Sandstone is a sedimentary rock composed of mostly of quartz sand, but it can also contain significant amounts of feldspar, and sometimes silt and clay. Sandstone that contains more than 90% quartz is called quartzose sandstone. When the sandstone contains more than 25% feldspar, it is called arkose or arkosic sandstone. When there is a significant amount of clay or silt, geologists refer to the rock as argillaceous sandstone. Argillaceous sandstones are often gray to blue and consequently are referred to as bluestone. Because it is composed of light colored minerals, sandstone is typically light tan in color. Other elements, however, create colors in sandstone. The most common sandstones have various shades of red, caused by iron oxide (rust). In some instances, there is a purple hue caused by manganese.

Sandstone began as large deposits of beach or river sands that were later compacted and lithified ("turned into stone"). The grains of sand of which sandstone is composed is the mineral quartz (SiO2). The quartz grains came from the weathering and erosion of igneous rocks, particularly granite, that have high amounts of quartz (granite is an intrusive igneous rock composed of feldspar, quartz and biotite mica).

Sandstone is deposited by water or air and therefore can represent a number of different geologic environments. In many cases, the sand was deposited in shallow lakes or oceans, and beach environments. In others, the sands were deposited by large rivers and therefore represent an inland river environment. Many are deposited in deltas where rivers empty into oceans. Some sandstones were deposited in ancient desert environments by blowing winds.

Sandstone is a detrital sedimentary rock. This means that it is composed of the weathered fragments of other pre-existing rock. In most cases it is stratified, that is, deposited in layers. The layers often run parallel to each other. This is typical in lake and ocean deposits of sand. Rivers and deserts, however, represent environments in which the direction of the water or wind can change regularly. As a result, the layers of sand are deposited in different directions, always at an angle. This creates a special sedimentary structure that geologists call cross-bedding. The direction in which the beds of sandstone dip indicates the direction in which the water or wind was moving at the time of deposition.

Sandstone is a very significant aquifer. An "aquifer" is a rock body that has a high degree of porosity (which means it has a large volume of space between the individual grains of which the rock is composed) and a high permeability (which means the spaces are connected so water can move through the rock). The Ogallala Sandstone, for example, is an immense aquifer (it is called both the Ogallala Aquifer and the High Plains Aquifer) that lies beneath the Great Plains of the Midwestern United States. It covers approximately 174,000 mi2 and is found under portions of South Dakota, Nebraska, Wyoming, Colorado, Kansas, Oklahoma, Texas and New Mexico. Today the Ogallala Aquifer provides 12 billion cubic meters of water each year. Unfortunately, more water is being removed than is going back into this aquifer (a process called replenishing.)

Name

Sources

Sandstone has two major applications, as crushed stone and as dimension stone. “Dimension stone” is any rock material that is cut into specific sizes, typically as blocks and slabs. Dimension stone is used in the construction of roadways and road structures such as bridges, and in buildings, both commercial and residential.

Crushed Sandstone - Crushed sandstone represents less than 6% of the total tonnage of rock quarried and crushed for different construction needs in the United States. Approximately 1.7 billion tons of crushed rock is produced in the United States annually. Therefore, less than 102 million tons of crushed sandstone is produced in the U.S. each year. The majority of this sandstone is used in road and highway construction and maintenance.

Resources for crushed stone in general, and crushed sandstone specifically, are enormous. The world supply will likely never be depleted.

Dimension Stone - Of all the dimension stone quarried in the United States (which includes rock such as sandstone, marble, granite, limestone, and slate), sandstone represents 13% of the 1.5 million tons used annually. 195,000 tons of sandstone is quarried for use in construction every year. Even more is imported from other countries. Resources for sandstone as dimension stone, both in the United States and worldwide, are more than adequate to meet projected needs for the near and distant future.

Uses

Substitutes and Alternative Sources

There are a number of alternative materials that could be used in place of sandstone. As crushed rock, any number of alternative rock materials can be used in road construction. For example, limestone, granite, slate and other rock materials are plentiful and easily accessible. Where there is a need or desire to recycle materials, steel slag and glass slag can be crushed and used in road construction, eliminating both the need to quarry fresh material and to dispose of the slag. As dimension rock, bricks, ceramic tiles, concrete, and resin-agglomerated stone can replace sandstone. (“Resin-agglomerated stone” is a material composed of crushed pieces of stone held together by resin, then cut to the dimensions and shapes needed for each application.) Aluminum, steel and some plastics can also be used in place of sandstone, depending on the application and properties required of the material for that application.

Gneiss

MII Photos

Granite

Background

Granite is a very common intrusive igneous rock. It is coarse-grained and is composed of the minerals feldspar, quartz and biotite and muscovite mica. It has high silica content and occurs only in continental crust. Granites are light-colored, usually in grays and pinks, their color being determined by the color of the feldspar in the granite. Darker granites and even green granite are known.

Granite is very hard and dense. It can be readily cut into very large blocks and it takes an extremely high polish. Weathered granite, by comparison, crumbles easily. When granite is weathered and eroded, the feldspar and mica break down into clay minerals, leaving the very resistant quartz grains behind. Most beach sand is composed of quartz grains derived from granite.

Granite can contain a number of accessory minerals including apatite, magnetite and zircon. When superheated, element-rich waters alter granite, a variety of rare minerals are deposited in spaces in the granite, such as tourmaline and topaz. The feldspar in granite contains radioactive elements. The breakdown of these elements releases radiation, which turns colorless quartz crystals in the granite into black smoky quartz crystals.
The name granite is derived from the Latin word granum, which means grain, an obvious reference to the granular texture of granite.

Name

Sources

As indicated above, granite is typical of and widespread in continental crust. Much of the North American continent is underlain by granite. The Canadian Shield is an extensive region of central and eastern Canada of massive granite (mixed with some metamorphic rocks) that covers approximately 1.7 million square miles. It extends into northern and northeastern United States. It is also called the Precambrian Shield because it first formed in the Precambrian Era over 545 million years ago. Some of the Shield is as old as 2 billion years. By contrast, granite also occurs in small, local intrusions called stocks.

Sources of commercial granite are found throughout the United States. New Hampshire and Vermont produce significant quantities of crushed granite and even more as dimension stone. The official nickname of New Hampshire is "The Granite State." Massive blocks of granite are quarried and shipped all over the United States for buildings, monuments, memorials (including carvings, headstones, mausoleums, etc.) and sculptures. Barre, Vermont is known for its granite quarries and calls itself "The granite capital of the world." Elberton, Georgia, another producer of fine granite, also considers itself "the granite capital of the world." The Elberton granite deposit is 35 miles long, 6 miles wide and about 3 miles deep.

Granite has different colors depending on the color of its feldspar. Different regions of the United States produce different colors of granite. For example, light and dark gray granite is quarried in Vermont, North Carolina and Georgia. Oklahoma and South Dakota produce red and pink granite. White and pink granite is produced in New Hampshire. Other states producing granite products are Arkansas, Colorado, California, and Maine. To summarize, granite is quarried from New England to the Southwestern United States and in many states in between.

Granite is also quarried in Canada, India and Brazil, Finland, Norway, Portugal, Spain, Namibia, Zimbabwe, and South Africa, to name but a few countries.

Uses

There is an enormous abundance of granite throughout the United States, so it is not a surprise that a significant amount of granite is used in crushed stone applications. Crushed granite represents 16% of the total crushed stone produced in the U.S., and it is the second-most utilized crushed stone in the U.S. Crushed limestone is by far the most commonly used crushed rock in the U.S., representing 70% of total crushed rock consumption. The 16% represented by crushed granite (265,000 tons per year) is used in road construction and railroad beds. Larger pieces of granite are used to stabilize the land around roadways to minimize and even eliminate soil erosion.

Granite is used extensively as dimension stone. It is used in the construction of buildings, both as building blocks and as veneers on frame structures. Because it can be smoothed to a very high polish, granite has found extensive use in memorials, headstones, monuments, carved decorations on buildings, statues and the like. Approximately 1.5 million tons of dimension stone is produced annually in the United States. Of this, granite accounts for over 400,000 tons (27%), second only to limestone.

Substitutes and Alternative Sources

Granite is enormously abundant and easily accessible in many parts of the world. In regards to crushed stone, there are plenty of options, limestone being the most commonly used, for crushed stone applications such as road construction, railroad beds, concrete, etc.

The limitations on the availability of granite for construction purposes (that is, as dimension stone) are related to particular colors, grain size and even patterns in the local stone. A review of the distributors of granite products shows that each granite quarry produces a stone with its own particular color and overall appearance. It is conceivable that granite with a particular look will eventually be quarried out at a particular quarry. However, granite as a commodity will continue to be abundant, easily accessible and economically profitable for countless generations to come.

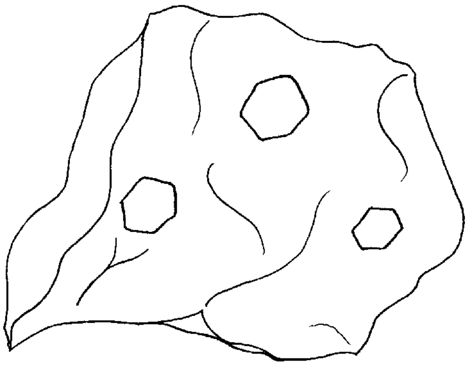
By Darryl Powell

Darryl Powell is a 1984 graduate of the University of Rochester, Rochester, New York with a B.S. in Geological Sciences. For six years Mr. Powell was an Adjunct Professor at Finger Lakes Community College in Canandaigua, New York, where he taught "Introduction to Physical and Historical

Geology." He creates Earth Science educational kits for NeoSCI, Inc., a science education resource company based in Rochester, New York. He also writes Earth Science materials for NewPath Learning, Inc. based in Victor, New York. Mr. Powell is the founder of Diamond Dan Publications, a small company focused on creative activity books and activity-based learning games about rocks and minerals, based in Manchester, New York.

GRAPHITE

Background



Pure graphite is a mineral form of the element carbon (atomic number 6) and its symbol is C. It forms in veins in metamorphic rocks as the result of the metamorphism of organic material included in limestone deposits. It is an extremely soft mineral at 1 to 2 on Mohs' hardness scale. It is black and has a black streak. (*Streak* is the color of a mineral when it is crushed to a powder). Its softness and streak make graphite useful in making “lead” for pencils. Crystals are uncommon, but when they occur, they are found as rough, six-sided (*hexagonal*) flakes, as in the drawing. It breaks into minute, flexible flakes that easily slide over one another. Mineralogists call this *basal cleavage.* This feature is the cause of graphite’s distinctive greasy feel. It is this greasy characteristic that makes graphite a good lubricant. Because it is a solid material, it is known as a *dry lubricant.* Graphite is the only non-metal element that is a good conductor of electricity. In nature, graphite is found in two distinct forms, *flake graphite* and *lump graphite*. Lump graphite is more compact than flake and lacks the distinctive flaking mentioned earlier.

Name

Graphite was named from the Greek verb *graphein* meaning *to write* because it was used in the manufacture of pencils. The name was given by Abraham Gottlob Werner in 1789.

Its "Old World" (that is, old European) name was *plumbago* which means *black lead*, a reference to its use in pencils.

Sources

It is estimated that the world reserves of graphite exceed 800 million tons. China is the most significant graphite-producing nation, providing nearly one-half of the United States’ annual graphite demand. Flake graphite is also imported to the United States from Brazil, Canada, and Madagascar. Lump graphite is imported from Sri Lanka. Graphite resources in the United States are very small. At one time a significant deposit at Ticonderoga, New York, was exploited, but this source no longer produces graphite. For a number of years, the United States has not produced natural mineral graphite and is completely dependent on the combination of imported, synthetic graphite, and recycled graphite sources.

Uses

Because graphite flakes slip over one another, giving it its greasy feel, graphite has long been used as a lubricant in applications where “wet” lubricants, such as oil, can not be used. Technological changes are reducing the need for this application.

Natural graphite is used mostly in what are called *refractory* applications. *Refractory* applications are those that involve extremely high heat and therefore demand materials that will not melt or disintegrate under such extreme conditions. One example of this use is in the crucibles used in the steel industry. Such refractory applications account for the majority of the usage of graphite.

It is also used to make brake linings, lubricants, and molds in foundries. A variety of other industrial uses account for the remaining graphite consumed each year.

Substitutes and Alternative Sources

Molybdenum disulfide is a good dry lubricant substitute for graphite. However, unlike graphite, molybdenum disulfide is not as stable in oxidizing conditions. Manufactured graphite powder can be used in the steel industry. However, as long as graphite deposits remain abundant, and the cost of raw graphite remains low, producing large quantities of manufactured graphite will be unnecessary for many years to come.

KYANITE

(including related minerals, Sillimanite and Andalusite)

Background

Kyanite and its related mineral “cousins,” sillimanite and andalusite, are called polymorphs. This means that they are three distinct minerals, but they all have the same chemical formula, Al_2SiO_5 (aluminum silicate). Because they are chemically the same, they can all be used in the same applications.

All three form in metamorphic rocks (rocks that are changed by intense heat and pressure), specifically in schists and gneisses that were formed out of sedimentary rocks with a high clay content. Studies have shown that each mineral forms under very specific temperature/pressure (T/P) conditions. Relative to one another, kyanite forms in a lower temperature/higher pressure environment; andalusite forms in a lower temperature/lower pressure environment, and sillimanite forms in a higher temperature/higher pressure environment.

Kyanite forms bladed crystals. It is generally blue, but can also be green or gray. It has a glassy luster. Kyanite has a unique physical feature in that it has two different hardnesses. When its hardness is measured across the crystal, it is 7; when it is measured down the length of the crystal, it is 5. All other minerals have a single hardness no matter where it is measured on the crystal.

Name

Kyanite is the variant spelling of the original name of this mineral, cyanite. The name was derived from the Greek word kyanos meaning blue in reference to this mineral’s most common color. The name was given by Abraham Gottlob Werner in 1789.

Sillimanite was named in honor of Professor Benjamin Silliman (1779-1864) who was the first professor of mineralogy at Yale University (as well as professor of chemistry for a time). The name was given by G.T. Bowen in 1824.

Andalusite was named after Andalusia, a province in southern Spain, where this mineral is found. The name was given by Jean Claude Delametherie in 1798.

Sources

There are substantial deposits of kyanite in the United States. The most important deposits are in Idaho and the Appalachian Mountain region in Eastern United States. Gneisses in Southern California also have significant kyanite resources. Presently, however, it is not economical to mine these deposits. Should economic conditions change, these deposits may be worth mining. South Africa supplies most of the andalusite imported for industrial consumption in the United States. France and India also produce andalusite and kyanite, respectively.

Uses

Kyanite and its related minerals are used to make a variety of refractory materials. Refractory materials are those that are resistant to very high temperatures. As a result, more than half of the kyanite consumed is used in refractories for the production of steel. Kyanite is also used to produce refractories for nonferrous (non-iron-bearing) metals. Some is consumed to make refractories for glass and heat-resistant ceramics. Kyanite is also used to make spark plugs and is used for non-refractory applications.

Substitutes and Alternative Sources

For refractory purposes, high-alumina materials, fire clays, and a product called synthetic mullite (produced in the United States and elsewhere), can be used in place of kyanite and its related minerals. Synthetic mullite is made from bauxite (aluminum ore), clays, and silica (quartz) sand.

Kyanite crystal group drawing used with permission.

Marble

Background

The word marble comes from the Greek word marmaros which means shining stone. To the geologist, marble is a non-foliated, granular metamorphic rock that is formed by the metamorphism of limestone and dolostone. It is usually formed by regional metamorphism but sometimes is formed by contact metamorphism. Both limestone and marble are calcium carbonate ($CaCO3$) which is also the composition of the mineral calcite. The metamorphism of limestone causes the calcite grains to grow in size and to interlock with one another. The result is that marble is noticeably more dense and harder than limestone. Limestone frequently contains invertebrate fossils. However, these fossils are almost always destroyed by metamorphism.

In industry, the term “marble” is also applied to serpentine rocks that can be polished to a high shine. Technically, “marble” and “serpentine” are two different metamorphic rocks. Serpentine is formed by the metamorphism of rocks called peridotites and another called pyroxenes. True marble is a carbonate rock (which means it has $CO3$ in its chemistry). Serpentine is a silicate rock meaning it has silicon and oxygen in its chemistry. It is important to be aware that the technical scientific terms (in this case “marble”) can have a different meaning in industry. Dark green serpentine “marble” is frequently referred to as verde antique.

Pure, bright white marble is highly desired because of its even color. Since the days of ancient Rome, it has been used for statues and architectural decorations because of its pure, bright color and its hardness. Marble’s hardness allows it to be polished to a smooth, bright, shining surface. However, marble typically has lines and veins running throughout it. This look is what is typically referred to as “marbling.” The lines and veins are from silt, sand, clay and other impurities that were in the original limestone from which the marble was formed.

A number of minerals and gems can form in marble. Spinel from Vietnam, ruby and sapphire from Myanmar (formerly Burma) and lazulite from Afghanistan are just a few examples.

Name

Sources

Marble is found, literally, all over the world. It is most notably located in regions of dramatic metamorphism, especially regional metamorphism. Carrara, Italy produced some of the most famous and desired marble in history. From the quarries of Carrara have come enormous blocks of pure white, extremely hard marble. The Pantheon was constructed from Carrara marble. Michelangelo’s famous sculpture David was carved from Carrara marble. Spain, Greece, Turkey, China, Poland, Ireland and Mexico have all produced marble of various colors and patterns. In the United States, Danby, Vermont and Marble, Colorado have produced significant quantities of high-quality marble for use as dimension stone both for construction as well as for carving purposes.

Quarries in the United States produce 11.8 million metric tons of crushed marble. Five companies operate a total of six mines in five different states. In order of production, from greatest to least, the states are Georgia, Vermont, Tennessee, Colorado and Alabama. A total of 1.3 billion tons of crushed rock is produced in the United States annually. Of this, less than 6% is marble. (In fact, sandstone, quartzite, scoria, volcanic cinder, marble and miscellaneous stone, all together, account for less than 6% of the total crushed stone production in the U.S.)

United States marble quarries produced approximately 210,000 tons for dimension stone annually (“dimension stone” is any rock that is quarried to be cut into specific sizes and shapes). Significant amounts of marble are imported from Italy, Turkey, China and Mexico.

Uses

Some marble is crushed and used in many applications, with many other types of crushed stone, most notably for road and highway construction and repair. A relatively small amount of marble is used in cement and lime production.

Marble as dimension stone is used for construction of buildings: 40% of the marble is cut as rough blocks which is used for building construction; another 34% is used as finishing stone where the marble is cut into thin sheets, slabs and veneers that are given a very high polish and used to finish or cover walls, floors and the exteriors of buildings.

Substitutes and Alternative Sources

Sources of marble are widespread and plentiful. There is no danger of running out of marble in the near, or distant, future. However, specific types of marble that have very specific colors or veining patterns, may become depleted. When a particular look is desired and the actual marble is no longer available, other materials are typically used, including ceramic tiles, brick, concrete, and resin-agglomerated stone. Additionally, a builder may choose to use aluminum, plastics, glass or steel in place of marble.

By Darryl Powell

Darryl Powell is a 1984 graduate of the University of Rochester, Rochester, New York with a B.S. in Geological Sciences. For six years Mr. Powell was an Adjunct Professor at Finger Lakes Community College in Canandaigua, New York, where he taught "Introduction to Physical and Historical Geology." He creates Earth Science educational kits for NeoSCI, Inc., a science education resource company based in Rochester, New York. He also writes Earth Science materials for NewPath Learning, Inc. based in Victor, New York. Mr. Powell is the founder of Diamond Dan Publications, a small company focused on creative activity books and activity-based learning games about rocks and minerals, based in Manchester, New York.

Muroochite

MII Photos

MICA

Mica: Micas commonly occur as flakes, books, or sheets. Sheet muscovite (white) mica is used in electronic insulators (mainly in vacuum tubes), ground mica in paint, as joint cement, as a dusting agent, in well-drilling muds, and in plastics, roofing, rubber, and welding rods.

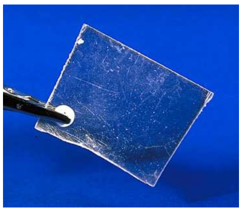


Photo Courtesy of Simon Williams, from

Muscovite

Mica Schist

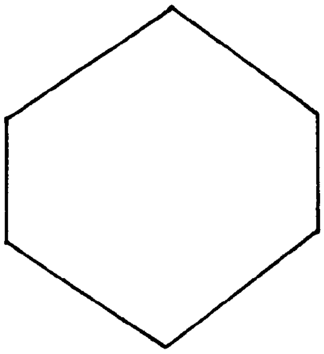
MII Photos

Background

Mica is a mineral name given to a group of minerals that are similar in their physical properties and chemical compositions. They are all silicate minerals, which means that chemically they all contain silica(SiO_4). Mineralogists call micas *sheet silicates* because their molecules combine to form distinct layers. These layers can be seen in muscovite mica specimens because it can be split (mineralogists call this feature *cleavage*) into very thin, flexible, transparent layers. This physical property is so distinctive that all minerals that cleave in this fashion are said to have *micaceous cleavage*.

There are 37 different mica minerals. In addition to the silicate tetrahedrons in all micas, Purplelepidolite.

contains the elements potassium, lithium, and aluminum. Black *biotite* contains potassium, iron, and magnesium. The two micas used as a commodity are: brown mica or *phlogopite* which contains iron and magnesium; and the "reddish, green, or white (or clear) mica" or *muscovite* which contains potassium and aluminum.



<=*A typical mica crystal.*

Large sheets of muscovite form in igneous rocks. Very large sheets or crystals of muscovite form in a pegmatite. A pegmatite is an extremely slow-cooling igneous rock in which very large crystals can form. Phlogopite generally forms in metamorphic rocks, especially in metamorphosed limestone, although it occasionally forms in igneous rocks, too.

Mica crystals are six-sided. They are fairly light and relatively soft, at 2 to 4 on Mohs' hardness scale for the univalent micas. Sheets and flakes of mica are flexible. Mica is heat-resistant and does not conduct electricity.

Two distinct forms of mica are utilized as a commodity. Scrap and flake mica is mica that either occurs naturally or is ground into very small flakes and pieces. Sheet mica is large pieces of mica that can be cut into various shapes for use in electronics.

Name

The name *mica* was probably created from the Latin word *micare* meaning *to shine* in reference to the shiny luster of the micas. Muscovite is very resistant to heat and electricity. As a result, it was commonly called "Muscovy." This mineral was commonly called *Muscovy Glass* after the Latin term *vitrum Muscoviticum*. In 1850, James Dwight Dana formally named this mineral *muscovite* based on the Latin term. The name *phlogopite,* named by F.A. Breithaupt in 1841, comes from the Greek word *phologopos* meaning *fiery* in reference to the reddish color seen on some specimens of this mica.

Sources

Scrap and flake mica is produced all over the world. In the U.S., scrap and flake mica was produced in Arizona, North Carolina, South Dakota, Georgia, New Mexico and South Carolina. North Carolina's production accounts for half of total U.S. mica production. The flake mica produced in the U.S. comes from several sources: the metamorphic rock called *schist* as a by-product of processing feldspar and kaolin resources, from placer deposits, and from pegmatites. Canada, India, Finland, and Japan export flake mica to the U.S.

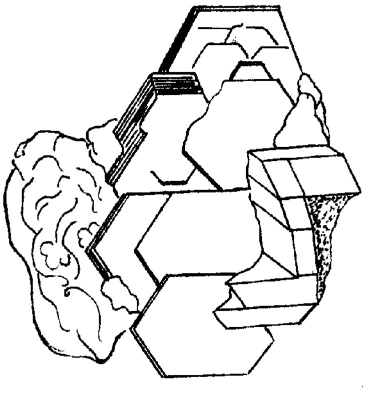
Sheet mica is considerably less abundant than flake and scrap mica. Sheet mica is occasionally recovered from mining scrap and flake mica. The most important sources of sheet mica are the *pegmatite* deposits. The United States has limited sheet mica resources. U.S. mining of sheet mica is costly and labor costs are high. As a result, the U.S. imports more than half its sheet mica from India, but also from Belgium, Germany, China, and a few other countries.

Uses

The principal use of ground mica is in gypsum wallboard joint compound, where it acts as a filler and extender, provides a smoother consistency, improves workability, and prevents cracking. In the paint industry, ground mica is used as a pigment extender that also facilitates suspension due to its light weight and platy morphology. The ground mica also reduces checking and chalking, prevents shrinkage and shearing of the paint film, provides increased resistance to water penetration and weathering, and brightens the tone of colored pigments. Ground mica also is used in the well-drilling industry as an additive to drilling “muds.”

Coarsely ground mica flakes help prevent lost circulation by sealing porous sections of the uncased drill hole. The plastic industry used ground mica as an extender and filler and also as a reinforcing agent. The rubber industry uses ground mica as an inert filler and as a mold lubricant in the manufacture of molded rubber products, including tires.

Sheet mica is used principally in the electronic and electrical industries. The major uses of sheet and block mica are as electrical insulators in electronic equipment, thermal insulation, gauge “glass”, windows in stove and kerosene heaters, dielectrics in capacitors, decorative panels in lamps and windows, insulation in electric motors and generator armatures, field coil insulation, and magnet and commutator core insulation. Mica is also used as segment plates between copper commutator sections to insulate copper from the steel; phlogopite mica is used because it wears at the same rate as the copper segments.



Substitutes and Alternative Sources

Some lightweight mineral and rock materials, such as vermiculite, diatomite and perlite are similar to micas and can be used in place of mica. A long list of manufactured materials, such as styrene, polyester, Teflon® , Plexiglass® , etc., can be used in place of sheet mica in the electronic applications. Paper made from ground mica can be used in place of sheet mica for insulating applications.

Phlogopite crystals from New York Mica drawings used with permission. © 2001 Darryl Powell

Obsidian

MII Photo

Olivine

MII Photos

Periodotite

MII Photo

Phyllite

MII Photos

Feldspar

Plagioclase Feldspar

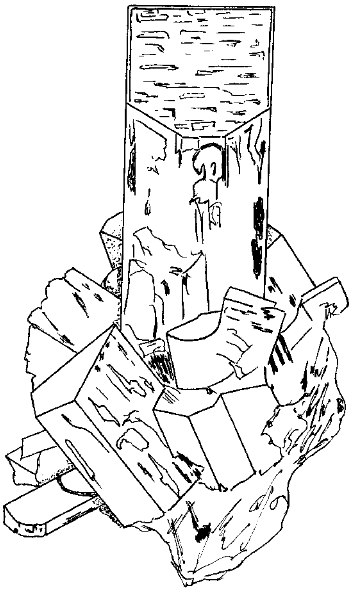
Potash Feldspar

Potassium Feldspar

MII Photos

Feldspar: A rock-forming mineral, industrially important in glass and ceramic industries, pottery and enamelware, soaps, abrasives, bond for abrasive wheels, cements and concretes, insulating compositions, fertilizer, poultry grit, tarred roofing materials, and as a sizing (or filler) in textiles and paper. Albite is a feldspar mineral and is a sodium aluminum silicate. This form of feldspar is used as a glaze in ceramics.

Background



Feldspar is the mineral name given to a group of minerals distinguished by the presence of aluminum (Al) and the silica ion (SiO_4) in their chemistry. This group includes aluminum silicates of soda (sodium oxide), potassium (potassium oxide), or lime (calcium oxide). Feldspar is the single most abundant mineral group on Earth. Together, the varieties of feldspar account for one half of the Earth's crust. The minerals included in this group are orthoclase, microcline, and the plagioclase feldspars. They form in a variety of thermal environments, during the crystallization of liquid rock (magma), by metamorphism of rocks deep in the earth, and in sedimentary processes.

Feldspars are relatively hard at 6 on Mohs' hardness scale. Feldspars are generally light-colored, including white, pink, tan, green, or gray. The color varies due to impurities within the crystal structure. Feldspar is the mineral that gives granite its pink, green or gray color.

When feldspar weathers from igneous or metamorphic rocks, it can accumulate as sand. It is, however, easily weathered, and eventually will break down into clay.

Name

The name *feldspar* is a contraction of the longer name *fieldspar*, some early specimens were found in fields. The term *spar* is a generic term used by geologists to refer to any non-metallic mineral with a glassy (vitreous) luster that breaks on distinct flat surfaces (planes). The name was officially given its name by Johan Gottschalk Wallerius in 1747.

Sources

Feldspar is mined from large granite bodies (called *plutons* by geologists), from pegmatites (formed when the last fluid stages of a crystallizing granite becomes concentrated in small liquid and vapor-rich pockets that allow the growth of extremely large crystals), and from sands composed mostly of feldspar.

Because feldspar is such a large component of the Earth's crust, it is assumed that the supply of feldspar is more than adequate to meet demand for a very long time to come. It is so abundant that geologists and economists have not even compiled data on potential deposits of feldspar for future consumption. Present mines worldwide are adequately meeting the need for raw feldspar.

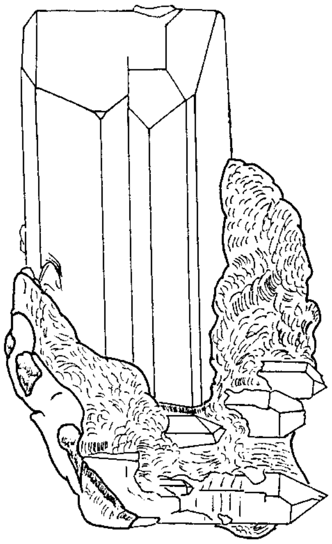
The United States produces about $45 million worth of feldspar annually. North Carolina generates nearly half of the raw feldspar produced in the United States. Six other states produce smaller amounts. Other countries producing feldspar include Brazil, Colombia, France, Germany, India, Mexico, Norway and Spain.

Uses

Feldspar is used to make dinnerware and bathroom and building tiles. In ceramics and glass production, feldspar is used as a *flux*. A flux is a material that lowers the melting temperature of another material, in this case, glass.

Substitutes and Alternative Sources

Feldspar can be replaced by other minerals and mineral mixtures of similar physical properties. Minerals that could be used to replace feldspar include pyrophyllite, clays, talc, and feldspar-silica (quartz) mixtures. The abundance of feldspar will make these substitutions unnecessary for the foreseeable future.



Green Feldspar (variety Amazonite) with quartz and albite.
From Pikes Peak region, Colorado

Drawings © 1999 Darryl Powell

Used with permission

PUMICE

Background

Pumice is a type of extrusive volcanic rock, produced when lava with a very high content of water and gases (together these are called *volatiles*) is extruded (or thrown out of) a volcano. As the gas bubbles escape from the lava, it becomes frothy. When this lava cools and hardens, the result is a very light rock material filled with tiny bubbles of gas. Pumice is the only rock that floats on water, although it will eventually become waterlogged and sink. It is usually light-colored, indicating that it is a volcanic rock high in silica content and low in iron and magnesium, a type usually classed as *rhyolite*. If the lava hardens quickly with few volatiles, the resulting rock is volcanic glass, or *obsidian*. Pumice and obsidian are often found together.

In commerce, *pumice* is the term applied to larger pumice stones, while *pumicite* consists of fine grains or ash. *Pozzolan* is a fine-grained pumicious material (both natural and man-made), which combines with lime to make a smooth, plaster-like cement. These three similar materials may be found and mined together, but they have different characteristics and different uses.

Name

The name pumice is derived from the Latin word *pumex*, meaning foam. Pozzolan (or *pozzolana*) is an Italian word, named from Pozzuoli, the place near Naples where pozzolan was first mined and used as cement, during Roman times.

Sources

Since pumice is a volcanic rock, and retains its useful properties only when it is young and unaltered, pumice deposits are found in areas with young volcanic fields. Worldwide, over 50 countries produce pumice products. The largest producer is Italy, which dominates pozzolan production and also produces some pumice. Other major pumice producers are Greece, Chile, Spain, Turkey, and the

United States.

In the United States, Arizona, California, New Mexico and Oregon are the major producers of pumice, accounting for the majority of the nation’s pumice and pumicite production.

Uses

Pumice and pumicite are used to make lightweight construction materials such as concrete block and concrete. About three-quarters of pumice and pumicite is consumed annually for this purpose.

The remainder of the pumice mined is used in abrasives, horticulture, landscaping, and for washing blue jeans.

Pozzolan is used to make fine-grained, lightweight cement for finishing floors and building interiors.

Substitutes and Alternative Sources

Expandable shale can be substituted for pumice and pumicite in the building block and concrete applications. There is no lack of pumice and pumicite, as world resources are extensive. However, the costs related to mining and trucking the material from the mine to processing plants and the market will determine whether pumice from a particular mine is cheap enough to use. In other words, it is economics, not the abundance of pumice, which determines whether or not substitutes for pumice are necessary.

Pyrolucite

MII Photos

Rhyolite

MII Photos

Sheelite

Sheelite

Sheelite on Fluorite

MII Photos

Scoria - Volcanic Ash

Serpentine

MII Photos

Shale

MII Photo

Background

Shale is a detrital sedimentary rock composed of very fine clay-sized particles. Detrital sedimentary rocks are sedimentary rocks composed of the weathered and eroded particles of larger pieces of rock. Clay forms from the decomposition of the mineral feldspar. Other minerals present in shale are quartz, mica, pyrite, and organic matter. Shale forms in very deep ocean water, lagoons, lakes and swamps where the water is still enough to allow the extremely fine clay and silt particles to settle to the floor. Geologists estimate that shale represents almost ¾ of the sedimentary rock on the Earth's crust. Geologists are specific about the definition of the rock called "shale." Shale is composed of clay-sized particles that are less than 0.004 mm in size. Siltstone is composed of particles that are between 0.004 and 0.063 mm in size. When the sedimentary rock is a mixture of clay and silt, geologists call the rock mudstone.

Layers of other sediments eventually cover the silt and mud that collects on ocean and lake floors. The weight of these sediments compacts the mud leading to lithification (lithification literally means turning to stone). The lithification process creates very fine layering in the shale. This layering is called lamination. Shale splits easily into relatively thin sheets due to this lamination.

Shale can be red, green or black. The different colors are due to different minerals in the shale. Black shale typically has a very high content of oily kerogen. Kerogen is organic matter trapped in the sediments that is the remains mostly of plants and some water-born microorganisms. Kerogen is not oil, but is thought to be the material that, through complex geological processes, becomes oil. Though still economically unfeasible, a process of heating (in an oxygen-depleted environment) can remove kerogen from shale in the form of liquid oil and natural gas.

Name

Sources

Shales are very common in the continental crust all over the Earth. In the United States, significant deposits of oil shale are found in the western states. It is estimated that the world’s largest oil field is found in the oil shales under northwestern Colorado. The western U.S. oil shales only cover approximately 17,000 square miles, a relatively small geographical region (including the states of Colorado, Wyoming and Utah). They are very thick, however, and as a result they hold a tremendous reserve of oil, a reserve that represents nearly ¾ of the world’s recoverable oil shale reserves.

Uses

Shale is too soft and too easily broken into small pieces to be used as dimension stone or even as crushed stone (although some shale is used as “slate” for garden walkways and paving stones). The greatest potential use of shale today is as a new source of oil. It is presently estimated that 1.75 x 1015 barrels of oil are trapped in the world’s oil shales. This is 100 times the total liquid petroleum geologists expect will be removed from known oil reserves.

There are many significant problems removing oil from oil shales. Environmental considerations as well as complicated technical problems make it far too expensive and presently unrealistic to remove large quantities of oil from shale.

Substitutes and Alternative Sources

There are plenty of alternatives to shale for crushed stone applications (for example, road and highway construction and repair) such as limestone, sandstone, quartzite, and granite. These alternatives are so abundant that there is little need to consider or use shale in these applications. As mentioned above, shale’s physical properties do not lend it to be useful as dimension stone: it is simply too soft and its laminations cause it to break into thin layers much too easily.

There is little need to consider any kind of substitute or alternative for shale since, presently, it has no important use or application.

By Darryl Powell

Darryl Powell is a 1984 graduate of the University of Rochester, Rochester, New York with a B.S. in Geological Sciences. For six years Mr. Powell was an Adjunct Professor at Finger Lakes Community College in Canandaigua, New York, where he taught "Introduction to Physical and Historical Geology." He creates Earth Science educational kits for NeoSCI, Inc., a science education resource company based in Rochester, New York. He also writes Earth Science materials for NewPath Learning, Inc. based in Victor, New York. Mr. Powell is the founder of Diamond Dan Publications, a small company focused on creative activity books and activity-based learning games about rocks and minerals, based in Manchester, New York.

Siderite - Iron Carbonate

MII Photos

Siltstone

MII Photos

Slate

MII Photos

Background

Slate is a foliated metamorphic rock derived from the metamorphism of shale. It is formed by regional metamorphism from tectonic plates colliding with one another creating immense pressure. Its foliation does not coincide with the layering or foliation of the original shale. Foliation in regionally metamorphosed sediments runs perpendicular to the direction of the forces of metamorphism.

Geologists recognize that metamorphism occurs in different grades. The grade represents the amount of pressure and heat involved in the metamorphism of a particular rock. Slate represents low-grade metamorphism of shale. As the pressure increases, the grade of metamorphism increases through a series of different rock types. With increased metamorphism the crystals in the rock become larger. The mineral grains in slate cannot be seen with the naked eye. However, increased metamorphism causes the mineral grains in slate to grow resulting in a higher-grade metamorphic rock called phyllite. The larger mineral grains give phyllite a shiny appearance. As the grade of metamorphism increases phyllite becomes schist, which has easily-identifiable quartz and mica grains. Further increased metamorphism results in a still higher grade metamorphic rock called gneiss (pronounced nice). If the metamorphism increases to an even higher grade, gneiss partially melts into magma (liquid rock) and upon cooling becomes migmatite. It is impossible to tell the difference between metamorphic migmatite and igneous granite in hand specimens. They are differentiated by the geologic environment in which they are found.

Slate has a dull appearance and occurs in a number of colors including light and dark gray, green, purple and red. It is not unusual for pyrite crystals to form in slate. Pyrite forms due to iron minerals present in the original shale from which the slate formed.

Name

Sources

Slate is found worldwide in geologic settings where the continental crust is compacted and folded by the collision of two continental plates.

In the United States, slate is abundant in the so-called Slate Belt of eastern Pennsylvania in the Appalachian Mountains. Slate is quarried in the Green Mountains of Vermont. Vermont is the largest producer of slate in the United States. The slate deposits of Vermont run westward into eastern New York State where it is quarried in the town of Granville. This region is locally known as “Slate Valley.” Some smaller occurrences of slate have been important in the U.S. The slate found in Monson, Maine was abundant early in the 20th century, but has been nearly depleted with only one quarry still working. President John F. Kennedy’s grave marker is made from the dark slate quarried in Monson, Maine.

Worldwide, significant slate occurrences are found in Wales, England, Italy, Portugal, Germany, Brazil and China. Production of slate in China for export throughout the world is growing rapidly each year.

Uses

A very small amount of slate is crushed and used for road construction, concrete mixes and other construction purposes. In these instances, it is used locally when it is more expensive to import other crushed stone products such as limestone or granite.

Of all the dimension stone applications of various rock types, slate represents only 1% of dimension stone applications. This represents approximately 15,000 tons of slate used annually in the United States. Slate’s foliation allows it to be broken into sheets of any desired thickness. Therefore, for centuries it has been used for roofing and for pavement stones around homes, buildings and gardens. The same feature made slate a most suitable material for making pool table tops. Until the invention of “white boards” and erasable markers, slate was used in schools as chalkboards, both small sizes for individual students and large wall-sized sheets for teachers. The days of slate chalkboards are nearly gone.

Substitutes and Alternative Sources

Slate roof tiles are extremely expensive, but also extremely durable. Homes shingled with slate seldom need to have the roof replaced, except for individual shingles due to storm damage or after many, many years of use. Because of the expense, shingles made of a variety of other materials are more commonly used in construction today. Some use wooden shake shingles. Others use terra cotta tiles. Other options include corrugated plastics and metal roofing. Perhaps the most common are asphalt shingles which are made of paper soaked with bitumen and covered with granular aggregate.

Any kind of rock that forms a flat surface can be used for yard and garden decorations and walkway stones.

By Darryl Powell

Darryl Powell is a 1984 graduate of the University of Rochester, Rochester, New York with a B.S. in Geological Sciences. For six years Mr. Powell was an Adjunct Professor at Finger Lakes Community College in Canandaigua,

New York, where he taught "Introduction to Physical and Historical Geology." He creates Earth Science educational kits for NeoSCI, Inc., a science education resource company based in Rochester, New York. He also writes Earth Science materials for NewPath Learning, Inc. based in Victor, New York. Mr. Powell is the founder of Diamond Dan Publications, a small company focused on creative activity books and activity-based learning games about rocks and minerals, based in Manchester, New York.

Smithsonite

MII Photos

Sodium Rich Plagioclase

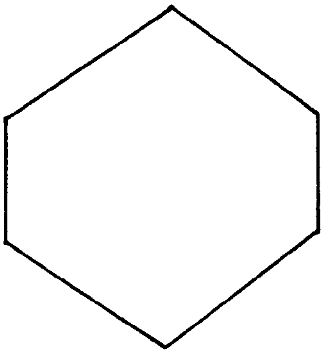
MII Photos

Syenite

MII Photos

TALC and PYROPHYLLITE

Background



A perfect talc crystal.

Talc crystal image used with permission.
© 1998 Darryl Powell

Two different minerals with similar physical properties are talc and pyrophyllite. Their physical properties are nearly identical. Both are very soft: talc is the softest mineral on the Mohs' hardness scale at 1, and pyrophyllite is 1 to 2. Because they are so soft, they can be easily cut and crushed. Archaeological discoveries have shown that talc was carved in ancient Babylonia to make signature seals. Chinese "soapstone" carvings are carved from fine-grained pyrophyllite.

Both talc and pyrophyllite have perfect cleavage in one direction. This means that these minerals break into thin sheets. As a result, both feel greasy to the touch (which is why talc is used as a lubricant). They are both formed in metamorphic environments as the result of changes in silica-rich dolomite.

Steatite and *soapstone* are impure, massive forms of talc that lack the distinctive cleavage mentioned above.

Name

The name *talc* is thought to be derived from the Arabic word *talg* or *talk* meaning *mica* since talc forms mica-like flakes. In other words, it displays *micaceous cleavage*. The name in its present form was given by Georgius Agricola in 1546.

The name *pyrophyllite* comes from the Greek words *pyr* meaning *fire* and *phyllon* meaning *leaf*, a reference to the fact that it flakes when heated. The name was given by R. Hermann in 1829.

Sources

There are numerous talc and pyrophyllite resources worldwide. The United States produces enough talc and pyrophyllite to meet its annual needs. Of the seven states producing talc, most is mined in Montana, New York, Texas and Vermont. All the pyrophyllite produced in the United States is mined in North Carolina. Despite the volume of talc/pyrophyllite produced domestically, some is imported from China, Canada, Japan, and other countries. Of the countries importing U.S.-produced talc, Canada is the largest importer.

Unlike other commodities, talc and pyrophyllite are not recycled.

Uses

Ground talc is used as an ingredient in ceramics, paper, paint, roofing, plastics, cosmetics, talcum and baby powders, and a variety of other assorted uses such as making rubber and plastics.

Ground pyrophyllite is used in the production of ceramics, heat-resistant products called *fractories*, and paint.

Soapstone was once used to make chemical-resistant sinks and countertops for laboratories. Before the days of furnaces, blocks of soapstone were heated on stoves and used as bed warmers.

Substitutes and Alternative Sources

Clays and pyrophyllite can be used in place of talc in the manufacture of ceramics. Kaolin (a clay mineral) and mica can be substituted for talc in the production of rubber, paint, and plastics. Kaolin can be used in place of talc in paper production. The available reserves of talc are sufficient for many decades to come so such substitutions are not necessary, though they may be cost-effective depending on the relative costs of talc, mica, pyrophyllite and kaolin.

Tincalconite (Borax)

MII Photos

Topaz

MII Photos

Tourmaline

MII Photos

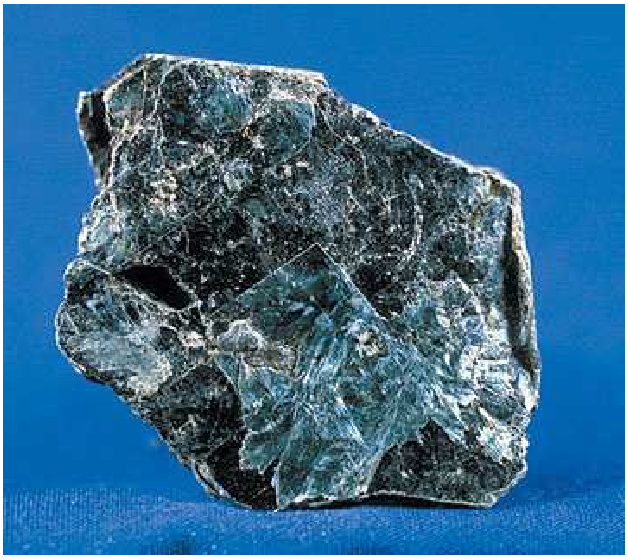
Travertine

MII Photos

Uranium

MII Photos

Vermiculite



MII Photos

TUNGSTEN

Wolframite

Tungsten: Used in metalworking, construction and electrical machinery and equipment, in transportation equipment, as filament in lightbulbs, as a carbide in drilling equipment, in heat and radiation shielding, textile dyes, enamels, paints, and for coloring glass. Major producers are China, Korea, and Russia. Large reserves are also found in the U.S., Bolivia, and Canada.

Background

Tungsten is a gray-white metallic element. Its atomic number is 74 and its atomic symbol is W (after the German name *Wolfram* given to this element). It is stable and is very resistant to acids and bases. It does, however, oxidize in air, especially at higher temperatures. It has the highest melting temperature of any metal (3422 degrees C, 6192 degrees F), and the second highest of all elements (Carbon is highest).

Tungsten was discovered in 1758 by Axel Fredrik Cronstadt; in 1781 Carl Wilhelm Scheele isoldated a tungsten oxide, and in 1783 the Spanish chemists (and brothers) Fausto and Juan Jose de Elhuyar first separated tungsten from the mineral wolframite.

It is interesting to note that tungsten is important to the health of plants and animals. Specifically, it is used by some enzymes (which are called *oxidoreductases*).

Name

Tungsten was named from the Swedish words "*tung sten*" meaning "*heavy stone.*"

Sources

Tungsten is retrieved from the ore minerals *scheelite* ($CaWO_4$, calcium tungstate) and *wolframite* ($(Fe,Mn)WO_4$, iron-manganese tungstate). Of the world's tungsten reserves, over 90% are outside the United States. Of these resources, nearly half are found in China, and Canada and Russia also have large reserves. About one-third of the U.S. imports of tungsten are from China, Russia provides about 25%, and a variety of other nations provide the rest. A significant amount of tungsten is recovered through recycling of scrap tungsten products. Recycled tungsten in the US accounts for nearly one-third of the tungsten consumed. Major production of tungsten concentrates come from Austria, Bolivia, Canada, China, Portugal, and Russia.

Uses

Tungsten is mixed with carbon to make a very strong, very resistant material called tungsten carbide. Tungsten carbide is used to make cutting tools and wear-resistant tools for metalworking, drilling for oil and gas, mining, and construction. These applications account for more than 60% of the tungsten consumed in the US each year.

Because it has such a very high melting point and low vapor pressure, tungsten is used in high temperature situations. For instance, the filaments in light bulbs are made of tungsten. It is used in other applications in electronics as well.

When added to steel, tungsten increases its strength. It is alloyed (mixed with) other metals to make "superalloys" which have special physical properties of high strength and heat resistance. Some of the applications for such superalloys are in turbine engines for jet aircraft and energy generation.

Other alloys bearing tungsten are used for armaments, heat sinks, radiation shielding, weights and counterweights, wear-resistant parts and coatings.

Substitutes and Alternative Sources

Tungsten is the only material used to make light bulb filaments. Experiments are being done with ceramic and ceramics mixed with metals to create alternative cutting materials. Cemented carbide made with tungsten carbide is still preferred to these materials.

ARSENIC

Background

Arsenic is an element (atomic number 33) classed as a *semi-metal* or *metalloid*. This means it has some properties of metals, and some properties of non-metals. Arsenic occurs in two distinct solid forms. One is a brittle, gray metal, while the other is a yellow, non-metallic form, rarely seen outside the laboratory. Arsenic and its compounds often have a garlic-like odor when crushed or when scratched with a hard object.

Elemental arsenic has very few uses. Nearly all the applications are as salts or oxides of arsenic. Arsenic compounds can be very toxic, and their uses are strictly controlled by health and environmental regulations.

Name

The name *arsenic* comes from the Greek word *arsenikon*, which means *orpiment*. Orpiment is a bright yellow mineral composed of arsenic sulfide (As_2S_3), and is the most highly-visible common arsenic mineral. Historians say that arsenic was discovered in 1250 C.E. by Albertus Magnus, a German monk who spent his life studying and classifying natural materials. It is believed that he heated soap and orpiment together and isolated elemental arsenic.

Sources

Arsenic metal very rarely occurs in its pure form in nature. The most common arsenic mineral is arsenopyrite, a compound of iron, arsenic, and sulfur. Several other, less-common minerals contain arsenic, including orpiment, realgar, and enargite, which are arsenic sulfides. Most arsenic is obtained not from an ore mineral of arsenic, but as a by-product in the treatment of gold, silver, copper, and other metal ores. In fact, environmental laws require that arsenic be removed from ores, so that it does not enter the environment in effluent gases, fluids, or solids.

Significant quantities of arsenic are associated with the copper-gold deposits in Chile, the Philippines, and many other countries. However, many countries produce by-product arsenic from smelting of metal ores. China is by far the largest producer, with Chile, Mexico, and Peru also important, and lesser production from about a dozen other countries with metal smelters.

The United States imports all the metallic arsenic and arsenic compounds that it consumes. Very little is recycled, except in waste from factories that make arsenic compounds.

Uses

Only about 5% of arsenic consumption is of the metallic element. Most of this is used to alloy (mix) arsenic with lead, copper, or other metals for specific uses. As a metalloid, arsenic is a semiconductor, like silicon. This means it conducts some electricity like a metal, but not all the electricity a true conductor like copper would conduct. Consequently, about 1/10 % of arsenic is consumed in the manufacture of gallium arsenide semiconductors for use in electronics. Some arsenic is also used in glass-making.

The majority of U.S. consumption is in the form of chromated copper arsenate (CCA), a chemical used as a wood preservative for telephone poles, fence posts, pilings, and foundation timbers. The CCA significantly reduces rot and eliminates wood destruction by termites, ants and other insects. However, the use of CCA is being phased out in the U.S., and a major decrease in the arsenic market is expected as a result.

Formerly the most important use of arsenic compounds, was as an insecticide sprayed in fields and orchards. This use has entirely disappeared in most countries, due to the poisonous nature of arsenic compounds. Arsenic contamination is a problem in some well-water and may be associated with mine drainage.

Arsenic is not recovered from any waste materials or in any recycling program. Some is recovered from runoff at wood treatment facilities.

Interestingly, a trace amount of arsenic is necessary for good health and growth of animals, including humans. 0.00001% is needed for growth and for a healthy nervous system.

Substitutes and Alternative Sources

A variety of alternative wood preservatives are available to replace CCA, as is plastic wood lumber.

BISMUTH

Background

Bismuth is a silvery-white metallic element with a pinkish tint on freshly-broken surfaces. Its chemical symbol is Bi, and its atomic number is 83. Bismuth was long thought to be a variety of lead or tin, which it resembles, until the chemist Claude Geoffroy showed in 1753 that it is a separate element.

Bismuth is rarely noticed in everyday life. Unlike the more common metals such as copper, lead, and iron, bismuth is rarely noticed by the average person.

Bismuth is relatively brittle for a metal. It has the interesting physical property of being less dense as a solid than it is as a liquid. The only other common substances which expand when they freeze are antimony metal and water. This property of expanding when cooling is responsible for much of bismuth's commercial uses. Bismuth is a poor conductor of electricity and heat (scientists say it has poor electrical and thermal conductivities). It is relatively stable and does not corrode in the atmosphere, unless attacked by strong acids. Bismuth is not known to have any role in either plant or animal life functions. Importantly, bismuth is non-toxic (not poisonous), unlike lead and most other heavy metals.

Naturally-occurring bismuth metal (known as *native bismuth*) is rare in nature, and does not occur in large enough quantities to be mined as a source of bismuth. More often it combines with other elements to form minerals such as bismithunite (bismuth sulfide, Bi_2S_3) and bismite (bismuth oxide, Bi_2O_3).

Name

The name *bismuth* is derived from the old German word *wismut*, meaning white metal, or meadow mines. The name *wismut* occurs in German records dating to several hundred years before the metal's identification as a separate element, indicating that its special properties were recognized early.

Sources

The most common bismuth minerals are bismuthinite and bismite. Generally, these and other bismuth minerals occur in minute quantities within ores of other metals, such as gold, silver, lead, zinc, and tungsten.

Bismuth is usually an indicator of high-temperature mineral deposits, forming in veins with quartz and various metallic minerals, or at the contact of granite intrusions with other rocks such as limestone.

Most bismuth is produced from mines in China, Mexico, Peru, and Bolivia. Only one Bolivian mine was a primary bismuth mine; in other countries the bismuth is a by-product of mining other metals. In addition, an important part of world production is from the small amounts of bismuth in ores of other metals, which is recovered in Belgium and Japan from foreign ores which are shipped to those countries for smelting. The United States does not produce any bismuth, except small amounts through recycling. Recycled bismuth makes up less than 5% of U.S. consumption.

Bismuth is a moderately priced metal, costing more than copper, lead, and zinc, but much less than gold or silver.

Uses

Bismuth is used in a number of very different applications. Almost none of the uses is for pure metallic bismuth. The majority is consumed in bismuth alloys, and in pharmaceuticals and chemicals. The remainder is used in ceramics, paints, catalysts, and a variety of minor applications.

Alloys of bismuth are useful for many reasons:

Bismuth and many of its alloys expand slightly when they solidify (freeze). This allows the bismuth to fill all corners of a mold to form a perfectly sharp replica of the mold or the item being replicated. This is also a valued property when used in soldering or plumbing (joining of pipes).

Many bismuth alloys have a low melting point, sometimes even below the temperature of boiling water. Thus a bismuth-alloy casting can be covered by plastic or other material to form an intricate machine part. The bismuth-alloy core is then removed by simply melting it in hot water and pouring it out. The use of low-melting bismuth alloys is widespread in sprinkler systems in buildings. When the alloy melts in fire-heated air, the sprinkler becomes unplugged, and water sprays the fire. This application accounts for over one-third of the bismuth used in the United States each year.

Bismuth metal is relatively inert and non-toxic. It has replaced toxic lead in many applications such as plumbing, bullets, birdshot, metal alloys, soldering, and other applications.

Fourthly, many bismuth alloys are relatively soft and malleable. *Malleable* means that a metal can be hammered into thin sheets Bismuth is alloyed with iron to create what is known as "malleable irons."

Bismuth compounds are used in stomach-upset medicines (hence the trademarked name Pepto-Bismol), treatment of stomach ulcers, soothing creams, and cosmetics.

Industry uses bismuth in a variety of other applications. Bismuth is a catalyst in the production of acrylic fibers. Bismuth replaces lead in some ceramic glazes and paints, because bismuth is non-toxic.

Substitutes and Alternative Sources

Substitutes for the medical applications of bismuth include magnesia, alumina and antibiotics. Scientists have discovered that a glass bulb filled with glycerine can be used in place of bismuth as the triggering mechanism for fire sprinkler systems. The element indium can be used in place of bismuth in the manufacture of low-temperature solders. However, indium is extremely expensive, whereas bismuth is much cheaper.

BORON

Background

Boron is a semi-metallic element, exhibiting some properties of a metal and some of a non-metal. Its atomic number is 5 and its chemical symbol is B. In elemental form it is a dark, amorphous, unreactive solid. (An *amorphous* substance is one that does not form crystals.)

Boron is used mainly not as the element boron, but as compounds of boric oxide (B_2O_3) and boric acid (H_3BO_3). Most people have never seen elemental boron.

Name

Boron was named for the mineral borax, thought to come from the Persian name *burah* for that mineral. Boron minerals, mainly borax, were traded over a thousand years ago, when sheep, camel and yak caravans brought borax from desert salt beds in Persia and Tibet to India and the Arab countries. There it was used mainly in making glass.

The element boron was not identified and isolated until 1808, when Sir Humphrey Davy of England, and Joseph-Louis Gay-Lussac and Louis Jacques Thenard of France, discovered that boron could be produced by combining boric acid (H_3BO_3) and metallic potassium.

Sources

The major ores of boron are a small number of borate (boron oxide) minerals, including ulexite ($NaCaB_5O_9.8H_2O$), borax ($Na_2B_4O_5(OH)_4.8H_2O$), colemanite ($Ca_2B_6O_{11}.5H_2O$) and kernite ($Na_2B_4O_6(OH)_2.3H_2O$). These minerals form when boron-bearing waters percolate into inland desert lakes and evaporate, leaving layers of borates, chlorides, and sulfates. These minerals are referred to as *evaporite minerals*. Very large deposits of evaporite boron minerals are found in the United States (especially California), Turkey, Chile and Argentina. Less-important deposits occur in Iran (formerly called Persia), and elsewhere.

In addition, boron silicate minerals are mined as boron ores in China, Russia, and a few other countries.

Turkey, the United States and Russia are the largest producers of boron minerals. Argentina, Chile, and China have important ore production, and five or six other countries produce minor amounts. The U.S. production is all from the deserts of southeastern California.

In addition to its own production, the United States imports borate minerals and processed compounds, and exports a large amount of finished products containing boron.

Uses

Boron compounds are used for many different purposes in industry and the home. In the United States, boron is used to make glass, ceramics, and enamels, including fiberglass for insulation.

Boron compounds are used to make water softeners, soaps and detergents. Other uses are in agricultural chemicals, pest controls, fire retardants, fireworks, medicine, and various minor applications.

Boron is a chemical used to make boron nitride, one of the hardest known substances, for abrasives and cutting tools.

The effect of boron on animals is under study. There is no evidence that boron is necessary for animal health, although in small quantities it might stimulate bone and muscle growth. On the other hand, it is an essential trace element for green algae and higher plants used in agriculture.

Substitutes and Alternative Sources

In detergents, boron compounds can be replaced with chlorine and enzymes. Lithium compounds can be used to make enamels and glass products. However, the known boron ores in the world should easily meet the world demand for boron compounds for many years to come.

BROMINE

Background

Bromine is a reddish-brown fuming liquid at room temperature, one of only a few elements which is liquid. Bromine liquid has a very strong, irritating odor, and is reactive and rather poisonous. Its atomic number is 35 and chemical symbol is Br.

Bromine is one of the four *halogen* elements, which are chemically related and show a systematic progression of physical and chemical properties. The other halogens are: fluorine, an extremely reactive gas; chlorine, a reactive, heavy gas; iodine, a relatively inactive solid; and astatine.

Name

Bromine compounds were in use long before bromine was identified and isolated. A purple excretion from certain mollusks was long ago used to make purple dye known as "Tyrian purple." It is now known that this excretion is a bromine compound.

Elemental bromine was discovered in 1826, by German and French scientists working independently. Important quantities of bromine were not isolated until 1860. Bromine was named from the Greek word *bromos* which means *stench*, a reference to its very strong odor.

Sources

It is no exaggeration to say that world bromine resources are unlimited. Seawater contains 65 parts per million (ppm) bromine, which translates into 100 trillion tons of elemental bromine! In addition, approximately 1 billion tons of bromine is believed to be in the water of the Dead Sea in Israel. Underground brines in Poland, the United States and elsewhere contain millions of additional tons.

A few bromine minerals have been identified, but none are important in commerce, because bromine compounds (*bromides*) are usually highly soluble in water, and tend to remain in solution in oceanic or underground brines.

The United States and Israel are the world's leading producers of elemental bromine. In the U.S., several companies produce nearly one-half of the world's bromine supply from deep brine wells located adjacent to oil fields in Arkansas and, to a lesser degree, in Michigan. Israel produces approximately 40% of the world's supply from brines in the Dead Sea. The remaining comes from nine other countries, including some where bromine is extracted from seawater.

Significant amounts of bromine are recovered by recycling the chemical sodium bromide.

Uses

Bromine and bromine compounds are used for a number of very different applications. Some bromine compounds are effective flame retardants, and nearly one-half of the bromine consumed annually is used in flame retardants for household and industrial applications. The agriculture industry uses bromine in pesticides. Bromine compounds are also used in oil-well drilling fluids, sanitary preparations, and an assortment of other applications including water purification chemicals, fumigants, dyes, medicines, and inorganic bromides (AgBr, silver bromide) used in films and photographic processes.

While pure liquid or vaporous bromine are poisonous, most bromides are not especially harmful in small amounts.

Substitutes and Alternative Sources

Chlorine and iodine can be used in place of bromine for water purification processes and other sanitation applications. A number of different alcohols (methanol, ethanol, etc.) can be used in place of ethylene dibromide in gasoline. As digital photography and printing grows, there will be a reduced need for silver bromide to make film.

There is literally more bromine available cheaply than could ever be consumed at current rates, for many decades to come.

CADMIUM

Background

Cadmium is a very soft, silvery-white metallic element. Its atomic number is 48 and its symbol is Cd. It is so soft that it can be cut with a knife. Cadmium has many chemical similarities to zinc, but is less reactive with acids than is zinc.

Cadmium is clearly toxic to animals, and during the past few decades has become familiar to the public mainly due to its undesirable presence in fertilizers and elsewhere, rather than for its positive industrial applications. Metallic cadmium is rarely used industrially in pure form.

Name

Cadmium was discovered in 1817 by the German chemist Friedrich Strohmeyer. He noticed that some samples of zinc carbonate (calamine) changed color when heated. Pure calamine, however, did not. He surmised there must be an impurity present and eventually isolated it by heating and reducing the zinc carbonate. What he isolated was cadmium metal. Strohmeyer coined the name *cadmium,* derived from the Latin word *cadmia* which means *calamine*.

Sources

Because cadmium is located just below zinc and above mercury in the Periodic Table, its physical and chemical properties are rather similar to those of zinc, and to a lesser degree, mercury. Most cadmium in nature occurs as an atomic substitution for zinc in zinc minerals, usually making up less than 1% of the mineral. Only a few relatively pure cadmium minerals are known. The best known of these is the mineral *greenockite* (cadmium sulfide, CdS), but even this mineral forms rare and rather small crystals.

In addition, cadmium can occur as an impurity in phosphate minerals. Some natural phosphate ores contain several hundred parts per million (ppm) of cadmium, and are thus undesirable to use as fertilizers.

Most cadmium used in industry is recovered from sphalerite (zinc sulfide), the principle ore of zinc where cadmium atoms replace some of zinc atoms in the sphalerite. On a worldwide basis, zinc ores around the world average about 1/400th as much cadmium as zinc. Although some zinc deposits have a higher cadmium/zinc ratio than others, those countries producing zinc from zinc ores also have the potential to produce significant quantities of cadmium. The cadmium is removed when zinc metal is purified in a refinery.

Cadmium is therefore produced in countries where zinc is refined, not necessarily in the countries where zinc ore is mined. China, Japan, and Korea are the world’s largest producers, with Mexico, the United States, the Netherlands, India, the United Kingdom, Peru, and Germany next. About 15 other countries produce smaller amounts.

Some cadmium is recovered from the recycling of nickel-cadmium batteries, which is required by law in some countries so that the cadmium is not discarded into the environment.

Uses

The single most important use of cadmium is in the production of nickel-cadmium ("Ni-Cad") batteries. About three quarters of the cadmium consumed annually is used to make batteries. Nickel-cadmium batteries are rechargeable and have found wide use in cellular phones, hand-held cordless power tools, cameras, portable computers, and a wide variety of household products. These applications account for the majority of the Ni-cad batteries produced. The remaining represents batteries used for emergency power supplies in hospital rooms, for emergency lights, telephone exchanges, etc.

Cadmium is useful in a small number of other applications. Cadmium sulfide (also called *cadmium yellow*) is used as a paint pigment. Cadmium is used to make low-temperature melting alloys, such as solder and Wood’s Metal for indoor sprinkler systems. The latter is an alloy of 50%Bi, 25%Pb, 12.5% Sn, and 12.5%Cd which melts at about 160 degrees Fahrenheit, the temperature of a very hot shower. Cadmium compounds are used both in black and white and color television tubes. It is used as a stabilizing compound in plastics.

Cadmium also has the physical property of being able to absorb neutrons. As a result, it is used in nuclear reactor control rods to dampen the nuclear reaction and keep the fission reactions under control.

China is the world’s largest consumer of cadmium, primarily for manufacturing batteries. Worldwide consumption of cadmium is stable or slightly declining, as its use is becoming more restricted due to environmental rules.

Soluble compounds of cadmium are poisonous, although the metallic and the sulfide forms are not soluble and therefore not very poisonous.

Substitutes and Alternative Sources

Due to the poisonous nature of cadmium, small Ni-cad batteries are being replaced by lithium-ion batteries and nickel-metal hydride batteries. This will obviously reduce cadmium consumption as this replacement increases. Presently, lithium-ion batteries are more expensive than Ni-cad, which will affect the pace at which this change occurs. Cerium sulfide can be used in place of cadmium sulfide as a paint pigment.

World reserves of cadmium are more than adequate for the foreseeable future, especially since the amount of cadmium produced depends on zinc smelter output, not the market for cadmium.

CEMENT

Background

The vast majority of cement is used to make concrete and concrete products. The manufacturing of and use of cement products make cement one of the most valuable and useful mineral products in the world.

Cement manufacture involves a mix or raw materials, typically about 85% limestone (or similar rocks like marble or marl) with the rest mainly clay or shale. This mixture is heated until it nearly melts, and is then ground into a powder. It takes about 1.7 tons of raw materials to make 1 ton of cement.

When cement is mixed water, it creates a paste. When that “paste” is then mixed with other materials, such as aggregates (sand, gravel and rocks), the paste binds them all together and makes an extremely tough and hard product, usually called concrete. The mixture hardens because a chemical reaction occurs between all of the mixed parts, not because the water “evaporates”. During this reaction, called hydration, crystals radiate outwards from the cement grains and mesh with other adjacent crystals or adhere to the adjacent aggregates. A typical mixture (by volume) to make concrete is about 10 to 15 percent cement, 60 to 75 percent aggregates and 15 to 20 percent water.

For all practical purposes, the only type of cement used in modern construction is called Hydraulic cement, and there are two major types of cement: portland cements and masonry cements. More than 95% of the cement produced in the United States is portland cement; masonry cement used for stucco, and mortar accounts for most of the balance.

It is not known who invented portland cement but it was patented by Joseph Aspdin in England in 1824. He called it Portland cement because its color resembled the stone quarried on the Isle of Portland off the southern British coast.

Name

The name *cement* is derived from the Latin word *caementum* meaning *rough stone*. The name *concrete* is derived from the Latin word *concretus*; *concretus* is the past participle of the word *concrescere* meaning *to grow together, to harden*.

Sources

Cement manufacture requires an abundant, close by, supply of limestone or similar rocks. About two-thirds of the states in the United States make cement. These states produce about 90 million tons of cements each year; that’s more than 850 pounds of cement for every person living in the United States. The largest cement-producing states are California, Texas, Pennsylvania, Michigan, Missouri, and Alabama. Together these states account for 50% of the annual U.S. cement production.

About 20% of the cement consumed in the Untied States is imported from other countries, with Canada, Thailand and China being the major suppliers.

Uses

About 75% of all the cement produced is used to make ready-mix concrete, which is used to make buildings, bridges, sidewalks, walls, and all sorts of constructed structures. The rest is used to make building materials such as concrete blocks, pipes, and pre-cast slabs, in road building and repairs, and other assorted uses.

Substitutes and Alternative Sources

Substitutes for cement and cement products include a variety of materials such as wood, glass, steel, aluminum, fiberglass, stone, clay brick, and asphalt. The substitute chosen depends on the item being constructed and the physical properties it needs to have.

In the United States there is increased use of a material called *pozzolans* in place of concrete. *Pozzolans* are materials that, when mixed with lime, harden like hydraulic cement. These materials include some volcanic rock and some industrial by-products such as fly ash and blast furnace slag.

CESIUM

Background

Cesium is a shiny, silvery-gold metallic element. Its atomic number is 55 and its symbol is Cs. It belongs to a group of elements called the *alkali metals*. Robert Bunsen and Gustov Kirchhoff from Germany discovered it in 1860 when they were studying the minerals left by the evaporation of mineral waters. Pure cesium metal, however, was not prepared until 1882 by another scientist named Setterburg.

The physical properties of cesium are very interesting. It is the softest of all metals and can even be cut with a knife. Some describe it as being like wax. Cesium is one of three metals that are liquid at or near room temperature (the other two are gallium and mercury). It is also a very reactive metal. For instance, when it mixes with cold water, there is an explosive reaction. Its melting point is so low that it will melt if it is held in the hand. However, because it is so reactive, it can seriously burn the skin, so it must be handled with great care. Cesium hydroxide is the strongest base known.

Only a few thousand kilograms of cesium is used each year. This fact, plus the fact that cesium is so reactive to air and water, results in very high prices for cesium and cesium compounds.

Cesium is not beneficial to animals or plants.

Name

When cesium burns, the light spectrum created contains two bright blue lines. Based on these blue lines, this element was named *cesium* after the Latin word *caesius* which means *sky blue.*

Sources

Most rocks typically contain very little cesium. Seawater also contains very little. Springs of mineral waters can contain as much as 9 mg/liter of cesium. However, there are a number of minerals that contain significant amounts of cesium, including mica, beryl, feldspar, petalite, and pollucite.

Most cesium is retrieved from the mineral pollucite. This mineral is typical of a special igneous rock known as a *pegmatite*.

The United States has *low-grade* deposits of cesium ore in South Dakota and Maine, from which it is presently too expensive to get the cesium out. As a result, the U.S. imports 100% of the cesium it uses and it imports nearly all of this cesium from Canada. Other nations producing cesium are Southwest Africa and Zimbabwe.

Uses

Cesium and cesium compounds have a number of interesting uses and applications. For example, they are used as catalysts in chemical reactions. Because it is easily ionized by light, metallic cesium is used in photoelectric cells and infrared detectors. (An element that is *ionized* is transformed from a neutrally charged element into an electrically charged *ion*.) Cesium compounds are used in specialized alkaline batteries that are designed to work in subzero climates. Cesium carbonate is used in the production of special glass and glass products.

The most accurate clock in the world, the "atomic clock," measures time based on the very precise vibration of the electrons in the outer shell of the cesium atom. This clock is accurate within 5 seconds every 300 years!

Cesium-137 is radioactive and may be used for radiation therapy to treat certain cancers.

Space travel engineers have discovered that burning cesium in space is a very efficient form of fuel. It is determined to be 140 times more efficient than any other fuel.

Substitutes and Alternative Sources

Estimates of the world resources of cesium have not been calculated. Presently, the supply meets demand and it appears it will do so for many years to come.

In addition, rubidium and rubidium compounds are as effective as cesium and can be used in place of cesium and its compounds.

DIAMOND

Background

Name

Sources

Uses

Alternative Sources

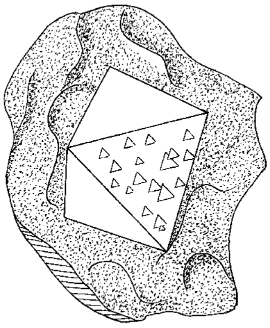
Background

Two different minerals are formed from the element carbon. One is graphite which is one of the softest minerals on Earth. The other is diamond which is the hardest substance on Earth (10 on Mohs' hardness scale). The difference in hardness is due to the way the carbon atoms attach to one another. In diamond, they attach in a three-dimensional manner that mineralogists describe as a *framework*.

Diamond forms at extremely high temperatures and pressures, conditions that are only possible very deep in the Earth’s crust or even the upper mantle. Large diamonds, particularly large diamonds without flaws, are extremely rare. These flawless diamonds are very valuable as gemstones. The vast majority of diamonds are small, flawed and colored by dark impurities. These impure diamonds are used in industrial uses.

Industrial diamonds make up more than half of the world’s production by weight. The weight of both gem and industrial diamonds is expressed in carats. One carat equals one fifth of a gram.

Diamond crystallizes in the isometric (cubic) system, and regularly forms cubes and octahedra (an octahedra is an 8-sided "diamond-shaped" crystal; see below).



In the diamond industry, the term "bort" is used for diamonds that have a rough, rounded form and which lack a distinct cleavage. *Cleavage* is the term used by mineralogists to describe the way some minerals break into flat surfaces. Bort refers to low grade, poor quality, industrial diamonds.

<= Diamond crystal in "blue ground" rock.

Used with permission.

© 2001 Darryl Powell

Name

The name *diamond* is a corruption of the Greek word *adamas* which means *invincible.* It was given in reference to diamond's great hardness.

Sources

Natural diamond has been discovered in approximately 35 different countries. Some diamonds have been found in the United States. Colorado, for instance, has produced a small number of diamonds.

The following countries produce industrial grade diamonds: Australia, Botswana, Brazil, China, Congo, Russia and South Africa.

Geologically speaking, natural diamonds are found in two environments. Most are found in *kimberlites*, which are pipe-like formations created as a result of volcanic and tectonic activity. *Kimberlite* is a blue rock typical of these pipes. The second source is *placer deposits*. The diamonds are easily weathered out of their kimberlite host rock and are washed away by streams and rivers. When these streams slow down, the diamonds are deposited in the stream sands in what are called *placer deposits*.

It is interesting to note that "synthetic diamond" is the form of diamond predominantly used in industry. The process allows the removal of impurities and produces a product with consistent physical properties; most of the carbon comes from graphite. Synthetic diamond accounts for the majority of industrial diamond consumption.

Uses

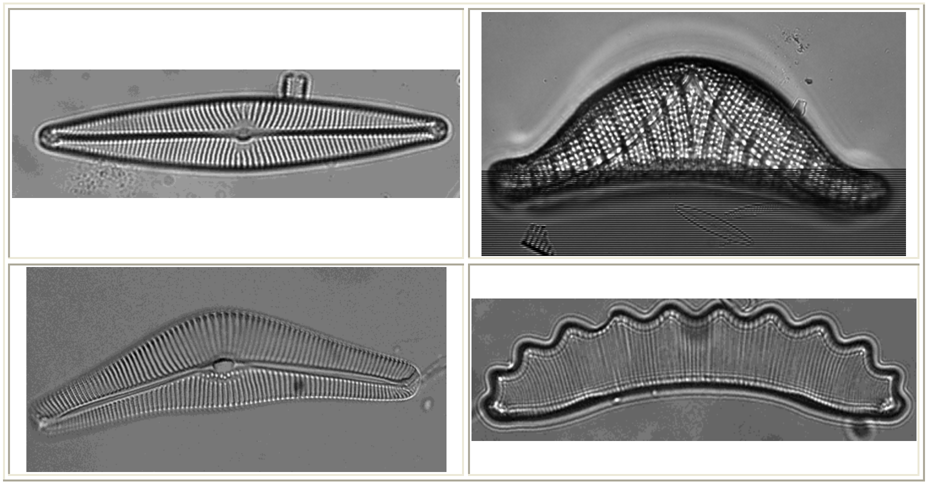
Because it is the hardest substance known, diamond will cut through any material. Consequently, it is used as an abrasive and in cutting and grinding applications. Industrial diamonds are embedded in large steel drill bits to drill into rock for wells to find water, oil, and natural gas. It is also important in the manufacture of machinery for drilling and cutting metal machine parts.

The United States is by far the world’s largest consumer and market for industrial diamonds. It is predicted that the U.S. will lead the world in diamond consumption well into the 21st century.

Substitutes and Alternative Sources

The mineral corundum can be used for some grinding and cutting applications since it is also an extremely hard mineral (number 9 on Mohs' hardness scale). Some manufactured materials can also be used in place of diamond, including carbon boron nitride, fused aluminum oxide, and silicon carbide.

DIATOMITE



Diatom photographs used with permission of the University of Michigan, Great Lakes Diatom Project. For further information, refer to their website *http://www.umich.edu/~phytolab/GreatLakesDiatomHomePage/groups/majorgroups.html*

Background

A *diatom* is an organism that is a member of the phylum of algae called *Bacillariophyta*. There are about 60,000 species of these algae presently known. Experts estimate that there are more likely 600,000 to 6,000,000 species in total!

Diatoms are single-celled (unicellular) organisms that live as individuals or in groups called colonies. They exist in all the waters of the Earth, both salt and fresh. They form shells made out of silica (the mineral name of this silica is *opal*) which they extract from the water. As can be seen in these pictures, their microscopic shells are very intricate and beautiful and have rightly been called "the jewels of the sea." Diatoms are very abundant and provide food for many aquatic animals.

When diatoms die, their silica shells accumulate on the floor of the body of water in which they lived. Thick layers of these diatom shells have been fossilized (that is, preserved) in the rock record. Such layers, or beds, of diatoms are called *diatomaceous earth*, or *diatomite*. Diatomaceous earth is white to cream color. It is very porous which makes it useful in a number of filtering applications.

Name

The name *diatom* comes from a Greek word *diatomos* that means *cut in half*, because the shells of diatoms have two overlapping, symmetrical halves.

Sources

In the United States, large deposits of diatomite are found in California, Nevada, Washington and Oregon. Of these states, California and Nevada produce the largest amount of diatomite. Significant producers of diatomite worldwide include France, China, Denmark, Russia, and Algeria. Diatomite resources worldwide will meet demand for the foreseeable future. However, new deposits that can be economically mined need to be identified.

The United States produces much of its own diatomite material. Still, some is imported from France, Mexico, and other nations.

Uses

Because of its porosity, diatomite has been used extensively as a filter for a variety of purposes. It is used to filter impurities out of everything from beer and wine to oils and greases. Similarly, diatomite is used to filter impurities from water to produce drinkable (potable) water in public water systems. In this situation, the diatomite removes bacteria and protozoa.

The oldest use of diatomite is as a very mild abrasive and for this purpose has been used in toothpaste and metal polishes.

It is also used in paper, paint, brick, tile, ceramics, plastics, soaps, detergents and other products as a *filler*. A *filler* is a substance that increases the volume of a product and/or fills in space.

Diatomite has also found value as an insulating material in high-temperature mechanisms like furnaces and boilers. It has also proven effective as a sound insulator.

Substitutes and Alternative Sources

Diatomite is easily replaced by other materials for most of its applications. For example, silica sand and an expanded form of the material *perlite* can be used in filtration applications. Talc, ground lime, ground mica, and clay can be used as filler material. Despite these many options, its ready availability, abundance and low cost will guarantee its use for many decades to come.

GALLIUM

Background

Gallium is a soft, silvery metallic element, with an atomic number of 31 and a symbol of Ga. The French chemist Paul-Emile Lecoq de Boisbaudran discovered gallium in 1875. Its existence was predicted in 1871 by a chemist named Mendeleev who said that gallium would be very much like aluminum in its physical properties, which proved to be quite accurate. In 1875, de Boisbaudran also isolated gallium by electrolysis of a solution of gallium hydroxide $Ga(OH)_3$ in potassium hydroxide (KOH).

Gallium has some physical properties that are worth noting. Like water, gallium expands as it freezes which means it becomes less dense. Solid gallium has such a low melting temperature (85.6° F, 29.8° C) it will turn to liquid when held in the hand! It is a liquid over a wider range of temperatures than any other element. By contrast, the boiling point of gallium is unusually high (3999° F, 2204° C).

Studies have shown that gallium is not useful to living organisms, although gallium and gallium compounds do not appear to be toxic.

Name

One theory says that the name *gallium* comes from the Latin word for France, Gallia. Another theory, however says that its discoverer, Paul-Emile Lecoq de Boisbaudran, may have taken the name from the Latin word *gallum* which means *the cock*, a reference to his own name (Lecoq).

Sources

Gallium does not easily combine with other elements or ions to form ore minerals. It is, however, found as a trace element in a number of minerals and ores, the most important of which is bauxite (aluminum ore). In fact, gallium is a by-product of aluminum production. On average, there is 50 ppm (parts per million) of gallium in bauxite. Based on this average, known U.S. bauxite deposits could produce 15 million kilograms of gallium. Two million kilograms are in the Arkansas bauxite deposits alone. World bauxite resources are so large (estimated at 55 to 75 billion tons) that gallium could be retrieved from these ores for many years to come.

It is also found in zinc ore (sphalerite) and in coal. Some U.S. zinc deposits have 50 ppm gallium. Although zinc deposits are a secondary source after bauxite for gallium, they may be a significant source of gallium in the future.

Gallium is not produced from ore in the United States, but some is produced from scrap and impure metals. Consequently, nearly all gallium consumed in the U.S. is imported. Gallium imports are from France, the leading refiner of gallium metal, Russia, Canada, Kazakhstan, and other countries.

Uses

Gallium is used in a variety of highly specialized electrical applications. Gallium arsenide (GaAs) is able to change electricity directly into laser light. Such gallium arsenide products represent the majority of annual gallium consumption. These products are used for lasers, photo detectors, light-emitting diodes (LEDs), solar cells, and highly specialized integrated circuits, semi-conductors and transistors.

Gallium is important in some sophisticated physics experiments. The search for a particle known as a solar neutrino involves enormous amounts of gallium. Two such experiments used a total of 90 tons of gallium in the quest to detect these particles.

Because of its high boiling temperature, gallium is used to make thermometers designed to measure very high temperatures.

Gallium is also used in making mirrors.

Substitutes and Alternative Sources

Silicon can be used in place of GaAs in solar cell applications. Gallium arsenide circuits are very specialized and do not have a substitute. Though there is little chance of running short of gallium in the foreseeable future, alternative sources, such as zinc deposits, might one day become important as the more easily accessible sources are used up.

GERMANIUM

Background

Germanium is a metallic-looking, grayish-white element. Despite its metallic appearance, it is not considered a metal, but a metalloid. This means that in some ways it is like a metal (for instance, its metallic appearance) but in other significant ways it is more like a non-metal (for instance, it is not as good a conductor of electricity as true metals are). Its atomic number is 32 and its symbol is Ge.

Germanium was discovered in 1886 by the German chemist Clemens A. Winkler. Winkler discovered germanium in the mineral argyrodite. However, germanium rarely forms distinct minerals. The existence of germanium was predicted in 1871 by the chemist Mendeleev. He predicted this new element would have properties very similar to silicon. His predictions ultimately proved to be very accurate.

Germanium is not necessary to human health; however, its presence in the body does stimulate metabolism. In addition, studies indicate it also plays a role in the function of the immune system.

Name

Clemens Winkler named germanium from the Latin word *Germania* meaning *Germany*.

Sources

Germanium was first discovered and isolated from a specimen of the mineral argyrodite. However, there are no significant argyrodite deposits. Germanium is retrieved as a by-product of zinc and copper-zinc-lead ores where it is found as a trace element. Germanium also occurs in significant quantities in carbon-based materials such as coal (though not all coal contains germanium).

Two U.S. companies in New York and Oklahoma refine ore material to produce pure germanium. Worldwide, about one-fourth of the germanium consumed comes from recycled metals, particularly metals used in the manufacture of electronic and optical devices.

Of the germanium imported into the United States, almost all comes from Belgium, China, and Russia.

Uses

Germanium is a metalloid. It does conduct electricity, but not as well as true metals. Therefore, it is described as a semiconductor. Consequently, germanium is important in the electronics industry where it is used to make transistors and semiconductors. The fiber optic industry uses a large portion of the germanium consumed annually.

It is also used as a catalyst in the production of polymers. Because infrared radiation can pass through germanium, it is used in infrared equipment and applications. It is also used in some other applications, including chemotherapy for treating certain cancers.

Substitutes and Alternative Sources

Germanium has been commercially retrieved from coal ash. Coal ash might one day become a significant source of germanium.

Silicon can be used in place of germanium for many electronic applications. Silicon is also less expensive. It has been found that zinc selenide and germanium glass can be used in place of germanium in some infrared equipment; however, these substances do not work as well and germanium is much preferred.

As a catalyst in PET (polyethylene terephthalate) plastics used in beverage containers, germanium has a few substitutes. Titanium does not give as clear a plastic product. An aluminum-based catalyst is also currently being developed.

HAFNIUM

Background

Hafnium is a bright silver, ductile, lustrous metallic element with a very high melting point. Its atomic number is 72 and its symbol is Hf. Hafnium is the 45th most abundant element in the Earth's crust with an average crustal abundance of 3 ppm (parts per million). The element was discovered by Dirk Coster and George Charles von Hevesey by separating it from zirconium in 1923.

Hafnium does not react with air, water, acids or bases. It is similar to the element cadmium in that it absorbs neutrons. This feature makes hafnium useful as a control rod material in nuclear reactors.

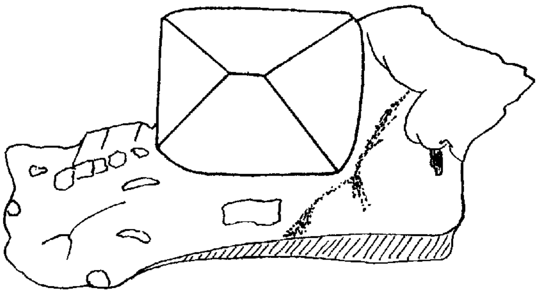
There is no biological use or benefit for hafnium. It is present in ocean water in very small amounts, specifically 0.008 ppb by weight (parts per billion). For comparison, hafnium is far more concentrated in the Earth's crust at 3,300 ppb by weight.

Name

The name *hafnium* was given by its Danish discoverers, Coster and von Hevesey, and was created from the Latin name *Hafnia* which means *Copenhagen*, in honor of the capital city of Denmark.

Sources

Hafnium is retrieved as a by-product from zirconium ore minerals. In a typical zirconium ore, there is a Zr:Hf ratio of about 50:1. The mineral *zircon* is the primary ore source of hafnium. Most zircon (and, therefore, hafnium) is mined from titanium-rich, heavy-mineral sand deposits. Hafnium and zirconium are both used in nuclear reactors. In this application, each must be pure and free from the other. The manufacture of nuclear-grade zirconium therefore produces hafnium as a by-product and, the manufacture of nuclear-grade hafnium produces zirconium as a by-product. This processing actually produces more hafnium than is consumed. Unused hafnium is stored as hafnium oxide or hafnium metal. Geologists estimate the hafnium resources in the United States total 130,000 tons. (By comparison, zirconium resources are about 14 million tons.) World resources of hafnium are estimated at over 1 million tons. Hafnium is imported to the United States in a variety of forms, including hafnium oxide and scrap metals containing hafnium. The majority of the hafnium imported comes from France. Other world producers of hafnium-bearing minerals include Germany, the United Kingdom, Brazil, China, India, Russia, South Africa, Ukraine, and the United States.



Zircon crystal from Colorado. © 2000 Darryl Powell. Used with permission.

Uses

The most significant use of hafnium is in the production of special alloys known as *superalloys*. Superalloys are alloys (mixtures) of metals that are designed to withstand high-stress situations, such as very high temperatures and pressures. Such metals can include iron, nickel, chromium, titanium, niobium, hafnium and other metals. Because of its ability to absorb neutrons, it is used to control nuclear reactions in fission reactors, including the nuclear reactors that power nuclear submarines. Hafnium is also used as a “scavenger” metal in the retrieval of oxygen and nitrogen. A scavenger metal is one which aids in the collection of gases without reacting with them to form other compounds.

Substitutes and Alternative Sources

Silver-cadmium-indium alloys can be used in place of hafnium as control rods in nuclear reactors. In the production of superalloys, zirconium can often be used in place of hafnium. In some applications, only hafnium gives the desired qualities and so no substitute is possible. However, the abundance of hafnium in storage (and the fact that its production outpaces its consumption) means there is no immediate danger of running short of this rare element.

HELIUM

Background

Helium is a very small and extremely light gaseous element. It is odorless and tasteless. It is the least reactive of all elements: that is, it is inert and is not known to react with any other element or ion. As a result, there are no helium-bearing minerals. However, helium is given off as a by-product of the breakdown of radioactive elements in rocks and minerals.

Helium was not first discovered on Earth; it was first discovered in the Sun! In 1868, the chromosphere of the Sun was studied during a solar eclipse. The study was done using an instrument that breaks a light into its spectrum, like a prism breaks sunlight into its rainbow colors. The instrument used is called a spectrometer. The French astronomer Janssen studied the spectrum produced during this event, and concluded that a new, yellow stripe was due to an element not previously known. In 1895, Sir William Ramsay proved the existence of helium on Earth in his studies of a radioactive ore material from Norway (the discovery of radium in 1898 showed that helium was indeed a by-product of the natural breakdown of radioactive elements). Helium was discovered to be an element by Norman Lockyer and Edward Frankland of England.

Studies of the molecules in the Earth's atmosphere show that helium makes up .0004% of the atmosphere. In other words, there is one helium molecule for every 200,000 air constituents molecules (which includes oxygen, hydrogen, nitrogen, helium, etc.).

There is no helium in the human body, and since it is so inert, helium is not harmful to any life form.

Helium can be cooled enough to liquefy it; however, it is the only element that cannot be frozen solid at very low temperatures.

Name

Since helium was first discovered by studying the Sun, its name was derived from the Greek word for sun, *helios*.

Sources

Some natural gas deposits have as much as 7% helium. Such deposits have been found in Texas, Russia, Poland, Algeria, China and Canada. Helium extracted from these natural gas reserves is the single source of helium.

It is believed the world helium resources – excluding those of the United States – totals 15.1 billion cubic meters. It is estimated that the United States has helium resources of 11.1 billion cubic meters.

Uses

Because it is inert, liquefied helium has a number of applications. It is used in cryogenics to freeze biological materials for long-term storage and later use (24%). It is also used in welding and to create controlled atmospheres. It is used to detect leaks in pipes. Its inert nature makes helium useful for cooling nuclear power plants.

Since helium molecules are so small, mixtures of helium and oxygen have proven to be useful in treating people with severe asthma or lung problems. It is also mixed with oxygen for use in deep-sea diving.

Most people are certainly familiar with the use of helium as a lighter-than-air substance. It holds up our birthday balloons. The motorized blimps that hover over sports stadiums are held up by helium. They are, in reality, very large balloons.

Substitutes and Alternative Sources

For super cold applications (particularly, at temperatures below –429 degrees F) there is no adequate substitute for helium. Another inert gas, argon, can be used in place of helium for some welding applications. Hydrogen can also be used in place of helium, but only in situations where the explosive nature of hydrogen will not be a problem. Hydrogen might be a good substitute for helium in some deep-sea diving situations.

INDIUM

Background

Indium is a soft, silver-white metallic element. Its atomic number is 49 and its chemical symbol is In. Indium was discovered in 1863 by the German chemists Ferdinand Reich and Heironymous Richter. They not only discovered this element, but also were the first to isolate pure indium. It was at first believed to be very rare. It is now known that it is relatively abundant in some but not all zinc sulphide (sphalerite or ZnS) ore deposits. Indium is very stable in both air and water; it does react with some acids. It forms only a very few rare minerals, such as indite, which is never abundant enough to be an ore of indium.

Indium has the unusual physical property that when it is bent (that is, when it is stressed) it creates a sound similar in pitch to a scream.

Indium is not necessary for any biological purpose. It has been shown that small amounts of indium cause an increase in metabolism.

Name

Indium was named after *indigo*, a significant color line in its atomic spectrum.

Sources

Indium is retrieved as a by-product of zinc ores, specifically from the mineral sphalerite, where its abundance can be as high as almost 900 parts per million (ppm) or as low as 1 ppm. By comparison, the average abundance of indium in the Earth’s crust is about 240 parts per billion (ppb). Indium can also be found in significant amounts in lead, copper, and tin ores. The highest concentrations of indium can be found in tin ores, and a large part of the indium production in Russia comes from tin ores.

Presently, indium is not recovered from ores in the United States. A small number of companies process low-grade indium metal and refine it to higher-grade indium. A small amount of indium is recovered by recycling old scrap which contains indium. The recycling of scrap from new technologically-advanced products is becoming a more significant source of indium.

Presently the United States imports all of its indium supply. The amounts imported each year vary but generally the majority of indium is imported from Canada, with significant amounts from China, Russia, France, and other nations including Belgium, Italy, Japan and Peru.

Uses

Indium is used to make what are called *thin film coatings* which are used to make such electronic devices as liquid crystal displays (LCDs). The compound indium-tin oxide (ITO) is used to make LCDs and this is the largest use of indium, accounting for 50% of annual consumption. Indium, as indium phosphide, is used to make photovoltaic devices (devices that transform light energy into electricity), semi-conductors, high-speed transistors, specialized solders and metal alloys. Indium alloys have been used in control rods for nuclear reactors.

Substitutes and Alternative Sources

Some compounds can be used in place of indium compounds for a number of its applications, but usually at a cost in product efficiency or product characteristics. For example, hafnium can be used in place of indium in nuclear reactor control rods. Gallium arsenide can be used to make photovoltaic cells and LCDs in place of indium phosphide.

IODINE

Background

Iodine is a shiny blue-black solid element. Its atomic number is 53 and it is grouped with other elements that, together, are called the halogens, although iodine is the least reactive of the elements in this group. The French scientist Bernard Courtois discovered it in 1811 when he treated seaweed ash with sulfuric acid.

When iodine is heated, it sublimates, that is, it goes from a solid to a vapor without going through the liquid phase.

Iodine is essential to many life forms, including humans, and is found in thyroid hormones. A lack of iodine in the body will result in a condition known as a goiter where the thyroid gland in the neck becomes enlarged. In order to assure an adequate amount of iodine in the diet, table salt is *iodized*. This approach has greatly reduced the incidence of goiter since so many people regularly use table salt.

Name

Iodine was named from the Greek word *iodes* which means *violet* in reference to its color.

Sources

Iodine is primarily retrieved from underground brines (water with many dissolved salts and ions) that are associated with natural gas and oil deposits. It is also retrieved as a by-product with nitrate deposits in caliche deposits. Chile’s production of iodine is from this source. Seawater contains 0.05 ppm (parts per million) iodine which means that there are approximately 76 billion pounds of iodine in the world’s oceans. Iodine was first discovered in seaweed. Dried seaweeds, particularly those of the Liminaria family, contain as much as 0.45% iodine. Seaweed was a major source of iodine before 1959. Seaweed is a significant source for iodine in the diets of many people around the world. Production from caliche is presently the most economical of the options listed here.

Chile is the world’s leading iodine producing nation. Japan is second. Russia also produces significant amounts of elemental iodine.

Uses

Iodine is used in a number of chemical and biological applications. Silver iodide is used in photography. Iodide is used as a disinfectant. Iodine compounds are used as a catalyst. It is used as a supplement in animal feeds. Potassium iodine is included in table salt as a simple way to assure adequate iodine in the human diet. It is also used to make inks and colorants.

Substitutes and Alternative Sources

For many of iodine’s uses, there is no adequate substitute. For example, other substances cannot replace its applications in pharmaceuticals, and human and animal nutrition. There are some chemical applications for iodine that can be accomplished using other chemicals. For example, bromine and chlorine can be used in place of iodine for ink and colorant purposes, and for disinfectant purposes.

NITROGEN

Background

Nitrogen is the most abundant gas in the atmosphere: 78% of the Earth’s atmosphere is nitrogen, 21% oxygen, and 1% other gases like carbon dioxide, argon and water vapor. Nitrogen is a gas that is relatively non-reactive, non-flammable, colorless, and odorless. It is an element and its symbol is N. Nitrogen is released into the atmosphere from volcanic eruptions and when dead plants and animals decay.

During the 18th century, scientists knew that the atmosphere is composed of at least two gases; they thought that one supports life (oxygen) and the other does not support life. The Scottish scientist Daniel Rutherford, who discovered nitrogen in 1772, called it “noxious air.”

Actually, both nitrogen and oxygen support life. The circulation of nitrogen through life forms and the atmosphere is known as the *Nitrogen Cycle*. The cycle begins when microbes remove nitrogen from the atmosphere and use it to make nitrates and other nitrogen compounds. Plants and algae absorb these compounds into their tissues. Organisms then eat these plants and the nitrogen is absorbed and assimilated into their tissues. When living organisms die, microbes break down their tissues into ammonia (this is called *ammonification*) which either evaporates into the air or is used again by microbes to create nitrates. The nitrogen cycle then begins again.

Nitrogen is essential to life: all plants and animals need it to grow properly. In fact, nitrogen is a basic building block of biological molecules such as proteins. Proteins are made up of smaller molecules such as amino acids and nucleic acids (DNA, RNA). It is the fourth most abundant element in the human body.

Nitrogen is seldom sold and used as a gas. It is nearly always combined with other elements, the most common of which is hydrogen to form ammonia. Nitrogen in this state is called “fixed nitrogen” because it is fixed or attached to another element. This fixed nitrogen is the form in which nitrogen is sold and consumed.

Name

The name *nitrogen* was created from the Greek words *nitron genes* which means *nitre* and *forming*. "Nitre" is a common name for the chemical compound potassium nitrate.

Sources

Some minerals containing nitrogen can occur in deposits large enough to be mined for their nitrogen content. Sodium and potassium nitrate mineral deposits are mined in the Atacama Desert of Chile. This, however, is a minor source of nitrogen.

Nearly all nitrogen is taken from the atmosphere. In a chemical reaction, air is made to react with hydrogen (which itself is retrieved from natural gas deposits) to make ammonia gas (NH_3). The ammonia is then combined with other molecules to create a number of end products.

China is the world’s largest ammonia producer and consumer; the United States is the world’s second largest ammonia producer and consumer. The United States produces much of the nitrogen needed for industry, all in the form of ammonia. Because natural gas is a component of ammonia, ammonia production plants are being built in locations where there are large natural gas deposits. In most cases, natural gas is less expensive in these locations. Some ammonia plants in areas with higher cost natural gas and fewer reserves, such as the United States and Europe, are being shut down. More than half of the ammonia made in the United States is made in Louisiana, Oklahoma and Texas, because these states have significant natural gas deposits. More than 80 nations produce ammonia.

Of the U.S. ammonia imports, the majority comes from Trinidad and Tobago, approximately one-third from Canada, and the rest from Mexico, Venezuela, and other nations. The United States also imports ammonia from Russia and the Ukraine.

Uses

The single greatest use of nitrogen is as fixed nitrogen in ammonia compounds. In the United States, the majority of ammonia consumption is for the production of fertilizers.

Nitrogen compounds are very explosive, and as such are used to make explosives.

Nitrogen and ammonia also have a number of other interesting uses. Liquid nitrogen is used to freeze cells in a process called cryogenics. The oil industry uses liquid nitrogen to create pressure in oil wells to force crude oil to the surface. Ammonia is used as a refrigerant, to freeze food and food products and for transporting food products. Ammonia is also important in the production of plastics, resins and synthetic fibers.

Substitutes and Alternative Sources

There is no substitute for nitrogen in plant nutrition. It is a basic element of life for plants and animals.

PEAT

Background

Peat is the partially decomposed remains of plant material, especially sphagnum moss. It is found in a wetlands environment where the addition of new plant material is faster than the decomposition of the accumulated plant material. A number of essential conditions that contribute to peat formation is provided in a wetlands: the plant material remains waterlogged, the temperature is low and there is a lack of oxygen both of which slow decomposition. “Wetlands” include floodplains, marshes, swamps, and coastal wetlands.

Peat is the first material formed in the process that transforms plant matter into coal. As coal formation progresses, volatile materials like water are driven off, and the percentage of carbon content of the material increases, making it increasingly dense and hard.

The majority of the peat harvested is called reed-sedge peat. The other harvested forms are sphagnum moss, humus and hypnum moss .

Name

The word *peat* has its roots in the Old Celtic root word *pett*- meaning *piece* in reference to a piece of peat that had been cut from a bog.

Sources

In the United States, Florida, Michigan, and Minnesota are the leading producers of peat, although 20 of the contiguous states and Alaska produce peat. The United States is estimated to have 110 billion tons of peat, and that approximately one-half of it is in presently undisturbed areas of Alaska.

Of the peat that is imported into the United States, most comes from Canada. Other significant producers of peat are Belarus, Estonia, Finland, Germany, Sweden, Lithuania and Russia. It is estimated that world resources of peat are 2 trillion tons.

Uses

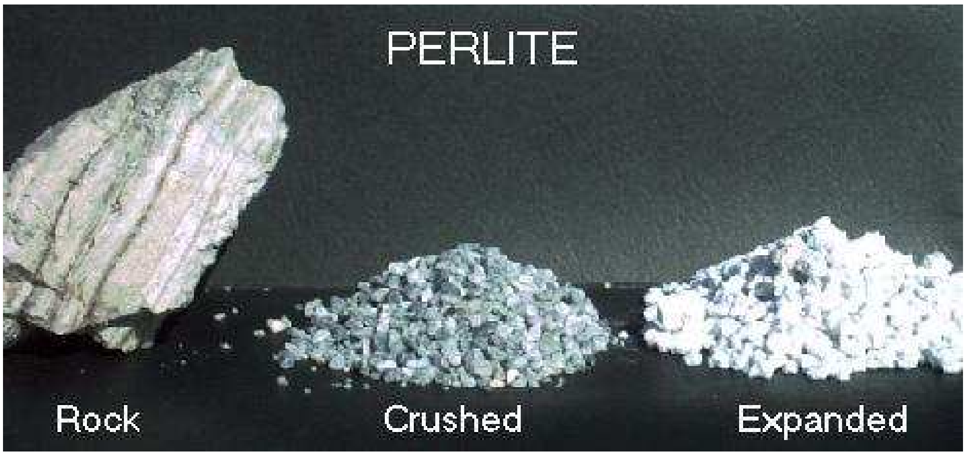
Approximately 95% of the peat consumed is in agriculture and horticulture for soil improvement (peat retains large amounts of water and liquid fertilizer), potting soils, for earthworm farms, and golf course maintenance. It is also used for other gardening and agricultural applications such as packing plants and growing mushrooms and vegetables. In some parts of Ireland, peat is burned in fireplaces to heat homes.

Because peat is so absorbent, it is used in industry to absorb oil spills. This same quality makes peat a good material to filter contaminants from water. Peat has also been used as a sterile absorbent in such products as diapers and feminine hygiene products.

Substitutes and Alternative Sources

Natural materials (leaves, plants, vegetable matter, etc.) can be composted. These materials compete for some peat applications (improving soil, for instance). But most products do not match the superior absorbent qualities of peat.

PERLITE



Perlite image courtesy of Redco II at www.perlite.net

Background

Perlite is a type of volcanic glass that expands and becomes porous when it is heated. When heated, it can expand to as much as twenty times its original volume. This expansion is the result of heated water: when the glassy lava rock is heated to 1600 degrees F (871 degrees C), the water molecules trapped in the rock turn into vapor which causes the rock to expand. (This is the same principle as the water in pop corn that causes the kernel to pop when it is heated.) Before it is expanded, perlite is commonly gray, but can also be green, brown, blue or red. After it has been heated, perlite is typically light gray to white.

Volcanic glass forms when molten rock (lava) pours out of a volcano and cools very, very quickly. Because is cools so quickly, there is no time for crystals to form or for water to escape. Instead, the lava hardens immediately into this glass-like material containing 2-5% water. It is a silicate rock, which means that it has a high percentage of silica (Si).

Perlite is known in industry in two forms. *Crude perlite* is prepared by the crushing and screening of perlite into various size fractions. *Expanded perlite* is perlite after it has been heated.

Name

The name perlite (also spelled *pearlite*) comes from the French word *perle* which means *pearl*, in reference to the “pearly” luster of classic perlite.

Sources

Unfortunately there is limited information about perlite production and consumption in the world. However, it is still accurate to say that the United States is one of the world’s largest producers and consumers of crude perlite and expanded perlite. A number of western states including Utah and Oregon produce perlite, with New Mexico being the most important perlite-producing state.

The United States, however, is not the only significant producer of perlite. Other countries that are believed to produce large amounts of crude and expanded perlite include China, Greece, Italy, Philippines, Mexico, and Turkey. Even though the United States has large resources of perlite, most is still imported, with nearly all imported from Greece.

Uses

Perlite is used in a number of different situations. The majority of perlite is used in construction products, mainly ceiling tiles and roof insulation products, but also as refractory bricks (a refractory brick is a brick designed to withstand very high temperatures), pipe insulation, and filling in masonry block construction. For example, loose perlite is poured into holes in concrete blocks after they are laid in place to improve the insulating quality of the construction. Perlite is also used as an insulator in other ways in the construction of buildings. It reduces noise and, since it is non-combustible, it also improves the fire resistance of different construction components in buildings.

Perlite is an important commodity in the horticulture industry where it is mixed with soil. The addition of perlite to soil increases the amount of air (i.e., oxygen) held in the soil, as well as the amount of water retained by the soil. This obviously improves the growing conditions for plants. This represents approximately 10% of annual perlite consumption.

Perlite is also used in a variety of different applications. For example, it is used as a filter for pharmaceuticals, chemicals, and beverages, and as a filler in the production of plastics and cements.

Industrial Applications

Industrial applications for perlite are the most diverse, ranging from high performance fillers for plastics to cements for petroleum, water and geothermal wells. Other applications include its use as a filter media for pharmaceuticals, food products, chemicals and water for municipal systems and swimming pools.

Additional applications include its use as an abrasive in soaps, cleaners, and polishes; and a variety of foundry applications utilizing perlite's insulating properties and high heat resistance. This same heat resistant property is taken advantage of when perlite is used in the manufacture of refractory bricks, mortars, and pipe insulation

Horticultural Applications

In horticultural applications, perlite is used throughout the world as a component of soilless growing mixes where it provides aeration and optimum moisture retention for superior plant growth. For rooting cuttings, 100% perlite is used. Studies have shown that outstanding yields are achieved with perlite hydroponic systems. Other benefits of horticultural perlite are its neutral pH and the fact that it is sterile and weed-free. In addition, its light weight makes it ideal for use in container growing. Other horticultural applications for perlite are as a carrier for fertilizer, herbicides and pesticides and for pelletizing seed. Horticultural perlite is as useful to the home gardener as it is to the commercial grower. It is used with equal success in greenhouse growing, landscaping applications and in the home in house plants.

Construction Applications

Because of perlite's outstanding insulating characteristics and light weight, it is widely used as a loose-fill insulation in masonry construction. In this application, free-flowing perlite loose-fill masonry insulation is poured into the cavities of concrete block where it completely fills all cores, crevices, mortar areas and ear holes. In addition to providing thermal insulation, perlite enhances fire ratings, reduces noise transmission and it is rot, vermin and termite resistant. Perlite is also ideal for insulating low temperature and cryogenic vessels. When perlite is used as an aggregate in concrete, a lightweight, fire resistant, insulating concrete is produced that is ideal for roof decks and other applications. Perlite can also be used as an aggregate in Portland cement and gypsum plasters for exterior applications and for the fire protection of beams and columns. Other construction applications include under-floor insulation, chimney linings, paint texturing, gypsum boards, ceiling tiles, and roof insulation boards.

Substitutes and Alternative Sources

There are a number of materials that can be used in place of perlite for many of its applications. These materials (such as diatomite, pumice, expanded clay and shale, etc.) may be used in place of perlite without losing any of the benefits that perlite provides. Despite the lack of detailed information about world perlite production, there appears to be an abundant supply of perlite that will last many decades into the future.

PHOSPHATE ROCK

Background

Phosphate rock is used for its phosphorus content. Hennig Brand discovered the element phosphorus in 1669. He prepared it in a set of experiments on urine; each experiment used at least 50 to 60 buckets! Phosphorus is a very important piece of the DNA and RNA molecules of which all life is formed. It is also important for the development of teeth and bones. The name *phosphorus* comes from the Greek word *phosphoros*, which means *bringer of light*. Phosphorus is mined in the form of phosphate rock.

Phosphate rock is formed in oceans in the form of calcium phosphate, called *phosphorite*. It is deposited in extensive layers that cover thousands of square miles. Originally, the element phosphorus is dissolved from rocks. Some of this phosphorus goes into the soil where plants absorb it; some is carried by streams to the oceans. In the oceans the phosphorus is precipitated by organisms and sometimes by chemical reaction. Phosphorus-rich sediments alternate with other sediments (geologists say these beds are *interstratified*). Phosphorus-rich beds usually have very few fossils; however, deposits in

Florida and North Carolina contain a large amount of marine fossils. Some geologists believe that the formation of these phosphorus layers occur under a very special condition in which no other type of sediment is present. In addition, it is believed that phosphorus-rich rock is deposited in a body of water in which there is no oxygen; this is called an *anaerobic* environment. Many theories say that phosphorus is absorbed by ocean plants that die. As they decompose, the phosphorus accumulates. Despite many theories, studies about the formation of phosphate rock continue and theories about its deposition are developing.

In addition to the sedimentary phosphate deposits, there are some igneous rocks that are also rich in phosphate minerals. Sedimentary phosphate deposits, however, are more plentiful.

Name

Sources

Large deposits of phosphate from igneous rock are found in Canada, Russia, and South Africa. Deep-sea exploration of the world's oceans has revealed that there are large deposits of phosphates on the continental shelf and on seamounts in the Atlantic and Pacific Oceans. Recovering these deposits, however, is still too expensive, so they remain untouched for now. In the United States, phosphate rock is mined in Florida, North Carolina, Utah and Idaho. Florida and North Carolina account for approximately 85% of phosphate rock production in the United States. U.S. companies export large quantities of phosphate fertilizers all over the world. Phosphate rock is imported to the United States as well. Nearly all of these imports come from Morocco, a major supplier of phosphate rock to the world.

Uses

Some phosphate rock is processed to recover elemental phosphorus. Pure phosphorus is used to make chemicals for use in industry.

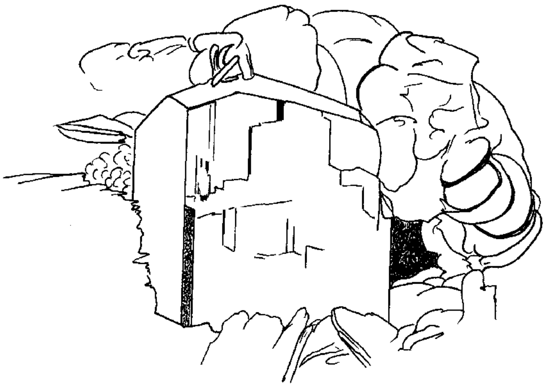
The most important use of phosphate rock, though, is in the production of phosphate fertilizers for agriculture. Some is used to make calcium phosphate nutritional supplements for animals.

Substitutes and Alternative Sources

Phosphorus is so important to life, that there is no substitute for it in agriculture. As for alternative sources, the phosphorus deposits on the ocean floor may one day be recovered when a profitable method of deep ocean mining is developed.

RHENIUM

Background



Rhenium is a rare, silvery-white metallic element. Its atomic number is 75 and its symbol is Re. Rhenium was discovered in 1925 by a team of German scientists named Walter Noddack, Ida Tacke-Noddack, and Otto Berg. They discovered rhenium as a trace element in platinum ores and the mineral columbite. It is very dense. It has a melting temperature of 3186 degrees C (5767 degrees F). It is not known to have any health benefit for animals or plants. Rhenium does not form minerals of its own, but it does occur as a trace element in columbite, tantalite and molybdenite. These minerals are the principal sources of columbium (commonly called niobium), tantalum and molybdenum metals.

Above: A columbite crystal in albite. Drawing used with permission.
© 2001 Darryl Powell.

Rhenium is a very rare element that is produced principally as a by-product of the processing of porphry copper-molybdenum ores. Because it is scarce, very little rhenium is actually processed and isolated each year as compared to the millions of tons of copper and millions of pounds of molybdenum that are extracted from these same porphry copper deposits. As a result, the processing of rhenium poses no environmental threat. The equipment that reduces sulfur dioxide in these processing plants also removes any rhenium that may escape through the smokestacks.

Name

Rhenium was named after the Greek word for the Rhine River, *Rhenus*.

Sources

Rhenium is obtained almost exclusively as a by-product of the processing of a special type of copper deposit known as a *porphyry copper* deposit. Specifically, it is obtained from the processing of the mineral molybdenite (a molybdenum ore) that is found in porphyry copper deposits. A *porphyry copper* deposit is a valuable copper-rich deposit in which copper minerals occur throughout the rock. The copper in these deposits occurs as primary *chalcopyrite* ($CuFeS_2$) or the important secondary copper mineral *chalcocite* (Cu_2S).

The identified rhenium resources in the United States are estimated to total 5 million kilograms. These resources are found in the southwestern United States. The identified rhenium resources in the rest of the world are estimated to total 6 million kilograms. Countries producing rhenium include Armenia, Canada, Chile, Kazakhstan, Mexico, Peru, Russia, and Uzbekistan. Even though the United States has significant rhenium resources, the majority of the rhenium consumed in the U.S. is imported. Chile and Kazakhstan provide the majority of the imported rhenium. The rest is imported from Mexico and other nations.

Very small amounts are gathered by recycling molybdenum-rhenium and tungsten-rhenium scrap metals.

Uses

Because of its very high melting point, rhenium is used to make high temperature alloys (an *alloy* is a mixture of metals) that are used in jet engine parts. It is also used to make strong alloys of nickel-based metals. Rhenium alloys are used to make a variety of equipment and equipment parts, such as temperature controls, heating elements, mass spectrographs, electrical contacts, electromagnets, and semiconductors. An alloy of rhenium and molybdenum is a superconductor of electricity at very low temperatures. These superalloys account for the majority of the rhenium use each year.

Rhenium is also used in the petroleum industry to make lead-free gasoline. In this application, rhenium compounds act as catalysts. (A *catalyst* is a chemical compound that takes part in a chemical reaction, and can often make the reaction proceed more quickly, but the chemical is not consumed in the chemical reaction.)

Substitutes and Alternative Sources

Substitutes for rhenium as a catalyst are being researched. Iridium and tin have been found to be a good catalyst for at least one reaction. Cobalt, tungsten, platinum and tantalum can be used in some of the other applications for rhenium.

RUBIDIUM

Background

Rubidium is a very soft, silvery-white metallic element. Its atomic number is 37 and its symbol is Rb. Rubidium was discovered in 1861 by the German chemists, Robert Bunsen and Gustav Kirchhoff. It is the 16th most abundant element in the Earth's crust (making rubidium a pretty common element). It belongs to a group of elements known as the *alkali metals*, such as sodium, potassium, cesium and lithium. Like the other alkali metals, rubidium reacts violently with air and water. When exposed to air, it bursts into flame. When put in water, it explodes. Its melting point is so low (103 degrees F, 40 degrees C) that it will melt on a very hot day. Scientists know that rubidium stimulates the metabolism. However, it is not known whether rubidium is beneficial to health. Rubidium does not combine with other elements or ions to create minerals. It is found, though, in trace amounts in the minerals that contain essential amounts of other alkali metals. These include the cesium and potassium rich zeolites, pollucite and leucite, and the lithium rich mica, zinnwaldite (a variety of the mineral lepidolite). One isotope of rubidium is radioactive. Because it is impossible to separate this isotope from non-radioactive rubidium, nearly all processed rubidium is slightly radioactive.

Name

Rubidium is named from the Latin word *rubidius* which means *dark red* or *deep red*, in reference to the dark red spectroscopic lines.

Sources

According to the United States Geologic Survey (USGS) there is no accurate information about rubidium resources around the world. It is known that the United States imports 100% of the rubidium it consumes. It is believed that Canada is the most important supplier of rubidium ore to the U.S. A small number of American companies process rubidium ore (lepidolite).

Most rubidium is retrieved from the minerals lepidolite (a mica mineral) and pollucite. Both of these minerals are typical of a special igneous deposit known as a *pegmatite*. (A *pegmatite* is an igneous deposit where the *magma* (molten rock) cools so slowly that very, very large crystals form. Unusual and rare elements are typical in the minerals found in pegmatites.)

Uses

There are very few uses for rubidium. It is used in some medical and electronic applications. In general, rubidium is used mostly in laboratory studies. Rubidium may some day be used in space travel in what are called *ion engines* that can power spacecraft. It may some day be used to create very thin batteries.

Substitutes and Alternative Sources

The physical and chemical properties of cesium and cesium compounds are so similar to those of rubidium and rubidium compounds, that they can be used interchangeably.

SAND and GRAVEL

Background

The use of sand and gravel as a commodity falls into two separate categories. Some is used in construction where it may be mixed with other materials or used as is. The second use is industrial where the sand and gravel are used in some way in the production of other materials. Because so much sand and gravel is consumed in each category, the United States Geological Survey (USGS) keeps track of sand and gravel consumption in these two separate categories.

Sand, whether it is found on beaches or in rivers and streams, is mostly quartz (silicon dioxide, SiO_2) grains. The weathering of rocks such as granite forms these quartz grains. In the process of weathering, the softer, weaker minerals in granite (such as feldspar) are weathered away. The more resistant quartz eventually is ground down in size, but does not break down chemically. In time, these quartz grains accumulate in rivers, streams, deltas and on beaches. Grains of other weathering-resistant minerals (such as garnet, rutile, ruby, sapphire, zircon, etc.) are often found in quartz sand as well.

For some applications, it is the silica content (quartz) of sand that makes it so valuable. The silica itself is needed to make products such as glass. In addition, the physical properties of sand, particularly its abrasive property, make it useful for traction on icy roadways and railroads, and for sandblasting.

Name

Sources

World resources of sand and gravel are very large. Recovering and processing these resources can be too costly depending on the location of a particular sand deposit and environmental laws about protecting or preserving the area. The sand and gravel deposits that have proven to be most valuable are from present and ancient river channels, river flood plains and glacial deposits.

Construction sand and gravel are produced in all 50 states in the U.S. The states producing the most are California, Texas, Michigan, Ohio, Arizona, Colorado, Minnesota, Washington, and Utah. Together, they produce 52% of the total amount of construction sand and gravel mined and processed in the United States. More than a billion tons of sand and gravel are produced annually in the U.S. As with many commodities, construction sand and gravel is also imported. These imports primarily come from Canada, but also from The Bahamas, Mexico, and assorted other nations.

Industrial sand and gravel are produced all over the world. The leading nations processing and producing industrial sand and gravel include the United States, Australia, Austria, Belgium, Brazil, Canada, France, Germany, India, Spain, Sweden, and South Africa. The United States is the world’s leading exporter of silica sand. (Presently it is impossible to report how many tons of sand and gravel produced each year because each nation defines and processes "silica sand" differently.) Because of the extensive, high-quality deposits of sand, combined with the technology to process sand and gravel into nearly any quality for any application, sand and gravel companies in the U.S. are able to provide a product for any application. The U.S. exports sand and gravel to nearly every region of the world.

The United States is probably both the world’s largest producer and largest consumer of sand and gravel. More than half of the U.S. imports of industrial sand and gravel imports come from Australia, but also from Mexico, Canada, and other nations.

Uses

Specific percentages on the uses of construction sand and gravel are not available. This is because a little more than 50% of the sand and gravel consumed for construction is for "unspecified" purposes. However, it is reported that the remaining 50% is used to make concrete, for road construction, for mixing with asphalt, as construction fill, and in the production of construction materials like concrete blocks, bricks, and pipes. It is also used to make roofing shingles, on icy roads in the winter, railroad ballast, and water filtration.

Industrial sand and gravel is used to make glass (39%), as foundry sand (22%), as abrasive sand (5%). The remaining 34% is used for an assortment of other uses.

Substitutes and Alternative Sources

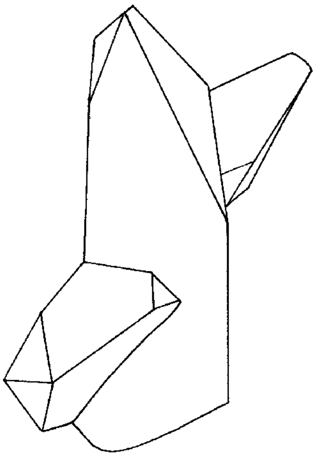
Crushed stone is an alternative material for construction applications.

There are suitable substitutes for blasting (abrasive) sand, foundry and refractory applications, but not for glass making.

SCANDIUM

Background

In 1879 a Swedish chemist named Lars Fredrik Nilson was looking for rare earth elements in the minerals euxenite and gadolinite when he discovered erbium and ytterbium; scandium was later separated from the ytterbium. At that time these minerals had only been found in Scandinavia, and the element was named after the region. Scandium is a soft, silvery-white metallic element with an atomic number 21. It easily oxidizes and tarnishes to pink or yellow. When placed in water, a chemical reaction occurs which releases characteristics that are similar to the rare earth as a member of the group. The smaller size ically more like aluminum, magnesium and



Intergrown monazite crystals.
Monazite contains very small amounts of scandium.

Scandium is more common in the sun and

stars than on Earth. It is relatively rare on Earth, although it is more abundant than boron. Scandium is widely dispersed in minute quantities in the Earth's crust. It is especially found in uranium minerals and trace amounts occur in iron and magnesium rich rocks. One of the few minerals having a notable scandium content is thortveitite. But occurrences are rarely large enough to be exploited as an ore. Other rare minerals have scandium, bazzite, kolbeckite, ixiolite-Sc, perrierite-Sc, and magbasite. Norway, Madagascar, and the United States have thortveitite which contains from 44 to 48% scandium oxide (ScO_2).

Scandium is very difficult to reduce to its pure state. In fact, it was not isolated in its pure form until 1937 and the first pound of pure scandium was not produced until 1960.

Name

The name *scandium* was derived from the Latin word *Scandia* which means *Scandinavia*.

Sources

Scandium has been recovered from mine tailings, particularly from tantalum deposits and uranium ore tailings. The majority of scandium production comes from thortveitite deposits. Processing the residues from mines with tantalum is another source of scandium. In the United States, scandium was recovered from thortveitite-rich mine tailings, like the tailings of the Crystal Mountain fluorite mine near Darby, Montana. Scandium also occurs in iron-magnesium rocks and minerals in an abundance of 5 to 100 parts per million (ppm). If it could be mined, this would be enough of a resource to supply the world demand.

Worldwide, scandium resources are found in China, Kazakhstan, Madagascar, Norway and Russia. Scandium is in tin and tungsten deposits in China. In Russia, it is in the mineral apatite and associated with uranium deposits. In Norway, scandium is in large thortveitite deposits.

Geologists believe there are still significant deposits of scandium-bearing minerals yet to be discovered.

Uses

Scandium is used in mercury vapor lamps to create a light that is very much like natural sunlight. This is very important for camera lighting for producing movies and television shows. Scandium is also used in the manufacture of crystals for laser research and aerospace applications (Russia). Scandium is alloyed with aluminum and is used to make lightweight, strong sporting equipment like aluminum baseball bats, bicycle frames, and lacrosse sticks. There is some evidence that at high temperatures, it is possible to dissolve scandium in titanium to make a strong, heat-resistant metal alloy.

Toxicity

Based on its chemical similarities to the rare earths, scandium is not expected to present a serious health hazard.

Substitutes and Alternative Sources

There is no adequate substitute for scandium for its lighting and laser applications. Titanium, aluminum alloys and carbon fiber are a substitute for use in athletic equipment and sporting goods.

SELENIUM

Background

Selenium is a gray, metallic element. Its atomic number is 34 and its symbol is Se. The Swedish scientist Jons Jacob Berzelius discovered selenium in 1817. In studying the sulfuric acid produced in a particular Swedish factory, he discovered an impurity which he eventually identified as selenium. Selenium occurs in three distinct forms: as a non-crystalline, gray metal; it can form as a deep red to black powder; and it can form as red crystals. It is stable in air and in water. Selenium is actually an important trace element to mammals and some plants. Too much selenium in a mammal's diet is poisonous and has been shown to cause deformities. When there is not enough selenium, a mammal can also have health problems. For example, sheep that graze in areas with too little selenium in the soil eventually have a problem known as "white muscle disease." Lack of selenium has also been connected to strokes in humans. The percentage amount of selenium in a healthy human is 0.00002 %.

Name

Selenium was named after the Greek word *selene,* meaning *moon*. This is a reference to the silvery-gray color of metallic, non-crystalline selenium. There is a mineral called *selenite* which is also named after the word *selene*;

however, selenite does not contain selenium.

Sources

Minerals containing selenium are very uncommon. Rarely, ores that contain high concentrations of selenium have been discovered. Most selenium is recovered as a by-product of processing copper ores. This appears to be the only affordable source of selenium. It is estimated that the copper deposits that are yet to be discovered will produce 2.5 times the amount of selenium in the presently known copper ores. Continued search and research will therefore lead to the discovery not only of future copper ores, but also of the selenium found within them.

Currently, less than one-fifth of the refined selenium production comes from recycling. Almost all of this recycling is of selenium-containing photo-receptors used in photo copiers.

The nations producing selenium include the United States, Belgium, Canada, Chile, Germany, Japan, Sweden, Philippines, Finland, Peru, Zambia, and other countries. The United States imports selenium, primarily from Canada, Philippines, Belgium, Japan, and other nations.

Uses

Selenium is known as a *photovoltaic* substance. This means that it converts light energy directly into electricity. It also displays what is called a *photoconductive action*, in which electrical conductivity increases as more and more light shines on the selenium. These unique features make selenium useful for photocells used to power everything from handheld calculators to large-scale photocells used to convert sunlight into electrical energy which is then stored in batteries.

Selenium has other interesting electrical properties. It can be used in devices to convert alternating current (AC) electricity to direct current (DC) electricity. Therefore, selenium is used in special electrical converters where an AC power supply must be changed into a DC current. These special converters are called *rectifiers*. Ultimately, less than one-fifth of the selenium consumed annually is used in these various electrical applications.

Even more selenium is used in the production of glass. It is used to remove the color from the glass used to make bottles. It is used in specialized sheet glass for windows where it reduces the amount of heat that enters a building from sunlight. The glass industry consumes more than one-third of the selenium used each year.

It is also used to make a variety of chemicals and pigments. This accounts for about one-fifth of the annual selenium consumption.

The remainder is used in a variety of applications. At one time, selenium was important in the manufacture of the drums in copying machines that transfer the image to the paper (newer copiers no longer use selenium on the image drum). It is also used in anti-dandruff shampoos, steel alloys, human dietary supplements, and rubber production.

Substitutes and Alternative Sources

Newer technologies are replacing some of the applications of selenium. For instance, high purity silicon is now being used in the production of rectifiers (see *Uses* above). Other elements are being used in the photoelectric applications. Cerium oxide is being used in glass production in place of selenium. Coal deposits contain 1.5 parts per million selenium. This is 80 times the amount of selenium found in copper deposits! Unfortunately, a method of removing this selenium from coal has not been developed. This could prove to be a significant source of selenium should technology advance.

SODIUM SULFATE

Background

Sodium sulfate (Na_2SO_4) is one of the most important minerals in the chemicals industry.

Natural sodium deposits are formed by a long geologic process of the erosion of igneous rocks, the transportation of sodium from these rocks and chemical reactions. First, the sodium is released from igneous rocks when they weather and break down. In the right situation, the sodium is carried by water in rivers, streams and as runoff and collects in basins. Then, when it comes in contact with sulfur, it precipitates out as sodium sulfate. The sulfur can come from the weathering of the mineral pyrite (iron sulfide), from volcanic sources, or from gypsum beds (gypsum is calcium sulfate).

The mineral *thenardite* is natural sodium sulfate. Thenardite was named after the French chemist Louis J. Thenard. It is soluble in water and has a salty taste like the mineral halite.

In the photo: Thenardite (sodium sulfate) crystals from Searles Lake, San Bernardino County, California. Copyright © 1995,1996,1997,1998 by Terran Technologies, Inc.. All rights reserved. Used with permission as per http://mineral.galleries.com

Name

Sources

In the United States, two companies operate natural sodium sulfate plants in California and Texas. The brine waters of Searles Lake in California are estimated to contain about 450 million metric tons of sodium sulfate. Approximately 12% of the salt in the Great Salt Lake of Utah is sodium sulfate. This translates into 400 million tons of sodium sulfate. In addition, Nevada, Washington and Wyoming also have identified sodium sulfate resources.

Many other nations around the world also have significant natural sodium sulfate deposits. These nations include Canada, Mexico, Spain, Turkey, China, Egypt, Italy, Romania and South Africa. The United States imports sodium sulfate from Canada, Mexico, and other nations.

In addition, significant amounts of sodium sulfate are produced as a by-product from the production of other materials such as ascorbic acid, boric acid, cellulose, rayon, and silica pigments, to name a few.

A small amount is recycled by the paper and paper pulp industry. Based on the amount of sodium sulfate consumed each year worldwide, there is enough natural sodium sulfate to last hundreds of years.

Uses

Most sodium sulfate consumed annually is used to make soaps and detergents. It is an especially important ingredient in powdered soaps. Not as much is needed to make liquid soaps. It is also used to make textiles, in the production of paper and paper pulp, in glass production, and a variety of other applications.

Substitutes and Alternative Sources

Emulsified sulfur and *caustic soda* (sodium hydroxide) can be used in place of sodium sulfate in paper production. It is easily replaced by a number of products in soap and detergent production. Soda ash and calcium sulfate can be used in place of sodium sulfate in glass production, but the glass produced is considered "less-than-perfect."

CRUSHED STONE

Background

In industry, two types of "stone" are quarried, processed, and sold as commodities: they are known as *crushed stone* and *dimension stone*.

Crushed stone is any type of natural rock that, in order to be mined, has to be first blasted from its natural state in the ground, and then processed (crushed and screened). The most common types of stone processed into crushed stone include limestone and dolomite, granite, and traprock. Smaller amounts of marble, slate, sandstone, quartzite, and volcanic cinder are also used.

Name

Sources

Crushed stone is produced in almost every state in the U.S. The type of crushed stone mined from any particular state depends on the general geology and rocks of the state. For instance, crushed limestone and dolomite is typical Indiana, Illinois and Ohio, marble and granite from Vermont, etc. Even though it is quarried and processed all over the United States, a small number of states account for more than half of the total crushed stone production. These states, in decreasing order of amount of stone produced, are Texas, Pennsylvania, Florida, Georgia, Illinois, Missouri, Ohio, North Carolina, Virginia and Tennessee. Most states are now recycling asphalt as well as concrete roads and structures by crushing these materials and using them in new road construction projects.

The United States does import small amounts of crushed stone. Most is imported from Canada, followed by Mexico, The Bahamas, and other countries. Crushed stone resources worldwide are large. However, high-quality stone, such as some limestone and dolomite used for very special purposes, are more limited to specific regions.

Uses

Crushed stone is used mostly as aggregate for road construction and maintenance. It is also used for making cement and lime and other chemical applications, and in agriculture. There are other uses for crushed stone, many of which are not accurately or completely reported.

Substitutes and Alternative Sources

Stone resources in the world are large and crushed stone should never be in short supply. However, if necessary, crushed stone substitutes for road building include sand and gravel, and slag. Substitutes for crushed stone used as construction aggregates include sand and gravel, slag, sintered or expanded clay or shale, and perlite or vermiculite.

DIMENSION STONE

Background

Dimension stone is any type of natural rock material that is quarried in order to make blocks or slabs of rock that are cut to specific sizes (width, length, and thickness) and shapes. Dimension stone is used because it is durable, strong and attractive. It is usually important that they can be polished. The rocks chosen for dimension stone include all rock types (igneous, metamorphic, and sedimentary). The most important rocks used as dimension stone are granite, limestone, marble, sandstone, and slate. Certain softer rocks such as alabaster (massive gypsum) and soapstone (massive talc) can also be considered dimension stone.

Name

Sources

The states usually producing the most dimension stone are Indiana, Vermont, Georgia, and Wisconsin. Based on tonnage, granite usually accounts for the largest amount of dimension stone production each year. Limestone production is next, followed by sandstone, quartzite, marble, slate, and miscellaneous stone. Dimension stone is also imported from Italy, India, Canada, Spain, and other nations. The overall supplies of dimension stone are enough to meet annual demand.

Uses

Rough block production represents more than half of the dimension stone produced annually. Rough blocks of various dimension stone are used mostly in construction and to make monuments. Dressed stone is used to make curbstones for streets, flagstones for roofs and walkways, and other decorative uses such as for carvings and statues. Dressed stone represents more than half by tonnage of total dimension stone sold or used.

Substitutes and Alternative Sources

Depending on the application, dimension stone can be replaced with steel, concrete, plastics, glass and other similar materials. In building or monument construction, for instance, the material chosen very much depends on the design choices and goals of the architect. A particular stone might be chosen for its color and texture, or for the look it gives to a building or a room.

Traprock

Image from the USGS

Background

“Traprock” is not a geological term. It is a term used in the quarrying (mining) and rock commodities industries to refer to any number of dark-colored igneous rocks that are crushed and used, primarily, for road construction. The most common rock type in the traprock category are gabbro and basalt. Dark-colored igneous rocks have high iron and magnesium contents and relatively lower silica content (compared to continental crustal rocks, like granite, that have high silica contents and very low iron and magnesium contents). This dark magma originates in the Earth’s mantle. Dark igneous rock that is intruded into the crust cools more slowly and becomes coarse-grained. Geologists call this rock gabbro. When it is extruded onto the crust’s surface, it cools quickly and becomes fine-grained. Geologists refer to this as basalt. Diabase is another fine-grained igneous rock that is considered traprock. Diabase is composed mostly of the minerals feldspar and pyroxene.

Traprock is commonly found intruded between layers of pre-existing rock. Liquid rock that is intruded into the crust is referred to as plutonic rock and the mass of hardened magma is called a pluton. In some geologic settings, the magma does not intrude into the surrounding country rock, but pours out onto the surface in thick flows. Geologists call such flows sills.

When basalt cools, it naturally forms vertical fractures. If you look at the top of the basalt, you can see that the fractures result in six-sided columns. Less often the basalt columns can be four- or eight-sided. Horizontal fractures also form in the basalt. As these blocks weather they typically fall into piles that resemble steps. Because they look like giant steps or stairs, these basalt piles were given the name trap from the Swedish word trappa (which is related to the Danish word trappe and the German word treppe) all of which mean stairs. Geologists call this type of formation columnar basalt.

Name

Sources

In the United States, traprock is found in the Hudson River Valley of southeastern New York State down to northern New Jersey, where it is found as an extruded layer of basalt known as The Palisades Sill. Another significant traprock deposit is in southern New England. The Columbia River Plateau is another massive flood basalt that covers about 160,000 square kilometers in portions of Washington, Oregon and Idaho.

There are significant traprock deposits throughout the world. For example, the Deccan Plateau is a series of extensive flood basalts that cover over 500,000 square kilometers in west-central India. The Siberian Plateau is another extensive flood basalt that covers over 2 million square kilometers.

Uses

Traprock is used primarily as crushed rock for road construction. It is also crushed and mixed into concrete . Crushed traprock is also used as railroad ballast. Railroad ballast is crushed rock poured between railroad ties to complete the bed on which trains run.

Some traprock is cut and polished for use as dimension stone in construction. It is used as veneers on buildings, and is cut for use as tiles and other decorative construction purposes. Traprock can be polished to a very high polish. Because of its dark green to black color and ability to be polished, it has found some popularity as a material for headstones.

Substitutes and Alternative Sources

There are many rock varieties available for both crushed rock and dimension stone applications. Limestone is used as crushed stone more than any other stone. Other stones used in road construction are marble, granite, sandstone, and quartzite. There is more than enough of all of these rock types for both crushed rock and dimension stone applications well into the future. The need for alternative sources and substitutes is likely unnecessary.

Crushed limestone is produced and shipped all over the United States. However, in many situations it is more economical to use hard, dense rock that is found locally rather than incur the cost of importing crushed rock from elsewhere. Traprock is one of those stone products that is quarried, crushed and used locally.

By Darryl Powell

Darryl Powell is a 1984 graduate of the University of Rochester, Rochester, New York with a B.S. in Geological Sciences. For six years Mr. Powell was an Adjunct Professor at Finger Lakes Community College in Canandaigua, New York, where he taught “Introduction to Physical and Historical Geology.” He creates Earth Science educational kits for NeoSCI, Inc., a science education resource company based in Rochester, New York. He also writes Earth Science materials for NewPath Learning, Inc. based in Victor, New York. Mr. Powell is the founder of Diamond Dan Publications, a small company focused on creative activity books and activity-based learning games about rocks and minerals, based in Manchester, New York.

STRONTIUM

Background

Strontium is a silvery-yellow, metallic element. Its atomic number is 38 and its symbol is Sr. It is a relatively soft element.

Strontium was first discovered in 1790 by the Scottish scientist Adair Crawford who was studying samples of a new mineral. This new mineral, strontianite, is now known to be composed of strontium carbonate, $SrCO_3$. Crawford determined that this new mineral contained an element that had never been recognized before, which he identified and called *strontium*. Pure strontium was not isolated until 1808.

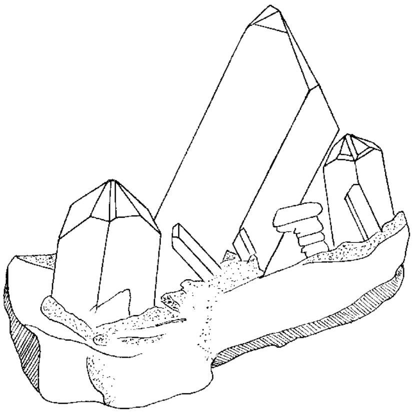
Strontium belongs to a group of elements known as the alkali earth metals. Like other alkali metals, it is chemically active and will react with both air and water.

Two radioactive isotopes of strontium, Strontium-89 and –90, are created by atomic bomb explosions and are found in their radioactive fallout. This radioactive strontium is absorbed by the body and replaces calcium in the bones. Once they become part of the bone, they remain there for the lifetime of the organism, giving off radiation.

There is no biological benefit to strontium.

Name

Named after the village of "*Strontian*" in Scotland.



Celestite crystals from Madagascar. © 2001 Darryl Powell. Used with permission.

Sources

Strontium is recovered from two strontium minerals, strontianite (strontium carbonate) and celestite (strontium sulfate). The most common of these two minerals is celestite. Strontium minerals have not been mined in the United States since 1959. Consequently, U.S. companies import 100% of the strontium minerals needed for strontium. They are imported exclusively from Mexico. In addition, strontium compounds are imported from Mexico (90%) and Germany (9%) and 1% from other nations.

Worldwide resources of strontium minerals have not been completely studied. However, experts estimate that world resources of strontium exceed 1 billion tons.

Uses

Most strontium (76% of the strontium consumed each year) is used to make compounds that are applied to the glass picture tubes on color television sets. This compound blocks the X-rays created by the picture tube.

Some strontium (10%) is used to make special magnets called ferrite ceramic magnets.

Strontium is the element that gives road flares and fireworks a bright red color. Pyrotechnics and flares account for 5% of the annual strontium consumption.

Substitutes and Alternative Sources

There are a few elements that can be used in place of strontium for some of its applications. There are two possible problems with such a substitution. First, no element or compound works as well as strontium in these applications. Second, the possible substitutes can be more expensive than strontium.

TELLURIUM

Background

Tellurium is a metallic, silvery-white element. Some even describe its appearance as "very metallic." Its atomic number is 52 and its symbol is Te. It was discovered in 1783 by Baron Franz Joseph Muller von Reichenstein of Romania, the chief inspector of mines in Transylvania at the time. Tellurium is very brittle and easily pulverized. It does not react with air or water.

As a commodity, tellurium is used in industry as pure tellurium metal, tellurium dioxide (TeO_2), and alloyed (that is, mixed) with other metals.

Tellurium has no known benefit to humans. It does have a strange effect on humans, though. When tellurium is ingested, even in very small amounts, it causes very bad, garlic-smelling breath and body odor.

There are a very small number of tellurium minerals. It combines with oxygen to form tellurite, and with gold and silver to form sylvanite $(Au,Ag)Te_2$. The most common gold telluride mineral is called calaverite($AuTe_2$).

Name

The name *tellurium* came from the Latin word *tellus* meaning *earth*.

Sources

Tellurium is recovered from the residue produced in refining blister copper from deposits containing recoverable amounts of tellurium. There are large quantities of tellurium in some gold and lead deposits, but the tellurium is not being recovered from these at this time. In addition, tellurium is present in coal and some lower-grade copper deposits, but the cost of recovering the tellurium from these deposits is too high to make it worth the effort. These deposits are called *subeconomic deposits*.

Nations producing tellurium and tellurium dioxide are the United States, Canada, Japan, Peru, and a number of other countries. As with most commodities, companies in the United States import tellurium. Of the tellurium imported each year, most comes from the United Kingdom, followed by Philippines, Belgium, Canada, and a number of other nations.

Uses

Half of the tellurium consumed each year is used to improve the machinability of special iron and steel products. It is alloyed with copper to make copper more ductile (that is, easier to stretch into wires), and with lead to prevent corrosion. These, and other nonferrous tellurium alloys, account for approximately 10% of tellurium use. Tellurium is also used to make catalysts and chemicals. Some of these chemicals are used in the petroleum industry and in making rubber. Tellurium is added to selenium-based photoreceptors to broaden the spectral range of copiers. Tellurium is also used in other electronic applications, and in the production of blasting caps for explosives.

Substitutes and Alternative Sources

Selenium, bismuth and lead can be used in place of tellurium in many of its metallurgical uses. Selenium and sulfur can be used in place of tellurium in the production of rubber.

THALLIUM

Background

Thallium is a soft, bluish-white metallic element. Its atomic number is 81 and its symbol is Tl. It looks much like lead, but chemically is very similar to aluminum. It is so soft that it can be cut with a knife. It reacts easily with air, water, and most acids. It does not react violently like the alkali metals. Thallium was discovered in 1861 by the English chemist William Crookes.

Thallium and thallium compounds are very toxic, so some of their earlier uses (such as a rodent poison and an insecticide) have been discontinued. They can enter a body through the skin, by inhaling dust or fumes, and by direct ingestion. As a result, strict rules about the use of thallium and thallium compounds have been created by the U.S. Environmental Protection Agency (EPA).

Adding thallium to mercury lowers mercury's freezing temperature, permitting its application in low-temperature thermometers..

Name

When an element is burned, it creates a very specific spectrum of light. Thallium's spectrum includes a distinctive bright green line. The name *thallium* comes from the Greek word *thallios* which means *a green twig*, which is a reference to this green line.

Sources

The thallium concentration in the Earth's crust is 0.7 parts per million (ppm). It forms a small number of rare minerals, including crookesite and lorandite. These minerals form with the zinc mineral sphalerite. As a result, thallium is recovered as a by-product of processing zinc ores. It is also recovered from lead and copper ores, and from the dust that accumulates in the flues of the copper, zinc and lead smelters.

It is estimated that the thallium resources worldwide total approximately 17 million kilograms. These resources are found in Canada, Europe and the United States. As late as 1999, thallium was not recovered from ores in the U.S. Thallium is imported by the U.S. from Belgium, Mexico, Germany, and the United Kingdom.

In addition to these resources, approximately 630 million kilograms of thallium is contained in coal. As with other commodities, a way of recovering thallium from coal at a reasonable cost has not yet been developed.

Manganese nodules that form on the ocean floor contain thallium. However, it is still too expensive to gather these nodules, so they are presently not a source for thallium.

Uses

Thallium is used in a number of electronic devices. It is used in selenium rectifiers, gamma radiation detection equipment, and infrared radiation detection and transmission equipment.

It also has non-electrical uses. For example, thallium is added to glass to increase its density and refractive index (that is, its ability to break light into its component colors). It is also used as a catalyst to create certain organic compounds. Radioactive thallium compounds are used in medical applications.

As mentioned above, thallium is no longer used to make insecticides or for rodent control.

Substitutes and Alternative Sources

The supplies of thallium are more than enough to meet the demand for this element. As a result, there is presently no need to search for or to develop substitutes or alternative sources for thallium. Should these resources be used up, retrieving thallium from coal or from the deep ocean manganese nodules may one day become possible or even necessary.

THALLIUM

Background

Thallium is a soft, bluish-white metallic element. Its atomic number is 81 and its symbol is Tl. It looks much like lead, but chemically is very similar to aluminum. It is so soft that it can be cut with a knife. It reacts easily with air, water, and most acids. It does not react violently like the alkali metals. Thallium was discovered in 1861 by the English chemist William Crookes.

Thallium and thallium compounds are very toxic, so some of their earlier uses (such as a rodent poison and an insecticide) have been discontinued. They can enter a body through the skin, by inhaling dust or fumes, and by direct ingestion. As a result, strict rules about the use of thallium and thallium compounds have been created by the U.S. Environmental Protection Agency (EPA).

Adding thallium to mercury lowers mercury's freezing temperature, permitting its application in low-temperature thermometers..

Name

When an element is burned, it creates a very specific spectrum of light. Thallium's spectrum includes a distinctive bright green line. The name *thallium* comes from the Greek word *thallios* which means *a green twig*, which is a reference to this green line.

Sources

The thallium concentration in the Earth's crust is 0.7 parts per million (ppm). It forms a small number of rare minerals, including crookesite and lorandite. These minerals form with the zinc mineral sphalerite. As a result, thallium is recovered as a by-product of processing zinc ores. It is also recovered from lead and copper ores, and from the dust that accumulates in the flues of the copper, zinc and lead smelters.

It is estimated that the thallium resources worldwide total approximately 17 million kilograms. These resources are found in Canada, Europe and the United States. As late as 1999, thallium was not recovered from ores in the U.S. Thallium is imported by the U.S. from Belgium, Mexico, Germany, and the United Kingdom.

In addition to these resources, approximately 630 million kilograms of thallium is contained in coal. As with other commodities, a way of recovering thallium from coal at a reasonable cost has not yet been developed.

Manganese nodules that form on the ocean floor contain thallium. However, it is still too expensive to gather these nodules, so they are presently not a source for thallium.

Uses

Thallium is used in a number of electronic devices. It is used in selenium rectifiers, gamma radiation detection equipment, and infrared radiation detection and transmission equipment.

It also has non-electrical uses. For example, thallium is added to glass to increase its density and refractive index (that is, its ability to break light into its component colors). It is also used as a catalyst to create certain organic compounds. Radioactive thallium compounds are used in medical applications.

As mentioned above, thallium is no longer used to make insecticides or for rodent control.

Substitutes and Alternative Sources

The supplies of thallium are more than enough to meet the demand for this element. As a result, there is presently no need to search for or to develop substitutes or alternative sources for thallium. Should these resources be used up, retrieving thallium from coal or from the deep ocean manganese nodules may one day become possible or even necessary.

TIN

Cassiterite

Background

Tin has been known from ancient times. Ancient peoples found that heating the tin mineral cassiterite (sometimes found in streams as nuggets) in a charcoal fire, they could produce the silvery, soft metal we know as tin.

Tin is a silvery-white metallic element with atomic number 50. Tin is malleable, meaning it is easily shaped by hammering. Pure tin also has a relatively low melting point, easily attainable in a wood fire, and is therefore easy to melt and cast in a clay mold. Tin is stable in air and water, meaning it does not oxidize or react easily . When pure tin is bent rapidly, it makes a peculiar squealing noise: this is called the "tin cry."

The ancients found tin to be too soft to be of much use for other than decorative objects, and the use of pure tin in ancient times was restricted to mirrors, clasps, and decorative items. Some coins have been minted of tin, but the coins wear and bend rapidly. However, when mixed (alloyed) with copper, another metal which could be found in a nearly pure state in nature, then a new and much harder alloy resulted: bronze. This discovery marked the beginning of the historical period known as *The Bronze Age*. The advent of the Bronze Age, with the use of bronze spears, arrowheads, knives, sickles, and scythes, greatly enhanced the efficiency of hunters and farmers.

The most important ore mineral of tin, cassiterite (tin dioxide, SnO2) forms in high-temperature veins, usually related to igneous rocks such as granites and rhyolites. It is often found in association with tungsten minerals. When rocks containing cassiterite are weathered (decomposed by the action of surficial waters and oxidation), the cassiterite tends to remain intact, and eventually is concentrated in streams to form "placer" deposits, in a manner similar to gold nuggets in "placer" deposits. Ancient peoples recovered cassiterite from streams by panning, and even today panning or - more importantly - large-scale mechanical dredging of stream deposits and decomposed rock are a major means of producing cassiterite. Veins with a high enough cassiterite content to mine underground occur in China, Bolivia, Peru, and a few other countries.

Name

The name *tin* is an ancient Anglo-Saxon word. Tin in the form of cassiterite was mined in ancient Britain and was a major trade item between Britain and the Greeks and Phoenicians of the Mediterranean region. The chemical symbol for tin, Sn, comes from the Latin word for tin, *stannum*. Tin was one of only seven chemical elements known in pure form, and named by ancient peoples. The mineral cassiterite is named for the ancient Greek word for tin.

Sources

As noted earlier, the primary mineral source for tin is cassiterite. The most tin resources in the United States are in Alaska, but these are relatively insignificant, and the U.S. has long imported its tin from other countries.

World resources to meet the demand for tin are sufficient for many decades to come. The primary producers of tin are China, Indonesia, and Peru, with lesser amounts from Brazil, Bolivia, Australia, and about a dozen other countries.

Uses

Much tin is used to coat so-called “tin” cans. Since tin does not oxidize (rust) in air or water, it is applied to the surface of flat-rolled steel to make tin plate, which is then fabricated to produce “tin” cans. This use accounts for about one-fourth of the tin consumed annually. Alloys such as bronze and pewter are also a major use of tin. Tin is useful in electrical applications, mainly low-melting-point solders, that account for one-fourth of tin consumption. It is also used in construction, transportation (mainly in bearings requiring soft metal alloys) and other various industrial applications. For example, window glass is made by pouring molten glass onto molten tin; this process results in flat sheets of glass. An alloy of tin and niobium has proven to be a “superconducting” compound at very low temperatures.

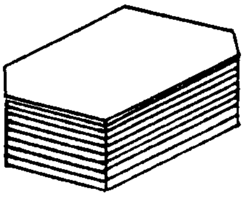
Substitutes and Alternative Sources

A number of materials can replace tin in its various applications. In the food packaging industry, plastics, paper, aluminum and glass can be used in place of metal “tin cans.” Tin can be used as a non-toxic substitute for lead in solders, pewter, and shotgun pellets. On balance, the world production and consumption of tin have not grown during the past 20 years, due mainly to the substitution of tin by plastic in the manufacture of cans and other containers, such as tubes for toothpaste and ointments.

VERMICULITE

Background

Vermiculite is a mineral that belongs to a group of minerals called *the mica minerals*. The mica group of minerals includes: biotite, muscovite, lepidolite, and phlogopite. Vermiculite is formed by the alteration and/or weathering of the minerals biotite and phlogopite. All mica minerals break into very thin sheets. Mineralogists call this *micaceous cleavage*. Like the mineral talc, vermiculite has layers of water sandwiched in between layers of silicate. Consequently, when vermiculite is heated, the water is driven off and the mineral expands. This expanded and lighter form of vermiculite is used extensively in industry, agriculture and construction.



A "book" of biotite crystals. A number of individual crystals are stacked upon one another. The breakdown of biotite and phlogopite creates vermiculite.

Name

The name *vermiculite* was created from the Latin word for worm, *vermiculus*. This is a reference to the fact that when vermiculite is heated, it expands into wormlike shapes.

Sources

Two companies with three operations in the United States, two in South Carolina and one in Virginia, mine vermiculite. Other deposits occur in Texas, Colorado, Nevada, North Carolina, and Wyoming.

Vermiculite is imported into the United States primarily from two countries: The majority of the imported vermiculite comes from South Africa; with a smaller amount coming from China. Other countries producing vermiculite include Russia, Australia, Zimbabwe, Brazil and Japan.

Uses

Vermiculite is used in a number of different applications. The majority of vermiculite is used annually for agriculture and insulation purposes. In agriculture it is used in horticulture and mixed with soil to create a more porous, absorbent soil. As an insulator, it is used both as a heat and sound insulating material. Vermiculite is added to concrete mixtures to create a lightweight concrete mix.

Substitutes and Alternative Sources

Several materials can be used in place of vermiculite for various applications. Expanded perlite can be used to make lightweight concrete. (Perlite is a form of volcanic glass, similar to obsidian. Unlike obsidian, it has a high water content, so that when it is heated, it expands and becomes much lighter.) Shale, slate and clay can be used as well; however, they are less expensive but considerably heavier than perlite and vermiculite. Fiberglass, perlite and slag wool can be used for insulating purposes in place of vermiculite. A number of different plant materials (peat, saw dust, wood chips, leaves, and other organic materials) can be used to condition and prepare soil for plants and horticulture.

Background

Name

Sources

Uses

Substitutes and Alternative Sources

ZIRCONIUM

Background

Zirconium (Zr) is a grayish-white, metallic element with an atomic number of 40. It naturally combines with silica and oxygen to form the mineral *zircon* ($ZrSiO_4$), the primary ore of this element. Zircon has been known since biblical times, and it has been called by a variety of names, including jargon, hyacinth and jacinth.

In the late 1700's, the German chemist Martin Heinrich Klaproth suspected that there was a new element to be found in this mineral. He reduced the mineral zircon to zirconium oxide in 1789, but never isolated the metal. In 1824, Swedish chemist Jöns Jacob Berzelius isolated an impure zirconium metal, but it wasn't until 1914 when pure zirconium was finally produced.

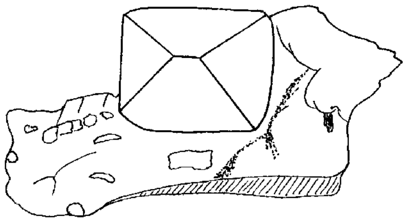
Zirconium reacts with oxygen, forming a thin coating of zirconium oxide on its surface. This coating protects the metal from further oxidation. Zirconium is quite resistant to corrosion by acids and other chemicals, and is valued in industry for this resistant quality.

Zirconium has no beneficial or adverse effect on living organisms, and is resistant to corrosion. Based on these properties, it has proven to be a good material for artificial limbs and joints.

Analysis of the rocks collected on the moon has shown that zirconium is a common element on the surface of the moon.

Name

Zirconium was named after the silicate mineral in which it was first discovered, zircon. The mineral name *zircon* was created from the Arabic word *zargun* which means *gold color*, a reference to the color of some zircon crystals.



-

A zircon crystal from Colorado. ©2000 Darryl Powell. Used with *permission.*

Zirconium is found in two minerals, zircon (zirconium silicate, ZrSiO4) and baddeleyite (zirconium oxide, ZrO_2). The most important of these ores, zircon, occurs as grains concentrated in sand deposits in the southeastern United States, and in Australia and Brazil. Russia and Brazil also have large deposits of baddeleyite. World resources are estimated to be more than 60 million tons worldwide.

Fourteen million tons of zirconium are in heavy-mineral sand deposits in the United States. The sands are called zircon sands because they contain sand-sized mineral zircon grains. Most heavy-mineral sands also have a high content of titanium-bearing minerals, such as ilmenite and rutile.

Several American metal companies in Oregon and Utah recover zirconium metal when recycling scrap metals created during metal production. Zirconium chemicals (like zirconium dioxide) are made in Alabama, New Hampshire, New York and Ohio.

In addition, zirconium ore and zirconium metal is imported. The ore is imported primarily from South Africa and Australia. Zirconium metal is imported primarily from France, Germany, Canada, and Japan.

Uses

Zirconium is used in a number of industrial applications because it is so resistant to corrosion. It is used in pumps and valves and the cores of nuclear reactors. Zirconium oxide is used to make laboratory crucibles and to line furnaces.

When zirconium is alloyed (mixed) with the element niobium, it becomes *superconductive*. This means that it is able to conduct electricity with very little loss of energy to electric resistance. Superconductivity is possible only at very low temperatures.

Another feature of zirconium is that it does not absorb neutrons (unlike hafnium, which absorbs neutrons, and is also found in zirconium deposits). This makes it useful in nuclear applications, where it is used as fuel cladding in nuclear reactors, and as a coating on nuclear fuel parts.

Zirconium is also used in everyday home products. Zirconium compounds are used in deodorants, flashbulbs, lamp filaments, and in artificial gemstones. Cubic zirconia is a hard, clear, gem-like material that is marketed as an inexpensive diamond-like gemstone. Colored cubic zirconia is sold as simulants of many different gemstones.

Substitutes and Alternative Sources

Different materials can be used in place of zirconium depending on the application. For example, titanium and other compounds can be used in a few of zirconium’s chemical applications. Niobium, stainless steel, and tantalum can be used in some limited nuclear applications.

Mineral Identification

Have you every visited a museum and seen all the exotic and beautiful crystals? Did you wonder how scientists were able to put names on all of these specimens? Upon completing this exercise you will be able to identify many of the common minerals. The next time you go hiking see if you can recognize the minerals you have now learned to identify. Do they look different in the field? Why is this?

PHYSICAL PROPERTIES

Approximately 3,000 minerals exist in nature. How do we identify them? Remember minerals differ from one another because each has a specific chemical composition and a unique three-dimensional arrangement of atoms within its structure. These differences result in a variety of **physical properties,** including the minerals' appearance, how they break, how well they resist being scratched, even how they smell, taste, and feel. Not all of these properties are equally useful. What if you were going to an airport to pick up someone you had never met, armed with a description provided by someone who had last seen your arriving passenger 25 years ago? Which features in the description would be most helpful? Height? Weight? Hair color? Some aspects of human features change markedly with time, while others, like eye color or shape of head, do not.

The problem is the same with minerals. Some properties never change. These are the most useful for identifying a mineral and are called diagnostic properties. Others, like a person's weight, may vary widely (not with time, but from specimen to specimen of the same mineral). You should be able to decide which of the following properties are truly diagnostic properties, and which are less useful.

- Color
- Streak
- Luster
- Cleavage/Fracture
- Hardness
- Crystal Shape
- Specific Gravity
- Other Properties

Color


The Many Colors of Fluorite

The color of a mineral is one of its most obvious attributes, and is one of the properties that is always given in any description. Color results from a mineral’s chemical composition, impurities that may be present, and flaws or damage in the internal structure. Unfortunately, even though color is the easiest physical property to determine, it is not the most useful in helping to characterize a particular mineral. The problem is shown to the left, in which the mineral fluorite (CaF_2) displays a rainbow of colors.

Some minerals do have only a single color that can be diagnostic, as for instance the yellow of sulfur. Also, although many minerals vary in color few span the spectrum of colors as fluorite does. Often we find most color variations of a given mineral are consistently light colored (white, tan, pink, yellow) or dark colored (gray, black, blue, green).

But Why are Minerals Colored?

The color of minerals depends on the presence of certain atoms, such as iron or chromium which strongly absorb portions of the light spectrum. The mineral olivine, containing iron, absorbs all colors except green, which it reflects, so we see olivine as green. All natural minerals also contain minute impurities. Some minerals such as corundum get their colors from these these impurities. Blue corundum (sapphire) is formed when small amounts of iron and titanium are dissolved in the solid crystal. Finally some crystals get their color from growth imperfections. Smoky (black) quartz is a good example. Growth imperfections interfere with light passing through the crystal making it appear darker, or almost black.

Examples of "Common" colored minerals

Native Sulfur (S)

Malachite $Cu_2CO_3(OH)_2$

Azurite $Cu_3(CO_3)_2(OH)_2$

Streak

A Streak Test (move your mouse over the picture to watch the animation)

The red-brown streak of the mineral hematite.

The color of a mineral when it is powdered is called the streak of the mineral. Crushing and powdering a mineral eliminates some of the effects of impurities and structural flaws, and is therefore more diagnostic for some minerals than their color. Streak can be determined for any mineral by crushing it with a hammer, but it is more commonly (and less destructively) obtained by rubbing the mineral across the surface of a hard, unglazed porcelain material called a streak plate.

The color of the powder left behind on the streak plate is the mineral's streak. The streak and color of some minerals are the same. For others, the streak may be quite different from the color, as for example the red-brown streak of hematite, often a gray to silver-gray mineral. The combination of luster, color, and streak may be enough to permit identification of the mineral.

Streak Color for a Few Common Minerals

- Black - Graphite
- Black - Pryite
- Black - Magnetite
- Black - Chalcopyrite
- Gray - Galena
- Limonite - Yellow-brown
- Hematite - Red-brown

Examples of Streak

Luster

Metallic/Nonmetallic Luster

Metallic Luster - Pyrite

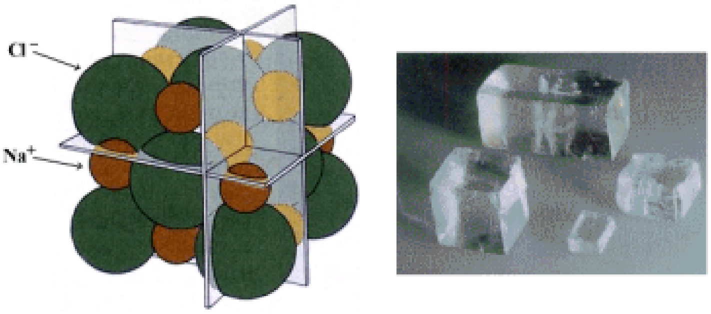
Nonmetallic Luster - Kaolinite

The luster of a mineral is the way its surface reflects light. Most terms used to describe luster are self-explanatory: metallic, earthy, waxy, greasy, vitreous (glassy), adamantine (or brilliant, as in a faceted diamond). It will be necessary, at least at first, only to distinguish between minerals with a metallic luster and those with one of the non-metallic lusters. A metallic luster is a shiny, opaque appearance similar to a bright chrome bumper on an automobile. Other shiny, but somewhat translucent or transparent lusters (glassy, adamantine), along with dull, earthy, waxy, and resinous lusters, are grouped as non-metallic.

Cleavage

A Demonstration of Cleavage
(move your mouse over the picture to watch the animation)

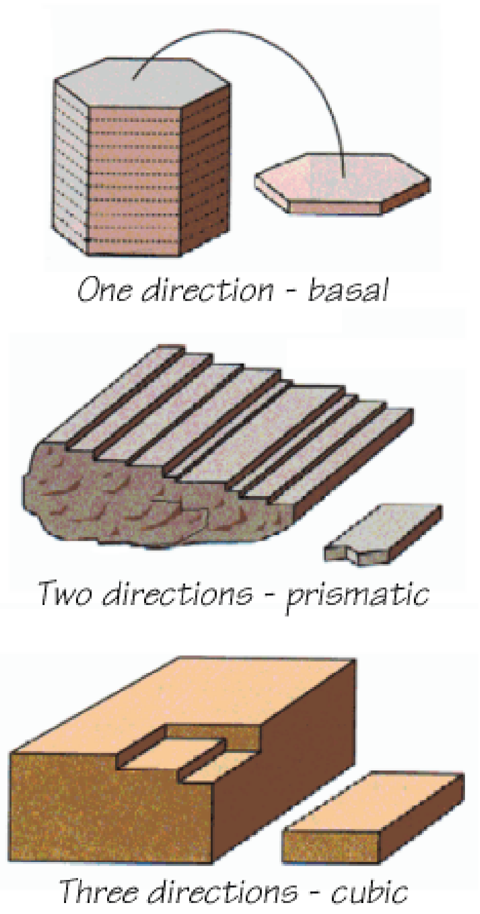
In some minerals, bonds between layers of atoms aligned in certain directions are weaker than bonds between different layers. In these cases, breakage occurs along smooth, flat surfaces parallel to those zones of weakness. In some minerals, a single direction of weakness exists, but in others, two, three, four, or as many as six may be present. Where more than one direction of cleavage is present, it is important to determine the angular relation between the resulting cleavage surfaces: are they perpendicular to each other (right angle), or do they meet at an acute or obtuse angle?



Relationship between crystal structure and cleavage for the mineral halite (NaCl)

When a mineral cleaves, it often exhibits many cleavage surfaces, but most of these are generally parallel to one another. A hundred cleavage surfaces parallel to one another all define a single direction of cleavage, because all of them are parallel to the same zone of bond weakness. It is the number of directions of cleavage that we record, along with the angles between them. Minerals with two or more cleavage directions generally have a "stair-step" appearance when viewed with a magnifying glass. A mineral with two directions of cleavage may indeed be broken in some other direction-by irregular fracture. Thus, a single specimen may exhibit smooth cleavage planes in some directions, and irregular breakage surfaces in others. The more breakage surfaces we can see, the more clues we have to the mineral's internal structure.

It may be difficult for the beginner to distinguish between cleavage and crystal faces. After all, both are smooth, planar surfaces. Two hints will help make the distinction easy. (1) If a mineral's outer surface shows a tarnish or alteration, the crystal faces will be tarnished or dull; if cleavage planes are present, they are usually recently made and will be fresher and less altered. (2) If many surfaces are present parallel to one another, they are most likely cleavage surfaces.



Types of Cleavage

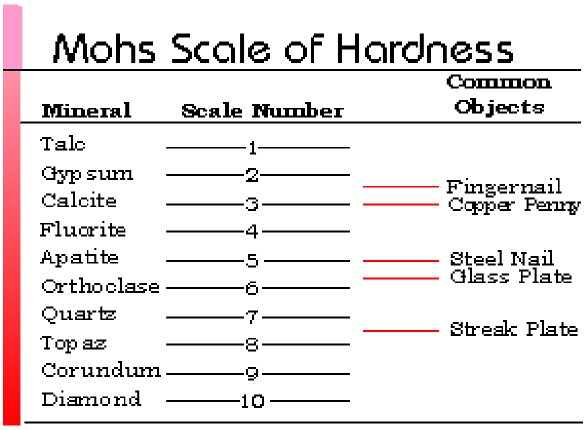
Examples of Cleavage

Fracture

When bonds between atoms are approximately the same in all directions within a mineral, breakage occurs either on irregular surfaces (splintery or irregular fracture) or along smooth, curved surfaces (conchoidal fracture), similar to those formed when thick pieces of glass are broken.

Hardness

Hardness Testing



Mohs Scale of Hardness

Mineral	Scale Number	Common Objects
Talc	1	
Gypsum	2	Fingernail
Calcite	3	Copper Penny
Fluorite	4	
Apatite	5	Steel Nail
Orthoclase	6	Glass Plate
Quartz	7	Streak Plate
Topaz	8	
Corundum	9	
Diamond	10	

Several items have been provided for your use in determining physical properties, including a glass plate (H=5.5), an unglazed porcelain streak plate (H=7.5), and a nail or pocket knife (H=5.0). Try scratching each of these with the others to determine their relative hardnesses. Where does your fingernail fit into this hardness scale? A copper penny? The hardness of any object is controlled by the strength of bonds between atoms and is measured by the ease or difficulty with which it can be scratched. Diamond is the hardest mineral, because it can scratch all others. Talc is one of the softest; nearly every other mineral can scratch it. We measure a mineral's hardness by

Diamond

The Hardest Known Substance

Diamond is the hardest naturally occurring substance known; it is also the most popular gemstone. Because of their extreme hardness, diamonds have a number of important industrial applications.

The hardness, brilliance, and sparkle of diamonds make them unsurpassed as gems. In the symbolism of gemstones, the diamond represents steadfast love and is the birthstone for April. Diamonds are weighed in carats (1 carat = 200 milligrams) and in points (1 point = 0.01 carat). In addition to gemstones, several varieties of industrial diamonds occur, and synthetic diamonds have been produced on a commercial scale since 1960.

A very high refractive power gives the diamond its extraordinary brilliance. A properly cut diamond will return a greater amount of

comparing it to the hardnesses of a standardized set of minerals first established by Friederich Mohs in the early nineteenth century, or with the common testing materials that have been calibrated to those standards.

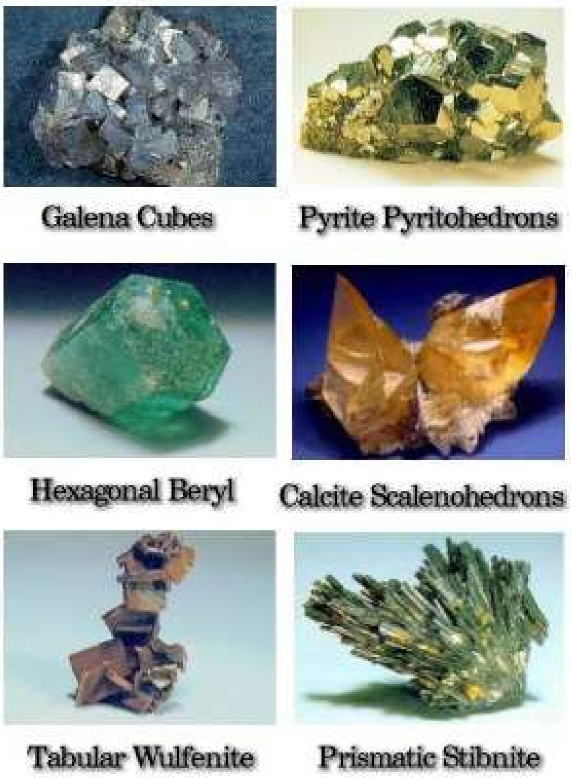
The Mohs Hardness Scale is a relative scale. This means that a mineral will scratch any substance lower on the scale and will be scratched by any substance with a higher number. Diamond is not 10 times harder than talc or 1.1 times harder than corundum, as would be the case with an absolute hardness scale. Most often we are able only to narrow down hardness to within a certain range; for example, if an unknown mineral scratches a copper penny but does not scratch a glass plate, its hardness must be greater than 3.0 and less than 5.5. Usually this range of values is sufficient to identify an unknown. Note: please always use care when testing hardness on a glass plate. If the glass gets broken DO NOT handle it!

light to the eye of the observer than will a gem of lesser refractive power and will thus appear more brilliant. This high dispersion gives diamonds their fire, caused by the separation of white light into the colors of the spectrum as it passes through the stone.

The scratch hardness of diamond is assigned the value of 10 on the Mohs scale of hardness; corundum, the mineral next to diamond in hardness, is rated as 9. Actually, diamond is very much harder than corundum; if the Mohs scale were linear, diamond's value would be about 42.

Crystal Shape

Various Crystal Shapes



When minerals form in environments where they can grow without interference from neighboring grains, they commonly develop into regular geometric shapes, called crystals, bounded by smooth crystal faces. The crystal form for a given mineral is governed by the mineral's internal structure, and may be distinctive enough to help identify the mineral. For example, quartz forms elongated, six-sided prisms capped with pyramid-like faces; galena and halite occur as cubes; and garnets develop 12- or 24-sided equidimensional forms. Interference from other mineral grains during growth may prevent formation of well-formed crystals. The result is shapeless masses or specimens that developed only a few smooth crystal faces. This type of specimen is much more common than well-formed crystals.

Specific Gravity

The specific gravity of a substance is a comparison of its density to that of water. Imagine a gallon bottle filled with water, a second filled with feathers, a third filled with lead weights. There are equal volumes of material present, but the bottle with the feathers will weigh less than that containing water; the bottle with lead weights will weigh the most. In order of increasing specific gravity, these materials would be: feathers, water, lead. Specific gravity can be measured precisely, or estimated by a comparison, as above. To compare the specific gravity of any two minerals, simply hold a sample of one in your hand

and "heft it," i.e., get a feeling for its weight. Then heft a sample of the other that is approximately the same size. If there is a great difference in specific gravity, you will detect it easily. It is often sufficient to note whether a mineral's specific gravity is significantly higher or lower than that of other minerals. Heft each of the specimens in your mineral set. Which ones have a high specific gravity? A low specific gravity?

Other Properties

Using Acid to Identify Calcite

There are a few other tests that can be used to differentiate one or more common minerals. Some of these should be used with great CAUTION!

- **Magnetism** - A few minerals are attracted to a magnet or are themselves capable of acting as magnets (the most common magnetic mineral is magnetite). Because these are so rare, this property helps narrow the possibilities drastically when trying to identify an unknown specimen.
- **Feel** - Some minerals, notably talc and graphite, feel greasy or slippery when you rub your fingers over them. The greasiness occurs because bonds are so weak in one direction that your finger pressure alone is enough to break them and to slide planes of atoms past neighboring atomic layers.
- **Taste** - Geologists use as many senses as possible in describing and

identifying minerals. Taste is one of the last tests to be conducted, because some minerals are poisonous. Some minerals taste salty-most notably halite (salt). Sylvite, a mineral similar in all other properties to halite, tastes bitter. Taste is thus a diagnostic property because it distinguishes between these minerals. NEVER TASTE A MINERAL UNLESS INSTRUCTED TO!

- **Reaction with Dilute Hydrochloric Acid -** This is actually a chemical property rather than a physical attribute of a mineral. Minerals containing the carbonate anion $(C0_3)^{2-}$ effervesce ("fizz") when a drop of dilute hydrochloric acid is placed on them. Carbon dioxide is liberated from the mineral and bubbles out through the acid, creating the fizz. This test is best performed on powdered minerals. Calcite (calcium carbonate) will effervesce readily in either massive or powdered form, but dolomite (calcium-magnesium carbonate) reacts best as a powder.

Identification of unknown mineral

Identification of an Unknown Mineral

Step 1

The first step of the identification process involves determining the luster of your unknown. Remember there are numerous types of lusters, but for identification purposes it is generally sufficient to distinguish only between metallic and nonmetallic minerals. Look at the images below. Which does your specimen most closely resemble? Metallic minerals have the sheen of a metal, like the frame of your desk. Nonmetallic minerals may appear glassy, meaning they allow light to pass through, dull or even waxy. Keep in mind you are not looking at color, simply the way a mineral specimen reflects room light.

There is one concern, many metallic minerals contain the element iron. When iron is exposed to oxygen in the air it starts to covert to an iron oxide compound we commonly call rust. Rust dulls the metallic luster of most minerals. If you have a sample that has been in your science collection for a few years it may have been shiny when new but has dulled with age (kind of like a "old" copper penny. That can sometimes make it difficult to be certain if a mineral has a metallic luster or not. There is one trick you can try. Take your streak plate and gently rub the mineral on the plate. If it leaves a very noticeable colored or black streak it is probably a metallic mineral. Note:If you rub any black mineral hard enough it will leave a black streak whether it is metallic or not, but you will find the nonmetallic minerals require a much greater effort to make a black streak!

Now if it was Luster - Metallic

Step 2

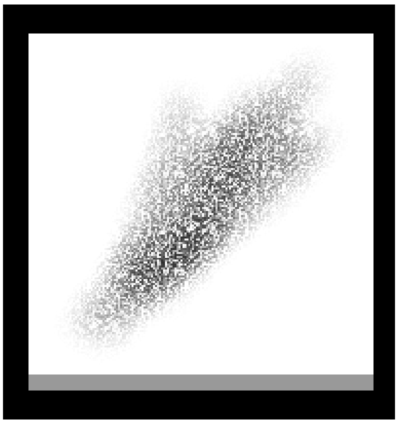
The next step of the identification process involves determining the hardness of your unknown. We will use a couple of simple objects to preform all of the necessary tests; your fingernail (H=2.5), a steel nail (H=5.0) and a glass plate (H=5.5).

First Test

Begin by attempting to scratch your unknown with your fingernail. Does it scratch the mineral? If, not try the second test. If you were able to scratch the mineral

Step 3

We are getting close! The next step of the identification process involves a simple streak test of your unknown. Simply rub the sample on the streak plate and click on the streak color that most closely matches those shown below.



BLACK

YELLOW-BROWN

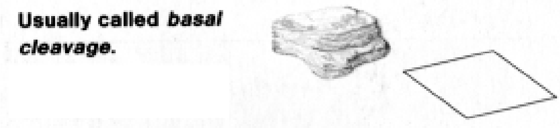
Note: Some minerals in this group have either a BLACK or GRAY streak, but unless seen side by side they can not be distinguished so we have grouped them together.

if it is :

Luster - Metallic
Hardness - Less than 2.5
Streak=Black/Gray

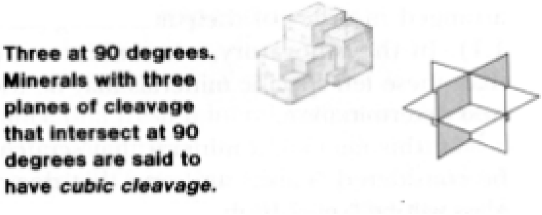
One Final Step! Let's examine the mineral for any signs of cleavage. Sometimes it will be obvious and other times it will be more difficult to see or even indistinct. Fortunately, we have narrowed our choices down to only two cleavge types for our unknown.

One Direction



Usually called ***basal cleavage.***

Three Directions
90 degrees



Three at 90 degrees. Minerals with three planes of cleavage that intersect at 90 degrees are said to have ***cubic cleavage.***

Luster - Metallic

Hardness - Less than 2.5

Streak=Black/Gray

One Direction (Basal) Cleavge

Graphite C	Black Streak	Basal Cleavge	Dark gray-black. Greasy feel. Leaves a mark on paper. H=1	

Your Mineral is Graphite!

GRAPHITE

Also called PLUMBAGO, or BLACK LEAD, graphite is a mineral consisting of carbon. Graphite has a layered structure that consists of rings of six carbon atoms arranged in widely spaced horizontal sheets. Graphite thus crystallizes in the hexagonal system, in contrast to the same element crystallizing in the octahedral or tetrahedral system as diamond. Such dimorphous pairs usually are rather similar in their physical properties, but not so in this case. Graphite is dark gray to black, opaque, and very soft (with a hardness of 1 on the Mohs scale), while diamond may be colorless and transparent and is the hardest naturally occurring substance. Graphite has a greasy feel and leaves a black mark, thus the name from the Greek verb graphein, "to write."

Graphite is formed by the metamorphosis of sediments containing carbonaceous material, by the reaction of carbon compounds with hydrothermal solutions or magmatic fluids, or possibly by the crystallization of magmatic carbon. It occurs as isolated scales, large masses, or veins in older crystalline rocks, gneiss, schist, quartzite, and marble and also in granites, pegmatites, and carbonaceous clay slates.

Graphite is used in pencils, lubricants, crucibles, foundry facings, polishes, arc lamps, batteries, brushes for electric motors, and cores of nuclear reactors. It is mined extensively in Sri Lanka; Madagascar; North Korea; Sonora, Mex.; Ontario; western Siberia; and New York.

Graphite was first synthesized accidentally by Edward G. Acheson while he was performing high-temperature experiments on carborundum. He found that at about 4,150 C (7,500 F) the silicon in the carborundum vaporized, leaving the carbon behind in graphitic form. Acheson was granted a patent for graphite manufacture in 1896, and commercial production started in 1897. Since 1918, petroleum coke, small and imperfect graphite crystals surrounded by organic compounds, has been the major raw material in the production of 99 to 99.5 percent pure graphite.

Luster - Metallic

Hardness - Less than 2.5

Streak=Black/Gray

Three Directions (Cubic) Cleavge

Galena PbS	Gray Streak	Cubic Cleavge	Shiny gray. Very heavy. Perfect cubic cleavage. H=2.5	

Your Mineral is Galena!

Galena

Also called LEAD GLANCE, a gray lead sulfide (PbS), the chief ore mineral of lead. One of the most widely distributed sulfide minerals, it occurs in many different types of deposits, often in metalliferous veins, as at Broken Hill, Australia; Coeur d'Alene, Idaho, U.S.; and Cornwall, England. Large deposits also occur as replacements of limestone or dolomite (e.g., Pine Point, Canada). Some deposits (e.g., at Darwin, California) are of contact-metamorphic origin. Galena is found in cavities and brecciated (fractured) zones in limestone and chert, as in the extensive Mississippi River valley deposits, where 90 percent of the U.S. production of lead is mined. The mineral has occasionally been observed as a replacement of organic matter, and sometimes occurs in coal beds.

Galena forms isometric crystals in which the ionic lattice is like that of sodium chloride. The mineral is often weathered to secondary lead minerals, the upper part of galena deposits often containing cerussite, anglesite, and pyromorphite. Nodules of anglesite and cerussite with a banded structure and a galena core are common.

In many cases, galena contains silver and so is often mined as a source of silver as well as lead. Other commercially important minerals that frequently occur in close association with galena include antimony, copper, and zinc.

Luster - Nonmetallic
Hardness - 2.5-5.0
Streak=Yellow-brown

One Final Step! Let's examine the mineral for any signs of cleavage. Sometimes it will be obvious and other times it will be more difficult to see or even indistinct. The only mineral in this particular group should not have any visible cleavage. If you see evidence of cleavage try returning to Step 2 or the previous step, Step 3.

If there is No Apparent Cleavage:

Luster - Nonmetallic

Hardness - Less than 2.5

Streak=Yellow-brown

No Apparent Cleavge

Limonite FeO(OH)-nH_2O	Yellow-brown Streak	No Cleavge	Commonly in earthy, powdery masses. H=3.6-4.0	

Your Mineral is Limonite!

LIMONITE

One of the major iron minerals, hydrated ferric oxide ($Fe_2O_3H_2O$). It was originally considered one of a series of such oxides; later it was thought to be the amorphous equivalent of goethite and lepidocrocite, but X-ray studies have shown that most so-called limonite is actually goethite. The name limonite properly should be restricted to impure hydrated iron oxide (with variable water content) that is colloidal, or amorphous, in character.

Often brown and earthy, it is formed by alteration of other iron minerals, such as the hydration of hematite or the oxidation and hydration of siderite or pyrite. It probably bears the same relationship to iron oxides that wad does to manganese oxides.

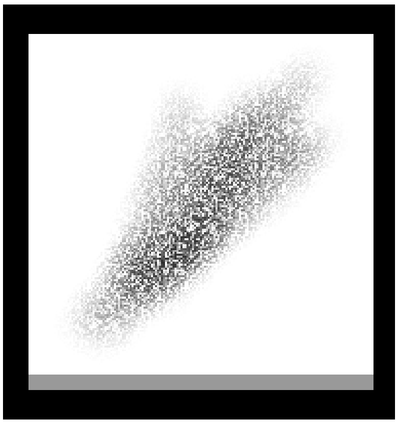
Second Test

Attempt to scratch your unknown with the steel nail. Does it scratch the mineral? If not, try the Third test.

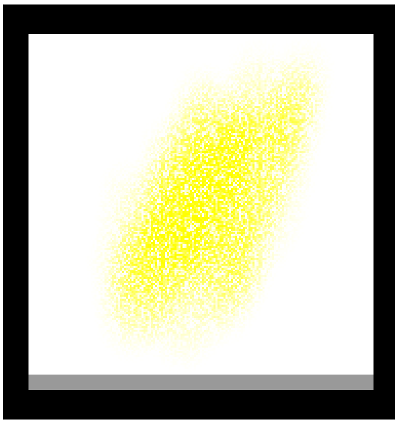
If you were able to scratch the mineral:

Luster - Metallic
Hardness - 2.5-5.0

We are getting close! The next step of the identification process involves a simple streak test of your unknown. Simply rub the sample on the streak plate and click on the streak color that most closely matches those shown below.



BLACK

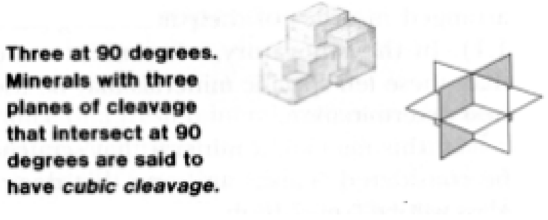


YELLOW

Luster - Metallic
Hardness - 2.5-5.0
Streak=Black/Gray
Step 4

One Final Step! Let's examine the mineral for any signs of cleavage. Sometimes it will be obvious and other times it will be more difficult to see or even indistinct. Fortunately, we have narrowed our choices down to only two cleavge types for our unknown.

Three Directions
90 degrees


Three at 90 degrees. Minerals with three planes of cleavage that intersect at 90 degrees are said to have *cubic cleavage.*

No Apparent Cleavage (CLICK HERE)

Luster - Metallic

Hardness - 2.5-5.0

Streak=Black/Gray

Three Directions (Cubic) Cleavge

Galena PbS	Gray Streak	Cubic Cleavge	Shiny gray. Very heavy. Perfect cubic cleavage. H=2.5 Your Mineral is Galena!	

Luster - Metallic

Hardness - 2.5-5.0

Streak=Black/Gray

No Apparent Cleavge

Chalcopyrite CuFeS_2	Black Streak	No Cleavge	Bronze yellow, but often tarnishes to an irridescent blue-purple. Similar to pyrite, but never in cubic crystals. H=3.5-4.0	

Your Mineral is Chalcopyrite!

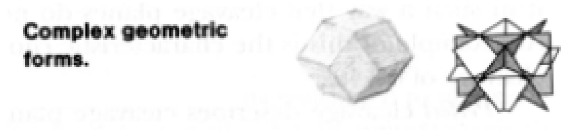
Chalcopyrite

The most common copper mineral, a copper and iron sulfide, and a very important copper ore. It typically occurs in ore veins deposited at medium and high temperatures, as in Río Tinto, Spain; Ani, Japan; Butte, Mont.; and Joplin, Mo. Chalcopyrite ($CuFeS_2$) is a member of a group of sulfide minerals that crystallize in the tetragonal system; the group also includes stannite. Both minerals have crystalline structures related to sphalerite.

Luster - Metallic
Hardness - 2.5-5.0
Streak=Yellow
Step 4

One Final Step! Let's examine the mineral for any signs of cleavage. Sometimes it will be obvious and other times it will be more difficult to see or even indistinct. Fortunately, we have narrowed our choices down to only two cleavge types for our unknown.

Six Directions



No Apparent Cleavage (CLICK HERE)

Luster - Metallic

Hardness - 2.5-5.0

Streak=Yellow

Six Directions (Complex) Cleavge

Sphalerite ZnS	Yellow Streak	Six directions of cleavage, only a few usually present	Often has resinous luster. At best is only submetallic. Can be black, brown, red, green or yellow. H=3.5	

Your Mineral is Sphalerite!

Sphalerite

Also called BLENDE, or ZINCBLENDE, zinc sulfide (ZnS), the chief ore mineral of zinc. It is found associated with galena in most important lead-zinc deposits. The name sphalerite is derived from a Greek word meaning treacherous, in allusion to the ease with which the dark-coloured, opaque varieties are mistaken for galena (a valuable lead ore). The alternative names blende and zincblende, from the German word meaning "blind," similarly allude to the fact that sphalerite does not yield lead.

In the United States the most important sphalerite deposits are those in the Mississippi River valley region. There it is found associated with chalcopyrite, galena, marcasite, and dolomite in solution cavities and brecciated (fractured) zones in limestone and chert. Similar deposits occur in Poland, Belgium, and North Africa.

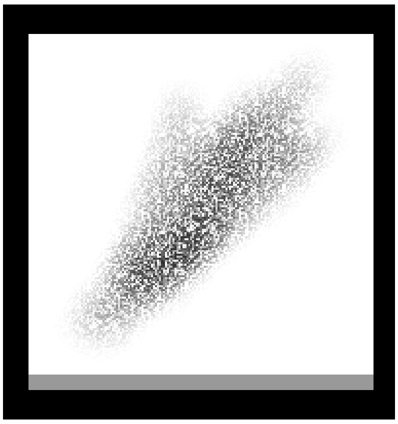
Sphalerite also is distributed worldwide as an ore mineral in hydrothermal vein deposits, in contact metamorphic zones, and in high-temperature replacement deposits.

Third Test

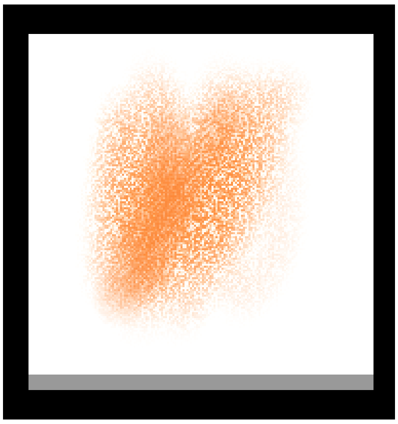
Attempt to scratch a knife blade with your unknown mineral. Does it scratch the knife? **If you were able to scratch the knife blade**

Luster - Metallic
Hardness - Greater than 5.0
Step 3

We are getting close! The next step of the identification process involves a simple streak test of your unknown. Simply rub the sample on the streak plate and click on the streak color that most closely matches those shown below.



BLACK



RED-BROWN

Luster - Metallic
Hardness - Greater than 5.0
Streak=Black/Gray
Step 4

Next, let's examine the mineral for any signs of cleavage. Sometimes it will be obvious and other times it will be more difficult to see or even indistinct. No mineral in this group should have cleavage, if your unknown does, try going back to Step 2 or the previous step, Step 3.

if there is no No Apparent Cleavage

Luster - Metallic
Hardness - Greater than 5.0
Streak=Black/Gray
No Apparent Cleavage
Step 5

There are two common minerals that fit the criteria you have entered. They are normally easily differentiated on the basis of color, one is brass yellow and the other silvery or black. However, there is a much simpler test we can use. Find the small magnet that came with your mineral identification kit. Try placing it on the unknown mineral.

If the Magnet is STRONGLY Attracted to the Mineral:

Luster - Metallic

Hardness - Greater than 5.0

Streak=Black/Gray

No Apparent Cleavge

Magnetite Fe_3O_4	Black Streak	No Cleavge	Iron black to silvery gray. Strongly magnetic. H=6.0	

Your Mineral is Magnetite!

Magnetite

Also called LODESTONE, or MAGNETIC IRON ORE, iron oxide mineral (Fe_3O_4) that is the chief member of one of the series of the spinel group. Minerals in this series form black to brownish, metallic, moderately hard octahedrons and masses in igneous and metamorphic rocks and in granite pegmatites, stony meteorites, and high-temperature sulfide veins. The magnetite series also contains magnesioferrite (magnesium iron oxide), franklinite (zinc iron oxide), jacobsite (manganese iron oxide), and trevorite (nickel iron oxide). All are magnetic, although franklinite and jacobsite are only weakly so; magnetite, which frequently has distinct north and south poles, has been known for this property since about 500 BC

If the Magnet is NOT Attracted to the Mineral:

Luster - Metallic

Hardness - Greater than 5.0

Streak=Black/Gray

No Apparent Cleavge

Pyrite FeS_2	Black Streak	No Cleavge, may have Concoidal fracture	Brassy yellow; commonly in cubes or 12-sided crystals with striated faces. Fool's gold. H=5.0	

Your Mineral is Pyrite!

Pyrite

Sometimes called IRON PYRITE, or FOOL'S GOLD, a naturally occurring iron disulfide mineral. The name comes from the Greek word pyr, "fire," because pyrite emits sparks when struck by steel. Nodules of pyrite have been found in prehistoric burial mounds, which suggests their use as a means of producing fire. Pyrite is called fool's gold because its color may deceive the novice into thinking he has discovered a gold nugget.

Pure pyrite (FeS_2) contains 46.67 percent iron and 53.33 percent sulfur; its crystals display isometric symmetry. Pyrite is widely distributed and forms under extremely varied conditions. For example, it can be produced by magmatic (molten rock) segregation, by hydrothermal solutions, and as stalactitic growth. It occurs as an accessory mineral in igneous rocks, in vein deposits with quartz and sulfide minerals, and in sedimentary rocks, such as shale, coal, and limestone.

Pyrite occurs in large deposits in contact metamorphic rocks. Deposits of copper-bearing pyrite are widely distributed and often of great size. They usually occur in or near the contact of eruptive rocks with schists or slates. Pyrite weathers rapidly to hydrated iron oxide, goethite, or limonite. This weathering produces a characteristic yellow-brown stain or coating, such as on rusty quartz.

Pyrite is used commercially as a source of sulfur, particularly for the production of sulfuric acid. Because of the availability of much better sources of iron, pyrite is not generally used as an iron ore.

For many years Spain was the largest producer, the large deposits located on the Tinto River being important also for copper. Other important producers are Japan, the United States (Tennessee, Virginia, California), Canada, Italy, Norway, Portugal, and Slovakia.

Now if it is Luster – Nonmetallic

Step 2

The next step of the identification process involves determining the hardness of your unknown. We will use a couple of simple objects to preform all of the necessary tests; your fingernail (H=2.5), a steel nail (H=5.0) and a glass plate (H=5.5).

First Test

Begin by attempting to scratch your unknown with your fingernail. Does it scratch the mineral? If not, try the next test.

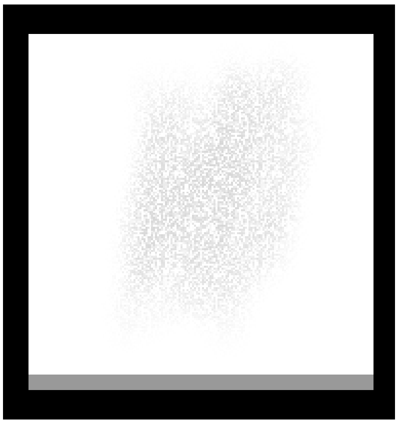
If you were able to scratch the mineral

Luster - Nonmetallic

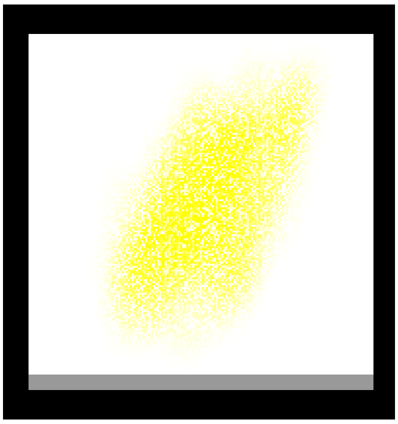
Hardness - Less than 2.5

Step 3

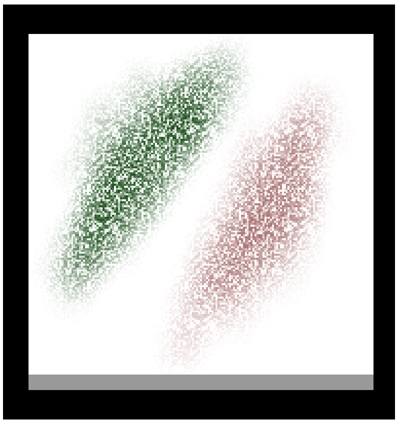
The next step of the identification process involves a simple streak test of your unknown. Simply rub the sample on the streak plate and click on the streak color that most closely matches those shown below.



WHITE



YELLOW

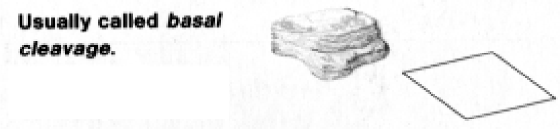


GREEN or BROWN

Luster - Nonmetallic
Hardness - Less than 2.5
Streak=White or Colorless
Step 4

One Final Step! Let's examine the mineral for any signs of cleavage. The minerals in this group should have no/indistinct cleavage or one direction of cleavage.

One Direction



No Apparent Cleavage

Luster - Nonmetallic
Hardness - Less than 2.5
Streak=White or Colorless
One Direction (Basal) Cleavage
Step 5

There are several nonmetallic minerals that have one direction of cleavage. They are often fairly easily differentiated on the basis of appearance. Feel frre to look at each of the possibilities and pick the one that best fits your unknown mineral. With a nail or your fingernail scrape off a few small flakes. Are they very tiny flakes? If so, run your fingers over the mineral, does it feel slippery or greasy?

If so:

Luster - Nonmetallic

Hardness - Less than 2.5

Streak=White/Colorless

One Direction Cleavage

Talc $Mg_3Si_4O_{10}(OH)_2$	White or Colorless Streak	1 direction, but difficult to see	Greasy or slippery feel; green, gray or white. H=1.0	

Your Mineral is Talc!

Talc

Talc is a common silicate mineral that is distinguished from almost all other minerals by its extreme softness (it has the lowest rating [1] on the Mohs scale of hardness). Its soapy or greasy feel accounts for the name soapstone given to compact aggregates of talc and other rock-forming minerals. Dense aggregates of high-purity talc are called steatite. Since ancient times, soapstones have been employed for carvings, ornaments, and utensils; Assyrian cylinder seals, Egyptian scarabs, and Chinese statuary are notable examples. Soapstones are resistant to most reagents and to moderate heat; thus, they are especially suitable for sinks and countertops. Talc is also used in lubricants, leather dressings, toilet and dusting powders, and certain marking pencils. It is used as a filler in ceramics, paint, paper, roofing materials, plastic, and rubber; as a carrier in insecticides; and as a mild abrasive in the polishing of cereal grains such as rice and corn.

Talc is found as a metamorphic mineral in veins, in foliated masses, and in certain rocks. It is often associated with serpentine, tremolite, forsterite, and almost always with carbonates (calcite, dolomite, or magnesite) in the lower metamorphic facies. It also occurs as an alteration product, as from tremolite or forsterite.

One of the remarkable features of talc is its simple, almost constant composition; talc is a basic magnesium silicate, $Mg_3Si_4O_{10}(OH)_2$. Unlike other silicates, even closely related ones, talc appears to be unable to accept iron or aluminum into its structure to form chemical-replacement series

If not, is the mineral a shade of dark green mineral? If so:

Luster - Nonmetallic

Hardness - Less than 2.5

Streak=White/Colorless

One Direction Cleavage

Chlorite Complex Fe-Mg sheet silicate	White or Colorless Streak	1 direction, perfect (small flakes)	Various shades of green. A mica-like mineral. H=2.0-2.5	

Your Mineral is Chlorite!

Chlorite

The name chlorite is from the Greek chloros, meaning "green".Chlorite has habits similar to the other micas: foliated books, scaly aggregates, and individual flakes in a quartz-feldspar matrix are common. Rare pseudohexagonal crystals are known.

Chlorite is a common mineral in low- to intermediate-grade metamorphic rocks, diagnostic of the greenschist facies. It is also a common secondary mineral after biotite, muscovite. and other mafic silicates in igneous and metamorphic rocks, and is sometimes found in sediments. Many greenish rocks owe their color to the presence of chlorite. Associated minerals include quartz and feldspars, epidote, muscovite, actinolite, albite, and a number of ferromagnesian silicates.

The remaining three possibilities either cleave into larger flakes or only cleave with difficulty. If the mineral cleaves in larger sheets (hint: it is nice and flat), are they silvery, light brown or colorless?

If so:

Luster - Nonmetallic

Hardness - Less than 2.5

Streak=White/Colorless

One Direction Cleavage

Muscovite $KAl_2(AlSi_3O_{10})(OH)_2$	White or Colorless Streak	1 direction, perfect	A colorless to silvery mica; can be peeled into transparent sheets. H=2.0-2.5	

Your Mineral is Muscovite!

Muscovite

Muscovite is a very common mineral found in igneous, metamorphic, and sedimentary rocks. In igneous rocks it is a common constituent of granitic pegmatite, granite, granodiorite, aplite, and related felsic rocks. It is somewhat less common in felsic volcanic rocks. Sericite is widespread in many igneous rocks, produced by the hydrothermal or late-stage magmatic alteration of feldspars and other minerals. The alteration may be selective, replacing only the cores of plagioclase grains or selected twin lamellae. Muscovite is a constituent of a wide variety of metamorphic rocks including slate, phyllite, schist, gneiss, homfels, and quartzite that are produced by metamorphism of common sedimentary rocks. Clastic sediments derived from crystalline terranes and not subjected to extensive weathering or transport often contain muscovite. It is therefore a common mineral in arkosic sandstone and related siliclastic sedimentary rocks

One of the earliest uses for muscovite was as a substitute for glass because thin cleaved sheets are transparent. It is still used infrequently for viewing windows in industrial furnaces and ovens. It is now widely used in electronics and industrial applications. Muscovite sheets and ground muscovite are used in the electronics industry to make components as diverse as capacitors, transistors, insulators, and the windows on microwave tubes used in microwave ovens. Industrial applications include use as a filler in plastic, paint, and wallboard cement, coatings on wallpaper to produce a silky luster, mold release agents in the manufacture of automobile tires, and as a constituent of drilling mud used when drilling for oil and gas. Consumer products that contain muscovite include nail polish, lipstick, and eye shadow. The subtle luster seen in many colored cosmetic creams is there because of the presence of pulverized muscovite.

The final mineral in this group is usually clear and colorless to chalky white . It does cleave, but nice thin flakes are rare, rather it usually makes kind of blocky pieces. If that is the case:

Luster - Nonmetallic

Hardness - Less than 2.5

Streak=White/Colorless

One Direction Cleavage

Gypsum $CaSO_4\text{-}2H_2O$	White or Colorless Streak	1 direction, poor	Clear, colorless or massive white and/or gray. H=2.0	

Your Mineral is Gypsum!

Gypsum

Gypsum crystals have a variety of habits, but most are tabular, less commonly they are prismatic or acicular. Large euhedral crystals are known as selenite. Granular or foliated masses are quite common. Satin spar consists of parallel aggregates of fibrous gypsum and may fill veins. Simple contact twins are common and may form "swallow tail" twins. Prismatic crystals may be curved, and tabular crystals and cleavage sheets may be bent in certain directions with relative ease. Granular-massive rock gypsum is known as alabaster if white or light colored.

Gypsum is a very common mineral in marine evaporite deposits and may be associated with halite, sylvite, calcite, dolomite, and anhydrite, as well as clay and silicate detrital grains. Gypsum in some evaporite deposits is produced by hydrating primary anhydrite. This requires a volume increase, so original planar anhydrite beds may become crumpled or disrupted as a result of the mineralogical change. Gypsum may also be produced as a precipitate from saline lakes, as an efflorescence on desert soils, or may precipitate around fumeroles or volcanic vents. Infrequently it is found in the near-surface, oxidized zone of hydrothermal sulfide deposits.

Gypsum is one of the earlier minerals to be exploited by people; its use goes back at least 5000 years. About 70% of the gypsum now mined goes to manufacture gypsum wallboard, also known as drywall. Gypsum wallboard is used to cover interior walls of most houses, apartments, and offices in North America and in many other parts of the world. To make wallboard, gypsum is calcined (heated) to drive off part of the water and is then ground to form a material called stucco (similar material is sold as plaster of Paris). Stucco is mixed with water, reinforcing fibers, and other additives to form a thick slurry that is extruded and wrapped with heavy paper to make wallboard. This material sets or hardens by recrystallizing to form gypsum. When cured it forms a stiff panel that is attached to interior wall framing with screws or nails. Joints between panels are finished with strips of mesh or heavy paper set in a plaster-like compound.

Gypsum also is used in portland cement to control the setting rate, and as a soil amendment to improve soil structure and workability, provide sulfur and calcium to plants, and control the availability of other soil nutrients. Calcined gypsum also has medical applications. It is used as a dietary supplement to provide needed sulfur both for people and animals, and is used to make casts to support broken bones, and as a special casting plaster to make dental molds. Alabaster, which is fine-grained white gypsum, is used as an ornamental stone and for sculpture, but its softness restricts its utility.

To review look for the following:

- Small flakes, slippery feel –it is talc
- Small green flakes -it is Chlorite
- Larger, silvery or transparent flakes-it is Muscovite
- Colorless to chakly white, poor cleavge perhaps a little blocky-it is Gypsum

Luster - Nonmetallic
Hardness - Less than 2.5
Streak=White or Colorless
No Apparent Cleavage

There are two minerals that have no apparent cleavage. In reality, both have excellent one directional cleavage, but each is so fine grained that the cleavage is only visible under a microscope. It is suggested you read both descriptions and select the one that fits the best. There is one simple test. Run your fingers over the mineral, does it feel slippery or greasy? If so: it is talc

If not, does the mineral appear to be dull, chalky white and perhaps smell earthy? If so:

In either case look at both mineral descriptions and pick the one that fits the best.

Luster - Nonmetallic

Hardness - Less than 2.5

Streak=White/Colorless

No Apparent Cleavage

Kaolinite $Al_2Si_5O_5(OH)_{10}$	White or Colorless Streak	1 direction, but difficult or impossible to see	Occurs in dull, earthy, powdery white masses. H=2.0	

Your Mineral is Kaolinite!

Kaolinite

Nonmetallic Luster - Kaolinite

Kaolinite is actually a group of common clay minerals that are hydrous aluminum silicates; they comprise the principal ingredients of kaolin (china clay). The group includes kaolinite and its rarer forms, dickite and nacrite, halloysite, and allophane, which are chemically similar to kaolinite but amorphous.

Kaolinite, nacrite, and dickite occur as minute, sometimes elongated, hexagonal plates in compact or granular masses and in micalike piles. They are natural alteration products of feldspars, feldspathoids, and other silicates.

Luster - Nonmetallic

Hardness - Less than 2.5

Streak=Yellow

Step 4

One Final Step! Let's examine the mineral for any signs of cleavage. Sometimes it will be obvious and other times it will be more difficult to see or even indistinct. The only mineral in this particular group should not have any visible cleavage. If it does try returning to STEP 3 or STEP 2.

if there is No Apparent Cleavage :

Luster - Nonmetallic

Hardness - Less than 2.5

Streak=Yellow

No Apparent Cleavage

Sulfur S	Yellow Streak	No cleavage or Conchoidal Fracture	Various shades of yellow; resinous luister. H=1.5-2.5	

Your Mineral is Sulfur!

Sulfur

Sulfur is found around fumaroles, volcanic vents, and in hot spring deposits associated with recent or active volcanism. The sulfur may precipitate directly from vapors or be produced as a result of bacterial action on sulfate minerals. Hydrothermal sulfide deposits may also contain native sulfur, usually in the near-surface oxidized zone.

The largest concentrations of sulfur are associated with salt domes formed of marine evaporite deposits. The evaporites are dominantly halite, but usually contain gypsum, anhydrite, and calcite. When the top of a salt dome encounters fresh meteoric groundwater within roughly a kilometer of the surface, halite is dissolved. Continuous upward movement of salt from its source allows a cap of less soluble calcite and gypsum to accumulate at the top of a salt dome. The cap commonly consists of an outer/upper zone of calcite, transitioning inward to gypsum and then anhydrite. Hydrogen sulfide is produced by anaerobic sulfur-reducing bacteria provided that hydrocarbons (oil/gas) are available by the following general reaction:

$CaSO_4 + CH_4$(hydrocarbons) + bacteria = $H_2S + CaCO_3 + H_2O$

The hydrogen sulfide is oxidized either by oxygen in the groundwater, hydrocarbons, or other chemical processes to form elemental sulfur:

$2H_2S + O_2 = 2S + 2H_2O$

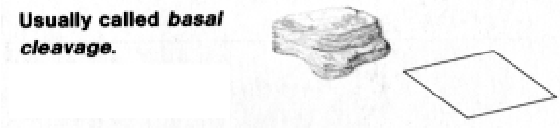
The actual reaction paths are greatly more complicated than these and may additionally involve aerobic bacteria. Because generation of sulfur involves breaking down sulfates and production of calcite, the sulfur is concentrated at the calcite—sulfate boundary in the cap rock of salt domes.

Sulfur from salt domes is usually extracted by injecting superheated water into the sulfur. The hot water mobilizes the sulfur and both water and sulfur are then pumped to the surface for processing. Sulfur is principally used to manufacture sulfuric acid, which is itself used in many chemical processes. Major uses of sulfuric acid include the manufacture of phosphatic fertilizer, leaching copper from copper ore, and a wide variety of other chemical processes. Sulfur also may be added directly to soil as a nutrient. A substantial amount of the sulfur used for industrial purposes is derived as a byproduct of extracting metals from sulfide minerals.

Luster - Nonmetallic
Hardness - Less than 2.5
Streak=Green or Brown
Step 4

One Final Step! Let's examine the mineral for any signs of cleavage. It will be obvious. The only mineral in this particular group should have very visible cleavage. If there is no cleavage try going back to STEP 2.

One Direction



Luster - Nonmetallic

Hardness - Less than 2.5

Streak=Black, Green or Brown

One Direction Cleavage

Biotite $KAl_2(AlSi_3O_{10})(OH)_2$	Green or Dark Brown Streak	1 direction, perfect	A dark-colored mica; usually black, brown or green. Can be peeled into thin sheets. H=2.5	

Your Mineral is Biotite!

Biotite

Biotite is a very common mineral. In igneous rocks it is characteristic of silicic and alkalic rocks such as granite, granodiorite, quartz diotite, pegmatite, syenite, nepheline syenite, rhyolite, rhyodacite, dacite, and phonolite. It also is found as a late-stage magmatic product in more mafic rocks including diorite, gabbro, norite, and anorthosite. Mg-rich biotite (phlogopite) is found in peridotite and other ultramafic varieties. In metamorphic rocks, biotite is very common in a wide variety of hornfels, phyllites, schists, and gneisses and may persist from greenshist facies through strongly migmatitic rocks. Mg-rich biotite is also found in marble and related metamorphosed carbonate-rich rocks.

Biotite also is a relatively common detrital mineral, particularly in immature sediments, but yields to clay minerals with extended weathering and transport.

Most vermiculite is a hydrated alteration product of biotite. Alteration, accomplished either by weathering or hydrothermal processes, results in leaching of interlayer K cations and replacement with Ca, Mg, and water, with ion exchanges in other sites as needed to maintain electric neutrality. As a result of adding the interlayer water, vermiculite is prone to dramatic expansion when heated. It owes its name to the observation that books of vermiculite, when heated, expand into worm-like shapes. For most applications, the vermiculite is heated to force it to expand, producing a low-density product that looks like dirty fluffed-up biotite. Expanded vermiculite is used as an insulation material, a filler in gypsum wall board or other construction materials, and in a variety of other industrial applications. The most frequently encountered use for most people is as an additive in potting soil used to grow house plants.

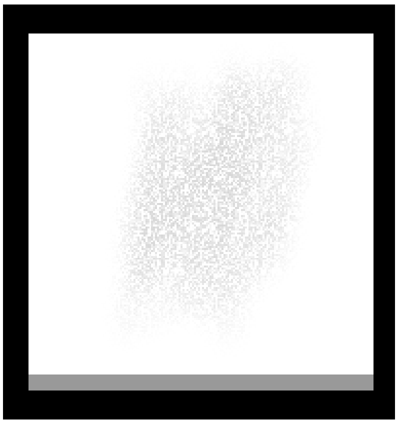
Second Test

Attempt to scratch your unknown with the steel nail. Does it scratch the mineral? If not, try the Third test.

If you were able to scratch the mineral:

Luster - Nonmetallic
Hardness - 2.5-5.0
Step 3

The next step of the identification process involves a simple streak test of your unknown. Simply rub the sample on the streak plate and follow on the streak color that most closely matches those shown below.



WHITE

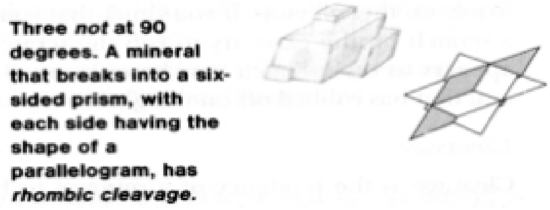
YELLOW-BROWN

if it was white:

Luster - Nonmetallic
Hardness - 2.5-5.0
Streak=White or colorless
Step 4

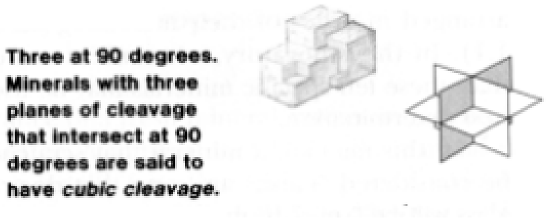
Next, let's examine the mineral for any signs of cleavage. All minerals in this particular group should have readily visible cleavage. Usually it will be obvious but occasionally it will be more difficult to see. If you see no evidence of cleavage try returning to Step 2 or the previous step, Step 3.

Three Directions not 90 degrees



Three *not* at 90 degrees. A mineral that breaks into a six-sided prism, with each side having the shape of a parallelogram, has *rhombic cleavage*.

Three Directions 90 degrees



Three at 90 degrees. Minerals with three planes of cleavage that intersect at 90 degrees are said to have *cubic cleavage*.

Four Directions octahedral

if it is Three Directions -not 90 degrees**:**

Luster - Nonmetallic
Hardness - 2.5-5.0
Streak=White or Colorless
3 Directions of Cleavage - Not right angles

Step 5

There are two minerals that have 3 directions of cleavage, not at 90 degrees (rhombohedral cleavage). There is a simple test to differentiate the two minerals. Using dilute (2%) hydrochloric acid, place a couple of drops of acid on the mineral specimen. Does it bubble or fizz vigorously?

If so:

Luster - Nonmetallic
Hardness - 2.5-5.0
Streak=White or Colorless
3 Directions of Cleavage - Not right angles

Calcite $CaCO_3$	White or colorless Streak	3 Directions of Cleavage at 60° or 120°	Varicolored; often white or colorless. Occurs as rhombic or scalenohedral crystals. Reacts vigorously with HCl. H=3.0	

Your Mineral is Calcite!

CALCITE

The name calcite is from the Latin calx, meaning burnt lime. Calcite has many habits, The most common are hexagonal prisms with simple to complex terminations;scalenohedra, often with combinations of other forms;rhombohedra, either acute or flattened; and tabs with well-developed basal faces. Polysynthetic twinning is common but usually requires a microscope to detect. Calcite is also found as a massive rock-forming mineral, as nodules or crusts, in speleothems, and as fine to coarse granular aggregates.

Calcite is a common and widespread mineral. It is an essential and major mineral in limestones and marbles, occurs in cave deposits, and occurs as a vein mineral with other carbonates, sulfides, barite, fluorite, and quartz. Calcite also occurs in some rare carbonate-rich igneous rocks and is a common cement in some sandstones. Calcite is common as a weathering product. Organic calcite is common in shells and skeletal material.

There are several varieties of calcite. Iceland spar refers to clear calcite, usually in rhombohedral cleavage fragments; dogtooth spar refers to crystals with steep scalenohedral forms; nail-head spar refers to flat rhombs or stubby prismatic crystals.

Calcite has two polymorphs, aragonite and vaterite. It is isostructural with magnesite, siderite, sphaerocobaltite, smithsonite, nitratite, dolomite and gaspeite. Calcite and rhodocrosite form extensive solid solutions at room temperature and a complete solid solution above about 550 degrees C. Calcite forms limited solid solutions with ankerite and dolomite at all temperatures.

If it the acid fizzes very slowly or not at all try taking a nail, pocketknife of steel file and powdering the mineral , Drop some acid on the powder. It should now bubble more vigorously, if so:

Luster - Nonmetallic
Hardness - 2.5-5.0
Streak=White or Colorless
3 Directions of Cleavage - Not right angles

Dolomite $Ca,Mg(CO_3)_2$	White or colorless Streak	3 Directions of Cleavage at 60° or 120°	Usually pink or white. Occurs as small, rhombic, poorly-formed. Reacts with HCl when powdered. H=3.5-4.0	

Your Mineral is Dolomite!

DOLOMITE

Dolomite is named after D. de Dolomieu, a French chemist and geologist. Crystals are typically rhombohedral, having the shape of cleavage fragments, often with curved faces. Less commonly they are prismatic or steep rhombohedra. Lamellar twinning is nearly always present but may be hard to see. Massive dolomite, showing rhombohedral cleavage, is common. Dolomite is isostructural with calcite). Fe and Mn may substitute for Mg in substantial amounts. Co, Pb, Zn, Ce, or excess Ca may also be present.

Dolomite is a common mineral, found in massive carbonate sediments and in marbles, often with calcite. It also occurs in hydrothermal veins with fluorite, barite, other carbonates, and quartz, and as a secondary mineral or alteration product in limestone. Dolomite is isostructural with calcite, and a number of other minerals.

If you do not have hydrochloric acid, examine the specimen carefully. Does it have large, shiny cleavage surfaces at 60 or 120 degree angles? If so:

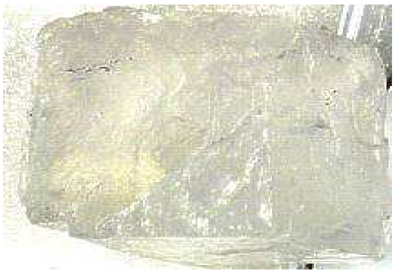
Your Mineral is Calcite!

If not, is it comprised of smaller, chalky white grains or crystals with poorly developed cleavage surfaces? If so:

Your Mineral is Dolomite!

If neither of these descriptions fits your mineral try going back to Step 4 or Step 3 now if it is Three Directions-90 degrees:

Luster - Nonmetallic
Hardness - 2.5-5.0
Streak=White or Colorless
3 Directions of Cleavage - Right angles

Halite NaCl	White or colorless Streak	3 Directions of Cleavage at 90°	White or colorless, cubic crystals. Excellent cleavage. Tastes salty. H=2.5	

Your Mineral is Halite!

Four-Directions -octahedral:

Luster - Nonmetallic
Hardness - 2.5-5.0
Streak=White or Colorless
4 Directions of Cleavage

Fluorite CaF_2	White or colorless Streak	4 Directions of Cleavage	Cubic or octahedral crystals; often purple, blue, green, yellow or colorless. H=4.0	

Your Mineral is Fluorite!

if you find it yellow:

Luster - Nonmetallic
Hardness - 2.5-5.0
Streak=Yellow-brown
Step 4

One Final Step! Let's examine the mineral for any signs of cleavage. Sometimes it will be obvious and other times it will be more difficult to see or even indistinct. The only mineral in this particular group should not have any visible cleavage. If you see evidence of cleavage try returning to Step 2 or the previous step, Step 3.

If No Apparent Cleavage : Your Mineral is Limonite!

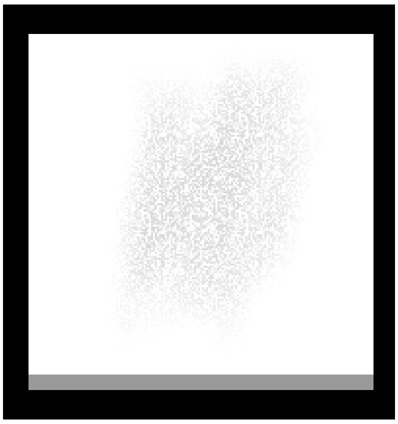
Third Test

Attempt to scratch your streak plate with your unknown mineral. Does it scratch the streak plate?

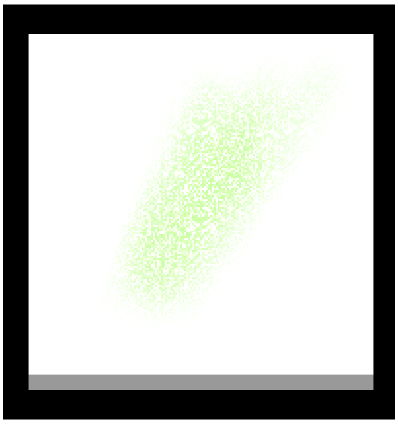
If you were NOT able to scratch the streak plate:

Luster - Nonmetallic
Hardness - 5.0-7.5
Step 3

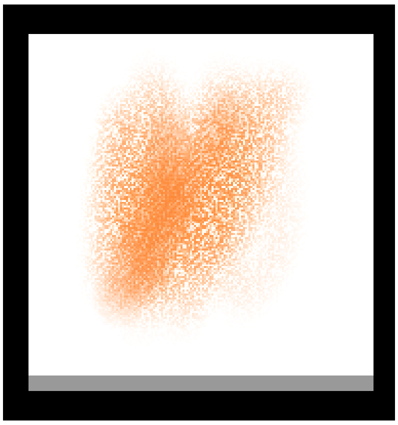
The next step of the identification process involves a simple streak test of your unknown. Simply rub the sample on the streak plate and followon the streak color that most closely matches those shown below.



WHITE
OR COLORLESS



PALE GREEN
OR COLORLESS

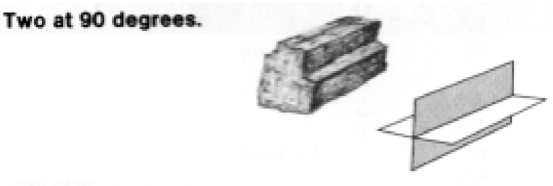


RED-BROWN

Luster - Nonmetallic
Hardness - 5.0-7.5
Streak=White or colorless
Step 4

Next, let's examine the mineral for any signs of cleavage. All minerals in this particular group should have readily visible cleavage. Usually it will be obvious but occasionally it will be more difficult to see. If you see no evidence of cleavage try returning to Step 2 or the previous step, Step 3.

Two Directions
at nearly 90 degrees



No Apparent Cleavage (CLICK HERE)

Luster - Nonmetallic
Hardness - 5.0-7.5
Streak=White or Colorless
2 Directions of Cleavage - Nearly right angles
Step 5

There are two minerals that have 2 directions of cleavage at 90 nearly degrees. They are both members of the much larger group of minerals called the *feldspars*. Since both are feldspars they can be difficult to distinguish from one another. First let's look at the specimen carefully (use a magnifying glass or hand lens if you have one). Do you see tiny striations (parallel lines on some cleavage surfaces?

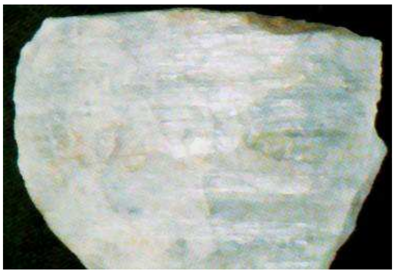
If so:

Luster - Nonmetallic

Hardness - 5.0-7.5

Streak=White or Colorless

2 Directions of Cleavage - Nearly right angles

Plagioclase $CaAl_2Si_2O_8$ $NaAlSi_3O_8$	White or colorless Streak	2 Directions, nearly 90°	Solid solution series between albite (Na) and anorthite (Ca). White, gray or black. Striations on some cleavage faces. H=6.0	

Your Mineral is Plagioclase feldpar!

Plagioclase

Plagioclase is actually a group of minerals. There is a continuous series from pure albite, $NaAlSi_3O_8$ (Ab), to pure anorthite, $CaAl_2Si_2O_8$ (An). The series is arbitrarily divided into six species or subspecies as follows:

- Albite An0-An10
- Oligoclase An10-An30
- Andesine An30-An50
- Labradorite An50-An70
- Bytownite An70-An90
- Anorthite An90-An100

Distinguishing the plagioclase series minerals from the potassium feldspars is difficult. Look for the twinning striations on basal cleavage surfaces. Differentiation between the individual species or subspecies within the plagioclase series is best done optically or by X-ray diffraction, but careful density determinations can give a good indication of composition. Rock type is also a useful guide (see below).

Some albite, oligoclase, and labradorite in coarse cleavages commonly exhibit a play of colors in shades of blue or blue-green, yellow, and brown. Those with bulk compositions in the albite-oligoclase range, which are typically light colored, are called penstenite.

Most anorthite occurs in contact metamorphosed limestones. Bytownite and labradorite are characteristic of igneous rocks of gabbroic composition and of the anorthosites; andesine, of andesites and diorites; oligoclase, of monzonites and granodiorites; albite, of granites and granitic pegmatites. The albite of pegmatites is of two distinct types; massive and lamellar, the latter widely referred to as cleavelandite. The plagioclases are also common in metamorphic rocks; in low-grade schists and gneisses, the plagioclase is typically albite; in medium-grade rocks, it is typically oligoclase or andesine. Pure or nearly pure albite occurs as veins in a few schists.

Albite and oligoclase are mined from some pegmatites and used in the manufacture of ceramics and as the abrasive in toothpaste.

The striations are the result of a process called twinning in which multiple crystals share a common growth plane. If you can not see any striations then you will be forced to rely on color. If the sample is white light gray or black: it is Plagioclase feldspar!

If it is pink or blue-green:

Luster - Nonmetallic

Hardness - 5.0-7.5

Streak=White or Colorless

2 Directions of Cleavage - Nearly right angles

Orthoclase $KAlSi_3O_8$	White or colorless Streak	2 Directions, nearly 90°	Pink, white or blue-green. H=6.0	

Your Mineral is Orthoclase feldpar!

Unfortunately, some varieties of orthoclase can also be white and easily mistaken for plagioclase. If neither description fits your mineral, try going back to Step 4 or Step 3 if it has No Apparent Cleavage :

Luster - Nonmetallic
Hardness - 5.0-7.5
Streak=White or Colorless
No Apparent Cleavage
Step 5

There are two minerals in this group. They are fairly easily discriminated. Although neither has cleavage, one often has conchoidal fracture. Also, it is usually white or colorless although rarely it can be light pink, purple, black or yellow. If your unknown specimen fits this description:

Luster - Nonmetallic

Hardness - 5.0-7.5

Streak=White or Colorless

No Apparent Cleavage

Quartz SiO_2	White or colorless Streak	Conchoidal fracture	Colorless or white; can be pink purple black or yellow. Often forms 6-sided crystals. H=7.0	

Your Mineral is Quartz!

The second mineral is often dark red, but can be green or brown. It may occur as 12-sided (dodecahedral) crystals. If your unknown specimen fits this description:

Luster - Nonmetallic

Hardness - 5.0-7.5

Streak=White or Colorless

No Apparent Cleavage

Garnet Complex Ca,Fe,Mg,Al,Cr,Mn silicate	White or colorless Streak	No Cleavage	Dark red, green or brown. Often forms 12-sided crystals. H=7.0	

Your Mineral is Garnet!

Garnet

The composition of naturally occurring garnets rarely approaches the formulas given in textbooks because of extensive atomic substitution. The specific name applied is that of the component that is present in largest amount. Ferrous iron and magnesium are interchangeable, and a series of intermediate compositions exist between almandine and pyrope; similarly, series of intermediate compositions exist between almandine and spessartine and between grossular and andradite.

Garnets differ somewhat in their mode of typical occurrence, as follows:

- Almandine: The common garnet of gneisses and schists is almandine. it is also recorded from granites, rhyolites, and pegmatites.
- Pyrope: Less common than the other garnets (except uvarovite), pyrope occurs in ultrabasic igneous rocks and serpentinites derived from them. It also occurs in high-grade, magnesium-rich metamorphic rocks.
- Spessartine: Many garnets from granite pegmatites and in vesicles in rhyolites are spessartine or intermediate between spessartine and almandine. Spessartine also occurs in metamorphosed manganese-bearing rocks.
- Grossular: Grossular is typically formed by contact or regional metamorphism of impure limestones and dolostones and, thus, is associated with calcite, wollastonite, and idocrase.
- Andradite: Andradite is formed by the metasomatic alteration of limestones by iron-bearing solutions, and it commonly occurs associated with ore deposits in calcareous rocks.
- Uvarovite: Uvarovite, which is rare, occurs in association with chromite and serpentinite.

Garnets, being resistant to both mechanical and chemical breakdown, also occur as detrital grains in sands and sandstones.

Garnet has some value as an abrasive because it is fairly hard, lacks cleavage, and hence breaks into irregular grains. Although garnet is a common mineral, material suitable for use as an abrasive has seldom been found in workable quantity. The requirements are for large isolated crystals that are crushed to provide the garnet sand used to make sandpaper. Severai thousand tons of such garnet have been produced annually at Gore Mountain, in the Adirondack Mountains of New York. Transparent unflawed garnet of good color can be cut into attractive gemstones. Much of the red garnet jewelry consists of pyrope from Czechoslovakia. Uvarovite would make a magnificent gemstone, but it does not occur in sufficiently large pieces. Green garnet gemstones are cut from a variety of andradite known as demantoid.

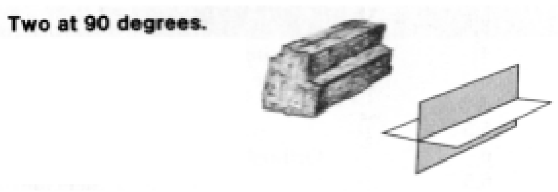
If neither description fits, try going back to Step 4 or Step 3

if it is PALE GREEN OR COLORLESS:

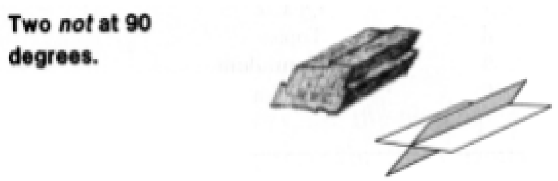
Luster - Nonmetallic
Hardness - 5.0-7.5
Streak=Pale green or colorless
Step 4

Next, let's examine the mineral for any signs of cleavage. Two minerals in this particular group have cleavage (although it is poorly developed). The other does not. You can return to Step 2 or the previous step, Step 3, by clicking on the appropriate hyperlinks.

Two Directions
at nearly 90 degrees



Two Directions
at 56 degrees and 124 degrees



No Apparent Cleavage

Two Directions at nearly 90 degrees:

Luster - Nonmetallic

Hardness - 5.0-7.5

Streak=Pale green or colorless

2 Directions - Nearly right angles

Pyroxene Ca,Fe,Mg silicate	Pale green or colorless Streak	2 Directions, 87° and 93°	Dark green stubby crystals. Very poor cleavage. H=5.0-6.0	

Your Mineral is Pyroxene!

Pyroxene

The pyroxenes are the most important group of rock-forming ferromagnesian silicates. They are a group of minerals that are closely related structurally, in physical properties, and in chemical composition, even though they crystallize in two different systems; orthorhombic and monoclinic. In all species of the group, the fundamental and common form is the prism. There are good cleavages parallel to the prism faces.

The chemical composition of the pyroxenes can be expressed by the general formula $(W,X,Y)_2Z_2O_6$, in which W, X, Y, and Z indicate elements having similar ionic radii and capable of replacing each other within the structure. In the pyroxenes, these elements may be:

- W = Ca, Na
- X = Mg, Fe+2, Mn+2, Ni, Li
- Y = Al, Fe+3, Cr, Ti
- Z = Si, Al

The proportion of W atoms is generally close to 1 or 0. Of the X group, manganese is generally present in minor amounts, and Li occurs as a major constituent only in spodumene ($LiAlSi_2O_6$). Of the Y group, Ti is present only in minor amounts, replacing Al and Fe+3. Z is generally Si; in natural pyroxenes.

The following table gives the names that have been applied to the common members of the group:

Orthorhombic

- Enstatite $Mg_2Si_2O_6$
- Bronzite $(Mg,Fe)_2Si_2O_6$
- Hypersthene $(Mg,Fe)_2Si_2O_6$

Monoclinic

- Clinoenstatite $Mg_2Si_2O_6$
- Pigeonite $(Mg,Fe)_2Si_2O_6$
- Diopside $CaMgSi_2O_6$
- Hedenbergite $CaFeSi_2O_6$
- Augite intermediate between diopside and hedenbergite,

- Acmite (Aegirine) $NaFeSi_2O_6$
- Jadeite $Na(Al,Fe)Si_2O_6$
- Spodumene $LiAlSi_2O_6$
- Omphacite $(Ca,Na)(Mg,Fe^{+3},Fe^{+2},Al)Si_2O_6$

Two Directions at 56 degrees and 124 degrees:

Luster - Nonmetallic

Hardness - 5.0-7.5

Streak=Pale green or colorless

2 Directions - Not right angles

Amphibole Ca,Fe,Mg,Al,OH silicate	Pale green/black or colorless Streak	2 Directions, 56° and 124°	Black, prismatic crystals. Good cleavage. H=5.0-6.0	

Your Mineral is Amphibole!

Amphibole

The amphibole group comprises a complex group of 57 silicate minerals that, although falling in both the orthorhombic and monoclinic systems, are closely related in crystallography and other physical properties as well as in chemical composition. A general formula of members of the amphibole group is $W_{(0-1)}X_2Y_5Z_8O_{22}(OH,F,CI)_2$, in which

- W = Ca, Na, K
- X = Ca, Fe+2, Li, Mg, Mn, Na
- Y = Al, Cr, Fe+2 Fe+3, Mg, Mn, Ti
- Z = Al, Si, Ti

Briefly, the amphiboles can be categorized in four groups: (1) the iron-magnesium-manganese group, which includes orthohombic anthophyllite, gedrite, and holmquistite and the monoclinic cummingtonite series; (2) the calcic amphibole group, which includes, among others, the tremolite-actinolite series, magnesio- and ferro-hornblende, and hastingsite; (3) the sodic-calcic group; and (4) the alkali-amphibole group, which includes the glaucophanes and riebeckites.

On the basis of composition, the most frequently encountered amphiboles may be conveniently grouped as follows:

Orthorhombic

- Anthophyllite Series $(Mg,Fe)_7Si_8O_{22}(OH)_2$

Monoclinic

- Cummingtonite Series $(Mg,Fe)_7Si_8O_{22}OH)_2$
- Tremolite-Actinolite Series $Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$
- Hornblende Series $Ca_2(Mg,Fe)_4Al(Si_7Al)O_{22}(OH,F)_2$

Alkali Amphibole Group

- Glaucophane Series $Na_2(Mg,Fe)_3Al_2Si_8O_{22}(OH)_2$
- Riebeckite Series $Na_2(Fe,Mg)_3Fe_2Si_8O_{22}(OH)_2$
- Arfvedsonite Series $Na_3(Fe,Mg)_4FeSi_8O_{22}(OH)_2$

Members of the anthophyllite series occur largely, if not wholly, in metamorphic rocks. Members of the cummingtonite series are also more-or-less restricted in occurrence to metamorphic rocks. The tremolite-actinolite series is also most common in metamorphic rocks. The series that we refer to as the hornblende series is more correctly called the magnesiohornblende-ferrohornblende series. Hornblende is the name applied to the dark gray or essentially black-to-greenish black amphiboles that occur in many igneous rocks. The alkali-amphibole group includes three series whose individual members are relatively common in either metamorphic or alkalic igneous rocks.

No Apparent Cleavage :

Luster - Nonmetallic

Hardness - 5.0-7.5

Streak=Pale green or colorless

No Apparent Cleavge

Olivine $(Fe,Mg)_2SiO_4$	Pale green or colorless Streak	No Cleavge	Green granular masses. H=6.5-7.0	

Your Mineral is Olivine!

Olivine

The olivine series is an example of continuous solid solution of two components, Mg_2SiO_4 and Fe_2SiO_4. Three names are used currently: forsterite for pure or nearly pure Mg_2SiO_4, fayalite for pure or nearly pure Fe_2SiO_4, and olivine for the common intermediate varieties. Forsterite and olivine are incompatible with free silica because they react with it to give pyroxene; as a consequence, olivine and quartz cannot crystallize together in a rock. Fayalite, however, does not react in this way, and fayalite occurs in some granites and rhyolites.

The composition of olivine generally corresponds closely to $(Mg,Fe)_2SiO_4$, there being little replacement by other elements. Substitution by calcium is evidently strongly temperature dependent, because only a little of the olivine from plutonic rocks contains more than 0.1 percent CaO, whereas most of the olivine of volcanic rocks contains more than this amount, typically ranging up to a maximum of about 1 percent CaO. Manganese is present in most olivines and generally correlates positively with Fe content, ranging from about 0.1 percent in forsterites up to 2.5 percent in fayalite. Olivines from ultrabasic rocks generally contain some nickel, commonly about 0.3 percent. A noteworthy feature of olivine is the virtual absence of aluminum; evidently replacement of Mg and Si by Al is unacceptable in the olivine structure.

Olivine alters readily. Hydrothermal alteration generally results in the formation of serpentine, whereas surface or near-surface alteration results in oxidation of the iron and removal of the magnesium and silica, commonly leaving a brown or red-brown pseudomorph that consists of goethite or hematite.

Olivine is typically a mineral of mafic and ultramafic igneous rocks; in some places, it constitutes major rock masses (dunite); some basalts contain nodules of granular olivine, some that are derived from the earth’s mantle. Olivine is a common mineral in stony and stony-iron meteorites. Forsterite is formed by the metamorphism of dolomitic limestone. Fayalite melts at 1205°C, forsterite at 1890°C; thus, magnesium-rich olivine, with a very high melting point, is used in the manufacture of refractory bricks. Transparent olivine of good color has been cut into attractive gemstones (peridot).

if it is RED-BROWN:

Luster - Nonmetallic
Hardness - 5.0-7.5
Streak=Red-brown
Step 4

Next, let's examine the mineral for any signs of cleavage. Sometimes it will be obvious and other times it will be more difficult to see or even indistinct. No mineral in this group should have cleavage, if your unknown does, try going back to Step 2 or the previous step, Step 3.

if there is No Apparent Cleavage **:**

Luster - Nonmetallic

Hardness - 5.0-7.5

Streak=Red-brown

No Apparent Cleavge

Hematite Fe_2O_3	Red-brown Streak	No Cleavge	Often in earth masses, distnctly red-brown. H=5.5-6.5	

Your Mineral is Hematite!

Third Test-**If you were able to scratch the streak plate:**

Luster - Nonmetallic

Hardness - Greater than 7.5

Step 3

There are NO minerals in your set that have a hardness greater than 7.5. Please return to Step 2.