STATE OF IDAHO
C. Ben Ross, Governor

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IDAHO BUREAU OF MINES AND GEOLOGY
John W. Finch, Secretary

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THE RECOVERY OF GOLD FROM ITS ORES

By

A. W. Fahrenwald

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University of Idaho
Moscow, Idaho

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OCCURRENCE OF GOLD

Gold occurs in nature in the metallic state alloyed with small percentages of silver and chemically combined with the element tellurium. Native gold is found in veins associated with quartz and various sulfides, notably pyrite and pyrrhotite, galena, chalcopyrite, arsenopyrite, nickel and cobalt minerals, and less commonly zinc blende; with carbonates, especially ankerite. Generally the metal is finely disseminated in the body of the sulfides, or deposited on the surface of mineral particles, in the form of thin films or easily visible grains. Figure I is a photomicrograph* of a polished surface of a complex gold ore. Lead, iron, copper, silver, and bismuth minerals are present. The light spots are gold. The smallest pieces are about .001 inch in diameter. The patches marked "p" and "s" are respectively iron pyrite and sphalerite, the sulfide of zinc.

In the oxidized parts of veins the gold is often associated with limonite, and gold-bearing quartz may contain small amounts of copper carbonates and manganese oxides. When gold is apparently disseminated in igneous or metamorphic rocks, minute veinlets of quartz or carbonates usually accompany it. Gold is widely distributed. It is found in sea water (less than 1/40 grain per ton), and in insignificant amounts in a great variety of places.

The reason for the occurrence of gold in greater quantities in lodes than in neighboring rocks is not known with certainty, but it is considered that it has risen from below with other minerals in solution and has been precipitated chemically where it is found.

Tellurides of gold are contained in rich ores in western Australia, in Colorado, and elsewhere. The mineral calaverite, $AuTe_2$, a bronze-yellow gold telluride, contains 40 per cent of gold and the gold-silver telluride, sylvanite, $AuAgTe_4$, a steel-gray mineral, contains up to 28 per cent of gold. When the gold tellurides oxidize, the resulting native gold is often extremely pure and finely divided, and may be covered with tellurous oxide, called "tellurous" or "mustard gold." It resembles yellow clay, but turns bright on heating.

Among the minerals sometimes mistaken for gold may be mentioned pyrite, marcasite, and especially chalcopyrite, the iron-copper sulfide. These minerals, however, are very brittle, they oxidize when heated and are quite soluble in acids, while gold remains bright on heating to high temperatures. It is soft and malleabl

In panning or concentrating, many people have been mislead by heavy lead minerals of a yellow color, such as the molybdate, chromate, tungstate, and even the phosphate, but these are distinguishable under a lens or low-power microscope by their brittleness and transparency. Nearly all substances which may be mistaken for gold are soluble in hot acids. Gold is not.

When gold-bearing veins have become disintegrated and swept away into alluvial deposits, the particles of gold, where released, are found in the sand and gravel of the beds. Gold occurring in this way is called "alluvial" gold and is recovered by methods of hydraulic mining and dredging. For methods of recovering alluvial gold, the reader is referred to "Elementary Methods of Placer Mining," by W. W. Staley, Pamphlet No. 35, Idaho Bureau of Mines and Geology; "Placer Mining Methods

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* From a mineralogical report on ore of the Mayflower Gold Mines, Inc. By courtesy of Thos. H. Hite, Geologist.
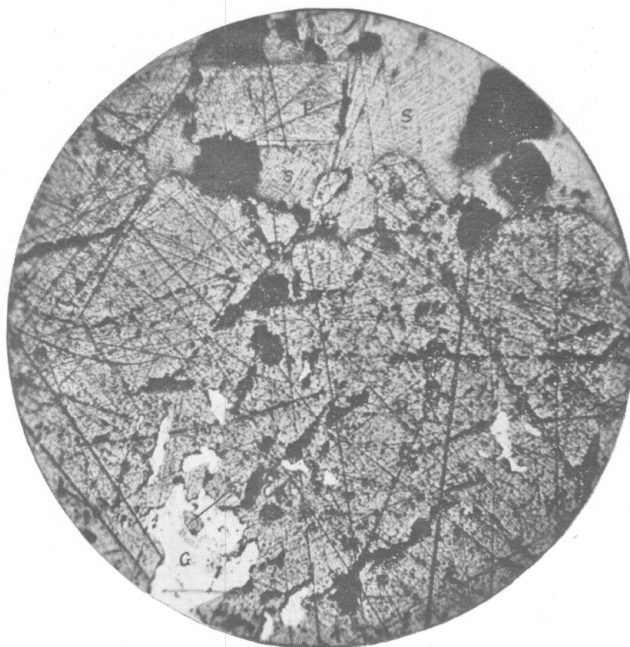
Figure 1

Photomicrograph of a polished surface of a complex gold ore.

and Costs in Alaska," by N. L. Wimmler, Bulletin No. 259, U. S. Bureau of Mines (1927); and Peele's "Mining Engineer's Handbook," published by McGraw-Hill Book Company, New York.

PROPERTIES OF GOLD

Gold is the only metal that has a yellow color when massive and pure. The color is greatly modified by impurities, silver lowering the tint, while copper heightens it.

Gold exceeds all other metals in malleability and ductility. It can be beaten, when pure, into leaves one three hundred thousandth of an inch in thickness. The presence of small percentages of bismuth, lead, or tellurium, renders it very brittle.

The specific gravity of gold is 19.27, i.e., it is 19.27 times as heavy as water. Its electric conductivity is not so great as that of either copper or silver. If the electric conductivity of silver is rated at 100, gold is 76.7.

The most effective solvents of gold are potassium or sodium cyanides, a mixture of hydrochloric and nitric acids (called aqua regia), and chlorine, or any chemical mixture that liberates free chlorine gas.

Gold is readily precipitated from cyanide solutions by metallic zinc (shavings or dust); some zinc is dissolved and the gold is precipitated as a black slime on the zinc. It is precipitated from its chloride solution by treatment with ferrous sulfate, sulfuretted hydrogen or sulfur dioxide.

Gold alloys with most metals, but only a few are of practical use in the arts. The most important are those which gold forms with mercury, silver, palladium, platinum, copper, and nickel. Metallurgically, its alloys of zinc and lead are important in recovering gold from molten lead bullion.

USES OF GOLD

It is possible here to indicate only a few of the ways in which gold performs its varied important, and, in some cases, vital functions in modern life. Gold has had a vital influence in the world's history, for the lure of gold has led men to wage war and subjugate whole peoples, and to colonize the most forbidding wastes.

The essential main uses of gold are: (1) Gold held in reserve by the federal government, (2) gold used in dentistry as pure gold and alloys, and (3) pure gold used in the arts, or alloyed with other metals.

Gold is held in stock by the federal government to provide the gold basis for the currency and credit requirements of the world's trade. There is practically no gold money in circulation. The circulating medium is currency, the actual value of which is determined primarily by the supply of gold within a country. The sole importance of the gold reserve is that it guarantees the convertibility of the currency into gold at par. Such convertibility, however, is possible only when, by proper adjustment of the supply of gold, the currency is maintained at an approximate parity with gold.

The following table gives the gold production in millions of dollars for each year from 1919 to 1928 inclusive, the amount consumed each year in arts and by the orient, and the balance available for money:

TABLE I

Total Gold Produced and Percentage Available
for Arts and Orient and Money

(Joseph Kitchin, Harvard Rev. of Economic Statistics (1928)

Year	Total Production	Consumed in Arts and Orient	Balance available for Money
1919	365	304	61
1920	336	110	226
1921	331	66	265
1922	319	218	101
1923	367	188	179
1924	394	334	60
1925	394	216	178
1926	399	154	245
1927	401	148	253
1928	409	163	246

It is seen that the amount of new gold likely to be available for monetary uses is difficult to calculate because of the uncertainty of purchases of gold by oriental countries. In the past 10 years the average annual addition to the monetary gold stock has been about 1.8 per cent of the total stock, and in the last three years about 2.3 per cent. Economists have estimated that an annual increase of 3 per cent in the gold stock is required to provide the gold base for the increasing currency and credit requirements of the world's trade. Such an estimate, however, is seriously effected by price levels, etc.

Gold alloys of various degrees of fineness (parts of gold in 1000) are available in a variety of colors. Red, yellow, green, and white gold can be produced by a suitable choice of the added silver and base metal alloying constituents. White gold alloys, which were originally introduced as platinum substitutes, are widely used in the less expensive grades of jewelry and are produced in both the solid and filled grades ranging from 10 to 20 carats* fine.

These alloys are usually of the gold-nickel-copper-zinc type and the whitest grades are difficult to fabricate on account of hardness. Where better working properties are required, the gold-palladium and gold-palladium-nickel alloys are used.

The color of the softer white golds is not very pleasing and the low-carat gold alloys tarnish to some extent.

Gold-platinum and gold-palladium alloys find an important application in making spinnerets used in the production of rayon, the substitute for silk.

Gold is used in limited quantity in the manufacture of scientific apparatus where it fills important needs.

A large amount of gold is used in dentistry. Gold is the base of a large variety of alloys used in dental work. Platinum and palladium raise the melting point of gold, increase its hardness, and lighten its color. Certain of these alloys possess unusually high tensile strength, in excess of 150,000 pounds per

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* A carat is one part in 24 parts. For example, a 22 carat gold is 22 parts gold and two parts of other alloying metal.

square inch.

Recently considerable interest has developed in white casting alloys consisting essentially of palladium-gold-silver and copper with the palladium content ranging from 14 to 25 per cent. The appearance of these alloys in the mouth is far less conspicuous than the yellow gold heretofore used.

PRODUCTION OF GOLD

For some concise and pertinent statements of gold production since the discovery of America, the reader is referred to a long press bulletin dated November 5, 1929, issued by the Director of the U. S. Bureau of Mines. This notice states that since the discovery of America world production of gold has been approximately 1,003,500,000 ounces; that this gold would make a cube 38.5 feet square.

Also a great volume of statistical information regarding the world production of gold since 1492 is contained in Economic Paper No. 6 by Robert Ridgway and the staff of the Common Metals Division of the U. S. Bureau of Mines, which may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., price 20 cents.

The following table gives the gold production of the world, by countries:

TABLE II

Gold Production of the World, by Countries, since 1920
(Mineral Industry*)

	1926	1927	1928	1929(a)
United States(inc. Philippines)	$ 46,276,000	$ 45,419,000	$ 46,165,000	$ 43,900,000
Mexico	15,972,000	14,991,000	14,452,000	13,475,000
Canada	36,263,000	38,300,000	39,082,000	39,841,000
Total North America	$ 98,511,000	$ 98,710,000	$ 99,699,000	$ 97,316,000
Central America	$ 1,800,000	$ 1,500,000	$ 1,250,000	$ 1,000,000
South America	$ 9,975,000	$ 10,166,000	$ 8,615,000	$ 8,450,000
Transvaal	$205,783,000	$209,250,000	$214,042,000	$215,278,000
Rhodesia	12,283,000	12,027,000	11,922,000	11,591,000
West Africa	4,334,000	3,689,000	3,264,000	4,606,000
Congo, Madagascar, etc.	4,013,000	3,905,000	3,861,000	4,000,000
Total Africa	$226,413,000	$228,871,000	$233,089,000	$235,475,000
Russia (inc. Siberia)	$ 20,510,000	$ 21,932,000	$ 24,806,000	$ 24,000,000
Other Europe	2,154,000	3,216,000	3,138,000	3,000,000
Total Europe	$ 22,664,000	$ 25,148,000	$ 27,944,000	$ 27,000,000
British India	$ 7,937,000	$ 7,944,000	$ 7,774,000	$ 7,507,000
East Indies	2,785,000	2,737,000	2,279,000	2,250,000
Japan and Chosen	10,340,000	10,295,000	9,823,000	9,650,000
China and others	4,622,000	3,474,000	2,786,000	2,500,000
Total Asia	$ 25,684,000	$ 24,450,000	$ 22,662,000	$ 21,907,000
Australia and New Zealand	$ 13,509,000	$ 13,313,000	$ 13,079,000	$ 12,228,000
Total for World	$398,557,000	$402,158,000	$406,338,000	$403,366,000

(a)
    Preliminary estimates

*McGraw-Hill Book Co., New York

In Table III is given the gold production of the United States, by states.

TABLE III
Production of Gold in the United States, by states[a]

	1926	1927	1928	1929	1930[b]
	Fine oz.	Fine oz.	Fine oz.	Fine oz.	Fine oz.
Alaska	328,866	286,298	330,604	379,669	399,779
Alabama	. . . .	. . . . .	. . . . .	10	10
Arizona . . .	232,200	203,088	189,519	211,108	151,428
California . .	581,700	564,981	513,249	409,020	438,912
Colorado . . .	346,297	259,111	258,564	220,285	214,195
Georgia . . .	140	15	34	58	203
Idaho	12,640	15,209	20,351	19,597	20,748
Montana . . .	57,707	56,076	59,661	55,854	45,724
Nevada . . .	170,889	149,445	177,730	158,991	134,410
New Mexico . .	20,105	26,098	34,961	33,026	29,576
North Carolina	121	34	131	174	184
Oregon	13,303	14,425	11,865	17,657	13,975
Pennsylvania .	106	126	987	745	639
South Carolina	15	. . . . .	10	. . . . .	. . . . .
South Dakota .	286,961	322,681	318,095	312,328	402,422
Tennessee . .	416	426	537	653	1,030
Texas	164	324	556	1,263	1,122
Utah	181,832	199,518	211,418	237,221	200,103
Virginia . .	10	. . . . .	. . . . .	. . . . .	. . . . .
Washington .	8,833	19,398	16,414	3,972	3,720
Wyoming . . .	. . . . .	. . . . .	34	48	450
Total	2,238,616	2,117,253	2,144,720	2,056,629	2,053,629
Philippine Islands .	96,426	79,872	88,531	151,757	178,934
Total . .	2,335,042	2,197,125	2,233,251	2,208,386	2,232,593

(a) Figures of Bureau of the Mint and U. S. Bureau of Mines.
(b) Preliminary figures.

Of the countries, Africa leads by a large margin. Of the states, California ranks No. 1 in gold production; South Dakota a close second; Utah, third, and Idaho ranks ninth.

The gold produced in Idaho comes from placer and dredging operations, from the mining and milling of gold ores, as a by-product in the milling and smelting of lead and zinc ores, and to a small extent from copper ores.

The principal districts from which gold is now produced in the United States are the Whitewood district, South Dakota; the Marysville, Oroville, Folsom, Grass Valley, and Jackson districts, California; the Cripple Creek, Eureka, San Meguel, (Telluride), and California districts, Colorado; the West Mountain (Bingham Canyon), Tintic, and Park City districts, Utah; the Verde, Warren, and Ajo districts, Arizona;

the Robinson, Jarbridge, Tonopah, and Comstock districts, Nevada; the Southeastern district, Seward Peninsula, and Yukon Basin, Alaska; and the Summit Valley (Butte), Montana.

Production of Gold by Sources

Table IV gives data of gold production in the United States, by sources.

TABLE IV

Gold produced in the United States*, by Sources (Mineral Industry)

Year	Placers	Dry and siliceous ores	Copper ore	Lead ore	Zinc ore	Copper-lead and Copper-lead-zinc ores	Lead-zinc ore	Total
1919	704,377	1,780,567	186,701	41,945	86	1,043	38,563	2,753,282
1920	603,002	1,523,331	171,055	46,776	3,657	3,731	31,435	2,382,987
1921	677,435	1,548,251	52,765	61,924	76	159	4,400	2,345,010
1922	537,910	1,560,789	130,928	35,415	2,807	2,467	22,935	2,293,251
1923	551,929	1,510,098	271,690	38,109	3,321	3,801	25,969	2,404,913
1924	450,720	1,602,469	310,413	39,947	227	1,995	38,560	2,444,331
1925	436,251	1,414,446	348,025	50,378	375	5,515	52,384	2,307,374
1926	457,717	1,295,570	365,223	45,724	1,194	3,335	63,763	2,232,526
1927	451,215	1,162,404	367,639	41,504	1,563	2,631	80,076	2,107,032
1928	416,832	1,195,894	414,771	35,959	130	6,973	77,595	2,148,064
Per cent, 1919	25.6	64.7	6.8	1.5	....	....	1.4	....
Per cent, 1928	19.4	55.7	19.3	1.7	....	0.3	3.6	....

* Philippine Islands and Porto Rico excluded.

Here we see that the gold recovered from placers has declined from 25.6 per cent in 1919 to 19.4 per cent in 1928, from dry and siliceous ores from 64.7 per cent to 55.7, from copper ore increased from 6.8 per cent to 19.3 per cent, from lead ore increased from 1.5 per cent to 1.7 per cent, and from copper-lead and copper-zinc ore increased from 1.4 per cent in 1919 to 3.6 per cent in 1928. These changes probably are due more to new and improved metallurgical methods (flotation in particular) than to trends in mining or to discoveries of new ore.

METHODS OF DETECTING AND ASSAYING GOLD ORE

Gold occurring free in quartz can be easily identified by the man in the field by simply crushing a few pounds of the rock in an iron mortar or on an anvil, and carefully panning with a miner's "gold pan." Particles of gold will appear in the pan after the bulk of the quartz sand has been washed off. Gold associated with various sulfides and as telluride is much less easy to detect by simple methods. Ores of this type require a fire assay and this should be done by a competent and reputable assayer.

There is a certain type of assayer who is willing to, and actually does, give favorable assay reports when there is absolutely no gold in the sample submitted to him for assay. This person claims he has a new and secret method or process that **gets** the gold and that the old fire assay is not capable of recovering the gold, all of which is nonsense. The motive back of such claims is dishonest. Methods of assaying are given in a number of books on the subject. A Manual of Fire Assaying by Fulton and Sharwood, published by the McGraw-Hill Book Company, Inc., 370-7th Avenue, New York, is one of the best. There are many reputable public assayers, and their assaying is dependable. State schools of mines sometimes do private assaying. The Idaho School of Mines, however, although it does make assays for Idaho people, does not cater to this kind of work and prefers to have the prospector, or whoever is interested in gold assays, send his samples to the public assayers. Their laboratories are as well equipped to make rapid and reliable assays as are the schools of mines. A short list of competent assayers is published under Professional Classification in the Engineering and Mining Journal. A list also may be obtained from the nearest school of mines or your state mine inspector.

The fire assay is the only reliable method of determining gold in ores. It is comparable to commercial smelting methods and it gives the true gold content of the ore, and should be accepted as final.

The assayer reports the gold content of an ore in terms of ounces per ton and in dollars. The mint value of gold is $20.67813 per troy ounce, 1000 fine. The number of ounces present times the value $20.67 is the assay value of the sample in gold.

CLASSIFICATION OF GOLD ORES

From the viewpoint of gold recovery methods, and for convenience to the reader, gold ores may be classified as follows:

1) Quartz ores in which the gold is free, i.e., in the form of metallic gold particles ranging in size from particles easily visible to the eye to particles as fine as dust and detectable only with a high-power microscope.

2) Ores in which the gold is free but intimately associated physically with such minerals as pyrite or galena, either in the crystal or as a painted film on the crystal surface.

3) Ores in which the gold content, as a compound with tellurium or partly as free gold, is associated almost wholly with one or several minerals in the ore such as galena, pyrite, arsenopyrite, chalcopyrite, etc.

"The Ores of Copper, Lead, Gold, and Silver," by Charles H. Fulton, U. S. Bureau of Mines Technical Paper 143, contains a great deal of information bearing on this subject.

METHODS OF GOLD RECOVERY

Gold is recovered from its ores by one, or a combination, of the following methods:

I. Amalgamation
II. Cyanidation
III. Concentration
IV. Smelting

All gold and/or silver ores yield a high percentage of their gold content when smelted with lead or copper ores, and an almost complete saving of gold is affected in the process of refining the lead and copper. Molten copper or lead are strong collectors of gold and silver. Gold is separated from copper bullion electrolytically and from lead bullion generally by agitation with a small percentage of metallic zinc for which it has a strong affinity and with which it forms a chemical compound.

Table V gives the percentage of gold produced by the various methods of recovery.

TABLE V

Percentage of Gold Produced by Various Methods of Recovery*
(Mineral Industry)

Year	Amalgamation		Cyanidation		Placers		Smelting**	
	Gold	Silver	Gold	Silver	Gold	Silver	Gold	Silver
1919	31.5	0.5	28.5	18.8	25.6	0.15	14.4	85.5
1920	28.5	.4	24.3	13.4	25.3	.13	21.9	86.1
1921	32.6	.45	23.9	16.0	28.9	.18	14.6	83.4
1922	35.4	.3	23.6	14.4	23.5	.1	17.5	85.2
1923	28.4	.3	25.3	14.3	22.9	.1	23.4	85.3
1924	30.6	.4	23.0	13.9	18.4	.1	28.0	85.6
1925	32.6	.3	20.7	9.5	18.9	.1	27.8	90.1
1926	30.6	.3	20.4	8.3	20.5	.1	28.5	91.3
1927	30.8	.3	17.9	7.0	21.4	.1	29.9	92.0
1928	31.9	.4	17.0	7.3	19.4	.1	31.7	92.3
1929	29.6	.35	15.8	5.3	19.8	.1	34.8	94.3

*Philippine Islands and Porto Rico excluded.
**Both crude ores and concentrates.

Much of the gold produced by smelting comes as a by-product in the smelting of copper and lead ores. Due to the flotation process there has been an increase in the tonnage of gold concentrates smelted. Comparatively little true gold ore is directly sold for smelting. Smelting charges and deductions on the full weight of ore, with the cost of freight and loading in accessibility and bad roads, often make it advisable to adopt some method which may be metallurgically inferior, as regards percentage recovery, but which puts the precious metal in a form such as bullion, rich precipitate, or high grade concentrate, in which it is more profitably salable.

AMALGAMATION PROCESS

History

The amalgamation process is one of the oldest known methods of gold recovery. It is mentioned by Pliny in his "Natural History" and descriptions of amalgamation processes for both gold and silver are to be found in various 16th Century treatises. The history of the process is given in detail by Pearcy (John Pearcy, Silver and Gold, 1880).

Principle of the Process

The process is based on the fact that mercury dissolves gold. A saturated solution of gold in mercury contains 13.5 per cent of mercury. Physically the alloy is a paste and is called "amalgam."

The Process

The amalgamation process comprises (1) crushing the ore in water to pass, say, about a 14 or 20 (sometimes finer) mesh sieve, (2) passing the crushed ore in the form of a thin pulp over a mercury-covered copper, or silver-coated, plate, (3) removing the gold-mercury amalgam at regular intervals and re-dressing the plates with new mercury, and (4) distilling the mercury from the gold amalgam, thereby producing nearly pure gold, and recovering the mercury for reuse on the plates.

In the early practice, the crushing was done by gravity stamps. In a number of places this practice is still retained. The modern trend, however, is to use secondary crushers of the jaw or gyratory type, and a ball or rod mill to reduce to whatever mesh is desired.

The technique of the steps 2, 3, and 4 of the process has changed little in the many years of the use of the amalgamation process.

Forms of Gold and Losses in Amalgamation Process

Ores that can be treated successfully by amalgamation are called "free-milling" ores. It is practically never possible to obtain high extraction of gold by amalgamation alone. This is due principally to two reasons, namely, (1) fine (flour) gold that fails to settle upon, and make contact with, the plates, and (2) a type of gold occurrence in which the gold particles are brown and lusterless. This may be due to coatings of oxide of iron, manganese, or tellurium. Free-milling ores seldom yield more than a 70 per cent recovery. This is the explanation of the existence (mostly in the past) of tailing piles about the country assaying several dollars a ton in gold. Many or most of them have since been profitably retreated by cyanidation or flotation. Present operators, even the small ones, are not satisfied with the gold recovery possible by plate amalgamation only, but follow the plates with cyanidation or flotation, or table concentration.

Amalgamation as used today recovers only relatively coarse gold and for this purpose plays an important role in gold metallurgy. Cyanide acts too slowly in dissolving coarse gold, but readily dissolves fine gold. Flotation concentration is not effective on coarse gold. The small operator who wishes only to treat a small tonnage of high-grade ore in remote places, and looks for quick returns rather than for 100 per cent recoveries, probably still will find the amalgamation process the best available method. A small stamp or preferably a ball mill and a few square feet of mercury-covered copper plate usually meet his needs. However, to the larger operator amalgamation is now only an adjunct to a more elaborate plant of high over-all efficiency.

THE CYANIDE PROCESS

Discovery

The cyanide process was invented in 1887 just at a time when there was pressing need for improvement in the treatment of gold ores. It was about then that the industry, after languishing for many years, was receiving a fillip from the discovery of the Rand gold field. At that time the available gold extraction processes were cheap but in general could only extract some 60 per cent of the values and in some cases gave no extraction whatever. Smelting, although effective, was costly and required the supply of large quantities of rich ore, together with lead ore and cheap fuel at no great distance from the gold mines.

The cyanide process was put forward by J. S. MacArthur and R. W. and W. Forrest, and was received at first with derision, partly because the chemical

was rare and had been little studied. Cyanide was best known at the time as a deadly poison.

The process was first used mainly on the tailings from amalgamation in the Transvaal, but was applied later to both gold and silver ores without previous amalgamation, and this practice became the general rule by 1925.

For a thorough review of the early history of the cyanide process, the reader should refer to a serial article by A. W. Allen in the September 3rd, and October 1st and 8th, 1927, numbers of the Engineering and Mining Journal.

Principle of the Process

The process is based on two scientific facts, namely, (1) that gold is soluble in dilute solutions of potassium or sodium cyanide, and (2) that the dissolved gold is precipitated from its cyanide solution by metallic zinc.

The Process

The process comprises the following steps: (1) Crushing the ore to a suitable fineness in cyanide solution,or in water and cyanide, then added to the ore-water pulp. (2) Agitation of the pulp to effect dissolution of the gold content of the pulverized ore. (3) Separation of the gold-containing cyanide solution from the pulverized ore. (4) Precipitation of the gold from the cyanide solution by passing it over zinc shavings, or agitating it with zinc dust. (5) Refining the black gold-zinc precipitate which contains an excess of zinc, and small amounts of other elements, producing gold bullion. If silver is present, the gold and silver are separated by dissolving the silver with sulfuric or nitric acid. (6) Melting and casting the gold bullion into bars for shipment to the mint. In modern practice the gold solution prior to precipitation is subjected to a vacuum treatment to remove dissolved air. This treatment is known as the Crowe process. This treatment gives a more rapid and thorough precipitation of the gold by the zinc with less consumption of zinc.

For gold extraction the strength of cyanide solution ranges from .01 per cent to .05 per cent. Lime also is used in the process in just sufficient amount to maintain the solution in an alkaline condition; two or three pounds per ton usually are sufficient. For roasted concentrates more lime may be needed and a cyanide solution as high as 15 or 20 pounds of cyanide per ton of solution.

The cyanide process is highly technical and for its successful operation the attention of an experienced metallurgist is required.

Not all ores yield to high recovery by the cyanide process. Arsenical and antimonial ores always have given trouble. They require a preliminary low temperature roast.[1] Gold ores containing constituents, such as copper[2], readily soluble in cyanide solution, consume so much cyanide as to make the process inapplicable. It is on these ores that the flotation process has found wide application.

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[1]Leaver, E. S. and Woolf, J. A., Cyanide Extraction of Gold and Silver Associated with Arsenic and Antimonial Ores: U. S. Bureau of Mines Tech. Paper 423 (1928).

[2]Leaver, E. S. and Woolf, J. A., Effect of Copper and Zinc in Cyanidation with Sulfide-Acid Precipitation: Am. Inst. of Min. & Met. Engrs. Tech. Pub. No. 250 (1929).

GRAVITY CONCENTRATION

Woolen blankets have long been used for catching gold at Brazilian mines, where mercury is sickened by bismuth and tellurium minerals. They were introduced into early Californian and Australian mills, and have been used in mills treating the rich Goldfield, Nevada, ore. They are generally laid overlapping on inclined tables, the pulp flowing over them for an hour, or several hours, when they are folded, replaced by fresh blankets, and the accumulation washed off in a tank.

On the Rand, amalgamation on copper plates had been generally discarded by 1925, owing to the difficulty of preventing theft and the danger from mercury poisoning. Instead of passing the crushed ore from the tube mills over amalgamated plates, it is concentrated on a surface of corduroy, which retains the heavy particles including all coarse gold. The corduroy also catches osmiridium and other valuable minerals of the platinum group which had previously been lost.

Wool blankets were found equally effective, but corduroy gives a less bulky concentrate, and the lock-up of gold is very small. Canvas gave a still smaller bulk, but caught only 75 per cent as much gold; riffles were only 57 per cent as effective.

Canvas concentration as practiced in California is described by W. H. Storms, Engineering and Mining Journal, Vol. 60, (July 13, Nov. 9 and 16, 1895), and by E. B. Preston, Bulletin 6, California State Mineralogist.
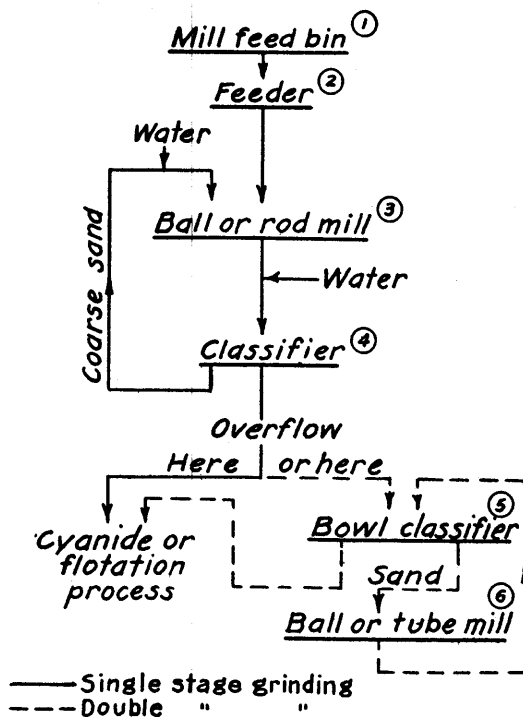
Gravity tables and vanners often serve a useful purpose in gold recovery flow sheets. Flotation, however, is rapidly replacing these and other methods of gravity concentration.

THE FLOTATION PROCESS

Flotation probably is the most important gold recovery process today. Practically the only kind of gold the flotation process will not recover is coarse gold, i.e., coarser than about 35 to 48 mesh. It recovers fine, free gold, gold associated in any form with sulfides, and gold in oxidized lead and copper ores. A combination of amalgamation, cyanidation, and flotation almost insures high gold recovery from any gold ore. When gold is recovered from its ore by flotation, a high grade concentrate contains the gold. This concentrate may be ground and, with or without roasting, treated with cyanide solution, with the ultimate production of gold bullion, or it may be, and most often is, shipped to a lead or copper smelter where it is paid for on the basis of its precious metal and base metal contents. It is a process easily available to the small operator who may use it with good results with a minimum of metallurgical advice.

Principle of the Process

The principle of the process is briefly that most metals and metallic minerals crushed in water and treated with a small amount of certain reagents (xanthates and aerofloat for example) collect this reagent on their surfaces, giving them a "dry" tendency (like paraffin) toward water. In this condition bubbles introduced into the water in which the particles are stirred and suspended attach to these particles. A frothing or foaming agent, such as pine oil, is added to produce an intense froth which collects on the top of the pulp. This froth contains the gold and sulfides or other floatable substances. (For a statement of the history and invention of the flotation process, see the July 15, 1916, issue of Chemical and Metallurgical Engineering, by George E. Collins,

Mill feed bin ①

Feeder ②

Water

Ball or rod mill ③

← Water

Coarse sand

Classifier ④

Overflow

Here | or here

Cyanide or
flotation
process

Bowl classifier ⑤

Sand ⑥

Ball or tube mill

——— Single stage grinding
— — — Double   "   "

FLOW-SHEET OF CLOSED-CIRCUIT GRINDING UNIT

Figure 2

Mill feed bin ①

Mercury   ← Water

Stamp battery ②

Clean-up from battery

Reused mercury   — New mercury

Mercury-coated copper plate ③

Mercury Trap ④   Retort ⑤

Mercury

Tailing   Sponge gold

Melting furnace ⑥

Gold bullion ⑧   Slag ⑦
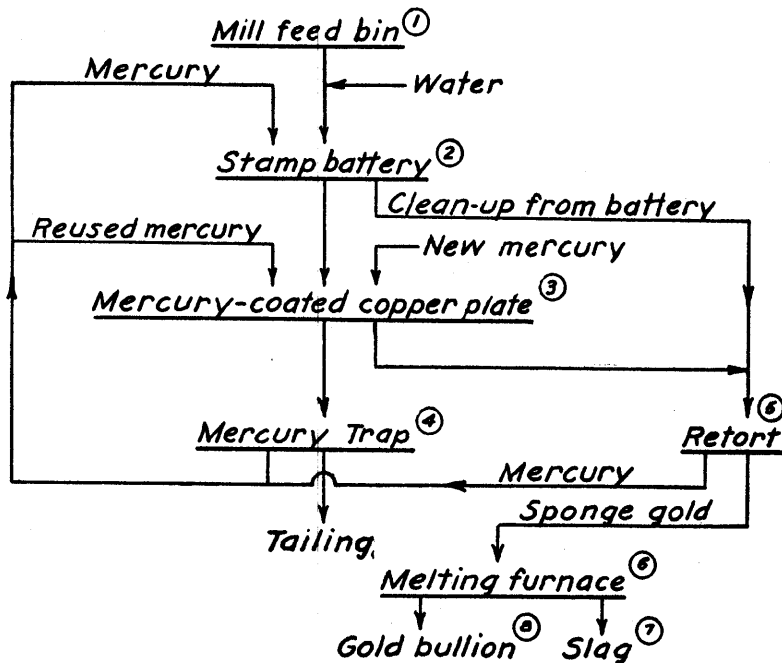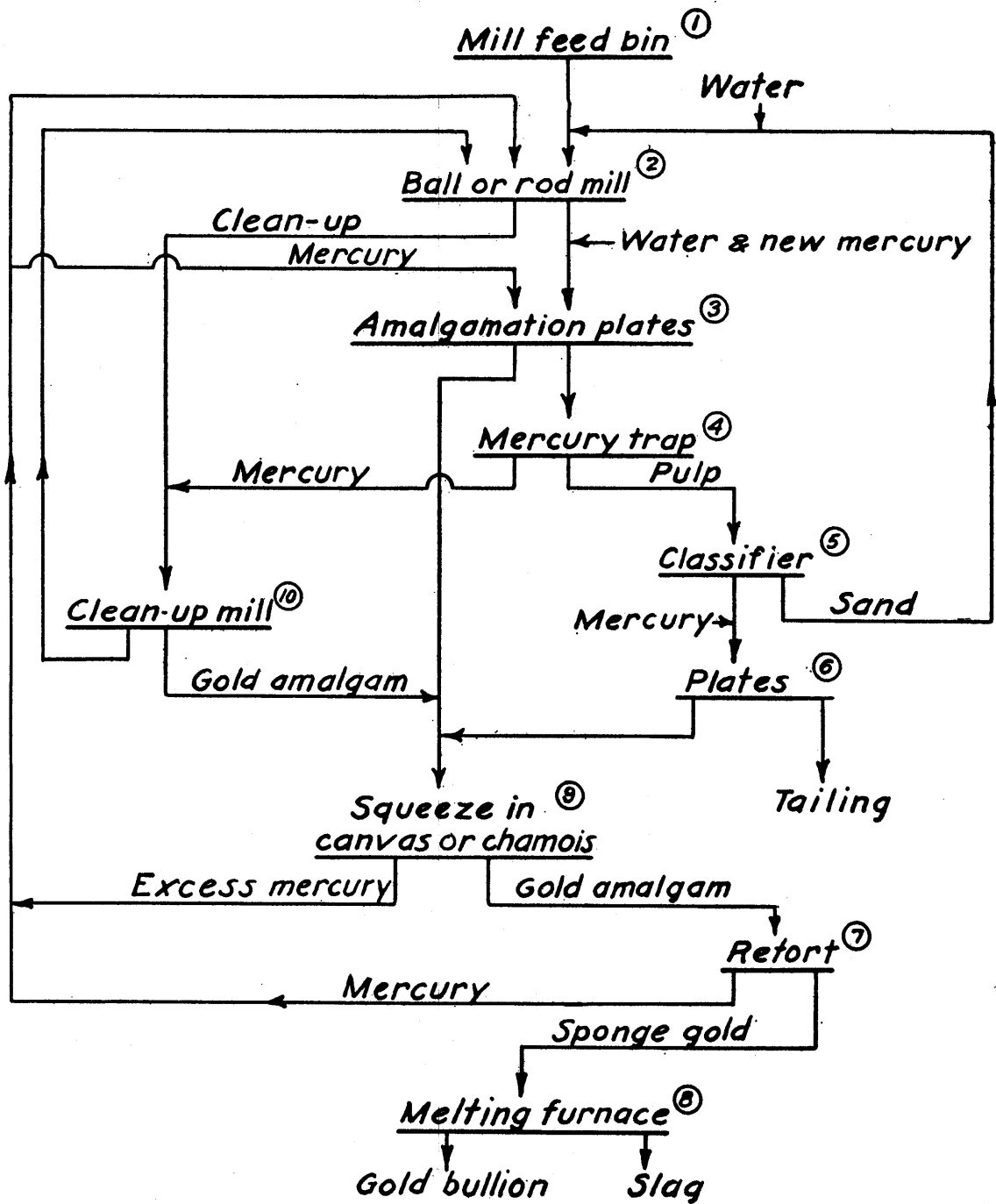
FLOW-SHEET OF STAMP MILL AMALGAMATION PROCESS

Figure 3

4) Traps are pockets provided in launders at end of the plates to catch excess mercury flowing off the plates. This mercury may be used for dressing plates or added to stamp mortar, or, if it contains enough gold, it is squeezed in canvas or chamois and retorted.

5) Retorts and condenser may be purchased from The Mine and Smelter Supply Company, Denver. Heating is done in an oil-fired furnace. Temperature of 360° C. is required. Care should be taken not to inhale mercury fumes.

6) The oil-fired crucible furnace is suitable for small plants. Larger plants use an oil-fired tilting furnace.

7) Slag is produced by adding soda and borax. It is broken up and stamped or shipped to a smelter.

8) Gold bullion is sold to the United States Mint.

Figure 4 is a flow sheet of the amalgamation process, in which grinding is accomplished in a ball or rod mill. Plates are shown both before and after the classifier. The bulk of the gold, if it is free, will be caught on the plate immediately following the ball mill. The use of a plate between the ball mill and the classifier may cause dilution troubles, since water in liberal volume must be added to the pulp to cause it to flow freely over the plate. This plate may be omitted and only the plate following the classifier used. In this case, however, considerable coarse gold will build up in the classifier which, of course, is recovered periodically by cleaning it out. A small amount of mercury may be fed at intervals into the ball mill, if a plate is used immediately following the mill. Gold also accumulates in the ball mill and can be recovered only when the mill is down for relining.

Notes on Figure 4 flow sheet:

1) See (1) Figure 2.

2) For the small operator the ball mill is preferable. At the Homestake a small amount of mercury is added to the ball mill.

3) The addition of some new mercury is required at this point. The mercury consumption is determined by the amount of gold in the feed. The loss of mercury in well regulated plants is about 0.1 oz. per ton of ore milled. Plate area required varies; the average is about two square feet per ton milled. In stamp milling, six to eight tons of water are required for each ton of ore. With use of ball mills, this large volume of water causes classifier problems and necessitates introduction into the system of a thickener. Oscillating circular plates obviate these problems.

4) See (4) Figure 3.

5) The classifier overflow should not contain probably more than three tons of water to each ton of ore. The overflow can, however, be diluted as desired for proper plate operation.

6) Plates used here catch only relatively fine gold. The coarse gold remains in the ball mill and classifier circuit, from where it is removed by periodic clean-ups.

7) See (5) Figure 3.

8) See (6) Figure 3.

9) The clean-up mercury from the various places where it is caught contains a considerable excess of mercury. This is removed by squeezing in a canvas or chamois bag. The excess is returned for reuse on the plates.

Mill feed bin ①

Water

Ball or rod mill ②

Clean-up
Mercury

← Water & new mercury

Amalgamation plates ③

Mercury trap ④

Mercury   Pulp

Classifier ⑤

Clean-up mill ⑩   Sand

Mercury →

Gold amalgam   Plates ⑥

Squeeze in ⑨
canvas or chamois   Tailing

Excess mercury   Gold amalgam

                                     Retort ⑦

Mercury

                       Sponge gold

Melting furnace ⑧

Gold bullion   Slag

FLOW-SHEET OF AMALGAMATION PROCESS EMPLOYING
BALL OR ROD MILL AND CLOSED-CIRCUIT GRINDING

Figure 4

10)   In cleaning out the ball mill, the classifier and the
       mercury traps, it is necessary to include in the clean-
       up sand and concentrate as well as the mercury and the
       gold it contains. This material is placed in a small
       mill along with a small charge of balls. The mill is
       rotated for several hours, discharged, and the mercury
       separated from the pulp. The mercury is strained through
       canvas to remove excess mercury. The pulp is returned to
       the ball mill.

Figure 5 represents a flow sheet of the cyanide process with its variation.
The solid lines give the standard all-sliming process including agitation of
the pulp in two or more agitators (Pachuca tanks or mechanical-air agitators),
thickening and filtration of the pulp. The thickener over-flow is the strong
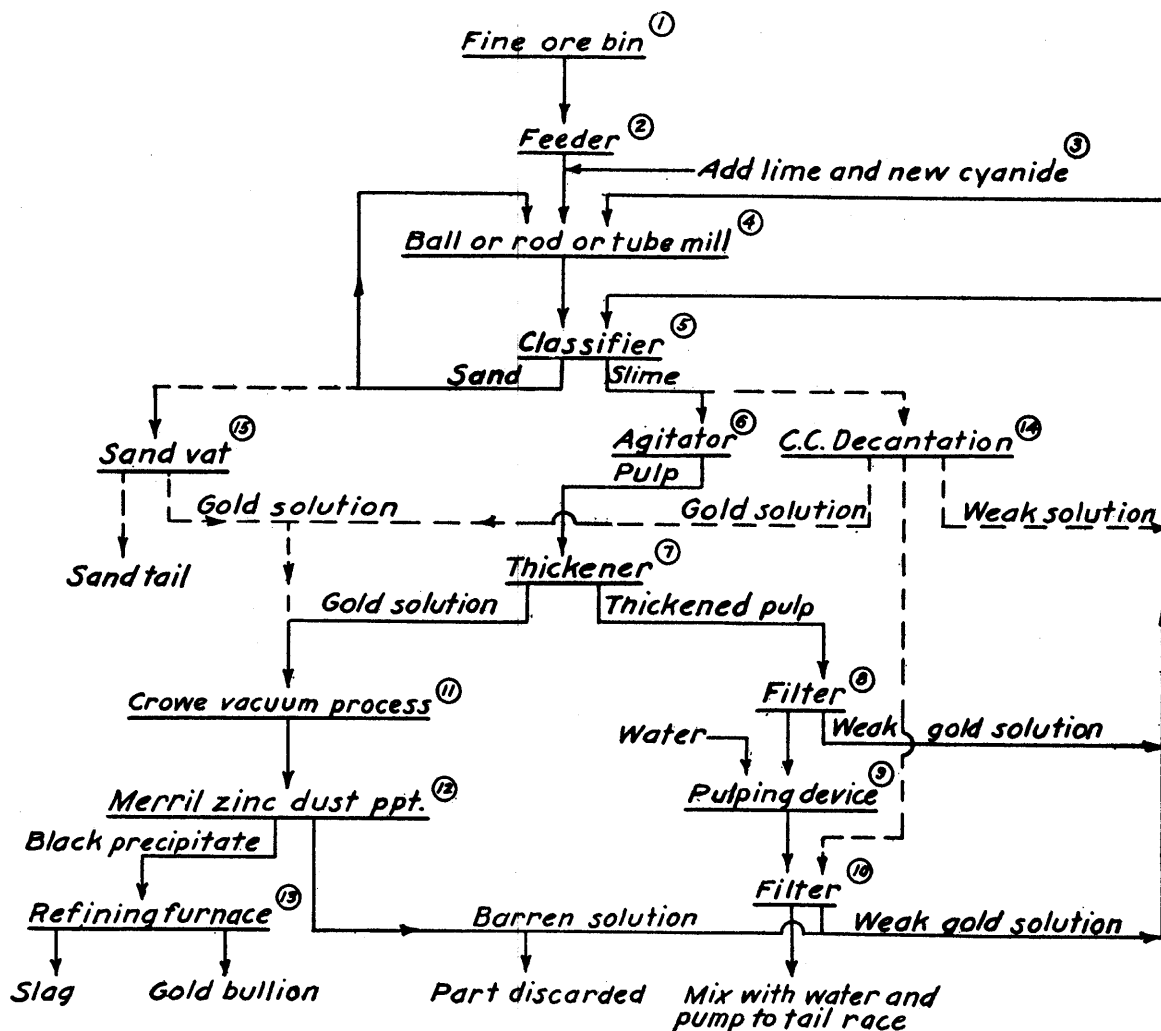gold solution and goes, as shown, to the precipitation department.

In some plants the counter-current decantation process is used, and in
this case the agitators are omitted. The counter-current decantation process
includes an agitator, and a series of thickeners. The pulp from the agitator
is pumped to a thickener that makes an over-flow (which is the strong gold
solution) and a thickened pulp. The thick pulp is pumped to a second thicken-
er that also makes a thickened pulp and a clear over-flow. The system com-
prises a series of tanks and the pulp advances from tank to tank through the
system. The final tank makes a thickened pulp quite free from gold solution
and may be discarded, or may, as shown, be filtered for recovery of the last
trace of gold solution. Fresh water is admitted to the final thickener of
the system and advances, by pumping from tank to tank, to the second thickener
of the system, or counter to the flow of the thickened pulp. The over-flow
from the second thickener contains some free cyanide and gold in solution, and
is returned to the ball mill or classifier after it has been made up to the
required strength by addition of new cyanide.

The counter current decantation process is shown in the flow sheet by the
dotted lines.

If the combination process of sand-leaching and slime-agitation is to be
employed, the flow sheet is modified as shown by the waved lines. Some ores
give up their gold value so readily that the extraction may be accomplished by
sand percolation or leaching in porous-bottomed tanks. From one to several
days is required for the dissolution of the gold.

Notes on Figure 5 flow sheet:

1)   See (1) Figure 2.
2)   See (2) Figure 2.
3)   New cyanide and lime are added, usually at this point,
      in amount equal to consumption of these reagents. Lime
      may be added to ore bin.
4)   See (3) Figure 2.
5)   See (4) Figure 2.
6)   The Pachuca tank, a tall, small diameter tank, provided
      centrally with an air lift, is much used. The Dorr
      mechanical-air agitator is also widely used. The object
      is to have large capacity tanks in which pulp can be
      thoroughly agitated and aerated. Gold is dissolved in
      this operation. A number of tanks are made available
      and the process is either intermittent or continuous.

Fine ore bin ①

Feeder ②

Add lime and new cyanide ③

Ball or rod or tube mill ④

Classifier ⑤

Sand   Slime

Sand vat ⑮

Gold solution

Sand tail

Agitator ⑥
Pulp

C.C. Decantation ⑭

Gold solution   Weak solution

Thickener ⑦

Gold solution   Thickened pulp

Crowe vacuum process ⑪

Filter ⑧

Water   Weak gold solution

Merril zinc dust ppt. ⑫

Pulping device ⑨

Black precipitate

Refining furnace ⑬

Barren solution

Filter ⑩

Weak gold solution

Slag   Gold bullion

Part discarded

Mix with water and pump to tail race

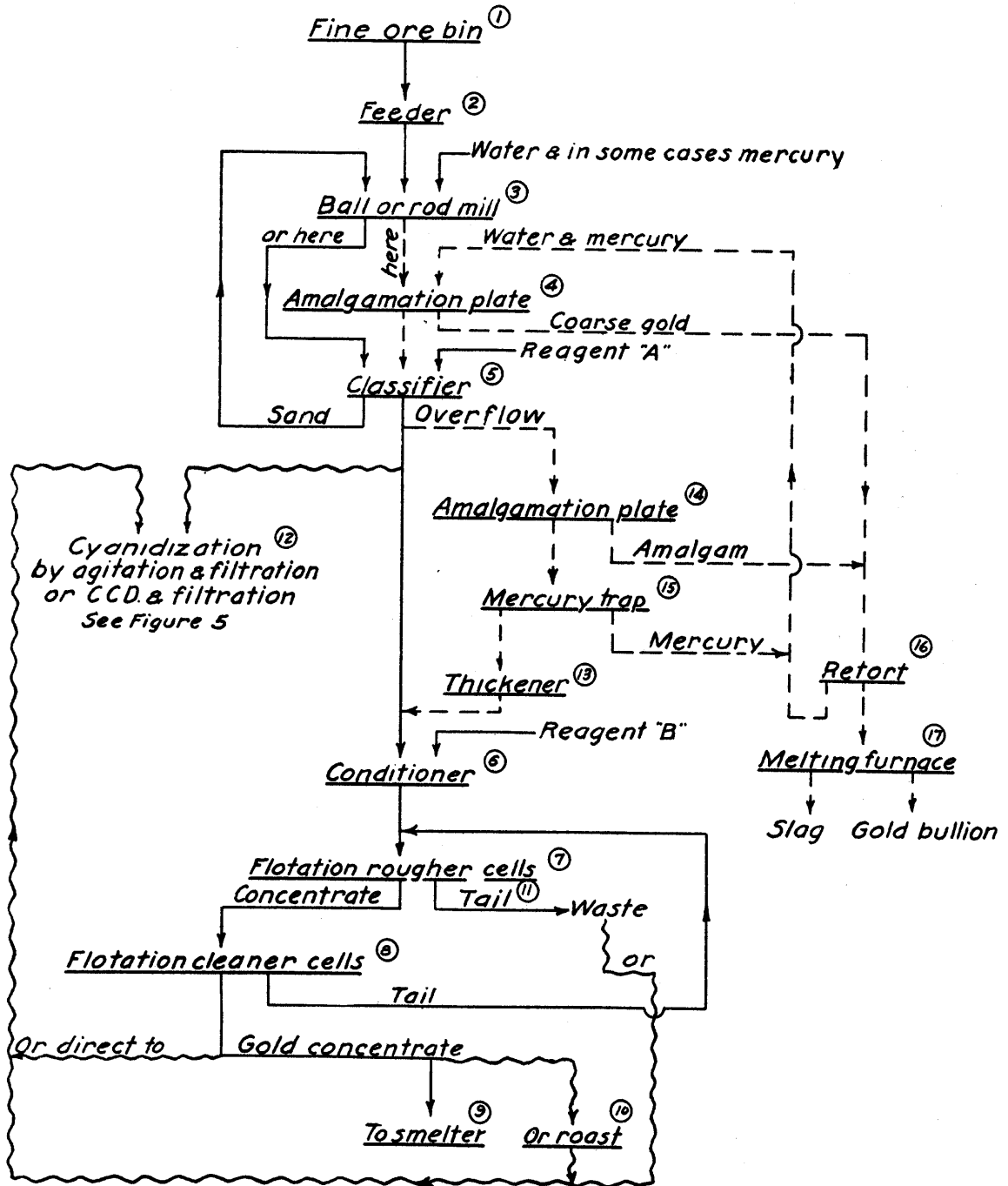FLOW-SHEET OF CYANIDE PROCESS SHOWING ALTERNATIVE SCHEMES

Figure 5

7) The Dorr thickener, a large diameter, relatively shallow tank, containing slow-moving pulp raking mechanism, is most widely used. Clear solution (containing the gold) overflows the rim of the tank and thick pulp discharges through a spigot at the bottom of the tank.

8) The thickened pulp of (7) is further dewatered and water-washed on filter. The filter is continuous and of the vacuum type. The dried cake contains 8 to 10 per cent water.

9)
&
10) It is necessary to remove completely gold solution from the solids. This is best done by repulping the dried cake with water and refiltration. Solutions from both filters are weak in cyanide and gold, and are used in the ball mill circuit along with enough new cyanide to make up to proper strength.

11) The overflow from (7) is the strong gold solution and is ready for treatment with zinc for precipitation of gold values. It is first sprayed into a vacuum tank which removes dissolved oxygen. This is the Crowe process.

12) The solution is then agitated with zinc dust. Some zinc goes into solution and the gold comes down as a black precipitate. The solution called "barren solution" is removed from the precipitate by filtration in pressure-type plate and frame filters. The filter medium is canvas and filter paper. Part of this solution is discarded and part is kept in the system for re-use, because it contains a small percentage of gold solvent.

13) The gold precipitate contains considerable zinc which, after a roast, is fluxed off in a furnace, or it is removed by treatment with acid.

14) A system of treating the ore and water pulp in a cyanide solution to effect gold dissolution known as the "counter current decantation system" is often used in place of the agitation system. It already has been briefly described.

15) Sand-leaching is an old and well established practice applicable to some ores. It is still practiced at the Homestake mine. It saves grinding, but requires large tank volume and building area.

Figure 6 is a combination amalgamation, flotation, and cyanidation flow sheet.

Straight flotation is shown by the solid lines. When amalgamation is employed to catch coarse gold, its introduction into the flow sheet is indicated by the dotted lines. Amalgamation may or may not be necessary and this can be learned only through metallurgical studies in the laboratory or by careful studies in the plant.

If a combination of flotation and cyanidation is required to give the desired extraction, and if calculations indicate the combination to be more economical than either process alone, the cyanide process is introduced as indicated by the waving lines.

The flotation concentrate may go direct to the smelter or it may be cyanided either after, or without, a preliminary roasting. Roasting may be, and most often is, necessary for good extraction of the gold from the concentrate. Direct disposal of the concentrate to the smelter is the simplest, most convenient, and usually the most economical, procedure to follow.

Fine ore bin ①

Feeder ②

Water & in some cases mercury

Ball or rod mill ③

or here   Water & mercury

here

Amalgamation plate ④

Coarse gold

Reagent "A"

Classifier ⑤

Sand   Overflow

Cyanidization ⑫
by agitation & filtration
or C.C.D. & filtration
See Figure 5

Amalgamation plate ⑭

Amalgam

Mercury trap ⑮

Mercury

Thickener ⑬

Retort ⑯

Reagent "B"

Conditioner ⑥

Melting furnace ⑰

Slag   Gold bullion

Flotation rougher cells ⑦
Concentrate   Tail ⑪ →Waste

Flotation cleaner cells ⑧

Tail   or

Or direct to   Gold concentrate

To smelter ⑨   Or roast ⑩

FLOW-SHEET OF COMBINATION AMALGAMATION, FLOTATION,
AND CYANIDE PROCESSES

Figure 6

Flotation tails may contain sufficient values to consider their treatment by cyanidation. This alternative is indicated in the flow sheet.

Combination processes are more expensive in first cost and to operate, and are justified only after thorough metallurgical studies and calculations.

The above flow sheets do not include all operating plant details. They are here included simply to give a general picture of gold recovery processes.

Each ore requires individual consideration for best metallurgical and commercial results.

Notes on Figure 6 flow sheet:

1) See (1) Figure 2.
2) See (2) Figure 2.
3) See (3) Figure 2.
4) See (3) Figure 3. In this flow sheet excessive dilution not only in the classifier, but also in the flotation system, must be avoided. The pulp should contain not much in excess of 30 per cent water. If large volume of water is added at this point, or at (14), a thickener in the flow sheet will be required.
5) See (4) Figure 2. Certain flotation reagents may be added at this point.
6) In the flotation process it is often necessary to give the pulp a preliminary agitation with certain reagents in advance of the flotation cells. This device is called a conditioner. It is a small tank in which is installed a pulp-stirring mechanism.
7)
&
11) The first set of cells receiving the pulp make a concentrate containing the gold values and a tailing. The tailing generally is discarded. Should it contain economic values, it may, as is being done in a number of plants, be treated by the cyanide process.
8) The grade of the concentrate may be markedly increased by a second frothing treatment. The tailing from this second flotation treatment is returned to the initial flotation cells, or it may be returned to the ball mill and ground with the ore.
9)
&
10) The gold concentrate is most conveniently sold to a smelter. In some instances, however, it may be more economical, because of the isolated location of the mine, to cyanide the concentrate producing gold bullion. The concentrate may or may not require a preliminary roasting before cyanidation. From some concentrates the gold is readily extracted by cyanide while others are highly refractory.
12) See Flow sheet Figure 5.
14), 15), 16), and 17)   See Figure 3.

PLANT AND OPERATING COSTS IN MODERN GOLD MILLING PRACTICE

Information Circular No. 6433, U. S. Bureau of Mines, March, 1931, entitled "Amalgamation Practice at Porcupine United Gold Mines, Ltd., Timmons, Ontario," written by Ronald A. Vary, gives complete details of operation, refining, and costs of a modern 30-ton gold amalgamation plant employing also blankets and tables. The operating cost per ton of ore treated is $1.851.

Information Circular No. 6408, U. S. Bureau of Mines, February, 1931, entitled "Milling Methods and Costs at the Homestake Mine, Lead, South Dakota," by that famous gold metallurgist Allan J. Clark, is a veritable treatise on the subject of modern gold milling.

The ore assays about $5.00 a ton, 62.8 per cent is recovered by amalgamation, and 30.2 per cent by cyanidation. The total gold recovery is 93.0 per cent. The total milling cost for the year 1929 was $.503 per ton of ore milled. Detailed costs of every part of the operation are given.

Information Circular No. 6236, U. S. Bureau of Mines, February, 1930, entitled "Milling Practice at the Alaska Juneau Concentrator," by P. R. Bradley, is another excellent contribution to the subject of milling gold ores.

The outstanding features of the operations upon the Alaska Juneau ore are - an ore body of such size and character as to permit a caving system of mining whereby ore is mined and delivered to the mill at a cost of $0.26 to $0.29 per ton; rejection by screening and hand-sorting of approximately 50 per cent of the material mined, at a cost of $0.13 to $0.15 per ton rejected; milling of the sorted ore at a cost of $0.31 to $0.33 per ton milled, giving a total operating cost of $0.51 to $0.57 per ton trammed from the mine.

Information Circular No. 6476, U. S. Bureau of Mines, July, 1931, entitled "Milling Methods and Costs at the Argonaut Mill, Jackson, California," is an article giving complete metallurgical and operating data on a present day gold milling plant employing amalgamation and gravity concentration. The mill heads in 1929 assayed $6.07 in gold; 69.0 per cent is recovered by amalgamation and 18 per cent by concentration. The ore is crushed in stamps through a 24 mesh screen, and amalgamation is affected both in the mortar and on shaking tables. The total milling cost in 1929 was $0.96 per ton of ore treated.

Information Circular No. 6411, U. S. Bureau of Mines, March, 1931, entitled "Milling Methods and Costs at the Spring Hill Concentrator of the Montana Mines Corporation, Helena, Montana," by L. N. Grant, is an example of a plant that recently has been converted from cyanidation to all-flotation recovery of gold. The gold is associated with pyrite, arsenopyrite, and bismuth. Modern equipment is used throughout the flow-sheet. The total milling cost per ton of ore treated is $1.007.

"Gold Milling in Canada," Bulletin of the Canadian Institute of Mining and Metallurgy, January, 1930, by J.J. Denny, is another excellent reference for those interested in modern gold recovery methods.

COST OF ERECTING GOLD TREATMENT PLANTS

The cost of a metallurgical plant for gold recovery depends upon a number of factors. Large tonnage plants cost less per ton of ore to be treated than small ones. Simple flow sheets are less costly than those for complex ores; hence, the difficulty of extracting the gold is a prime factor in determining the initial plant cost. Accessibility and location, which determine cost of materials and transporting and installing equipment, are large variable factors.

The cost of building a straight amalgamation mill will run from $450 to $700 per ton of ore treated per 24 hours. All-slime cyanide plants cost from $800 to $1,400 per ton per 24 hours; all-flotation plants, from $600 to $800, depending upon the size of plant (tons of ore treated per 24 hours).

For metallurgical cost and operating data, the reader is referred to the following manufacturer's bulletins:

Bulletin 2901 - Results in Modern Flotation: Denver Equipment Company, 1419-17th Street, Denver, Colorado.

Metallurgical Bulletin - The General Engineering Company, 159 Pierpont Avenue, Salt Lake City, Utah.

Notes on the Flotation Process - Southwestern Engineering Corp., 606 South Hill Street, Los Angeles, California.

"The Trend of Flotation," - Colorado School of Mines Quarterly, Vol. XXIV, No. 4, October 1929.

The above publications, the first three of which may be had on request, and the last at a small charge, contain data sufficient to answer practically any question pertaining to ore dressing and milling.

METALLURGICAL TESTING OF GOLD ORES

Gold ore having been found in what appears to be sufficient quantity to be of commercial interest, the problem arises as to its proper metallurgical treatment. The large company knows the proper course to take, namely, that a thorough metallurgical study by a competent metallurgist should first be made to determine the most economic extraction, i.e., the type of metallurgical treatment that will net the greatest return per ton of ore treated. The inexperienced, however, may not get off to a good start. In short, the proper procedure is to obtain the help and advice of a reputable and experienced metallurgist.

MARKETING GOLD BULLION AND RICH GOLD PRODUCTS

Gold is the easiest of all metals to sell. The only procedure necessary is to take or send by express the gold bullion, pure or impure, to the nearest United States Mint or government assay office, where the metal will be assayed and settlements made on the basis of $20.67183 per troy ounce, 1000 fine. Silver in gold bullion is paid for at the current market price. Base metal content is not paid for.

The Treasury Department maintains an assay office in New York, Helena, Montana, Deadwood, South Dakota, Salt Lake, Utah, and Seattle, Washington. At New Orleans, Louisiana, and Carson City, Nevada, there are mints that are conducted as assay offices. All the institutions mentioned are bullion-purchasing offices for the larger institutions in Philadelphia, San Francisco, and Denver, where coining operations are centered. The assay offices also assay gold and silver ores for prospectors and any others interested. The charge for gold or silver is $1.00.

Gold-bearing material, such as gold ore or gold concentrate, will be bought by any copper or lead smelter. The minimum amount of gold settled for, say, in the case of a lead or copper concentrate, is .01 to .05 ounces per ton. Often the entire assay content is paid for, but most smelters pay only for 95 per cent of the assay content, and the price paid varies from $19 to $20 per ounce.

Gold concentrate invariably contains silver. The smelter pays for 90 to 95 per cent of the silver content as determined by fire assay, at the New York quotation, if more than one ounce is present.

The value of a ton of ore or concentrate at the smelter is determined not only on the gold content, but also on (1) the valuable recoverable base metals, such as lead, copper, and bismuth, (2) the undesirable constituents from the purely smelting point of view, such as, for example, zinc, sulphur, arsenic, and antimony, and (3) the desirable constituents from a fluxing point of view, such as, for example, iron or lime, or silica. Lead in concentrate is usually paid for at 90 per cent of the lead content (wet assay less $1\frac{1}{2}$ per cent) at the New York quotation, less 1.65 cents per pound. If less than 5 per cent of lead is present, it is not paid for.

Payment for copper in concentrate is determined on the basis of the wet assay less than 1 to 1.5 per cent and therefore, naturally, when the copper content of an ore or concentrate is less than 1.5 or 1 per cent, it is not paid for. A second deduction of $2\frac{1}{2}$ to $3\frac{1}{2}$ cents per pound of copper is made to cover freight, selling, and delivery charges.

Zinc is an undesirable constituent in smelting gold ores or concentrates. The free maximum per cent allowable at nearly all smelters (excepting those employing the Waelz process) is 5 to 10 per cent. The penalty is from 25 to 50 cents per unit (one unit equals 20 pounds per ton) for each unit in excess of the allowable amounts.

Sulphur is penalized at the rate of about 25 cents per unit above the allowable free maximum per cent which ranges from one to four per cent. The maximum penalty is $2.50 a ton.

Silica may be penalized, or it may command a premium. If a smelter is so located that it receives an excess of basic ore or concentrates, i.e., material containing high per centages of iron, it will pay a premium for the silica. For example, the Consolidated Mining and Smelting Company of Canada, Trail, B. C., pays a premium for silica at the rate of 7 cents a unit and penalizes iron at the rate of 5 cents a unit.

It thus pays the seller to "shop around" and learn the conditions prevailing at the various smelters. He should write to several of the smelters within possible shipping distance of his property, giving a complete chemical analysis of the material for sale, and obtain from the smelter a quotation of the net value of a ton of ore at that smelter. These quotations, in conjunction with freight rates, which the smelter also is in a position to give, provides, of course, the necessary data upon which a decision is reached as to the most profitable place to do business. The smelter also makes a base charge for smelting the ore. This base charge varies with the grade of the ore from $4 to $10 per ton.

Freight rates also are based on the value of the ore. The higher the value of the material, the higher the freight rate.

Good references on the subject of buying and selling ores and metallurgical products are as follows:

C. H. Fulton - "The Buying and Selling of Metallurgical Products:" U. S. Bureau of Mines Technical Paper 83, (1915).

Arthur J. Weinig and Irving A. Palmer - "The Trend of Flotation;" Colorado School of Mines Quarterley, Vol. XXIV, No. 4, October 1929.

FLOTATION OF METALLIC GOLD

Introduction

Gold has a constant and invariable value of $20.67 an ounce fixed by law, as already stated. It is the only metal whose value is not effected by the law of supply and demand, or by economic depressions. Hence, naturally, in times of depression when the market prices of other metals are so low as to discourage base metal mining, there developes increased interest and activity in gold mining. In such times too, conditions are decidedly favorable to profitable gold mining because of cheap labor, supplies, and transportation.

The School of Mines at the University of Idaho receives almost daily letters, or people call in person, requesting information relative to methods of gold recovery.

It is the purpose of this short paper to give a few examples of gold flotation and to discuss the application of flotation to the treatment of gold-bearing materials.

Metallic gold, like metallic copper and metallic silver, floats readily if proper flotation conditions are provided. Surprisingly coarse gold can be successfully floated even in the absence of froth stabalizing minerals such as the sulfides. In the case of quartz and oxidized siliceous ores, the condition necessary is very similar to that required for flotation of metallic copper in Michigan copper ores. Sufficient frothing agent is added to produce a clean white foam which runs freely ever the lip of the flotation cell. The metallic gold particle are entangled in the watery froth which readily breaks up on leaving the flotation cell.

When the gold is free, but associated with sulfides, the free (liberated) gold and the gold locked in the sulfide particles float in a froth that readily forms on the surface of the pulp in the flotation cell. This sulfide-laden froth is much more stable.

The gold in fine placer sand or in black sand resulting from sluicing and table concentration operations also floats freely.

Limitations of Flotation Process

The flotation process of course has its limitations. Very coarse gold cannot be lifted by the bubbles. It is difficult to indicate by the use of sieve scale numbers, for example, such as 48 mesh or 65 mesh, the size of particles that can be floated. The shapes of the particles determine this, assuming, of course, the particle surfaces are clean and lustrous. Much of the gold in ores is in the form of thin flakes, and some of it occurs as compact particles. The gold particles in most black sand concentrates have the form of thin discs. Pieces of this ahape as large as $\frac{1}{2}$ millimeter in diameter float readily. "Float" or "flour" gold, which always has given trouble in amalgamation and gravity concentration processes, floa easily.

Crushing and Grinding

The purposes of crushing and grinding are (1) to liberate the gold and sulfide from the worthless rock, and (2) to reduce the material to a fineness that

can be handled in the flotation machine. It is difficult to keep coarse sand in circulation and suspension in the cells, and perhaps 10-mesh sand is about as coarse as can be successfully handled. Gold ores of the complex sulfide class often require very fine grinding, and in some cases the finest grinding possible in practical operation is not sufficient to give satisfactory liberation. On such ores, it is of course impossible to get satisfactory recoveries by flotation. Fortunately this type of ore is not often encountered.

Use of Amalgamation Ahead of Flotation

In any case, coarse gold probably should be removed by amalgamation, although this operation often may be avoided without sacrifice in total recovery. When grinding is done in a ball mill in close circuit with a classifier, the coarse gold accumulates in the system and does not escape in the classifier over-flow. Much gold is retained in the ball mill in the liner joints and this is recovered when the mill is shut down for relining. The classifier may be "cleaned up" at regular intervals. The clean-up material is dewatered and shipped to the smelter or it may be treated in a clean-up barrel with mercury.

There may, however, be certain economic advantages in catching the coarse free gold on plates from which the gold may be recovered daily. As already stated, the freight rate charged by the railroads is based on the grade (value) of the concentrate, the higher the grade, the higher the freight rate. Also often the base charge made by the smelter for smelting the concentrate is on a sliding scale, the charge increasing with concentrate grade.

When amalgamation is employed in conjunction with flotation, it must precede the flotation treatment, since the flotation reagents seriously prevent gold from attaching to the mercury. Also reuse of the mill water recovered from the tails is out of the question, because it contains the harmful chemicals.

Ratio of Concentration and Grade of Product

The flotation process, unlike the amalgamation or cyanide processes, in most cases, is not a gold recovery process. The gold value is contained in a concentrate which is a small and variable fraction of the original ore. Clean quartz ores, naturally, give a very high-grade concentrate and high ratio of concentration. Massive sulfide ores give low-grade concentrate and low ratio of concentration. In flotation concentration of gold ore, naturally, the effort is to make as high a ratio of concentration as possible. This is accomplished by skillful use of flotation equipment and chemical reagents and is a job for the experienced flotation metallurgist.

Machinery Needed

The machinery needed in the average small gold flotation plant is a rock crusher, ball mill, classifier, flotation machine, reagent feeders, and a concentrate filter.

Examples of Gold Flotation

Example No. 1

The gold was partly free and partly intimately associated with pyrite. The silver occurs principally with tetrahedrite. Results:

	Gold	Silver
Feed	0.210 oz.	15.08 oz.
Tails	0.041 oz.	4.07 oz.
Concentrate	44.00 oz.	3000.00 oz.
Recoveries	80.5%	72.8%

Many years ago this ore was treated by straight cyanidation, but the recoveries were low and the consumption of cyanide high.

Example No. 2

The ore is a very intimate mixture of arsenopyrite, pyrite, and pyrrhotite, with calcite. The gold and silver are associated with the sulfides. Results:

	Gold oz.
Heads	0.35 to 0.40
Concentrates	7.00 to 9.00
Tails	0.03
Recovery	91.0 - 92.5%

Example No. 3

This is oxidized siliceous ore, the gold being free and not associated with sulfide minerals. Results:

	Gold oz.
Heads	.59
Concentrates	4.34
Tailing	.08
Recovery	88.00 %

The concentrate of this test when recleaned in a second cell assayed 8.25 ounces of gold per ton.

Example No. 4

In this ore the gold is associated with pyrite, galena, sphalerite, bismuthinite, and a few other sulfides. Under a microscope the gold appeared free as filling between the mineral crystals and incased in the sulfides, particularly the bismuthenite. Amalgamation under favorable conditions gave an extraction of 40 per cent of the gold. Results:

	Gold oz.	Silver oz.	Recovery Gold	Silver
Heads	1.53	17.1		
Concentrate	8.16	90.4		
Tailing	.48	3.8	77%	78%

By stage grinding and classification between stages, a flotation test on the same ore gave the following results:

	Gold oz.	Silver oz.	Lead %	Bismuth %	Recovery Gold	Silver	Lead
Heads	1.62	17.1	1.5	.04			
Concentrate	23.62	227.4	19.8	1.84			
Tailing	.47	2.8	.15		72%	85%	90%

The sample was ground to 68 per cent -325 mesh.

Example No. 5

This is highly siliceous gold ore containing small percentages of iron sulfide and galena. Amalgamation recovered only 24% of the gold, and cyanidation 74%. Results:

	Gold oz.
Heads	2.35
Concentrate	32.00
Tailing	.43
Recovery	83.00 %

The sample was ground through a -65 mesh sieve. Extraction of the gold in the -200 mesh part of the tail was 95%.

Example No. 6

This is highly siliceous gold ore with a small amount of pyrite. Amalgamation alone recovered 75 per cent of the gold. Cyanidation recovered 90 per cent of the gold. Results:

	Gold oz.
Heads	.43
Concentrate	6.26
Tailing	.03
Recovery	93.00 %

Example No. 7

This is highly oxidized siliceous gold ore. Results:

	Gold oz.	Silver oz.
Heads	.54	1.09
Concentrate	20.76	29.8
Tailing	.03	.4
Recovery	94.00 %	63.0 %

Example No. 8

This was a black sand concentrate resulting from concentrating by panning Snake River sand assaying 50.22 ounces per ton. The gold in the sand was in the form of thin plates from 0.1 to 1.0 millimeters in diameter by about .01 millimeters thick. The black sand was about 35 to 65 mesh in size. A 500-gram charge was floated in a gravity-flow mechanical flotation machine with proper flotation reagents. The following results were obtained:

	Gold oz.	Silver oz.	Recovery
Heads	50.22		
Concentrate	8620.00	1680.0	
Tailing	1.67	2.0	97.3 %

The value of the concentrate in gold is $172,400.00.

These results bring out unmistakably the high potentialities of flotation as a gold recovery process.

The gold in river sand is fine, much of it referred to as "flour gold," and its recovery always has presented a hard, if not insurmountable, problem. Gravity concentration gives a black sand concentrate which contains much, but not all, of the gold. The loss of gold is high and recovery of gold from the black sand concentrate in most instances cannot be efficiently made by working it with mercury, and cyanide acts too slowly.

In view of these results, the placer miner may find it advantageous to add to his kit of apparatus a flotation cell and a few chemical reagents.

These results suggest that possibly in the future river sands may be profitably handled by washing or screening and flotation of the fine gold containing sand. The concentrate will be a nearly pure gold ready for sale to the United States Mint.

Reagents

The reagents required for gold flotation are few and simple. The following usually are sufficient: Soda ash, 0.5 lb. to 2 lb.; sodium amyl or ethyl xanthate alone or sodium aerofloat, .005 to 0.05 lb. per ton. If aerofloat (15 per cent strength) is used, pine oil is not necessary, but if xanthate is used, pine oil is needed for frothing. In some cases, a very small addition of copper sulfate, or sodium cyanide, is beneficial. On oxidized ores sodium sulfide assists materially.

Close regulation of reagent feed is essential. For this purpose, standard and approved reagent feeders should be used, of which there are several on the market.

Treatment of the Concentrate

The concentrate, either with or without thickening in a suitable thickener, is filtered on a continuous vacuum filter. Where the tonnage of concentrate to handle is large, thickening of the concentrate as it comes off the flotation machine, is standard practice. At small plants, often the concentrate is filtered direct. The filter makes a product containing 8 to 10 per cent moisture.

The Well Equipped Plant

The well equipped flotation plant, of course, includes automatic weighing apparatus and samplers for sampling both mill feed and tails. The plant includes also a suitable assay office and assayer. A complete metallurgical balance sheet and cost data are kept by the metallurgist and his assistants. The small scale operator, however, gets along without these facilities and interests himself mainly in getting ore into the mill and smelter returns. It is remarkable too the good work that can be done by flotation with hay-wire equipment and common sense.

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            Edition.

MERCURY, Hg, a solvent of gold, is used in gold amalgamation processes.
Cost per pound - - - - - - - $0.72.

CYANIDE, KCN, or NaCN, and cyanamide cyanide, has the following uses in gold
metallurgy: Cleaning copper plates for mercury coatings, dis-
solving gold and silver in the cyanide process, and for depress-
ing iron and zinc, and for activating gold in gold flotation.
In cyaniding, the solution contains from 2 to 8 lbs. cyanide per
ton of solution. In flotation, from .1 to .01 lbs. per ton of
ore are added to the pulp. Cost per pound, barrel lots, $0.16.

LIME, CaO, is made cheaply by calcining limestone. Used in the cyanide pro-
cess (1 to 10 lb. per ton of ore) to neutralize pulp acidity and
to promote classification of pulps. Used in the flotation process
to depress iron minerals and as conditioner. It should not be
used in gold flotation. Cost per ton - - - - - - - $8.50.

ZINC DUST, Zn, used in the cyanide process (about .1 lb. per ton of ore) for
precipitating gold from cyanide solution.
Cost per pound - - - - - - $0.10.

SODIUM CARBONATE, Na_2CO_3, has a variety of uses. As a flux in gold refining
and fire assaying; in flotation pulps to maintain alkalinity and
to promote selectivity of mineral flotation.
Cost per 100 lbs. - - - - $1.15.

SODIUM SILICATE, (Soluble glass; sodium meta-silicate; liquid glass; water
glass) is a valuable reagent in flotation of some ores. It is
a strong depressant of gangue slime, producing a high-grade con-
centrate. Often beneficial (1 to 4 lb. per ton) in flotation of
oxidized ores. Cost per lb.(30%)100-lb.drums,$0.60.

SODIUM SULFIDE, Na_2S, in carefully controlled amounts ($\frac{1}{2}$ to 3 lb. per ton) is
an effective depressant of iron and zinc. Often highly benefic-
ial in flotation of some oxidized gold ores.
Cost per lb.(60 to 62%)100-lb. drums,$0.035,

ZINC SULFATE, $ZnSC_4$, is used occasionally alone but more often in conjunction
with cyanide to depress zinc and iron minerals in flotation.
Cost per 100 lbs. - - - - - $3.25.

COPPER SULFATE, $CuSO_4$, blue vitrol, is widely used ($\frac{1}{2}$ to 3 lb. per ton) as a
strong activator of zinc in the flotation process. It also aids
gold flotation from some ores when used in very small (.005 lb.
per ton) quantities. Cost per 100 lbs. - - - - - $3.25.

FERROUS SULFATE, $FeSO_4$, is a standard precipitant of gold from gold chloride
solutions.

HYDROGEN SULFIDE, H_2S, a gas soluble in water, also an effective precipitant
of gold from gold chloride solutions. It is made by the action
of sulfuric acid on a sulfide, usually iron sulfide. It is a
strong sulfidizing agent of oxide ores and is used for this
purpose in flotation.

LEAD ACETATE, (sugar of lead), Pb, $(C_2H_3O_2)_2$. $3H_2O$, is occasionally used in aiding the precipitation of gold and silver from cyanide solutions in the cyanide process. Lead nitrate may be used instead.   Cost per lb. in 100 lb. barrel, $0.11.

PINE OIL, steam distilled, is widely and principally used as a frothing agent in the flotation process.   Cost per gal. - - - - $0.45.

CRESYLIC ACID is used for the same purpose as pine oil and is widely employed particularly in lead ore flotation. It is effective on gold ore flotation.   Cost per gal. - - - - $0.50.

XANTHATES, ethyl, amyl, and butyl, are universally used as mineral flotation promoters in the flotation process. They float metallic gold, but must be used in minute amounts, from .05 to .001 lb. per ton of ore. Amyl xanthate is particularly effective on ox-idized ores.   Cost per 100 lbs. - - $0.20.

SULFURIC ACID, H_2SO_4, used in assaying in parting gold-silver beads. Silver is dissolved by it. At some cyanide plants sulfuric acid is used to dissolve the excess of zinc from the zinc-gold precip-itate resulting from the treatment of gold solutions with zinc dust. Sulfuric acid is also an activator of pyrite that has been previously depressed with lime.

                              Cost per ton tank - - $15.00.

AEROFLOAT is cresylic acid with phospho-pentasulfide in different strengths. It is a much used promoter in flotation.

                              Cost per 100 lbs. - - $20.00.

NITRIC ACID, HNO_3, is used in assaying to part gold-silver beads. When mixed with hydrochloric acid in the proportion of 82 parts hydro-cloric to 18 parts nitric acid, aqua regia is formed, which is a strong solvent of gold and platinum.

                              Cost per lb. in carboys $0.055.