GEOLOGICAL SURVEY
BULLETIN 280

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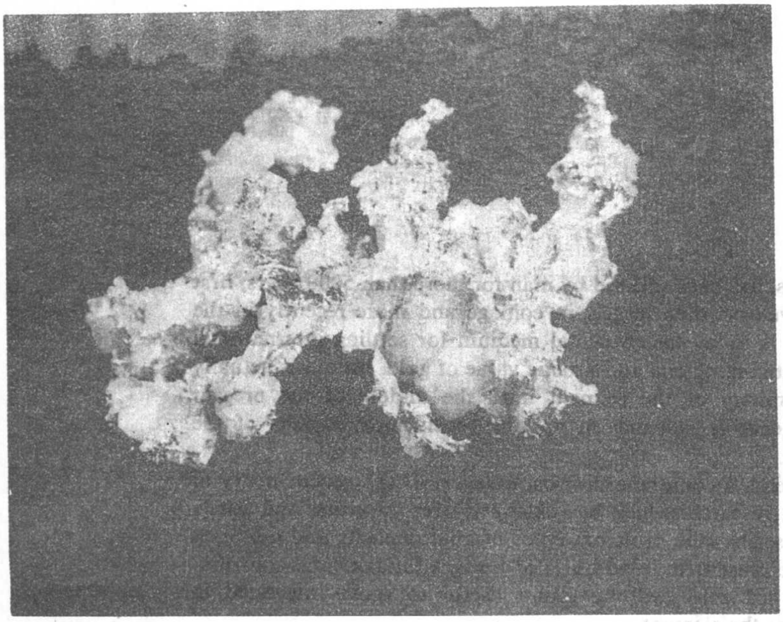
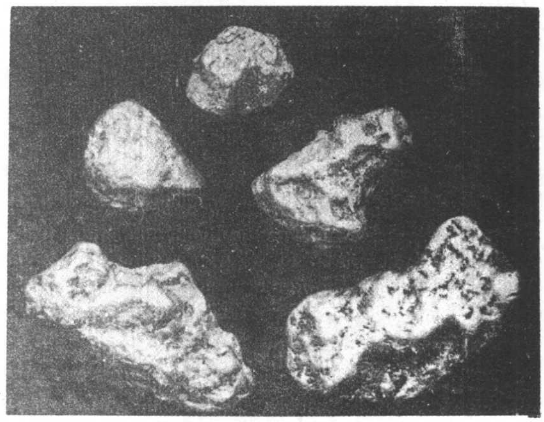
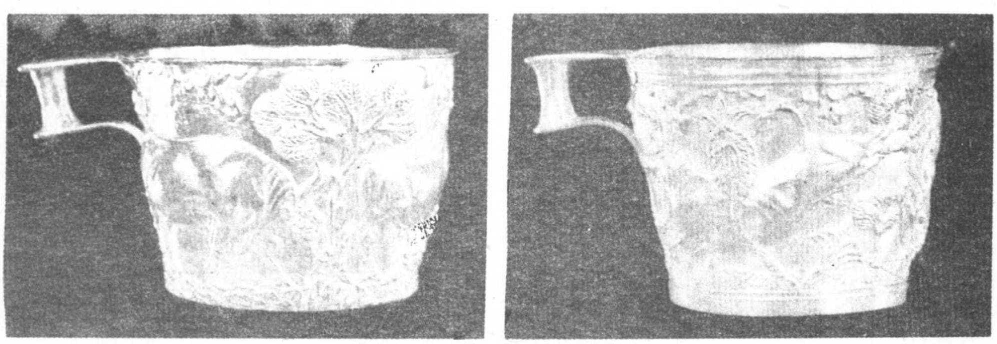


Native gold, Paymaster mine, South Porcupine, Ontario (Natural size).



Native gold nuggets, Goldrun Creek placer, Cassiar District, British Columbia (Natural size).



The gold cups of Vaphio: From the tholos tomb near Vaphio, Laconia, Greece. First Late Minoan, late 16th-early 15th century B.C., National Archaeological Museum, Athens.

Preface

Gold, the noblest of metals, has been utilized by man for more than 5000 years, first in artistic objects and jewellery, then largely in coinage and more recently in the industrial arts. The metal is today the principal medium for settling international accounts. Despite the great commercial and artistic value of gold, little was actually known about the geochemistry of the element until the middle of the present century; since then considerable research in various geochemical aspects of the metal has been carried out.

The author here presents a comprehensive compilation of the geochemistry of gold, partly from his own research, which has extended over 25 years, and partly from the literature. He describes the principal types of gold deposits and discusses their origin. The data here presented, in addition to being a fundamental contribution to the geochemistry of gold, will be found useful to those interested in geochemical prospecting for the element.

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Director General
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Ottawa, 25 August 1976

THE GEOCHEMISTRY OF GOLD AND ITS DEPOSITS

Abstract

Gold is a member of Group IB of the periodic table, which includes copper, silver and gold. In its chemical reactions gold resembles silver in some respects, but its chemical character is markedly more noble. The principal oxidation states of gold are Au(I)(aurous) and Au(III)(auric). These states are unknown as aquo-ions in solution, the element being present mainly in complexes of the type $[Au(CN)_2]^-$, $[AuCl_2]^-$, $[Au(OH)_4]^-$, and $[AuCl_4]^-$. There is only one naturally occurring isotope of gold: ^{197}Au.

In nature gold occurs predominantly in the native state or as a major constituent of various alloys containing mainly silver, copper or platinoid metals. Several gold and gold-silver tellurides are known of which the most common are sylvanite, calaverite, petzite, krennerite and nagyagite. The antimonide, aurostibite, $AuSb_2$, occurs as a hypogene mineral in some auriferous deposits, and there is also a selenide, fischesserite, Ag_3AuSe_2, and a bismuthide, maldonite, Au_2Bi, which is fairly well differentiated. The principal ore minerals of gold are the native metal, aurostibite and the various tellurides.

The abundance of gold in the upper lithosphere is about 0.005 ppm, and the Au/Ag ratio is about 0.1. The average gold content of igneous-type rocks in parts per million is – ultrabasic (0.004), gabbro-basalt (0.007), diorite-andesite (0.005) and granite-rhyolite (0.003). The average gold content of sedimentary rocks in parts per million is – sandstone and conglomerate (0.03), normal shale (0.004) and limestone (0.003). Certain graphitic shales, sulphide schists, phosphorites and some types of sandstones and conglomerates may contain up to 2.1 ppm Au or more.

The average gold content of soils is 0.005 ppm, and the average for natural fresh waters is 0.00003 ppm. Sea and ocean waters contain an average of 0.000012 ppm Au. Gold is a trace constituent of many plants and animals. Some coals are slightly enriched in gold with 0.05 to 0.1 ppm Au in the ash.

Gold is won both from deposits mined essentially for the element and as a byproduct of the mining and treatment of nickel, copper, zinc, lead and silver ores. The following types of primary deposits, exploited mainly for gold, can be distinguished:

1. Auriferous porphyry dykes, sills and stocks; coarse-grained granitic bodies, aplites and pegmatites.
2. Auriferous skarn-type deposits.
3. Gold-silver and silver-gold veins, stockworks, lodes, mineralized pipes and irregular silicified bodies in fractures, faults, shear zones, sheeted zones and breccia zones essentially in volcanic terranes.
4. Auriferous veins, lodes, sheeted zones and saddle reefs in faults, fractures, bedding plane discontinuities and shears, drag folds, crushed zones and openings on anticlines essentially in sedimentary terranes; also replacement tabular and irregular bodies developed near faults and fractures in chemically favourable beds.
5. Gold-silver and silver-gold veins, lodes, stockworks, silicified zones, etc. in a complex geological environment, comprising sediments, volcanics and igneous or granitized rocks.

Résumé

L'or est un élément du groupe 1B du tableau périodique, qui comprend le cuivre, l'argent et l'or. Du point de vue de sa réactivité chimique, l'or rappelle l'argent à certains égards, mais son caractère chimique est beaucoup plus 'noble'. Les principaux états d'oxydation de l'or sont Au (I) (aureux) et Au (III) (aurique). On ne trouve pas ces états d'oxydation sous forme d'aquo-ions en solution, mais surtout sous forme de complexes du type $[Au(CN)_2]^-$, $[AuCl_2]^-$, $[Au(OH)_4]^-$ et $[AuCl_4]^-$. Il n'existe à l'état naturel qu'un seul isotope de l'or: ^{197}Au.

Dans la nature, l'or se présente généralement à l'état natif, ou allié à d'autres métaux, surtout l'argent, le cuivre, ou les métaux du groupe du platine. On connaît plusieurs tellurures d'or et d'or et argent, dont les plus communs sont la sylvanite, la calavérite, la petzite, la krennerite et la nagyagite. L'antimoniure, l'aurostibite, $AuSb_2$, se présente sous forme de minéral hypogène dans certains gisements aurifères, et il existe aussi un séléniure, la fischesserite, Ag_3AuSe_2, et un bismuthiure, la maldonite, Au_2Bi, lequel est assez bien différencié. Les principaux minéraux d'or sont l'or natif, l'aurostibite et les divers tellurures.

L'abondance de l'or dans la partie supérieure de la lithosphère est d'environ 0.005 ppm et la proportion Au/Ag est d'environ 0.1. La teneur moyenne en or des roches ignées, exprimée en parties par million, est de 0.004 pour les roches ultrabasiques, de 0.007 pour les gabbros et les basaltes, de 0.005 pour la diorite et l'andésite, et de 0.003 pour le granite et la rhyolite. La teneur moyenne en or des roches sédimentaires, exprimée en parties par million, est de 0.03 pour les grès et les conglomérats, de 0.004 pour les schistes argileux normaux et de 0.003 pour le calcaire. Certains schistes graphiteux, certaines phosphorites, certains schistes cristallins sulfureux, et certains types de grès et de conglomérats peuvent contenir jusqu'à 2.1 ppm de Au ou davantage.

La teneur moyenne en or des sols est de 0.005 ppm et la teneur moyenne des eaux douces naturelles est de 0.00003 ppm. Les eaux marines et océaniques contiennent en moyenne 0.000012 ppm de Au. L'or se présente sous forme d'élément-trace chez de nombreux végétaux et animaux. Certains charbons son légèrement enrichis en or et leurs cendres contiennent de 0.05 à 0.1 ppm de Au.

On extrait l'or à la fois dans des gisements aurifères proprement dits et dans des gisements où il est un sous-produit de l'extraction et du traitement des minerais de nickel, de cuivre, de zinc, de plomb et d'argent. On peut distinguer les types suivants de dépôts primaires, que l'on exploite surtout pour l'or:

1. Les dykes, sills et stocks de porphyres granitiques aurifères, et les corps granitiques à grain grossier, les aplites et les pegmatites.
2. Les gisements aurifères de type skarn.
3. Les veines, stockwerks, filons, colonnes minéralisées et masses irrégulières silicifiées, aurifères-argentifères et argentifères-aurifères, situés dans les fractures, les failles, les zones de cisaillement, les zones à feuillets minéralisés et les zones de brèches, que l'on rencontre surtout dans les terrains volcaniques.
4. Les veines, filons, zones à feuillets minéralisés, et gîtes en selle aurifères, situés dans les failles, fractures, discordances stratigraphiques, et les zones de cisaillement, plis d'entraînement, zones broyées et voûtes anticlinales que l'on rencontre surtout dans les

6. Disseminated and stockwork gold-silver deposits in igneous, volcanic and sedimentary rocks.

(a) Disseminated and stockwork gold-silver deposits in igneous bodies.

(b) Disseminated gold-silver occurrences in volcanic flows and associated volcaniclastic rocks.

(c) Disseminated gold-silver deposits in volcaniclastic and sedimentary beds: deposits in tuffaceous rocks and iron formations and deposits in chemically favourable sedimentary beds.

7. Gold deposits in quartz-pebble conglomerates and quartzites.

Placers constitute the principal secondary type of gold deposit.

The quartz-pebble conglomerate deposits provide the bulk of the world's production of gold, some 56 per cent. The other deposits, mainly the vein and disseminated types, eluvial and alluvial placers and the various polymetallic veins, lodes, massive bodies and stockworks (byproduct gold) now provide the remaining 44 per cent of the production.

The epigenetic vein, lode, stockwork and disseminated types of gold deposits appear to have originated mainly by metamorphic secretion processes, the source rocks of the gold and its associated elements being mainly the enclosing volcanic and/or sedimentary piles. Modern gold placers are of sedimentary origin, the gold being winnowed into pay streaks as the result of both chemical (accretion) and physical (gravity) processes operating during weathering and subsequent sedimentation. The auriferous quartz-pebble conglomerate deposits appear to have originated as placers, the gold and many of its associated elements having undergone radical chemical reworking during subsequent diagenetic and metamorphic events.

The oxidation processes in gold deposits are complex and depend essentially on the Eh and pH. Colloidal and coprecipitation phenomena also play a large part. Iron and manganese minerals and carbonates in the gangue and ore greatly influence the reactions that lead to the secondary enrichment of the element. Gold is not easily solubilized in nature, and its soluble forms are readily reduced to the metal by a great variety of natural materials. The result of this behaviour is that the only common gold mineral found in the oxidized zones of auriferous deposits is the native metal. In this form it ultimately collects in both eluvial and alluvial placers, which have been exploited throughout the world since time immemorial.

Practically all the geochemical methods of prospecting are applicable in the search for auriferous deposits. The most effective methods appear to be those based on the sampling of stream and lake sediments and soils, analyzing these materials directly or analyzing heavy mineral separates obtained from them. The most specific indicator (pathfinder) elements for gold are Ag, As, Sb and Te.

terrains sédimentaires; et aussi, les gisements de substitution tabulaires et irréguliers, qui se sont formés à proximité de failles et fractures, dans des lits à caractères chimiques favorables.

5. Les veines, filons, stockwerks, zones silicifiées, aurifères-argentifères et argentifères-aurifères, situées dans un milieu géologique complexe, comprenant des sédiments, des roches volcaniques et des roches ignées ou granitisées.

6. Les disséminations et stockwerks aurifères et argentifères, dans les roches ignées, volcaniques et sédimentaires.

(a) Disséminations et stockwerks aurifères et argentifères dans les corps ignés.

(b) Disséminations aurifères et argentifères dans les coulées volcaniques et les roches associées volcaniclastiques.

(c) Disséminations aurifères et argentifères dans les lits volcaniclastiques et sédimentaires: les gîtes qui se sont formés dans les roches tufacées et les formations ferrifères; et, les gîtes qui se sont formés dans des lits sédimentaires de composition chimique favorables.

7. Les gîtes aurifères que l'on rencontre dans les bankets et les quartzites.

Les placers constituent le principal type de gisements secondaires d'or.

Les bankets (conglomérats contenant surtout des galets de quartz vitreux) fournissent la plus grande partie de l'or mondial, soit environ 56 pour cent. Les autres gisements, surtout les disséminations, veines filoniennes, et placers éluviaux et alluviaux, et les diverses veines filoniennes, filons, corps massifs et stockwerks polymétalliques (où l'or est un sous-produit) constituent actuellement les 44 pour cent restants de la production.

Les types de gisements aurifères épigénétiques, tels que les veines, filons, stockwerks, et disséminations semblent s'être formés surtout par des processus d'imprégnation diffuse au cours du métamorphisme, les roches mères de l'or et des éléments associés étant surtout les colonnes encaissantes volcaniques ou sédimentaires, ou les deux à la fois. Les placers aurifères modernes sont d'origine sédimentaire, l'or s'accumulant suivant des traînées, les 'pay streaks', sous l'effet de processus chimiques (accrétion) et physiques (gravité) qui agissent au cours de l'altération et de la sédimentation ultérieure. Les bankets aurifères semblent avoir été originellement des placers, où l'or et une grande partie des éléments qui l'accompagnent ont subi par la suite un remaniement chimique extrême, par diagénèse et métamorphisme.

Les processus d'oxydation qui ont lieu dans les gîtes aurifères sont complexes, et dépendent essentiellement du Eh et du pH. Des phénomènes colloïdaux et de coprécipitation jouent aussi un rôle important. Les minéraux riches en fer et en manganèse ainsi que les carbonates que l'on trouve dans la gangue et le minerai ont une influence profonde sur les réactions qui aboutissent à l'enrichissement secondaire en cet élément. Dans la nature, l'or est difficilement entraîné en solution, et ses formes solubles sont facilement réduites par un grand nombre de matériaux naturels pour donner l'or métallique. Il en résulte que le seul minerai aurifère que l'on rencontre habituellement dans les zones oxydées des gisements aurifères est le métal natif. C'est sous cette forme qu'il s'accumule finalement dans les placers éluviaux et alluviaux, que l'on exploite dans le monde entier depuis des temps immémoriaux.

Pratiquement, toutes les méthodes géochimiques de prospection conviennent à la recherche de gîtes aurifères. Les méthodes les plus efficaces semblent être celles fondées sur l'échantillonnage de sédiments et sols fluviatiles et lacustres, et sur l'analyse de ces matériaux eux-mêmes, ou des minéraux lourds obtenus par séparation. Les éléments indicateurs qui accompagnent le plus fréquemment l'or sont Ag, As, Sb et Te.

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I have given thee the gold countries;
given thee what is in them of electrum,
lapis lazuli, and malachite.
—An epistle to Seti I from the Sun God
as given in the inscription in the
Temple at Edfu, Egypt, circa 1300 B.C.

Chapter I. Introduction

Research on the geochemistry of gold was begun by the writer some 25 years ago and has continued at intermittent intervals in the field and laboratory since that time. The work is now essentially complete, and it was thought that increasing world interest in the metal merited a report at this time. This volume is meant as a companion to that on silver (Boyle, 1968*b*) and should be read in conjunction with it.

Historical notes on gold

Of all elements gold has been the most esteemed by man since the earliest times. The desire for gold has markedly influenced his history and was a deciding factor in the development of chemistry. The cry 'gold' has lured men across oceans and continents, over the highest mountain peaks, into the Arctic tundras, into scorching deserts and through impenetrable jungles. Its gleam prompted the expeditions and conquests of Jason of Thessaly, Cyrus and Darius of Persia, Alexander of Greece, Caesar of Rome, Columbus of Genoa, Cortez and Pizzarro of Spain, Raleigh of England and many others down through history. Gold, according to Pliny the Elder (*Historia naturalis,* 79 A.D.), is the first of man's follies, silver the second. To make gold from baser metals was a major preoccupation of the alchemists as was also their ceaseless efforts to discover the elixir of life and the fountain of youth. In fact, the alchemists considered that they had indeed discovered the fountain of youth in the potable gold made by solution of the metal in aqua regia followed by treatment with ethereal oils. Roger Bacon certainly thought so for, in urging the elixir "*aurum potable, oleum auri, quinta essentia auri*" on Pope Nicholas IV he related.

> An old man, when ploughing a field in Sicily, one day found some of the yellow potable gold in a golden phial, and, supposing it to be dew, drank up the liquor. He was thereupon transformed into a hale, robust, and accomplished youth. The youth was thereafter received into the service of the Sicilian king, where he served some eighty years.

A thousand and more years of alchemy and innumerable experiments to make gold by concocting mixtures and potions of every conceivable type gave us the basis of modern chemistry. We can truly conclude with Francis Bacon.

> Surely to alchemy this right is due, that it may be compared to the husbandman whereof Aesop makes the fable; that, when he died, told his sons that he had left unto them gold buried in his vineyard; and they digged all over the ground, and gold they found none; but by reason of their stirring and digging the mould about the roots of their vines, they had a great vintage the year following: so assuredly the search and stir to make gold hath brought to light a great number of good and fruitful inventions and experiments.

Cadmus, the Phoenician, is said by some early writers to have discovered gold, but this is surely legend. Others say that Thoas first found it in the Pangaeus Mountains in Thrace. The *Chronicum Alexandrinum* ascribes its discovery to Mercury, the son of Jupiter, or to Pisus, king of Italy, who quitting his own country went into Egypt. In actual fact the discovery of the element we call gold is lost in antiquity. Reference to the metal can be found in most of the ancient Hindu, Chinese and Hebrew manuscripts, and in some, such as the Old Testament, it is the first metal mentioned. Gold beads, gold-hafted flint knives, stone jars with gold-covered mouths, gold ornaments, gold jewellery and various golden decorations have been found in the excavations of the most ancient civilizations, in the Neolithic monuments of France, in the Celtic graves of Europe, among the Sumerian relics of Ur, in predynastic monuments and graves of Egypt and among the very ancient remains of Minoan Crete, India and China. The tombs of the Pharaohs, especially that of Tutankhamen (c.1371–c.1352 B.C.), contained many beautifully executed gold pieces, and representations of quartz-crushing and gold-refining processes dating back to at least 1350 B.C. have been reported from these tombs. In the Code of Menes, who reigned in Egypt about 3500 B.C., it was decreed that "one part of gold is equal to two and one-half parts of silver in value." By 1000 B.C. both gold and silver were probably in widespread use as coinage metals in all countries between the Indus and the Nile. Other uses for gold mentioned in old manuscripts from various civilizations include the fabrication of idols, shrines, altars, bowls, vases, flasks, drinking cups, funeral face masks, sarcophagi, mummy cases and ornamental weapons. The art and trade of the goldsmith and minter have, therefore, come down to us from antiquity. Their story is told in magnificent detail by Singer (1954), Sutherland (1969), Blakemore (1971) and Hobson (1971).

The chemists and archaeologists tell us that the earliest gold objects of all ancient civilizations were fashioned directly from native gold (Caley, 1964; Hartmann and Sangmeister, 1972). Later, around the middle of the first millennium B.C., a method of purifying native gold came into existence, and at about the same time the practice of alloying metals such as silver and copper with gold and thus debasing the metal came into use[1]. It was apparently Archimedes, in his bathtub, who devised a means of determining the amount of alloyed metals, although it seems probable that his principle was known long before the advent of Greek science.

[1]The practice of alloying metals with gold was called *diplosis* by the early Egyptian goldsmiths, meaning the art of 'doubling' the weight of gold without materially changing its outward appearance. In Colombia where platinoids were abundant in the early gold placers, the Spanish treasurers encountered no end of troubles with 'doubling' of the gold by individuals by means of alloying with the platinoids, elements unknown in Europe at that time (1750). It is said that to avoid this debasing practice that the treasurers ordered all of the platinum won from the placers to be thrown into the sea or nonauriferous rivers (Weeks, 1968).

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The early metallurgy of gold probably involved little more than separating the metal by gravity from the dross of the placers and the quartz and other gangue of veins. Later, probably prior to 1000 B.C., it was discovered that gold adhered to mercury, and this developed into the amalgamation process that still finds a use in the treatment of gold ores. In the latter part of the 18th century and the greater part of the 19th the chlorination process was used extensively. Chlorine was passed through the moistened ore forming gold chloride which was leached out with water, the gold was then precipitated by ferrous sulphate. In 1887 McArthur and Forrest invented the cyanide process of dissolving gold followed by its precipitation with zinc dust. This is the method now commonly used on a large scale for the extraction of the element from its ores.

The extraction of gold and silver from sulphide ores by the process of liquation[2] was probably known to the ancients, as the Greeks seem to have been familiar with it and the Romans are known to have practised the art.

The process of 'parting' gold and silver by cementation with salt, whereby the silver is converted to chloride and the gold is run off, was apparently known in the 6th century B.C. Parting, employing acids, was unknown to the Romans. As far as can be determined, the first reference to the parting of gold and silver by means of nitric acid is to be found in the treatises of the Moslem alchemists of the thirteenth century. Modern processes of separating silver and other metals from gold involve the treatment of molten gold with chlorine and precipitation of the metal by electrolysis. The latter produces a pure product with only mere traces of silver, copper and other metals.

Native gold is a relatively common mineral and is present in gold-quartz veins, in oxidized zones of many sulphide and other types of auriferous deposits and in placers in streams and rivers in most parts of the world. It would seem that much of the gold of the ancients came first from placers and later from primary deposits and their oxidized zones. One of the richest placer streams which supplied much electrum to the Middle East, and is said to have been the source of the wealth of Croesus, was the river Pactolus (Sarabat), a tributary of the Hermus (modern Gediz) after passing Sardis in Lydia (now Anatolia, Turkey). The Pactolus drains the auriferous region on the flanks of Mount Tmolus (the present Boz Sira Daglari); it is the river in which it is said that Midas, the mythical founder of the Phrygian Kingdom, on the advice of Bacchus, bathed in its water to rid himself of the fatal faculty of turning everything he touched into gold. The other two legendary sources of gold, mentioned repeatedly in the Old Testament, Havilah and Ophir, have not been precisely identified.

In Genesis 2:10–12 it is written:

"And a river went out of Eden to water the garden; and from thence it was parted, and became into four heads.

"The name of the first is Pison, that is it which compasseth the whole land of Havilah, where there is gold;

"And the gold of that land is good: there is bdellium and the onyx stone."

There has been much speculation as to the location of the land of Havilah, the most probable from a geological viewpoint being that the river Pison is the modern Coruh which drains into the Black Sea near Batumi and that Havilah is the Pontic goldfield in Turkey, near Trabzon. This field is also probably one of the sites where Jason and the Argonauts sought the Golden Fleece, since within historical times placer miners used sheep's fleeces in this and other fields to catch the gold in their crude sluices. This method of winning gold (Frontispiece) is recorded by Strabo (63 B.C.–A.D. 19?), the Greek geographer, who wrote "the mountain torrents are said to bring down gold, and these barbarians catch it in troughs perforated with holes and in fleecy skins."

Strabo's reference is probably to the river Phasis (the present Rioni in Georgian S.S.R., draining from the Caucasus) which drained the Colchis region, supposedly the goal of the Argonauts in the legend of Jason. Whether or not this river produced gold in ancient times is uncertain. If it did, it is another of the possible sites where the legendary Golden Fleece was sought.

Ophir, the fabulously rich land of gold from which King Solomon's Phoenician (Tharshish) navy brought large amounts of the metal (some 34 metric tons) to his kingdom, has led to much speculation as to its location. In Genesis X it is associated with Havilah, which as noted above was probably the Pontic goldfield on the Black Sea. This may account for the long period of time, some three years, to make the voyage from Ezion-geber at the head of the Gulf of Aqaba to Ophir and back (I Kings 10:22). The cargos mentioned, almug (sandalwood) trees, precious stones, ivory, apes and peacocks suggest circumnavigation of Africa. Tharshish or Tarshish (a region centred on Cadiz) suggests that the gold may have come from Spain, and specifically from the oxidized deposits of the Huelva region where the modern mining town of Tharsis often equated with Tarshish is located. Other possibilities are East Africa, principally Rhodesia, and specifically the Zimbabwe region, where some think King Solomon's mines and metallurgical plants were located. This may also have been the site of Punt, exploited by the Egyptians, and from whence in Queen Hatshepsut's time (1600 B.C.) and later great store of gold was brought by the Egyptian navy. Still other possibilities suggested for the site of King Solomon's mines are southern Turkey (Bolkar Mountains), northwest Saudi Arabia (the land of the ancient Midians and possibly the Eldorado of the Hebrews), Sudan (Ancient Nubia; *Nub* means 'gold' in ancient Egyptian), Altai (Purington, 1903), Ethiopia, India, Cuba, Peru, the Far East, particularly Japan, Arctic Canada and a hundred other places. The story of Ophir is well told by Rickard (1932) and Sutherland (1969). The history of ancient Rhodesian gold mines and of Zimbabwe is related in fascinating detail by Summers (1969).

The most ancient map known, the famous *Carte des mines d'or* at Turin, is a Rameside papyrus and fragments depicting a gold mining region in Egypt. On it are located roads, miner's houses, gold mines, quarries, auriferous mountains and so on. The papyrus is said to date back to about 1320 B.C. The exact site represented by the map is in some

[2]In the process of liquation the copper, arsenic, etc., ores were first smelted often with a siliceous flux, to yield an impure ingot. This ingot was then alloyed with lead if there was insufficient lead in the ores, and the alloy was heated to a temperature between the melting point of lead and copper, during which the lead would liquate out, carrying the silver (and gold) with it. The lead was then cupelled on bone ash.

doubt. Some have suggested the mines represented are those of the Wadi Kareim or the Wadi Hammamat, on the Qena-Qoseir road (Gardiner, 1914). Derry (1951) says that the area represented on the map is the Wadi Fawakhir in which the El Sid Gold Mine is situated.

Gold has a widespread occurrence in practically every country in the world. In Europe, Asia and Africa ancient gold mines are known in Spain, Great Britain, Greece, Turkey, Saudi Arabia, Iran, India, China, Japan, U.S.S.R. (Uzbek S.S.R., Armenian S.S.R. and elsewhere) and numerous other countries. Placers have yielded gold from the rivers Tagus, Guadalquiver, Tiber, Po, Rhone, Rhine, Hebrus (Maritsa), Nile, Zambezi, Niger, Senegal, Pactolus (Sarabat), Oxus (Amu Darya which flows through the golden land of Samarkand), Ganges, Lena, Aldan, Yangtze and hundreds of others too numerous to mention. The Egyptians mined gold extensively in Sinai, eastern Egypt and Sudan (Nubia) as far back as 4000 years ago. It was from them that the Persians, Greeks and Romans learned the techniques of gold prospecting, mining and metallurgy. The Greeks and Romans mined gold ores extensively in the metalliferous regions of their empires (Davies, 1935; Tylecote, 1962; Healy, 1978). Pliny the Elder (A.D. 23–79) in his *Historia naturalis*[3] written in the early years of our era, repeatedly mentions the mining and metallurgy of gold, and Agricola[4] and many others before him refer to the element often in some detail. Rickard (1932, 1934, 1944) and Forbes (1964) have traced the history of gold mining, metallurgy and usage in great detail.

Compared with the gold placers and mines of the Old World those in parts of the New may be just as ancient, although it would appear that the Aborigines of North and South America put little emphasis on gold beyond its use as ornaments, jewellery, sacrificial knives, etc. Columbus of Genoa found the natives in possession of gold nuggets, a fact which excited the Spaniards to later pursue their conquests of Mexico and South America. Their avarice for gold and their ceaseless search for Eldorado, irregardless of the circumstances and cruelty they wrought on the natives, convinced the latter that the white man's god was 'gold'. The letter of King Ferdinand of Spain to his colonists in America dated July 25, 1511 would seem to bear this out for it commanded them[5] "Get gold, humanely if you can; but at all hazards get gold". The Spaniards were afflicted by the *auri sacra fames*[6] as are many individuals of our present civilization. In the pursuit of golden treasure, gods as well as men are often destroyed as in Wagner's great opera "Der Ring der Nibelungen" of which "Das Rheingold" is the prelude.

It seems certain from the accounts of Peter Martyr, Bernal Díaz del Castillo, José de Acosta and others that the Aztecs, Incas and the various peoples preceding them washed gold from placers with the gourd and *batea* (wooden pan) far back in antiquity. They probably also obtained much gold from the oxidized zones of various types of primary sulphide deposits, since they mined these extensively for silver long before the arrival of the Spaniards.

Gold has influenced the exploration and settlement of the Soviet Union, United States, Australia, South Africa and Canada in many ways. Even theories of the origin of gold deposits have been a factor in the history of Canada. It will be recalled that an early theory about the origin of gold deposits postulated that they developed under the celestial influence of the sun. From this it was easy to draw the conclusion that the largest number of gold deposits would be generated in the regions bounded by the Tropics of Capricorn and Cancer where the sun's influence was greatest. Columbus, in fact, wrote in his journal as he approached Cuba in 1492, that "From the great heat which I suffer, the country must be rich in gold." It will be further recalled that a dispute (Nootka Sound Controversy) arose between Spain and Great Britain over the sovereignty of the lands bordering the northwest coast of America. Spain contended she possessed sovereignty by authority of the Papal Bull of Alexander VI in 1493, but Britain took the view that rights of sovereignty could be obtained only through trade and the establishment of colonies. Spain meanwhile had established a settlement on Nootka Sound and in 1789 seized four British ships in the sound. This act nearly led to war but was finally resolved in favour of the British viewpoint in a convention signed on October 28, 1790. It appears probable that among the factors that influenced the Spanish decision was the advice given the Spanish king, Charles IV, that gold was unlikely to occur in the northern regions of America because it was thought that the element was generated only in those regions most influenced by the sun.

The Soviet Union has long been a legendary source of gold. The land of Colchis drained by the river Phasis (the modern Rioni) in Georgian S.S.R. is reputed by legend to have provided great quantities of gold. Similarly the Persians are said to have obtained much gold from the Scythians, a polyglot group of tribes that inhabited the region north of the Black Sea, and from various Iranian and other tribes who inhabited the Ural-Uzbek-Altai region. The golden road to Samarkand was known centuries before Christ. With time the monopoly of gold mining became the sole preserve of the Imperial Czars who pursued extensive placer and lode mining first in the Urals, beginning about 1774, and later in many parts of Siberia, especially in the Altai region where alluvial deposits were exploited as early as 1820. In 1829 the placer deposits of the Lena were first exploited and in 1840 those of the Yenisei Ridge came into production; the placers in the drainage system of the Amur were apparently first worked around 1867, and those in the Far Eastern Maritime area appear to have been first exploited around 1870 or earlier.

Gold washing and mining have a relatively long history in the United States. In New Mexico, Arizona and probably California, the Spaniards operated mines from which they obtained silver and possibly some gold at least as far back as 1620. There are also old records mentioning early discoveries of gold nuggets in California in the period 1775–1780 (Clark, 1970). Gold was also known to the Indians, Spaniards and early settlers in the southern Appalachian region where mining began about 1792 (Becker, 1895). These deposits though rich were relatively small and soon depleted. The scene

[3] *Historia naturalis*, book XXXIII.
[4] Agricola, G., *De re metallica*.
[5] Helps, A., *The Spanish Conquest of America*, London, 1857.
[6] Quid non mortalia pectora cogis,
Auri sacra fames!

Accursed thirst for gold!
What dost thou not compel mortals to do.
–Virgil-Aeneid

then turned to California, to Coloma on the American River, where in the tail race of Sutter's Mill on the morning of January 24, 1848, James W. Marshall[7] plucked the first gold nugget from the sand that led to the great California gold rush of 1849–1850. There followed then in succession the discoveries of the Mother Lode and Grass Valley in California and the famous Comstock Lode in Nevada during the 1850's. The gold telluride deposits of Cripple Creek in Colorado were discovered in 1892, and by 1905 the Tonopah and Goldfield deposits in Nevada and the Alaskan placer deposits had been discovered.

Among the miners of the great California rush of 1849 was one Edward Hammond Hargraves, an Australian. After sojourning in California for some time and noting similarities in geology with areas where he had travelled in New South Wales he returned to the latter where, near Bathurst, on February 12, 1851 he discovered payable gold at the junction of Summer Hill Creek and Lewes Ponds (Lewis Pounds) Creek a tributary of the Macquarie River. This discovery led to the great gold rushes of Australia that have made that country famous as a gold producer. Previously (1823) gold was noticed by surveyor James McBrien in the Fish River between O'Connels Plain and Diamond Swamp north of the old Bathurst Road, near where the town of Oberon, New South Wales now stands. Many of the Australian miners stayed on to discover lead, zinc, copper, silver and tin deposits; others found a different 'Golden Fleece' on the grassy plains and hills of that fair continent. The history of the 'Midas Gullies' of Australia and of Australian mining is related in fascinating detail by Blainey (1969).

Gold was known to the Maoris long before the coming of the pakehas to New Zealand. However, there is little mention of the precious metal in the journals of the early explorers of New Zealand, and it was left mainly to the prospectors who had followed the great gold rushes to California and later to Australia to establish the presence of gold in commercial amounts. Alluvial gold was first discovered in 1852 at Coromandel (Hauraki Goldfield) North Island in Driving Creek by Charles Ring; later at Collingwood in Nelson, South Island in 1857; at Gabriels Gully in Otago by Gabriel Read in 1861; and in a number of sites along the western coastline of the South Island in 1864. Lode gold in the Hauraki Goldfield, the main centres being Waihi, Thames, Karangahake and Coromandel, was first exploited in the 1860's; the quartz deposits in Otago, South Island, were first worked in the 1870's; and the productive quartz lodes at Reefton produced their first gold in the early 1870's. The history of the discovery and mining of the gold deposits of New Zealand, of which there are many, ranging in age from Precambrian to Recent, is admirably told by Salmon (1963).

Gold and gold tellurides are widely distributed in the Fijian Islands, and the presence of these minerals was evidently known to the early Fijians. Baron A.B. de Este is said to have discovered gold in the Tavua area in 1872, but some 60 years were to pass before any serious prospecting was carried out. In 1932 Bill Borthwick and Jack Sinclair discovered payable gold on Vunisina Creek a small tributary of the Nasivi River. Further investigation of this prospect, which is associated with the Tertiary Vatukoula volcanic caldera, led to the development of a number of mines, of which the famous Emperor Mine has been in continuous production since about 1935. The history of prospecting in Fiji, and the development of the Emperor and other mines, is related in some detail by Fraser (1954).

Gold from West Africa found its way into Europe as early as the 10th century and probably before. Most of this gold came by Sahara caravan to Barbary and thence to Europe, the original sources being the Kingdoms of Ghana, Mali and Songhai. It is said that much of this gold came from a region known as Wangara (probably the basin of the Falémé, a tributary of the Senegal River and noted for its placers), but it seems more than probable that the gold had a much more widespread source considering the aurificity of West Africa. In any event one of the motives of the Portuguese voyages, inspired by Henry the Navigator was to ascertain and exploit the west African gold. The Portuguese were soon followed by a host of English, French, Dutch and Spanish entrepreneurs. It is thought that annually more than a quarter of a million ounces of gold reached Europe during the 15th and 16th centuries from African sources.

In South Africa an historic event took place in 1834 when a Boer, Carel Kruger, while on a hunting expedition north of the Vaal River discovered gold on the Witwatersrand, or White Waters Ridge. Little attention was, however, paid to the find, the goldfields of Barberton and the DeKaap Valley being the chief focus of gold prospecting through 1885. In 1886 George Harrison, an Australian gold-digger, and George Walker, an Englishman, discovered payable gold reef on the Witwatersrand. This discovery soon led to the development of the great reefs which constitute the largest gold deposits known and which have made South Africa the foremost gold producer in the world. The story of the discovery of the remarkable deposits of the Witwatersrand, of the growth of Johannesburg and of the men who struggled for control, not only of the gold reefs, but of what is now South Africa is told in an admirable way by Cartwright (1962), Rosenthal (1970) and Robert Crisp in *The Outlanders* (Granada Publishing Limited, Mayflower Books Ltd.; Frogmore, St. Albans, Herts.; England, 1974).

There are a few references to gold in the annals of the voyages of Cabot, Jacques Cartier and Samuel de Champlain, and it is certain that these gentlemen explorers had an eye to the metal wherever they went. The references are, however, vague and the existence of gold in some of the sites mentioned appears doubtful. Jacques Cartier for instance in his second voyage[8] mentions that the Indians informed him that the people of the Kingdom of the Saguenay possessed a great store of gold and copper. Further, in the third voyage[9] he mentions diamonds and flakes of fine gold as thick as a man's nail near Cap-Rouge, southwest of Quebec City. In Roberval's[10] account of his voyage in 1542–1543, he records that Cartier brought to St. John's in Newfoundland diamonds and a quantity of gold ore which he found in the country of

[7]Del Mar (1880, p. 165) says that it was Marshall's daughter who first discovered gold in the tail race of Sutter's Mill.

[8]Biggar, H.P.: *The voyages of Jacques Cartier*, Publications of the Public Archives of Canada, No. 11, 1924, p. 201.
[9]*Ibid.*, p. 255.
[10]*Ibid.*, p. 264.