As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural and cultural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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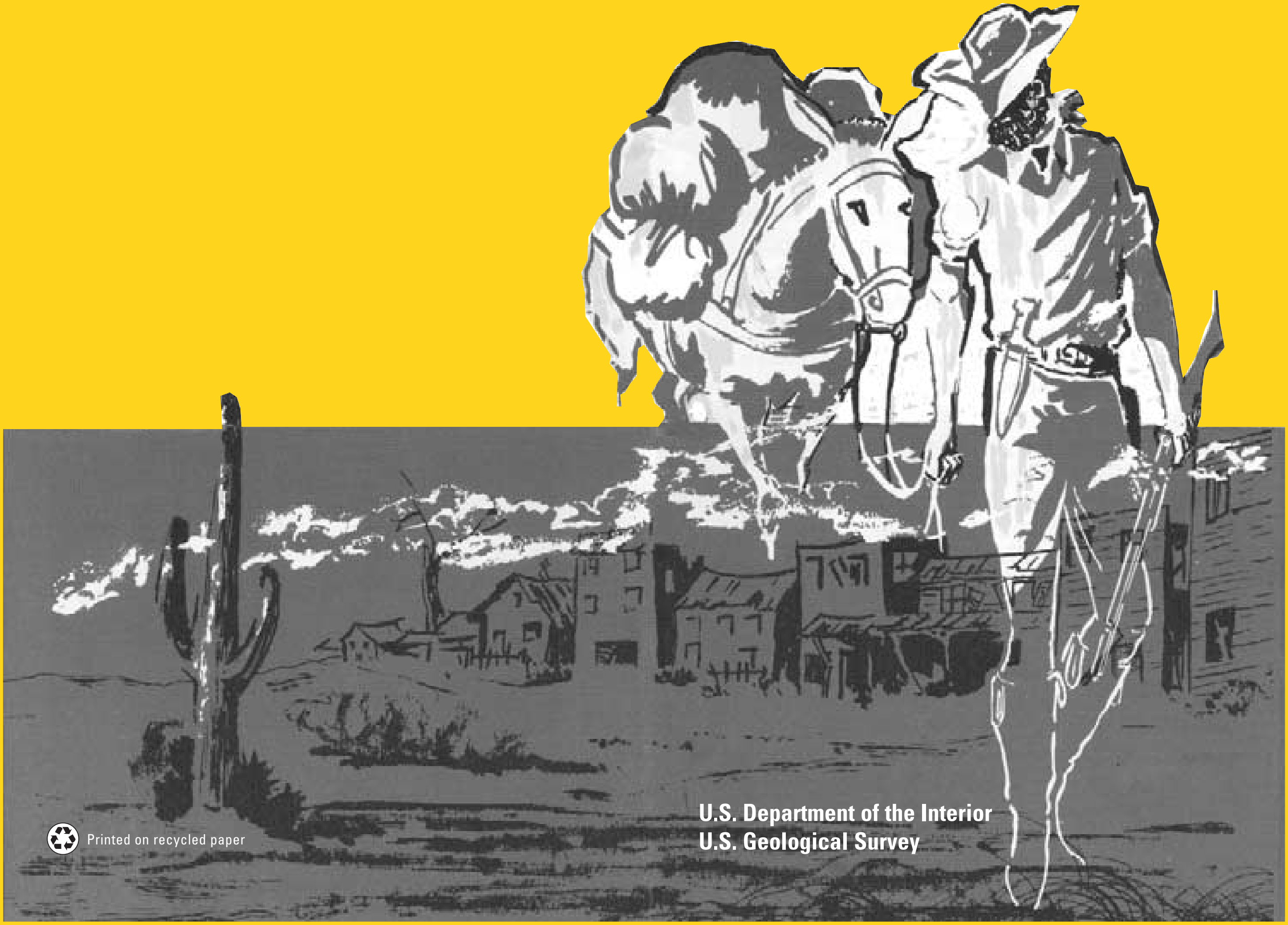
Gold



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U.S. Department of the Interior
U.S. Geological Survey

GOLD

by Harold Kirkemo, William L. Newman, and Roger P. Ashley

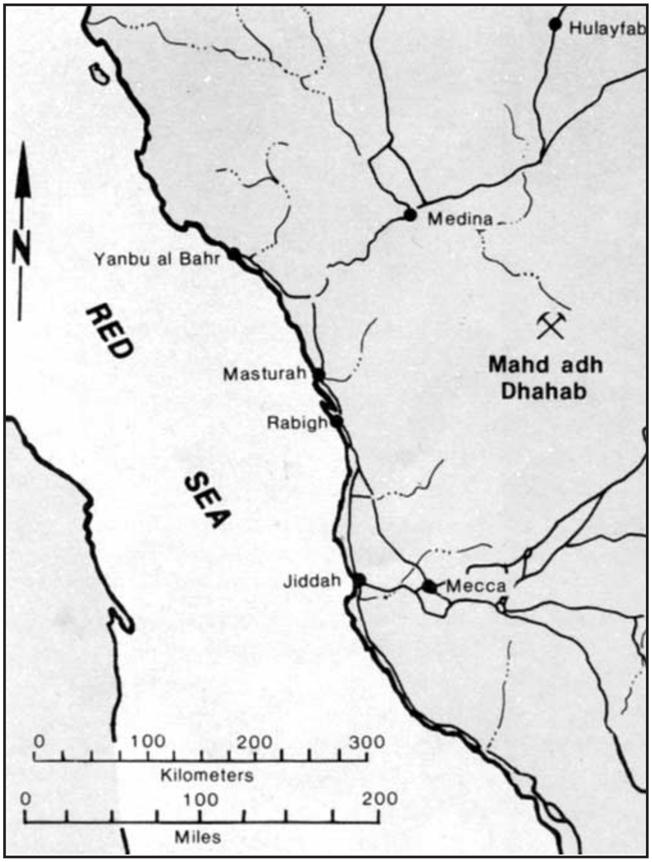
Throughout the ages men and women have cherished gold, and many have had a compelling desire to amass great quantities of it—so compelling a desire, in fact, that the frantic need to seek and hoard gold has been aptly named "gold fever."

Gold was among the first metals to be mined because it commonly occurs in its native form, that is, not combined with other elements, because it is beautiful and imperishable, and because exquisite objects can be made from it. Artisans of ancient civilizations used gold lavishly in decorating tombs and temples, and gold objects made more than 5,000 years ago have been found in Egypt. Particularly noteworthy are the gold items discovered by Howard Carter and Lord Carnarvon in 1922 in the tomb of Tutankhamun. This young pharaoh ruled Egypt in the 14th century B.C. An exhibit of some of these items, called "Treasures of Tutankhamun" attracted more than 6 million visitors in six cities during a tour of the United States in 1977-79.

The graves of nobles at the ancient Citadel of Mycenae near Nauplion, Greece, discovered by Heinrich Schliemann in 1876, yielded a great variety of gold figurines, masks, cups, diadems, and jewelry, plus hundreds of decorated beads and buttons. These elegant works of art were created by skilled craftsmen more than 3,500 years ago.

Tutankhamun's gold mummy case (*photo by Lee Boltin*).

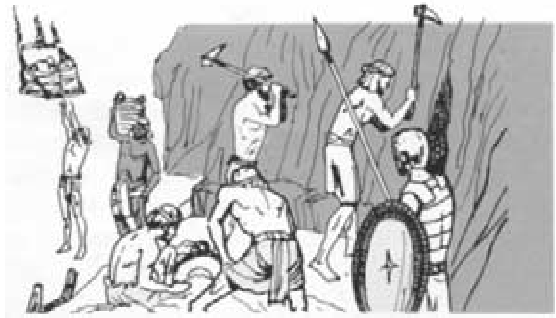
Sketch of the so-called mask of Agamemnon, one of many gold items from the tombs at Mycenae.



Location of the Mahd adh Dhahab gold mine.

The ancient civilizations appear to have obtained their supplies of gold from various deposits in the Middle East. Mines in the region of the Upper Nile near the Red Sea and in the Nubian Desert area supplied much of the gold used by the Egyptian pharaohs. When these mines could no longer meet their demands, deposits elsewhere, possibly in Yemen and southern Africa, were exploited.

Artisans in Mesopotamia and Palestine probably obtained their supplies from Egypt and Arabia. Recent studies of the Mahd adh Dhahab (meaning “Cradle of Gold”) mine in the present Kingdom of Saudi Arabia reveal that gold, silver, and copper were recovered from this region during the reign of King Solomon (961-922 B.C.).



(Below)
An air view of the Mahd adh Dhahab gold mine in Saudi Arabia. Swarms of gold-bearing quartz veins (seen as long irregular trenches at *a*) have been mined for gold and silver for more than 3,000 years. Some of the veins have been followed downward to depths as much as 300 feet. Similar quartz veins lace the hill to the right *(b)*, but these veins are not rich enough to mine.
Lumps of charcoal (the remains of wood fires used to smelt the metals) were recovered from ancient slag piles and dated by scientists of the U.S. Geological Survey using the carbon-14 method. Some of the charcoal is as much as 3,000 years old indicating that the mine was active during the reign of King Solomon.
The Saudi Arabian Mining Syndicate worked the mine from 1939 to 1954, getting ore from below the ancient workings as well as from an open cut *(c)* and from old surface dumps. The mill *(far left)* and buildings were erected by the Syndicate.

Mahd adh Dhahab gold mine.

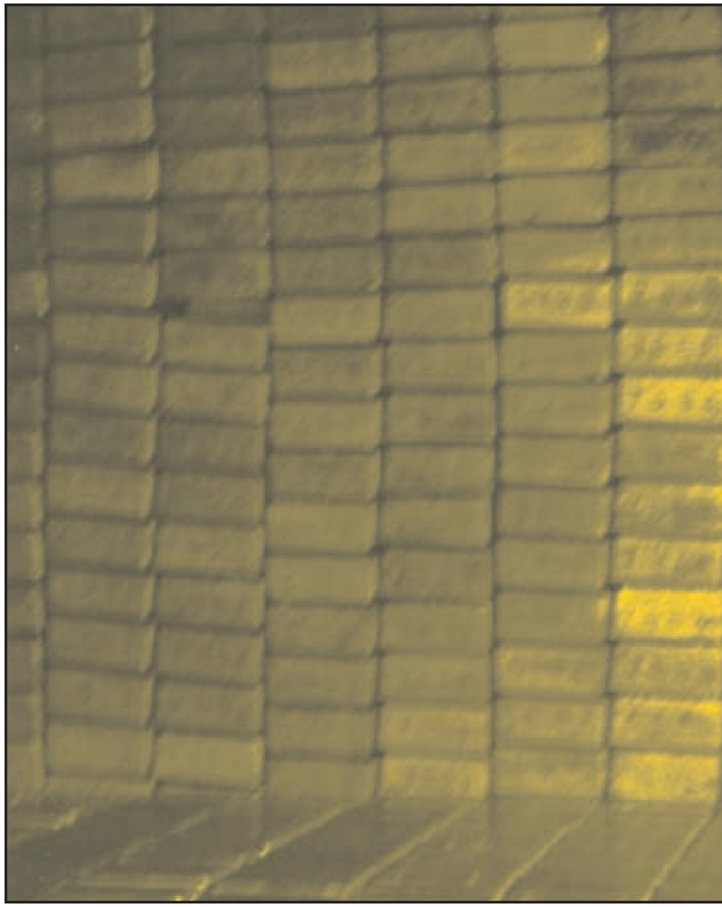
The gold in the Aztec and Inca treasuries of Mexico and Peru is believed to have come from Colombia, although some undoubtedly was obtained from other sources. The Conquistadores plundered the treasuries of these civilizations during their explorations of the New World, and many gold and silver objects were melted and cast into coins and bars, destroying the priceless artifacts of the Indian culture.

Nations of the world today use gold as a medium of exchange in monetary transactions. A large part of the gold stocks of the United States is stored in the vault of the Fort Knox Bullion Depository. The Depository, located about 30 miles southwest of Louisville, Kentucky, is under the supervision of the Director of the Mint.

Gold in the Depository consists of bars about the size of ordinary building bricks (7 x 3.6 x 1.75 inches) that weigh about 27.5 pounds each (about 400 troy ounces; 1 troy ounce equals about 1.1 avoirdupois ounces). They are stored without wrappings in the vault compartments.

Aside from monetary uses, gold is used in jewelry and allied wares, electrical-electronic applications, dentistry, the aircraft-aerospace industry, the arts, and medical and chemical fields.

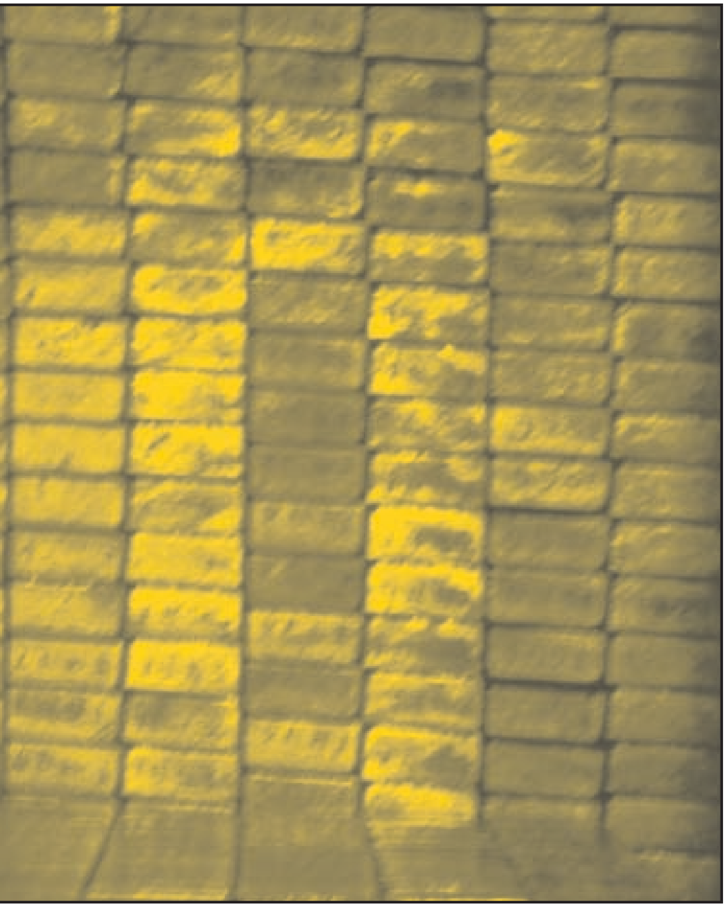
The changes in demand for gold and supply from domestic mines in the past two decades reflect price changes. After the United States deregulated gold in 1971, the price increased markedly, briefly reaching more than $800 per troy ounce in 1980. Since 1980, the price has remained in the range of $320 to $460 per troy ounce. The rapidly rising prices of the 1970's encouraged both experienced explorationists and amateur prospectors to renew their search for gold. As a result of their efforts, many new mines opened in the 1980's, accounting for much of the expansion of gold output. The sharp declines in consumption in 1974 and 1980 resulted from reduced demands for jewelry (the major use of fabricated gold) and investment products, which in turn reflected rapid price increases in those years.

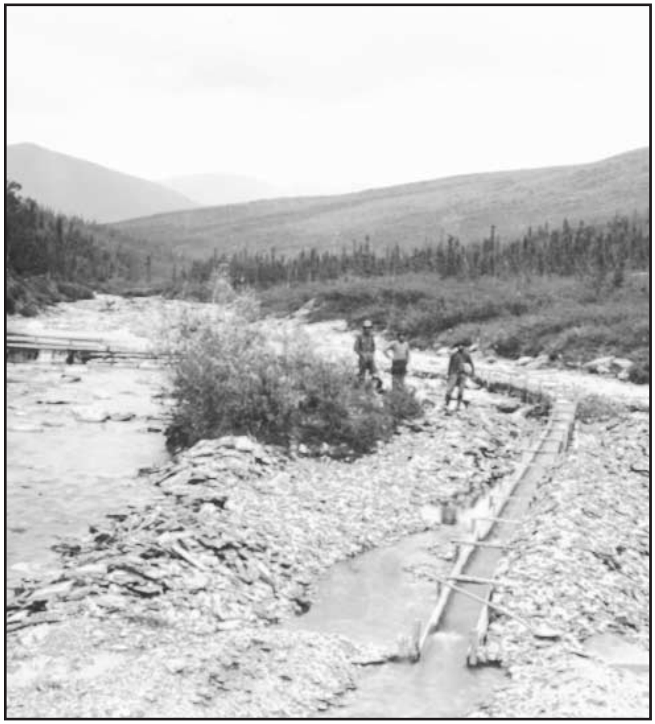


Stacks of gold bars in the Fort Knox Bullion Depository *(photo courtesty of the U.S. Mint).*

Gold is called a "noble" metal (an alchemistic term) because it does not oxidize under ordinary conditions. Its chemical symbol *Au* is derived from the Latin word "aurum." In pure form gold has a metallic luster and is sun yellow, but mixtures of other metals, such as silver, copper, nickel, platinum, palladium, tellurium, and iron, with gold create various color hues ranging from silver-white to green and orange-red.

Pure gold is relatively soft—it has about the hardness of a penny. It is the most malleable and ductile of metals. The specific gravity or density of pure gold is 19.3 compared to 14.0 for mercury and 11.4 for lead.





Recovering gold in a long sluicebox. Gold-bearing gravels are shoveled into the upper end of the sluiceway; a series of riffles set across the bottom of the box traps the gold. Myrtle Creek, Alaska, circa 1900.

Impure gold, as it commonly occurs in deposits, has a density of 16 to 18, whereas the associated waste rock (gangue) has a density of about 2.5. The difference in density enables gold to be concentrated by gravity and permits the separation of gold from clay, silt, sand, and gravel by various agitating and collecting devices such as the gold pan, rocker, and sluicebox.

Mercury (quicksilver) has a chemical affinity for gold. When mercury is added to gold-bearing material, the two metals form an *amalgam*. Mercury is later separated from amalgam by retorting. Extraction of gold and other precious metals from their ores by treatment with mercury is called amalgamation.

Gold dissolves in aqua regia, a mixture of hydrochloric and nitric acids, and in sodium or potassium cyanide. The latter solvent is the basis for the cyanide process that is used to recover gold from low-grade ore.

The degree of purity of native gold, bullion (bars or ingots of unrefined gold), and refined gold is stated in terms of gold content. “Fineness” defines gold content in parts per thousand. For example, a gold nugget containing 885 parts of pure gold and 115 parts of other metals, such as silver and copper, would be considered 885-fine. “Karat” indicates the proportion of solid gold in an alloy based on a total of 24 parts. Thus, 14-karat (14K) gold indicates a composition of 14 parts of gold and 10 parts of other metals. Incidentally, 14K gold is commonly used in jewelry manufacture.

“Karat” should not be confused with “carat,” a unit of weight used for precious stones.

The basic unit of weight used in dealing with gold is the troy ounce. One troy ounce is equivalent to 20 troy pennyweights. In the jewelry industry, the common unit of measure is the pennyweight (dwt.) which is equivalent to 1.555 grams.

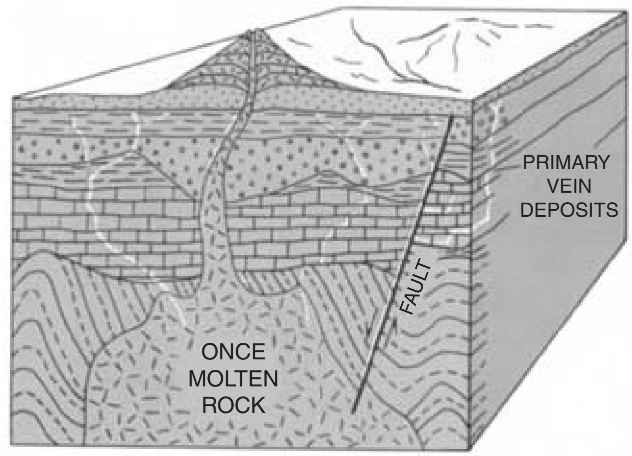
The term “gold-filled” is used to describe articles of jewelry made of base metal which are covered on one or more surfaces with a layer of gold alloy. A quality mark may be used to show the quantity and fineness of the gold alloy. In the United States no article having a gold alloy coating of less than 10-karat fineness may have any quality mark affixed. Lower limits are permitted in some countries.

No article having a gold alloy portion of less than one-twentieth by weight may be marked “gold-filled,” but articles may be marked “rolled gold plate” provided the proportional fraction and fineness designations are also shown. Electroplated jewelry items carrying at least 7 millionths of an inch (0.18 micrometers) of gold on significant surfaces may be labeled “electroplate.” Plated thicknesses less than this may be marked “gold flashed” or “gold washed.”

Gold is relatively scarce in the earth, but it occurs in many different kinds of rocks and in many different geological environments. Though scarce, gold is concentrated by geologic processes to form commercial deposits of two principal types: lode (primary) deposits and placer (secondary) deposits.

Lode deposits are the targets for the “hardrock” prospector seeking gold at the site of its deposition from mineralizing solutions. Geologists have proposed various hypotheses to explain the source of solutions from which mineral constituents are precipitated in lode deposits.

One widely accepted hypothesis proposes that many gold deposits, especially those found in volcanic and sedimentary rocks, formed from circulating ground waters driven by heat from bodies of magma (molten



Mineralizing solutions travel upward along fractures and form primary deposits.

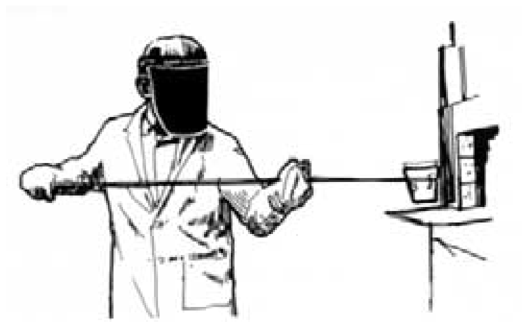
rock) intruded into the Earth’s crust within about 2 to 5 miles of the surface. Active geothermal systems, which are exploited in parts of the United States for natural hot water and steam, provide a modern analog for these gold-depositing systems. Most of the water in geothermal systems originates as rainfall, which moves downward through fractures and permeable beds in cooler parts of the crust and is drawn laterally into areas heated by magma, where it is driven upward through fractures. As the water is heated, it dissolves metals from the surrounding rocks. When the heated waters reach cooler rocks at shallower depths, metallic minerals precipitate to form veins or blanket-like ore bodies.

Another hypothesis suggests that gold-bearing solutions may be expelled from magma as it cools, precipitating ore materials as they move into cooler surrounding rocks. This hypothesis is applied particularly to gold deposits located in or near masses of granitic rock, which represent solidified magma.

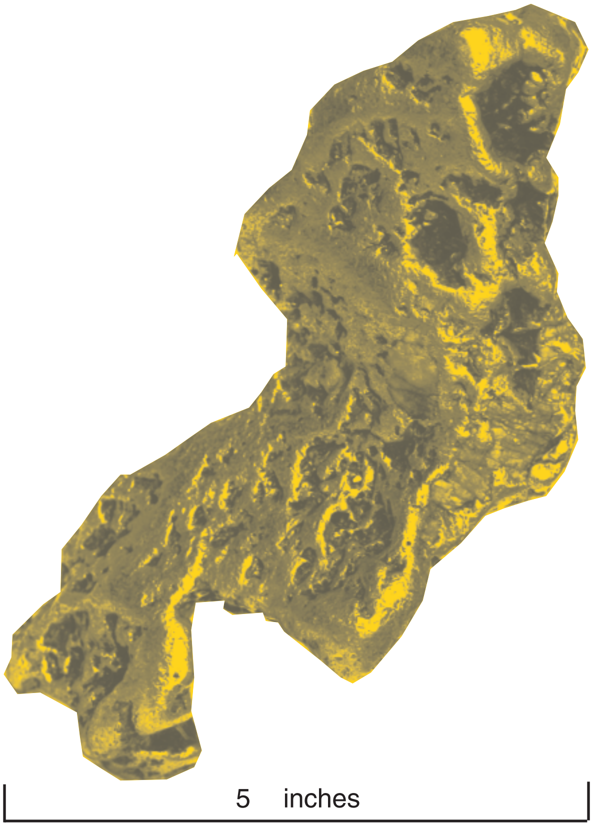
A third hypothesis is applied mainly to gold-bearing veins in metamorphic rocks that occur in mountain belts at continental margins. In the mountain-building process, sedimentary and volcanic rocks may be

The gold content of rocks is commonly determined by means of a *fire* assay, a method known to metalworkers for 3,000 years or more. In modern practice, a weighed sample of pulverized rock is melted in a flux consisting of lead oxide, soda, borax, silica, and flour or potassium nitrate, along with a measured amount of silver as lead-silver alloy, in a furnace at a temperature of 1000° Celsius (1800°F). The lead fraction contains the gold and added silver and settles to cool as a button. The button is then remelted and oxidized in a bone-ash cupel, which absorbs the lead oxide, leaving behind a bead consisting of precious metals in the silver collector. The bead is dissolved in acid and usually analyzed by atomic absorption spectrometry.

deeply buried or thrust under the edge of the continent, where they are subjected to high temperatures and pressures resulting in chemical reactions that change the rocks to new mineral assemblages (metamorphism). This hypothesis suggests that water



is expelled from the rocks and migrates upward, precipitating ore materials as pressures and temperatures decease. The ore metals are thought to originate from the rocks undergoing active metamorphism.



Gold nugget weighing 81.9 troy ounces from the Union Placer mine near Greenville Plumas County, California *(photo courtesy of Smithsonian Institution).*

The primary concerns of the prospector or miner interested in a lode deposit of gold are to determine the gold content (tenor) per ton of mineralized rock and the size of the deposit. From these data, estimates can be made of the deposit's value. One of the most commonly used methods for determining the gold and silver content of mineralized rocks is the fire assay. The results are reported as troy ounces of gold or silver or both per short avoirdupois ton of ore or as grams per metric ton of ore.

Placer deposits represent concentrations of gold derived from lode deposits by erosion, disintegration or decomposition of the enclosing rock, and subsequent concentration by gravity.

A gold dredge at work on Goldstream Creek near Fairbanks, Alaska, circa 1937 (*photo by Bradford Washburn).*

Gold is extremely resistant to weathering and, when freed from enclosing rocks, is carried downstream as metallic particles consisting of "dust," flakes, grains, or nuggets. Gold particles in stream deposits are often concentrated on or near bedrock, because they move downward during high-water periods when the entire bed load of sand, gravel, and boulders is agitated and is moving downstream. Fine gold particles collect in depressions or in pockets in sand and gravel bars where the stream current slackens. Concentrations of gold in gravel are called "pay streaks."

In gold-bearing country, prospectors look for gold where coarse sands and gravel have accumulated and where "black sands" have concentrated and settled with the gold. Magnetite is the most common mineral in black sands, but other heavy minerals such as cassiterite, monazite, ilmenite, chromite, platinum-group metals, and some gem stones may be present.

Placer deposits have formed in the same manner throughout the Earth's history. The processes of weathering and erosion create surface placer deposits that may be buried under rock debris. Although these "fossil" placers are subsequently cemented into hard rocks, the shape and characteristics of old river channels are still recognizable.

Laboratory researchers develop new methods of analyzing rocks for gold content.

The content of recoverable free gold in placer deposits is determined by the free gold assay method, which involves amalgamation of gold-bearing concentrate collected by dredging, hydraulic mining, or other placer mining operations. In the period when the price of gold was fixed, the common practice was to report assay results as the value of gold (in cents or dollars) contained in a cubic yard of material. Now results are reported as grams per cubic yard or grams per cubic meter.

Through laboratory research, the U.S. Geological Survey has developed new methods for determining the gold content of rocks and soils of the Earth's crust. These methods, which detect and measure the amounts of other elements as well as gold, include atomic absorption spectrometry, neutron activation, and inductively coupled plasma-atomic emission spectrometry. These methods enable rapid and extremely sensitive analyses to be made of large numbers of samples.

Gold was produced in the southern Appalachian region as early as 1792 and perhaps as early as 1775 in southern California. The discovery of gold at Sutter's Mill in California sparked the gold rush of 1849-50, and hundreds of mining camps sprang to life as new deposits were discovered. Gold production increased rapdly. Deposits in the Mother Lode and Grass Valley districts in California and the Comstock Lode in Nevada were discovered during the 1860's, and the Cripple Creek deposits in Colorado began to produce gold in 1892. By1905 the Tonopah and Goldfield deposits in Nevada and the Alaskan placer deposits had been discovered, and United States gold production for the first time exceeded 4 million troy ounces a year—a level maintained until 1917.

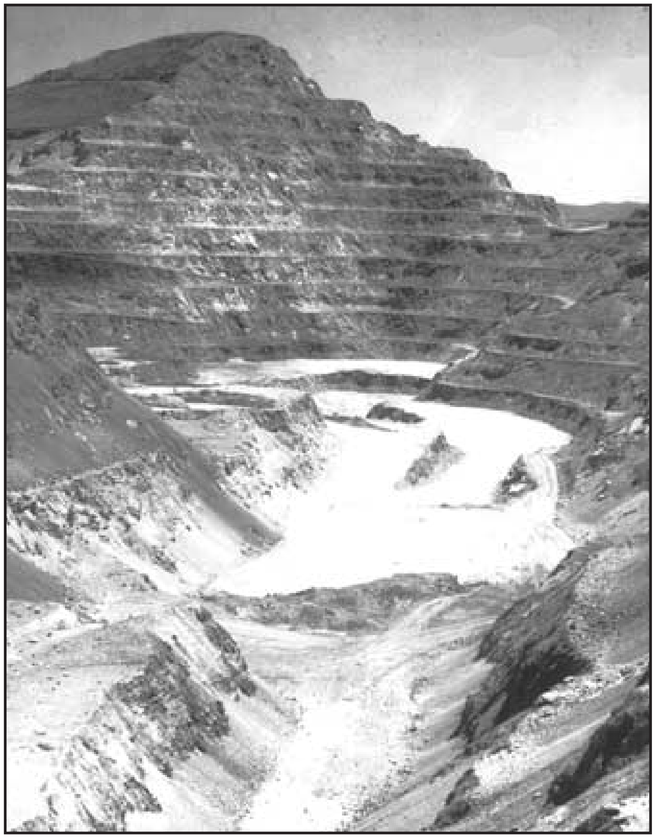
During World War I and for some years thereafter, the annual production declined to about 2 million ounces. When the price of gold was raised from $20.67 to $35 an ounce in 1934, production increased rapidly and again exceeded the 4-million-ounce level in 1937. Shortly after the start of World War II, gold mines were closed by the War Production Board and not permitted to reopen until 1945.

From the end of World War II through 1983, domestic mine production of gold did not exceed 2 million ounces annually. Since 1985, annual production has risen by 1 million to 1.5 million ounces every year. By the end of 1989, the cumulative output from deposits in the United States since 1792 reached 363 million ounces.

Mining rich gold-silver at Goldfield, Nevada, circa 1905.

Consumption of gold in the United States ranged from about 6 million to more than 7 million troy ounces per year from 1969 to 1973, and from about 4 million to 5 million troy ounces per year from 1974 to 1979, whereas during the 1970's annual gold

production from domestic mines ranged from about 1 million to 1.75 million troy ounces. Since1980 consumption of gold has been nearly constant at between 3 and 3.5 million troy ounces per year. Mine production has increased at a quickening pace since 1980, reaching about 9 million troy ounces per year in 1990, and exceeding consumption since 1986. Prior to 1986, the balance of supply was obtained from secondary (scrap) sources and imports.



The main pit at the Carlin mine, Nevada, July 1974 *(photo by R.P. Ashley).*

Total world production of gold is estimated to be about 3.4 billion troy ounces, of which more than two-thirds was mined in the past 50 years. About 45 percent of the world's total gold production has been from the Witwatersrand district in South Africa.

The largest gold mine in the United States is the Homestake mine at Lead, South Dakota. This mine, which is 8,000 feet deep, has accounted for almost 10 percent of total United States gold production since it opened in 1876. It has combined production and reserves of about 40 million troy ounces.

In the past two decades, low-grade disseminated gold deposits have become increasingly important. More than 75 such deposits have been found in the Western States, mostly in Nevada. The first major producer of this type was the Carlin deposit, which was discovered in 1962 and started production in 1965. Since then many more deposits have been discovered in the vicinity of Carlin, and the Carlin area now comprises a major mining district with seven operating open pits producing more than 1,500,000 troy ounces of gold per year.

About 15 percent of the gold produced in the United States has come from mining other metallic ores. Where base metals—such as copper, lead, and zinc—are deposited, either in veins or as scattered mineral grains, minor amounts of gold are commonly deposited with them. Deposits of this type are mined for the predominant metals, but the gold is also recovered as a byproduct during processing of the ore.

Gold-bearing quartz veins in fractured schist, Providence mine, Soulsbyville district, California.

Most byproduct gold has come from porphyry deposits, which are so large that even though they contain only a small amount of gold per ton of ore, so much rock is mined that a substantial amount of gold is recovered. The largest single source of byproduct gold in the United States is the porphyry deposit at Bingham Canyon, Utah, which has produced about 18 million troy ounces of gold since 1906.

Geologists examine all factors controlling the origin and emplacement of mineral deposits, including those containing gold. Igneous and metamorphic rocks are studied in the field and in the laboratory to gain an understanding of how they came to their present location, how they crystallized to solid rock, and how mineral-bearing solutions formed within them. Studies of rock structures, such as folds, faults, fractures, and joints, and of the effects of heat and pressure on rocks suggest why and where fractures occurred and where veins might be found. Studies of weathering processes and transportation of rock debris by water enable geologists to predict the most likely places for placer deposits to form.

The occurrence of gold is not capricious; its presence in various rocks and its occurrence under differing environmental conditions follow natural laws. As geologists increase their knowledge of the mineralizing processes, they improve their ability to find gold.

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