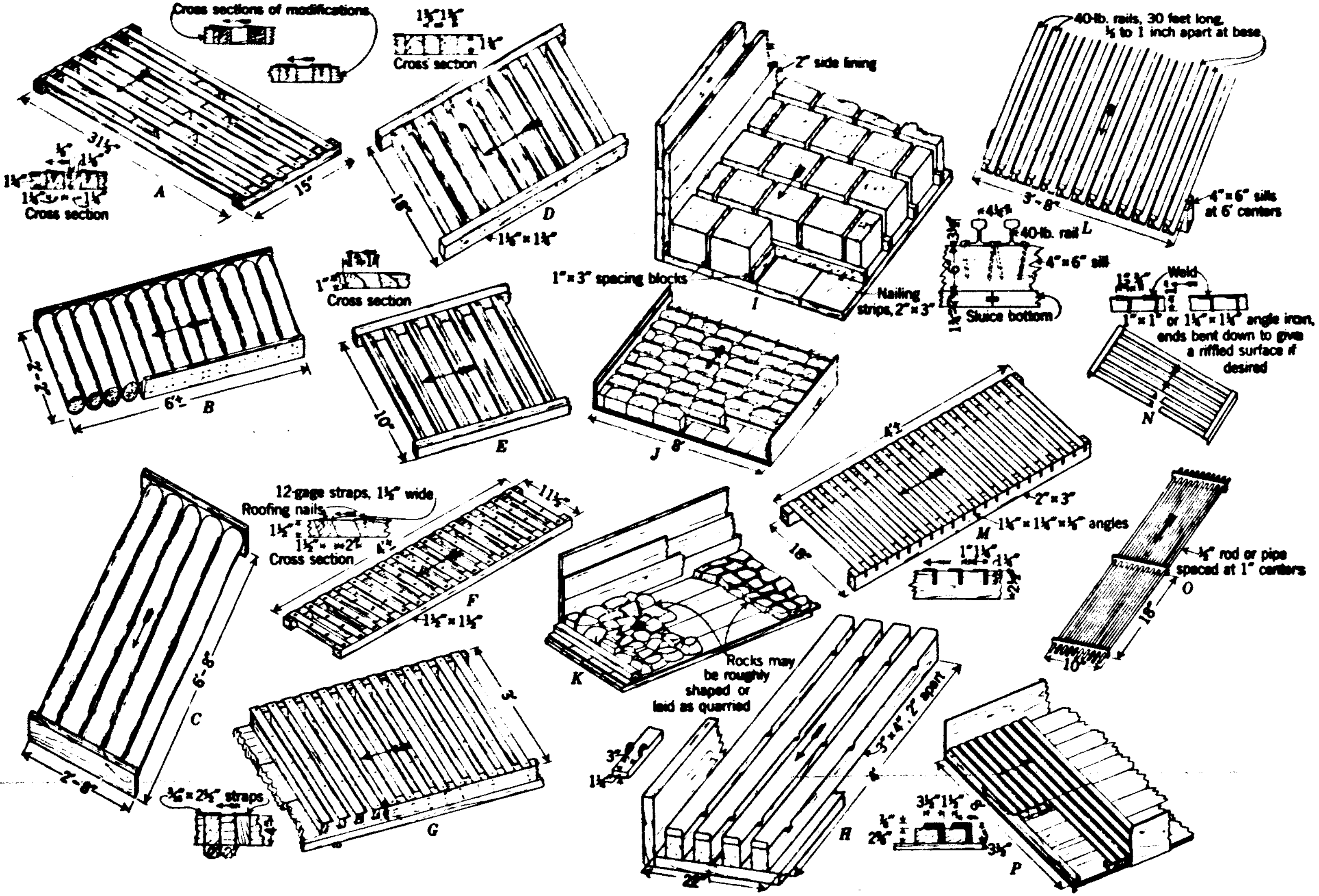

Figure 14.- Types of riffles: A, transverse wooden, steel-capped riffles used on dredges; B, transverse pole riffles; C, longitudinal pole riffles; D, transverse wooden riffles, square section; E, transverse wooden riffles, beveled section; F, transverse wooden riffle, steel-capped, inclined section; G, transverse wooden riffles, steel-clad, with overhang; H, longitudinal wooden riffles capped with cast-iron plates; I, wooden-block riffles for large sluices; J, wooden-block riffles for undercurrents; K, stone riffles; L, longitudinal rail riffles on wooden sills; M, transverse angle-iron riffles; N, transverse angle-iron riffles with toe tilted upward; O, longitudinal riffles made of iron pipe; P, transverse cast-iron riffles used in undercurrents.

riffles of this type may be slanted downstream, as shown in figure 14,E, and the top surfaces may be beveled to increase the "boiling" action, as with the dredge riffles. The effectiveness of this practice is not known, and the authors know of no conclusive tests having been made. Longitudinal riffles of 2- by 4-, 3- by 4-, or 2- by 6-inch material are used at some places. A longitudinal wooden riffle capped with cast iron is shown in figure 14,H.

Sluices in the Rock Creek sapphire mines were 12 inches wide and set on a grade not to exceed one half inch to the foot. A relatively flat grade is necessary to save the sapphires. Riffles were 2 by 4 inches in size set across the sluice 4 inches apart; they were tilted downward. The sluice was cleaned up each day. The sapphires were separated from the sands in a jig. They were then put through a set of seven screens, and other heavy minerals were picked out by hand. The black sand and other fine heavy minerals were drawn through the screen in the jig; the sapphires were taken off on top of the screen.

Wooden-block riffles (fig. 14, I and J) are held by Bowie[36] to be unexcelled in regions where the material is available cheap. The blocks are 4 to 12 inches thick and of corresponding diameters or widths. They may be round, partly squared, or cut from square timber. One- or two-inch wooden strips separate the rows of blocks, and they are held securely in place by nails driven in both directions. Wooden-block riffles are perhaps the hardest of all types to set because of their tendency to float away. They must be nailed to the spacing strips, as stated, and wedged securely at the sides. The spacing strips are held down at either end by the side lining of the sluice. Wooden-block riffles are durable, can be worn down to half their original thickness or less, and if made of long-grained wood (such as pitch pine, which "brooms" instead of wearing smooth) may catch some gold in the endgrain. When discarded, they are commonly burned and the ashes panned to recover any gold so caught. The life of 10- or 12-inch wooden-block riffles may be a few months to several seasons and, according to Bowie, ranges from 100,000 to 200,000 miner's inches of water; that is, with a flow of 1,000 inches one would last 100 to 200 days. The grade of the sluice apparently has much to do with the life of block riffles. At the Superior mine where the sluice was 48 inches wide and had a grade of 2 3/4 inches in 12 feet a set of blocks lasted two seasons, during which time 140,000 cubic yards was sluiced. At the Salmon River mine the grade was 7 inches in 12 feet and the width of the boxes 30 inches. Here block riffles lasted 60 to 70 days, during which time about 18,000 cubic yards was washed. On account of differences in the wearing rates only one variety of wood should be used in a section of a sluice. Douglas fir wears longer than other native western conifers.

Stone riffles are durable and fair gold catchers. Stones ranging from the size of cobbles to 8 or 10 inches in diameter are packed closely on the bottom of the sluice. (See fig. 14,K.) They may be held at intervals of a few feet by transverse wooden strips. In some instances the stones are roughly hand-shaped and set similarly to street paving. Stone riffles are difficult to set and generally are not used in portions of a sluice that are cleaned up frequently. Their main advantage is their long life. Because of their roughness, stone riffles require a steeper slope than wood blocks, a feature that sometimes would prohibit their use.

Where large quantities of gravel are put through sluices, iron or steel riffles generally are preferred. Their superior wearing quality as compared with that of wood permits longer runs without stopping to replace the riffles. Their durability may more than compensate for their higher cost.

Steel rails and angle iron are common riffle materials used in various ways. Old rails or angle iron can often be obtained cheaply in mining districts or near railroads. Various

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36 Bowie, A. J., A Practical Treatise on Hydraulic Mining in California: Van Nostrand Co., New York, 3d ed., 1889, p. 225.

other steel products such as pipe and channels have been utilized for riffles. Cast iron is also used and has the advantage of a lower first cost than steel rail or angle iron.

Iron or steel riffles should not be used in units too long to be handled readily. Rope blocks on movable tripods have found favor at some places for lifting heavy riffle sections.

When used as transverse riffles lengths of steel rail usually are set upright, the flanges almost touching or not more than 1 or 2 inches apart. Where grade is lacking and gold saving is not particularly difficult, longitudinal rail riffles make excellent paving for a sluice as they provide a smooth-sliding bottom for the gravel and boulders. The rails ordinarily are bolted together by tierods passing through wood, pipe, or cast-iron spacing blocks, forming riffle sections the width of the sluice and any convenient length. At the La Grange mine in Trinity County, Calif., 40-pound rails costing about $125 per ton proved more satisfactory than wood riffles.[37] When 16- by 16- by 13-inch wood blocks were used the riffles tended to "sand up." Moreover, the blocks had to be replaced every 2 or 3 weeks. Lengthwise rails 8 inches apart lasted 2 months and rails 5 inches apart, 4 months. Strangely enough, transverse rails 5 inches apart lasted 6 months. The rails were spaced by cast-iron lugs and set right side up on timber sills. When the head of the rail was worn off the remainder was used for side lining. This sluice was handling a flow of about 4,000 inches of water and 1,000 cubic yards of material per hour, boulders as large as 7 tons being washed through. The eddies behind the rails were believed to be the cause of the improved recovery as compared with that using block riffles. The lower part of the branching sluice line was cleaned up every other season only.

The combination of steel rails and wooden sills used at the La Grange mine appears to make an excellent gold saver, and modifications have been used at many large mines. Figure 14,L, illustrates a combination of longitudinal rails and transverse timber sills.

At the Round Mountain mine 25-pound rails were placed longitudinally in a 36-inch sluice with a grade of 4 inches in 12 feet. After about 150,000 cubic yards had been run through the sluice the center rails showed considerable wear and were removed to the outside. At the Lewis mine on Rogue River a set of riffles made of 40-pound rails lasted 15 seasons. The sluice was 30 inches wide and had a grade of 8 inches in 12 feet. About 7,000 cubic yards was washed yearly. Only material under 5 inches in diameter was run through the sluices.

Angle iron is commonly used for making riffles, as illustrated in figure 14, M and N. Many methods of assembling the lengths of angle iron into riffle sections are in use, and no one method can be said to excel. The irons may be set with flat upper surfaces or inclined slightly to increase the riffling action. Usually the gap between the riffle bars is 1/2 to 1 inch. The effectiveness of this type of riffle is believed by some operators to depend largely on the vibration of the riffles under the impact of boulders which keeps the sand trapped under the angles in a loose condition favorable to gold saving.

Figure 14,Q, illustrates an unusual all-metal riffle used at a Colorado drift mine, which was said to be giving satisfaction and appears to be simple to construct and convenient to use. The riffling effect could be increased, with some loss of velocity, by spacing the transverse bars closer.

Cast-iron riffles of all shapes and sizes have been used. If available at low cost they are very economical, as they wear slowly, can be quickly and securely placed, and are efficient gold savers if designed so as not to pack with sand. In an undercurrent at the Indian Hill mine, Calif., cast-iron riffles were in use that were 4 feet long, shaped like angle irons, and had equal 3 1/2-inch legs 7/8 inch thick. (See fig. 14,P.)

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37 MacDonald, O. F., The Weaverville-Trinity Center Gold Gravels, Trinity County, Calif.: U.S. Geol. Survey Bull. 430, 1910, pp. 48-58.

One property in California was reported to be using old car wheels for sluice paving. They were laid close together, flange side up, in a box just wide enough to hold one row of wheels. The riffling action caused by the hubs, webbing, and spaces between adjacent wheels and under the flanges was said to have resulted in a satisfactory gold recovery. A gravel-washing plant in Arizona was provided with riffles made of standard 2-inch pipe and 2 1/2-inch angle iron welded into riffle sections resembling pole riffles. This riffle should be fast-running and as efficient as any longitudinal type of riffle, relatively light, and easy to handle. It would not be durable enough for very heavy gravel and would be relatively expensive unless salvaged material and welding equipment were available.

For shallow sluice streams carrying only fine material various gold-saving materials are used, including brussels carpet, coco matting, corduroy, and burlap. These may be held down by cleats or by wire screen. Fabrics often are used in combination with riffles to catch fine gold and hinder its being washed out of the riffles by eddies. A corduroy woven specially for a riffle surface is used by some large Canadian lode-gold mines to catch their "coarse" gold before flotation or cyanidation. As such gold would be considered fine by most placer miners it seems probable that such a fabric would be useful for treating finely screened placer sands. The corduroy in question has piles about 1/4 inch wide and 1/8 inch high, spaced about 1/4 inch apart. The piles are beveled slightly on one side. The cost in Canada is about $1.00 per square yard.

Heavy wire screen such as that used for screening gravel makes an excellent riffle for fine or medium-size gravel in fairly shallow sluice streams, and generally it is used with burlap or other fabric underneath.

Expanded metal lathing and woven metal matting are common types of riffles for fine material and are used with carpet or burlap. If the thin strands of metal slant considerably in one direction, the material should be placed with this direction downstream. Eddies in back of the strands will then form gold catchers, whereas if the recesses face upstream they will at once fill with a tight bed of sand and lose their effectiveness.

A matting woven of twigs or cane is recommended by Idriess[38] as an efficient gold catcher for a small, portable sluice box for shoveling-in operations or prospecting. Turf, as used at the Hockensmith placer in Idaho, is said to make an efficient trap for fine gold.

Solid-rubber riffles were noted at one washing plant. Sponge-rubber riffle material is on the market, but it was not observed in use and nothing is known by the authors of its merits or cost.

Another form of riffle often used as an auxiliary to other types is a mercury trap, consisting of a board the full width of the sluice with 1- or 1 1/2-inch auger holes in which mercury is placed. Instead of round holes, transverse grooves or half-moon-shaped depressions, 2 to 4 inches wide and with the rounded, deep side downstream, may be cut in a wide board and partly filled with mercury. These riffles have no apparent advantage over the ordinary transverse-bar type and are suitable only for fine gravel, as large pebbles would splash the mercury out of the traps.

Many ingenious and odd kinds of riffles are encountered in the field, some of which have been patented. It is very unlikely, however, that the advantage of any unusual or freakish design of riffle is sufficient to offset the cost of royalties on patented inventions.

Undercurrents

An undercurrent, as defined before, is a device for sluicing separately a finer part of the gravel passing through the main sluice. The fine material and a regulated quantity of

38 Idriess, I. L., Prospecting for Gold: Angus & Robertson, Sydney, 3d ed., 1932, pp. 64-65.

water pass through a stationary grizzly in the bottom and usually near the end of the sluice to one or more wide sluice boxes, commonly called tables, paved with suitable riffles. If the main sluice is in sections, with drops between, the water and sand may be returned from the undercurrent tables to the main stream, and several undercurrents may be installed at convenient points along a sluice.

The screen or grizzly in the main sluice may present the most difficult problem in building a satisfactory undercurrent. The screen should divert all the undersize yet not take so much water that it causes plugging of the main sluice below the undercurrent. The proper size of opening can be determined only by experiment. A screened or barred opening, the full width of the main sluice and a few inches to a foot or more long, will usually draw off as much water as can be spared. New water may be added to either the undercurrent or main sluice if the screen opening does not take out the right quantity for successful operation. Usually minus 1/4- to 1/2-inch material is desired for the undercurrent, and either punched-plate screen or iron-bar grizzlies may be used to make the separation. Grizzlies should be made of tapered bars or screens punched with tapered holes with the largest openings downward, otherwise they will plug and render the undercurrent ineffective.

Because undercurrents need a wide, shallow stream, grades of 12 to 18 inches per 12 feet must be used, depending largely on the type of riffle. Cobblestone, block, transverse or longitudinal wooden strips, rails, screens, or fabrics may be used for riffles. Often several types of riffles are used on successive parts of one undercurrent. Undercurrents may be a few to 25 or 30 feet wide and 10 to 50 feet long.

Most of the gold recovered by undercurrents is so fine that it does not settle in the relatively swift, deep current of the main sluice, but part consists of gold that is freed from its matrix of clay by dropping through the grizzly and rolling over the undercurrent riffles. All coarse gold is saved in the first few boxes of the main sluice unless conditions are radically wrong. Unless the undercurrent is installed at the end of the sluice, or at least below where gold is recovered, not all the saving in the undercurrent should be credited to its installation. In the early days when hydraulicking was at its height undercurrents were much favored, sometimes 5,000 to 10,000 square feet of undercurrent being used along a single sluice line. The gold saved in them occasionally exceeded 10 percent of the total clean-up but more often was less than 5 percent. As this recovery usually was effected by 5 or 10 large tables and as considerable would have been saved by the main sluice without the undercurrents, the economy resulting from their use was perhaps doubtful. Bowie[39] presents details of the use of undercurrents in early Californian practice and indicates that their particular field lay in the treatment of cement gravels. Of the several undercurrents observed by the authors in use in 1932 it is doubtful, as shown before, if many were justifying their installation. Table 13 gives data on undercurrents in use at mines operating in 1932.

Operation of Sluice Boxes

Under favorable conditions a properly designed and constructed sluice box requires little attention other than periodic clean-ups and minor repairs which are made at the same time. Unfortunately, such a combination rarely occurs, and an appreciable part of the miner's operating expense is chargeable to work along the sluice lines.

39 Bowie, A. J., A Practical Treatise on Hydraulic Mining in California: Van Nostrand Co., New York, 3d ed., 1889, pp. 252-262.

The best results are obtained when a steady flow of water and gravel passes through the sluice. An excessive flow of clear water through the sluice will bare the riffles, causing some gold to be lost. On the other hand, a continued overload of gravel will plug the sluice at some point so that sluicing must be stopped for the time needed to clear the obstruction; this time lost may be appreciable. If plugging cannot be prevented by increasing the grade or the flow of water or reducing the feed, one or more sluice tenders must work along the sluice with forks or shovels to keep it open. This added cost may be serious at small mines. All effort should be directed toward getting the gravel into the box and letting the water do the rest.

Large boulders are another cause of expense and lost time. When the maximum size of boulder that the sluice will carry is known, all boulders larger than this should be prevented from entering the boxes. Relatively little work directed to this end will save hours of delay in clearing plugged sluices and unnecessary wear and tear on the boxes and riffles.

An exception is found in the operation of "booming." A necessary condition of this work is a heavy head of water which usually fills the sluice to the brim. Sometimes little or no work can be done in the pit while the water is on, and the entire crew may profitably patrol the sluice with long-handled shovels to guard against stoppages which might be disastrous because of the large flow of water and gravel. Before each "boom" all oversize boulders should be moved out of the course of the water.

Cleaning Up

Clean-up time should be kept to a minimum. This can be done by cleaning up as seldom as practicable and by using efficient methods. Large hydraulic mines, particularly if the water season is short, clean up only once a season except perhaps the upper one or two boxes. Dredges clean up every 10 days or 2 weeks, because large amounts of gold are recovered in relatively short sluices with attendant possible loss when the upper riffles become heavily charged. This necessary delay is used for routine repairs on the dredge. In ground-sluicing the clean-up period ranges from weeks to months, while in shoveling-in operations the sluice may be partially cleaned up daily. The danger of theft from the upper, richer boxes can be lessened by filling them with gravel at the end of each day's work.

The general principle is the same in all clean-up operations, but practice differs widely. Clear water is run through the sluice until the riffles are bare, the stream being reduced enough to prevent washing out the gold. Then the water is turned off or reduced to a very small flow, and the riffles of the first box are lifted, washed carefully into the box, and set aside. Any burlap or other fabric used under the riffles likewise is taken up, rinsed into the box, or placed in a tub of water where it can be thoroughly scrubbed. Then the contents of the sluice are shoveled to the head of the box and "streamed down" with a light flow of water. The light sand is washed away, and rocks and pebbles are forked out by hand. This operation is repeated until the concentrates are reduced to the desired degree of richness. Gold or amalgam may be scooped up, as it lags behind the lightest material at this stage, or all the black sand with the gold, mercury, and amalgam may be removed and set aside for further treatment. Successive boxes are treated similarly, until the sluice is bare. The last step is to work over the whole sluice with brushes and scrapers to recover gold and amalgam caught in cracks, nail holes, or corners. At the Wisconsin mine a small box was set up in the main sluice and the concentrate from the riffles shoveled into it to reduce the bulk. At the Round Mountain mine the concentrate from the lower section of the sluice was treated in a quartz mill.

Use of Quicksilver in Sluicing

Quicksilver is used at nearly all placer mines. If it is not used to catch gold in the sluices, at least it is probably used in extracting the gold from the concentrates. The average market price for mercury in 1932 was about $58 per 75-pound flask, but quicksilver purchased in 5- or 10-pound lots from a chemical-supply house costs about $1 per pound. Except in districts where placer mining is particularly active, drug stores or other local retailers charge about double this amount. The price in January 1934 was $67.54 per flask.

The characteristics of quicksilver that make it of value to the miner are: (1) Its power of amalgamating with gold and silver; (2) its high specific gravity (13.5), which causes it to lie safely under a stream of water and gravel, floating off on its surface everything but the native metals; and (3) its relatively low boiling point (about 675° F.), far below red heat, which allows it to be driven off by heat from the gold with which it has amalgamated.

Amalgamation is a process in which mercury alloys with another metal. All metals but iron and platinum amalgamate more or less readily. Clean and coarse placer gold alloys readily, but if the gold is partly coated with iron oxide or other substances (for example, "rusty" gold) it amalgamates with difficulty. The mercury itself should be clean enough to present a smooth, shiny surface; the presence of some gold or silver in the quicksilver, however, is said to facilitate amalgamation, that is, to make it more "active."

Quicksilver is placed carefully in the sluice boxes, where it finds its way to the many recesses in the riffes and lies in scattered pools, ready to seize and hold any particle of gold that touches it. It is used in this manner in almost all important hydraulic operations, but some operators place it in the boxes only shortly before the clean-up, evidently believing that the added gold saved by its use during sluicing does not compensate for the loss of the mercury that passes through the sluice with the tailings or escapes through cracks or other leaks. In exceptional instances the conditions are such that the mercury "flours", that is, breaks into minute, dull-coated drops. Flouring is aggravated by agitation or exposure of the mercury to air. The common practice of "sprinkling" it into sluice boxes may be condemned on this ground, as well as for the reason given by Bowie[40] that the fine particles formed by careless sprinkling are more readily washed away and lost. Flouring is responsible for the most serious losses of quicksilver with the tailings.

Even under the best conditions, 5 to 10 percent of the mercury used is lost. If steep grades, heavy gravel with consequent severe pounding and vibration, old and leaky sluices, or other adverse conditions exist, the loss of mercury may be 20 or 25 percent.

Only clean mercury should be placed in a sluice; even this tends to become fouled or sluggish and to lose its effectiveness. The best cleansing process is retorting, which is discussed later. However, straining the mercury through chamois or tightly woven cloth removes some of the surface scum and foreign material, or the mercury may be treated with potassium cyanide or other chemicals to dissolve the impurities. It should be handled as little as possible and kept from contact with grease or other organic material.

Wilson[41] suggests a cow's horn, sawed off near the small end to leave a hole that can be stopped with the finger, as a useful implement for charging sluices. Most miners charge the sluice from stoneware or heavy glass bottles such as are used for champagne.

Mercury should be kept or carried only in iron, glass, or earthenware containers because of its tendency to amalgamate with zinc (galvanized iron), tin, or other metals.

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40 Bowie, A. J., work cited, p. 244.

41 Wilson, E. B., Hydraulic and Placer Mining: John Wiley & Sons, New York, 3d ed., 1918, p. 230.

The quantity of quicksilver used differs according to conditions and custom. According to Bowie,[42] 200 or 300 feet of 6-foot sluice should receive about three flasks (225 pounds) as a first charge and a 24-foot square undercurrent, 80 or 90 pounds. At the Depot Hill mine one flask is placed in the first 4 or 5 boxes each month during the washing season. At the Plataurica two flasks were used in a season during which 100,000 cubic yards was washed. Dredge tables, with areas of 1,000 to 10,000 square feet, are charged with 150 to 3,000 pounds of mercury. According to Janin,[43] a 7-foot dredge with a table area of 2,800 square feet uses about 1,000 pounds on the sluices and in the traps. Probably in common practice the range is 1/10 to 1/4 pound per square foot of sluice area.

The sluice should be run long enough to plug all leaks before the mercury is added. Usually only the upper 2 or 3 boxes or a quarter or half of the sluice at most is charged with mercury, as otherwise considerable loss occurs. During a run more mercury is added periodically. Whenever the sluice is run down enough to expose the riffles the mercury can be examined. If it does not show here and there with clean surfaces nearly to the top of the riffles, more is added. As the quicksilver takes up gold near the head of the sluice it becomes pasty and finally quite hard, and more should be added to keep it in a fluid condition.

The use of mercury in recovering gold from sluice-box concentrates is discussed in the following section.

Amalgamating plates should be used only in treating fine material, generally well under one fourth inch in size and preferably not coarser than 10-mesh, as larger particles abrade the plates too rapidly and prevent building up of the amalgam. Consequently, the application of plates to placer mining is limited to the stamp milling of some drift-mine gravels and the treating of fine undercurrent or other screened sands. The use of plates in stamp milling is a phase of metallurgy beyond the scope of this paper, and reference is made to any standard text or handbook on gold milling.[44]

None of the other applications of amalgam plates to placer mining is of particular importance, probably because the recoveries seldom have justified the labor and expense. Plates may be set in undercurrents treating finely screened sands, such as beach sands or the Snake River gold-bearing sands. They usually are covered with burlap to assist in retaining the gold until it has come in contact with the amalgam. Many other amalgamating devices have been applied to such material, but none is known to the authors to have been of greater value than properly designed sluices and riffles.

SEPARATION OF GOLD AND PLATINUM-GROUP METALS FROM CONCENTRATES

General

No sluice box or other type of gold saver used in large-scale placer mining makes a clean separation of the valuable minerals. The concentrate obtained must be treated further to make a marketable product. Concentrate obtained in cleaning bedrock in some types of mining is treated similarly to sluice-box concentrates.

The concentrate may be cleaned by panning or rocking in auxiliary sluices or by blowing, or it may be amalgamated in a special type of apparatus. The treatment will depend mainly upon the scale of operations, the proportion of black sand in the concentrate, and the

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42 Bowie, A. J., work cited, p. 244.

43 Janin, Charles, Gold Dredging in the United States: Bull. 127, Bureau of Mines, 1918, p. 143.

44 See also Chapman, T. G., Treating Gold Ores: Ariz. Bureau of Mines Bull. 135, Univ. Arizona, 1932; a brief, nontechnical description of the methods of treating gold ores.

characteristics of the gold. The general methods of cleaning concentrate with pans, rockers, or small sluices are the same as those in small-scale mining, described in a previous paper,[45] except that more care is required and smaller quantities are treated at one time. In treating small quantities of concentrate, however, it should be remembered that colors of gold so fine as to present great difficulty in their separation by panning or rocking are probably of small value, and their loss would be inconsequential.

If precise results are desired for sampling or testing, the concentrates should be amalgamated.

Panning

Panning is the simplest method of separating the valuable constituents from the worthless material and generally is used in small-scale operation. The method, however is tedious if the gold is very fine and the concentrate contains much black sand. Mercury may then be used in the pan to collect the gold.

Rocking

Larger quantities of concentrate may be treated in a rocker and the resulting semifinal product cleaned further in a pan. A final or almost final product, however, can be made in a rocker, the flat, smooth bottom of which, set on a gentle grade with screen and canvas baffle removed, offe an ideal surface for the purpose.

The concentrates are placed at the upper end, and a small stream of water is poured over the sand while the rocker is swayed gently back and forth. The lighter material is washed down to the riffle at the lower end, and the coarser particles of gold are left behind. These are picked up with a scraper, and the operation is repeated, a portion of the concentrates presently being discarded with each washing until at length all gold of appreciable value has been recovered. This method is satisfactory with ordinary concentrates, but if the gold is very fine, slaky, or particularly light, porous, or angular, the separation is tedious and unsatisfactory, and amalgamation is to be preferred.

The same general method may be used in the mine sluice to recover the bulk of the gold amalgam.

Auxiliary Sluices

Sometimes an auxiliary sluice is used to reduce the volume of concentrate from the mine sluice or to treat concentrate after it is amalgamated. The small sluice in turn must be cleaned up. At one mine a 12-inch box was set up in the main sluice into which was shoveled the riffle concentrate from below.

Blowing

The grains of sand remaining in an almost final product may be removed from the gold by blowing. A flat metal or paper sheet, such as a piece of drawing paper or a large flat tin about 2 feet square with the edges bent up about one half inch, is best for the purpose. However, with care and skill the operation can be performed in a common gold pan, as is done by many prospectors, particularly when cleaning dry-washer concentrates. The material should

45 Gardner, E. D., and Johnson, C. H., Placer Mining in the Western United States: Part I. - General, Hand Mining, and Ground-Sluicing: Inf. Circ. 6786, Bureau of Mines, 1934, 73 pp.

be perfectly dry. Much effort is saved by using a magnet to take out any magnetite sand in the concentrates; often this mineral comprises as much as 90 percent of the material. A piece of paper folded around or held against the end of the magnet will keep the magnetite from sticking to the metal. When all the magnetite is removed, blowing gently on the remaining sand and gold will drive the former to the farther edge of the sheet, leaving the gold behind. In most instances the loss of a few fine colors is not serious.

Amalgamation

In Ordinary Gold Pans

A small quantity of quicksilver, ranging from an ounce to a quarter of a teaspoonful, will catch all the gold from a pan of sluice concentrates. The mercury is simply placed in the pan with about 5 pounds of concentrates and agitated under water until no more free gold can be observed. Then the sands are panned off, care being taken not to lose any of the amalgam or fine drops of mercury, which gradually will run together into a single mass. If the concentrates are nearly all black sand only a small quantity should be washed at a time, but if much light sand or rock is present larger quantities can be washed.

Copper-plated pans or pans with steel rims and copper bottoms are available and are useful for saving fine gold in concentrates. The copper is coated with mercury by first cleaning it with emery paper, then rubbing clean, bright mercury or amalgam on it until it presents a smooth, shiny surface. The gold in the material being treated is picked up quickly by the amalgam surface. Only fine sand can be treated to advantage as coarse sand or gravel will scour the amalgam off the copper. As fast as amalgam accumulates on the copper it is scraped off with a smooth, dull-edged, iron scraper such as a putty knife. More mercury may then be added to keep the surface bright and in a "receptive" condition.

Amalgamators

In nearly all large-scale operations most of the gold is amalgamated in the sluice boxes or on the riffle tables, and the amalgam is separated from the sands during clean-up operations or from the concentrates by rocking or panning. Tarnished or rusty gold or very fine gold, however, does not amalgamate readily because it is difficult to make contact between the gold and quicksilver. Such gold, generally included in a black-sand concentrate, requires agitation in the presence of quicksilver or, if rusty, grinding to remove the interfering coat for satisfactory amalgamation.

Mechanical amalgamators are used to treat such materials. Occasionally all of the concentrate from the sluice will be treated in an amalgamator, particularly if it contains rusty gold. The charges for the amalgamator should be kept clean; grease especially interferes with amalgamation.

A common type of amalgamator is the clean-up pan, which consists of a cast-iron, cylindrical, flat-bottomed barrel or tub 1 or 2 feet in diameter for small-scale work and 4 to 6 feet in diameter for mill service. The concentrate with 1 or 2 percent quicksilver by weight is placed in the pan with sufficient water to make the mass fluid and agitated by a revolving spider. The quantity of water added should be sufficient only to permit agitation without too great strain on the machine. The pulp should be thick enough to hold particles of mercury in suspension. Shoes on the lower end of the spider arms slide on a flat, circular race in the bottom of the barrel, thus adding some grinding to the agitation. After running for 1 or 2 hours the batch may be emptied through a drain plug in the bottom of the barrel and the mercury and amalgam separated from the sand by panning. Some pans are provided with side drain plugs at various elevations. The rotation may then be slowed from its usual speed of about 60 r.p.m., the shoes raised enough to stop the grinding, and water added. This will settle the quicksilver and amalgam; the waste sludge can then be flushed out through the upper drain plugs and almost complete cleaning of the amalgam and mercury made in the pan itself.

Another device, the so-called amalgam barrel, generally is used at large stamp mills and occasionally is employed in placer operations, particularly in dredging, to treat accumulated black sands, scrap metal, and other possible gold-bearing material from clean-up operations. It is merely a cast-iron or steel drum revolving on a horizontal axis like a ball mill and fitted with suitable drain plugs, handholes, manholes, or removable ends, depending on its size and use. The material to be treated is placed in the barrel with quicksilver, water, and a few iron balls, and the barrel is turned slowly for an hour or several hours. The barrel may then be flushed with water from a hose to wash away the lighter products of grinding, turned over, and emptied into a tub, the amalgam and mercury being recovered by panning. Potassium cyanide sometimes is added to brighten the gold, using only enough to make a very weak solution.

An amalgamator that occasionally is used, especially if a part of the gold is attached to particles of quartz, is the Berdan pan, which is relatively simple in construction and cheap to operate. The pan consists of a revolving cast-iron bowl, usually 3 to 5 feet in diameter, with a raised central hub for the drive shaft, giving it the form of a circular trough. The bowl is supported either by the drive shaft or by rollers and is set with a tilt of about 20 or 30° from the horizontal. It is driven at 10 to 30 r.p.m. either by a crown gear on the inclined shaft of the bowl or by a ring gear on the bottom of the bowl. One or two large cast-iron balls roll in the trough as the bowl revolves. Quicksilver is placed in the bowl with the charge, and as the device revolves a stream of water is directed into it and overflows at the lowest point of the rim. The material to be amalgamated may be added in batches or, if it is to be ground as well as amalgamated, by an automatic feeder, the slimes and fine material overflowing to waste; the bowl then acts as a classifier. For placer concentrates the batch process is used, 100 pounds or more being treated at a time. Too large a quantity of sand lessens the grinding effect of the balls.

A 1- or 2-cubic-foot, hand- or power-driven concrete mixer is a convenient amalgamating device for the small- to medium-scale placer miner, particularly if part of the gold is rusty. It costs only $20 to $30, excluding the small gasoline engine, and can be obtained from hardware stores or mail-order houses. The charge for such a machine is two or three pails of concentrates, 1 or 2 pounds of quicksilver, a few round cobblestones 3 or 4 inches in diameter, and water. About a 1-hour treatment will amalgamate practically all of the gold. The charge is emptied into a settling tub and then washed in a pan or small sluice box to recover the amalgam and mercury.

Regardless of the amalgamator used, too violent agitation of the mercury must be avoided otherwise excessive flouring hinders amalgamation and makes it difficult or impossible to recover the quicksilver.

Cleaning Amalgam

The mixture of quicksilver and amalgam from sluice-box clean-ups usually contains much more mercury than amalgam. It can be freed from sand, scraps of iron, and other solid impurities by careful panning and by washing with a jet of clean water. The amalgam can then be separated from the quicksilver by straining the mixture through buckskin, chamois skin, close-woven canvas, or other strong, tight cloth. This generally is done by hand, preferably under water to prevent scattering of the mercury. The quicksilver thus filtered off contains at the most only about one tenth percent of gold; this mercury is desirable for recharging the boxes as the small amount of gold makes it more active. The amalgam, after squeezing, still contains some mercury, part of which may drain off if the mass is suspended for several hours in a funnel or other similar container. With or without this last refinement, which one dredge operator used with success, the stiff, pasty amalgam is now ready for fire treatment to separate the gold. It contains 25 to 55 percent, commonly about a third by weight of gold and silver.

EXTRACTING GOLD FROM AMALGAM

Heating

Although retorting is the common method of separating the gold from the quicksilver in amalgam at dredges and other large-scale operations, the mercury in small quantities of amalgam may be volatilized by simple heating. A common method is to heat the amalgam on a clean iron surface over an open fire or forge, or in a furnace, until all the mercury is driven off. This is the usual expedient of the single miner or small operator who does not object to the loss of the small quantity of quicksilver involved. The mercury vapor may appear as heavy white fumes. Whether visible or not, mercury vapor is exceedingly poisonous, and the work must not be done except where a draft can be depended on to carry all the vapor away from the operator. As stated elsewhere, mercury boils at 675° F., a temperature about halfway between the boiling point of water and the first visible red heat of iron. However, it volatilizes at the boiling point of water enough to be dangerous to the health of persons exposed to it. Consequently, it should be handled carefully, particularly to avoid inhaling its vapors.

In another method of recovering the gold from small amounts of amalgam, a potato is used as a condenser. This is a device popular with prospectors because it is very simple, yet saves part of the mercury that would be lost by the method previously described. A large potato is cut smoothly in half, and in the flat surface of one half a recess is hollowed which should be considerably larger than the amount of amalgam to be treated. The amalgam is placed on a clean sheet-iron surface, the half potato is placed over it, and the whole is set over a hot fire. For convenience it may be done in a frying pan or the scrap of sheet iron put on a flat shovel so that it can be withdrawn readily from the fire. Some mercury vapor will escape under the edges of the potato, and, as before, these fumes must be avoided. After 15 or 20 minutes of strong heating the potato may be lifted off for inspection. If all the mercury is gone from the gold the potato may be crushed and panned, and a considerable part of the mercury will be recovered. It may be desirable to heat the gold further to anneal it; this can be done without removing it from the iron plate. Any tinned or galvanized metal intended for use in this process should be heated redhot and when scoured to remove all traces of the coating so that a clean iron surface will be presented.

A laboratory method of separating the gold is to put the amalgam in a small beaker and dissolve the mercury in a 1 to 1 solution of nitric acid and water. When all the mercury is dissolved, the gold may remain as a sponge, which can be washed gently in water and annealed in a small porcelain crucible. More frequently the gold will be recovered as a fine dust, which also can be washed and annealed but is less easy to handle.

Retorting

A very small amount of amalgam can be retorted quickly and easily in a laboratory in a glass tube 18 to 24 inches long, sealed at one end and bent 2 or 3 inches from that end to a putting in the charge. This prevents the gold from sticking to the iron, which sometimes causes trouble. A lining of paper serves the same purpose but tends to form an objectionable deposit in the condenser pipe.

The retort should not be filled over two thirds full of amalgam (a third or half full when retorting liquid mercury), otherwise there is danger of some of the contents boiling over into the condenser tube. The amalgam is broken into pieces and piled loosely. Then the cover is put on and clamped tightly with the wedge or thumbscrew provided, first making sure that the attached condenser pipe is clean and free of obstructions. The ground joint between the cover and body of the retort is seldom tight enough to prevent leakage and should be luted with clay or some sealing compound. One satisfactory cement is made readily by moistening a mixture of ground asbestos and litharge (red lead) with glycerin.

A low heat is applied at first, then after 10 or 15 minutes the temperature is increased just enough to start the mercury vaporizing and condensing. Too rapid heating harms the retort, and only enough heat should be used to maintain a steady trickle of quicksilver from the condenser. When no more mercury appears the temperature should be increased for a few minutes to red heat to drive the last of the quicksilver out of the retort; then the fire should be withdrawn from the retort and the latter allowed to cool. Some mercury vapor always remains in the retort, and the operator should take care not to breathe these fumes upon taking off the cover.