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PLACER MINING IN ALASKA

METHODS AND COSTS AT OPERATIONS USING HYDRAULIC AND MECHANICAL EXCAVATION EQUIPMENT WITH NONFLOATING WASHING PLANTS

BY BRUCE I. THOMAS, DONALD J. COOK, ERNEST WOLFF, AND WILLIAM H. KERNS

United States Department of the Interior—1959

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PLACER MINING IN ALASKA

METHODS AND COSTS AT OPERATIONS USING HYDRAULIC AND MECHANICAL EXCAVATION EQUIPMENT WITH NONFLOATING WASHING PLANTS[1]

BY

BRUCE I. THOMAS,[2] DONALD J. COOK,[3] ERNEST WOLFF,[3] AND WILLIAM H. KERNS[4]

Summary and Introduction

THIS PAPER, one of a series on placer mining in Alaska, describes mining methods and gives unit costs at operations where hydraulic and mechanical excavation equipment is used with nonfloating washing plants. The mining methods described were developed during the last 30 years to cope with conditions peculiar to arctic and subarctic regions and are now used by a large segment of the placer mining industry in Alaska.

The operations described have been classified into three main categories: Those having sluices at a bedrock level, those having sluices above bedrock, and those having mobile nonfloating washing plants (dryland dredges). Diesel-powered bulldozers and draglines convey or elevate gold-bearing gravel to the sluices, remove tailings, and strip waste gravel and other overburden. Diesel-powered centrifugal pumps supply water for sluicing and hydraulic stripping. Detailed descriptions and unit costs are presented for 14 operations to illustrate the numerous arrangements under the first 2 categories.

The volume of material moved during a mining season and the unit cost per cubic yard at these operations ranges from 3,000 cubic yards at a unit cost of $2.54 per cubic yard for a bulldozer-sluiceplate combination to 260,000 cubic yards at a unit cost of $0.16 per cubic yard for a bulldozer-dragline-hopper combination. Specific data were not available for illustration of a dryland dredge operation.

Purington's comprehensive report[5] on placer mining methods and costs, based upon field studies made in 1904, was accepted as authoritative for Alaskan practice for more than 20 years. Detailed field investigations conducted on all types of placer mining from 1922 through 1924 resulted in the publication of a second comprehensive report on placer mining methods and costs in Alaska.[6] Since the publication of these reports, marked changes have been made in placer mining methods and techniques owing, primarily, to the development of highly mobile excavating equipment and portable pumping units.

In 1953 the School of Mines Research Department of the University of Alaska began the collection of present-day placer mining methods and cost data to illustrate the changes that have taken place in the techniques used by one phase of the placer mining industry—opencut placer mining. The coopera-

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[5] Purington, C. W., Methods and Costs of Gravel and Placer Mining in Alaska: Geol. Survey Bull. 263, 1905, 273 pp.
[6] Wimmler, Norman L., Placer Mining Methods and Costs in Alaska: Bureau of Mines, Bull. 257, 1927, 236 pp.

tion of the Federal Bureau of Mines was sought in compiling and publishing these data. This circular is presented, therefore, to supplement and to modernize a portion of the last comprehensive publication on placer mining in Alaska.

ACKNOWLEDGMENTS

Appreciation is given to the many mine operators who so willingly made available basic cost data and detailed information on operating methods. Special acknowledgment is due Earl H. Beistline, Dean, School of Mines, University of Alaska, for integrating and coordinating these cooperative studies. The School of Mines, University of Alaska furnished the photographic illustrations.

HISTORY AND PRODUCTION

Before 1930 opencut placer mines operated with cumbersome steam-powered shovels, scrapers, draglines, cableway excavators, and reciprocating and pulsometer pumps. The development of the lightweight diesel engine, which resulted in the advent of diesel-powered bulldozers, draglines, and pumps, brought about a revolution in opencut placer mining methods in Alaska. The introduction in the mid-30's of efficient mobile excavating equipment and portable centrifugal pump units made it possible to work many deposits that could not be mined by the earlier more cumbersome machines. Improvements in gravel washing and recovery systems were developed simultaneously. Readily movable steel sluiceboxes with hoppers and grizzlies, mounted on steel trestles with skids, replaced awkward and less desirable wooden structures. The steel sluiceplate, often called a slick plate, was one of the most influential improvements; it was responsible for the development of simple and flexible mining techniques. The use of portable diesel-driven centrifugal pumps allowed the recirculation of waste water to supplement limited water supplies. Utilization of draglines and bulldozers in combination with established hydraulic methods facilitated the removal of both frozen and thawed overburden as well as the handling of gravel and bedrock during sluicing. Improved dryland dredges, using revolving trommels and stacker conveyors mounted on crawler-type tracks, were developed into successful washing and recovery devices at several properties.

Operation of placer mines using hydraulic and mechanical excavation equipment with nonfloating washing plants increased significantly in the early 40's; approximately 15 percent of the total gold production in Alaska is now recovered by these methods. Despite increasingly adverse economic factors, a consistent total yearly gold production is achieved by mines employing these methods. A 12-year summary of production from opencut placer mines using these methods is shown in table 1.

TABLE 1.—*Placer gold production from mines using hydraulic and mechanical equipment with nonfloating washing plants, in Alaska 1945–56*

Year	Number of mines	Gravel washed, cubic yards	Value of gold recovered	Value of gold recovered per cubic yard of gravel
1945	24	518, 500	$292, 215	$0. 564
1946	66	2, 091, 000	1, 313, 165	. 628
1947	75	2, 905, 000	1, 609, 650	. 554
1948	106	4, 170, 000	1, 962, 660	. 471
1949	117	3, 392, 000	2, 029, 265	. 598
1950	116	4, 908, 500	2. 386, 965	. 486
1951	84	2, 667, 000	1, 653, 540	. 620
1952	78	2, 137, 000	1. 388, 135	. 650
1953	87	3, 591, 000	1, 889, 685	. 526
1954	85	2, 866, 300	1, 710, 800	. 597
1955	91	3, 390, 000	1, 785, 805	. 527
1956	76	2, 295, 200	1. 558, 655	. 679
Total		34, 931, 500	19, 580, 540	[1] 1. 561

[1] Average.

CLIMATE

Placer mining in Alaska is carried on throughout the Yukon and Kuskokwim River basins and in the Seward Peninsula region of Alaska. Climatic conditions in this area, which comprises most of central Alaska south of the Brooks range, vary from place to place. In general, it can be classed as an area of light precipitation and extreme variations in temperature. The summers range from warm to hot; the winters are frigid. Perennially frozen ground (permafrost) covers much of the area.

The operating season for opencut placer mining ranges from 90 to 140 days each year. During exceptionally dry summers, actual productive operations at some mines may be restricted to a much shorter period because of water shortage

LABOR AND WAGES

The number of men engaged in mines using hydraulic and mechanical equipment with nonfloating washing plants ranged from 500 to 650 from 1946 to 1950 inclusive and 300 to 350 from 1951 to 1956 inclusive. From 2 to 12 men are required to operate mines of this type, but few mines employ more than 8. The local supply of skilled and unskilled labor usually is not enough to meet the demands of the mine operators. Workers therefore are recruited from the larger centers of population; transportation expenses to the mines and return usually are paid by the employer if the employee works until the close of the mining season. If not available locally, skilled workmen are brought in from the States. Partner-owners who do their own preparatory work and hire only such labor as is needed during the comparatively short sluicing season operate many of the more successful mines.

Wages generally are lower than those paid by other industries in Alaska. This imposes a decided handicap on the operators in the recruitment of labor. There is no established placer mining wage scale, and consequently wages vary slightly from district to district. Base wages range from $1.25 per hour for unskilled labor to $2.75 per hour for skilled workmen. The average base wage approximates $1.75 to $2.00 per hour. Some operators pay top wages to key personnel; others offer a bonus based upon gross production or length of continuous service. Most mines are operated 9 to 10 hours per shift and 7 days per week during the sluicing season. At some mines board and lodging is furnished at no cost to the employee; where charges are made for board and lodging, they range from $2.50 to $4.00 per day.

MINING METHODS AND ARRANGEMENTS

Many perennially frozen and thawed buried gold placer deposits in Alaska cannot be mined profitably without modern earthmoving equipment. In general, such equipment is used to mine deposits where the size, depth, and character of gravel and topography and conditions of bedrock prohibit dredging or where an inadequate continuous water supply prohibits hydraulicking. Bulldozers, draglines, scrapers, and centrifugal pumps are used skillfully in combination with hydraulic methods to mine these deposits by opencut methods. The choice of excavation equipment, recovery system, and arrangement of the mining method is based essentially upon the size, tenor, and physical characteristics of the deposits as well as on the water supply. Often it may be practical to apply one of several arrangements to mining these deposits; the ultimate choice depending on the funds available for initial capital investment and the personal preference of the operator.

EQUIPMENT

Earthmoving equipment and centrifugal pumps are powered almost exclusively by diesel engines. Bulldozers and draglines of various makes and sizes constitute the most common types of mechanical earthmoving equipment. Slack line scrapers, carryalls, and back hoes have limited utility and are used only in special mining arrangements.

BULLDOZERS

Bulldozers used exclusively or in combination with other earthmoving equipment are employed in all phases of opencut placer mining. They are used for stripping muck and barren gravel overburden; pushing pay dirt to sluiceboxes; stacking tailing; constructing ditches, drains, and roads; and for freighting and general hauling. Rippers affixed to bulldozer blades successfully excavate bedrock where gold has penetrated fractures and joints.

The tractor sizes range from 60 to 180 hp., but the 150-hp. models generally are used. The length of the bulldozer blades conforms to the size of the tractors; straight dozer blades are preferred because angle dozers have less load capacity. Hydraulic-type bulldozers are preferred to the cable type because of the cutting advantage due to more effective downward pressure.

DRAGLINES

Draglines, although less mobile than bulldozers, can move dirt at lower cost per unit. Because of high initial cost, however, their use is limited to those operations having enough reserves to warrant the additional expenditure for equipment. Draglines are used essentially for the same purposes as bulldozers. The 1½-cu. yd. bucket capacity is preferred at most placer mines although the ¾-, 1-, and 2-cu. yd. sizes are not uncommon.

CENTRIFUGAL PUMPS

Diesel-driven centrifugal-pump units usually are mounted on skids for ready portability. Most pumps employed at Alaskan placer mines are of the single-stage type with double en-

trance volute and bronze impellers; cast-steel cases are split horizontally for easy access. Capacities range from 2,500 to 3,500 g.p.m. at heads of 80 to 100 feet. Trash or semisolids pumps of the single-entrance type with cast-steel impellers and rubber-lined cases are used at some operations.

HYDRAULIC GIANTS

Hydraulic giants are of conventional design; lightweight models are preferred to heavier models with cast-steel bases and goosenecks. Giant sizes 1 and 2, with deflectors on the larger No. 2 machines, are most common. Labor-saving automatic giants are employed at some mines; their use is not prevalent, however, because of high initial cost.

ARRANGEMENTS

For convenience this report classifies placer mining methods according to the position of the sluiceboxes in relation to bedrock. They are further identified by the combination and arrangement of the earthmoving equipment used in the mining process.

SLUICEBOXES ON BEDROCK

When hydraulic methods are used in conjunction with earthmoving equipment, sluiceboxes are set on bedrock. Pay gravels are washed into the sluiceboxes by hydraulic giants. Wings attached to the head of the sluices facilitate the operation by converging the material into the throat of the boxes. Figure 1 illustrates a typical installation of a sluicebox on bedrock.

A combination of bulldozer and hydraulic methods of moving gravel is most commonly used by sluice-on-bedrock operations. The methods of employing equipment vary among different operators, but two general arrangements prevail. At some plants one or more hydraulic giants mine the gold-bearing gravel and wash it into the sluicebox; a bulldozer removes and stacks tailing. At other plants bulldozers push gravel into position where it can be washed into the sluicebox by hydraulic giant (fig. 2); the tailing is stacked by hydraulic giant, by the same bulldozer that assists in feeding the sluice, by a second bulldozer (fig. 3), or by a cable excavator. A typical hydraulic-bulldozer arrangement is shown in figure 4.

At larger operations a dragline often is used in combination with hydraulicking and bulldozing. In the most popular arrangement goldbearing gravel is pushed into position by bulldozer and is washed into the sluice by hydraulic giant; tailing is stacked by dragline (fig. 5).

SLUICEBOXES ABOVE BEDROCK

Sluiceboxes above bedrock provide mobility and flexibility of arrangement and eliminate the digging of deep bedrock drains. Such sluices may be mounted either on steel trestles or on gravel ramps. Trestle-mounted sluices (often called elevated sluices) are fed by a hopper equipped with a grizzly to eliminate oversize. A dragline supplies hopper feed, and a bulldozer spreads the tailing. The trestles are designed to provide the necessary gradient and commonly are mounted on skids (fig. 6). Sluiceboxes on gravel ramps are used in conjunction with a sluiceplate. The sluiceplate is a simple rectangular steel box tapered out at one end so that it can be attached to the head of a sluicebox (figs. 7 and 8). The sluiceplate and sluicebox commonly form a single skid-mounted unit that is set on a gravel ramp formed to provide the proper gradient. A bulldozer pushes gravel over the side or the upper end; sluice water enters at right angles to or against the direction of gravel feed (figs. 9 and 10). The use of sluiceboxes mounted on trestles diminished shortly after introduction of the sluiceplate, which, originally, was devised to eliminate the necessity of feeding sluices by hydraulic giants when mining with bulldozers.

The simplest mining plan utilizing sluiceplates employs a bulldozer as the only dirt-moving equipment. Pay gravel is pushed onto the sluiceplate where it is broken up and washed into the sluice. The same bulldozer or a second one stacks the tailing as it accumulates in the sump below the tail box. When water supply is adequate for continuous sluicing and when the reserves of ore warrant additional expenditure for equipment, a dragline may be used to stack tailing. At a few operations where high gravel ramps are used sluiceplates are fed by dragline while another dragline stacks tailing. Mining arrangements and the various combinations of equipment used are illustrated in figures 11 to 17, inclusive.

SLUICES ABOVE BEDROCK, MOBILE

There are three successful mobile dryland washing plants operating in Alaska. These plants consist basically of a hopper, revolving trommel, table sluices, and stackers. The entire unit is mounted in a steel frame supported on crawler treads. Fed by a 1½-cu. yd. dragline (fig. 18), these plants can handle up to 3,000 cubic yards daily. Treatment costs per unit are invariably lower than those of smaller volume operations.

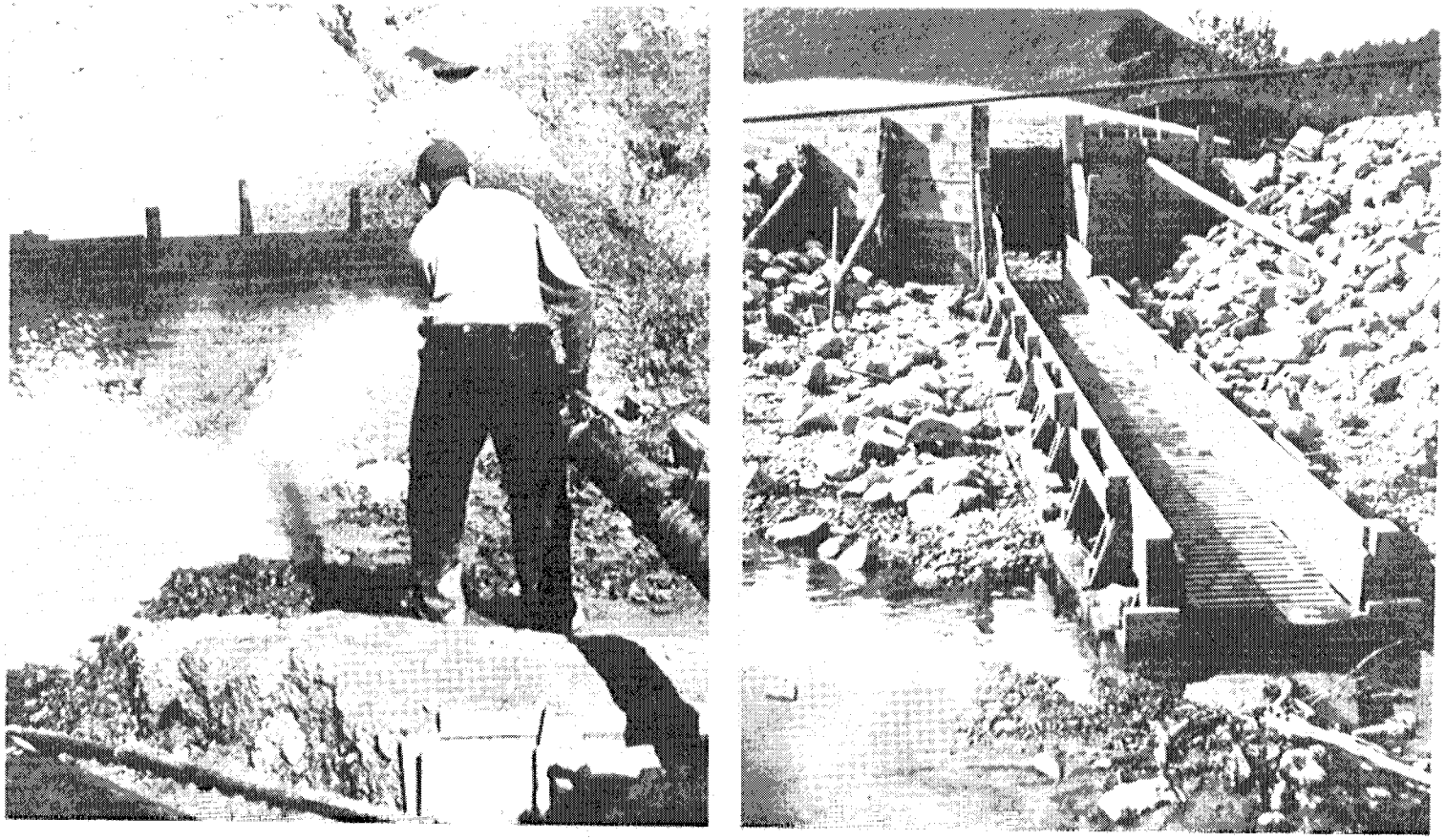

FIGURE 1.—A Sluice Set in Bedrock and Fed by Hydraulic Giant.

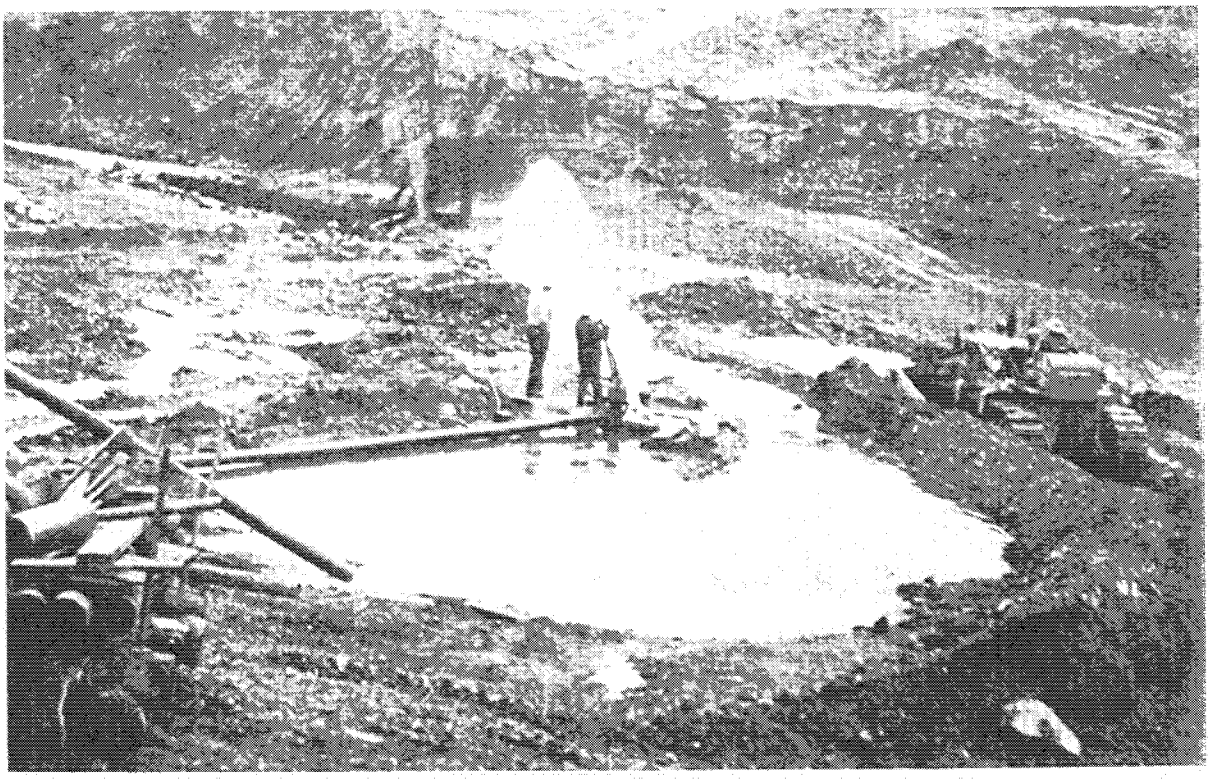

FIGURE 2.—Bulldozer Pushing Gravel Into Position for Hydraulicking Into Sluice.

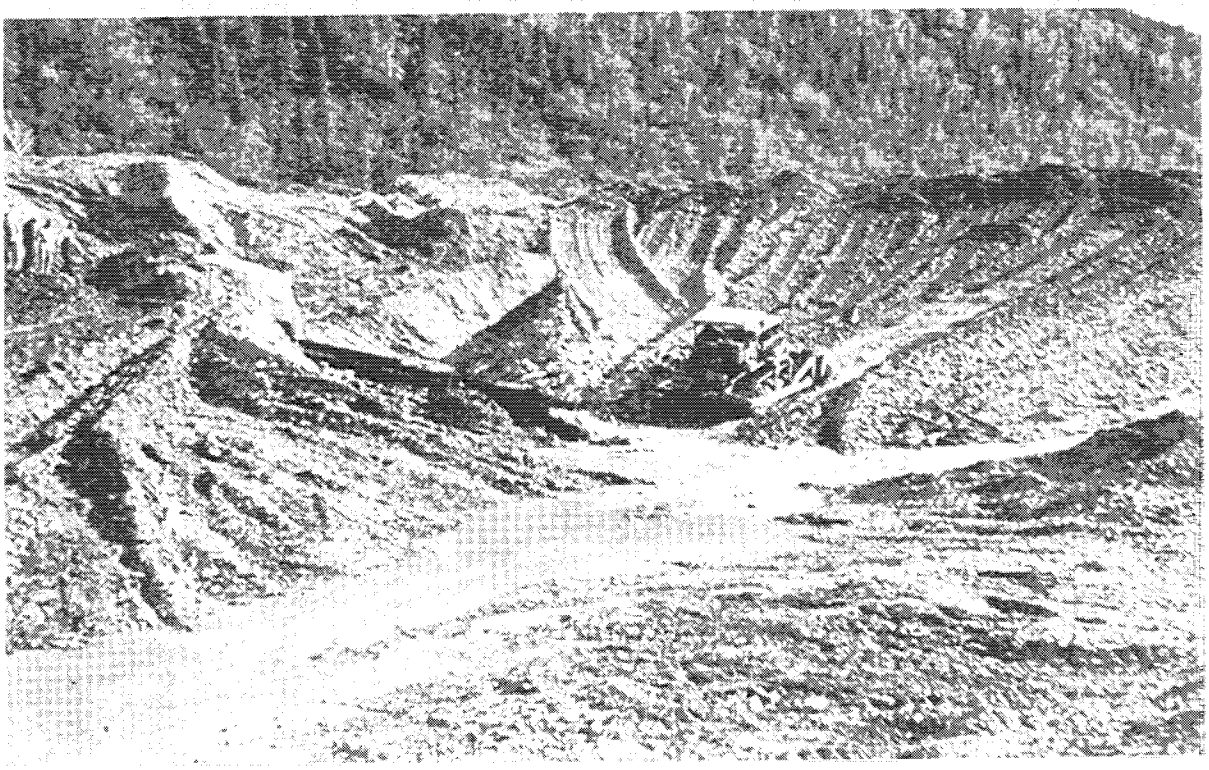

FIGURE 3.—Bulldozer Stacking Tailings.

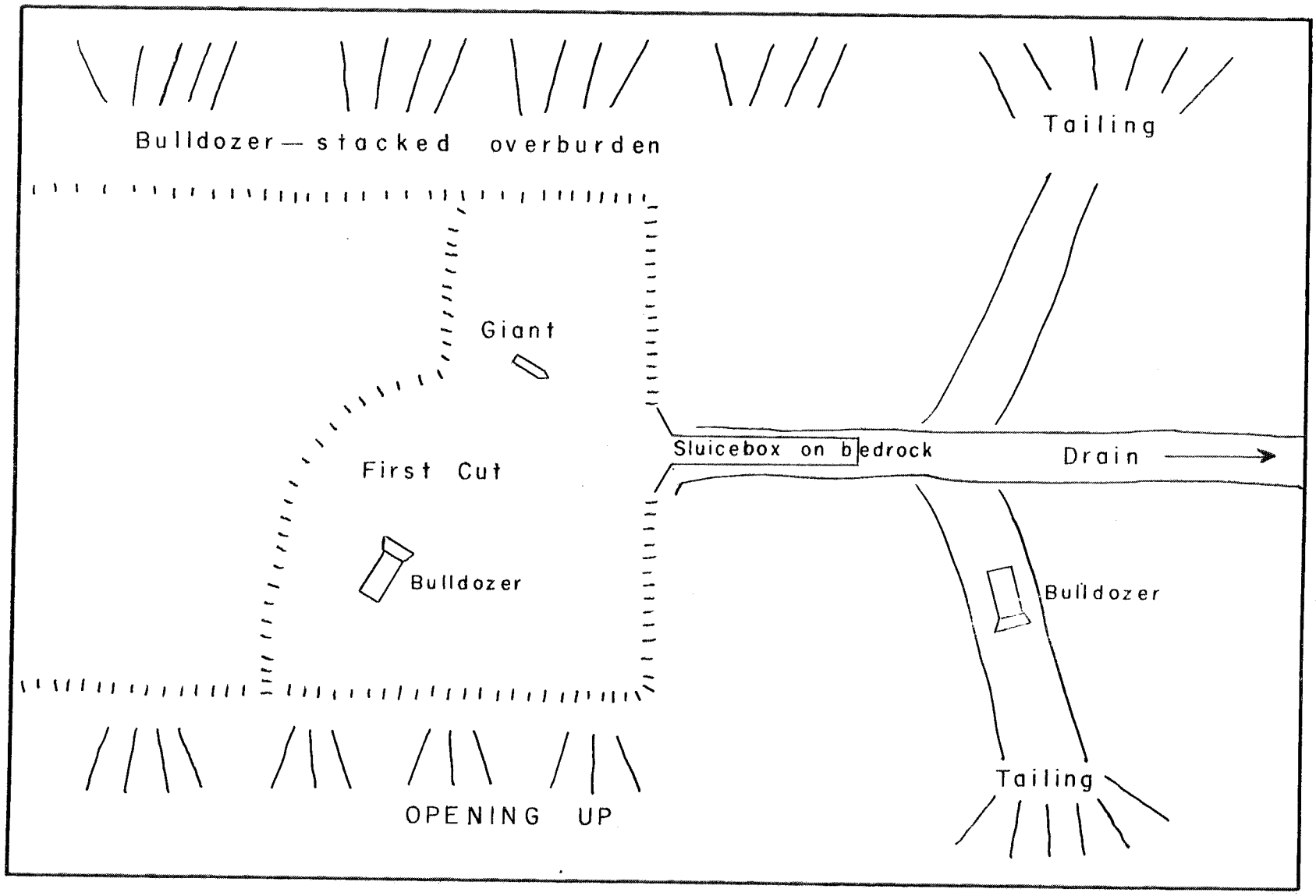

FIGURE 4.—Plan View of a Hydraulic-Bulldozer Arrangement.

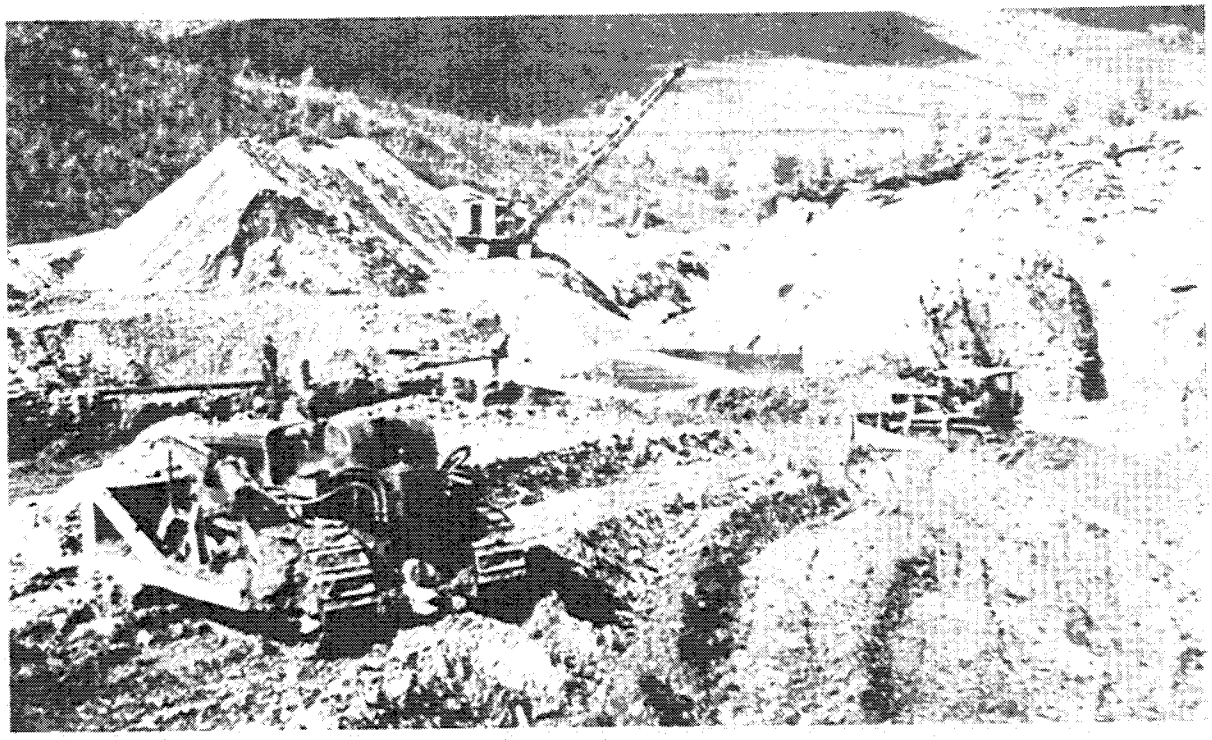

FIGURE 5.—A Bulldozer-Hydraulic-Dragline Operation.

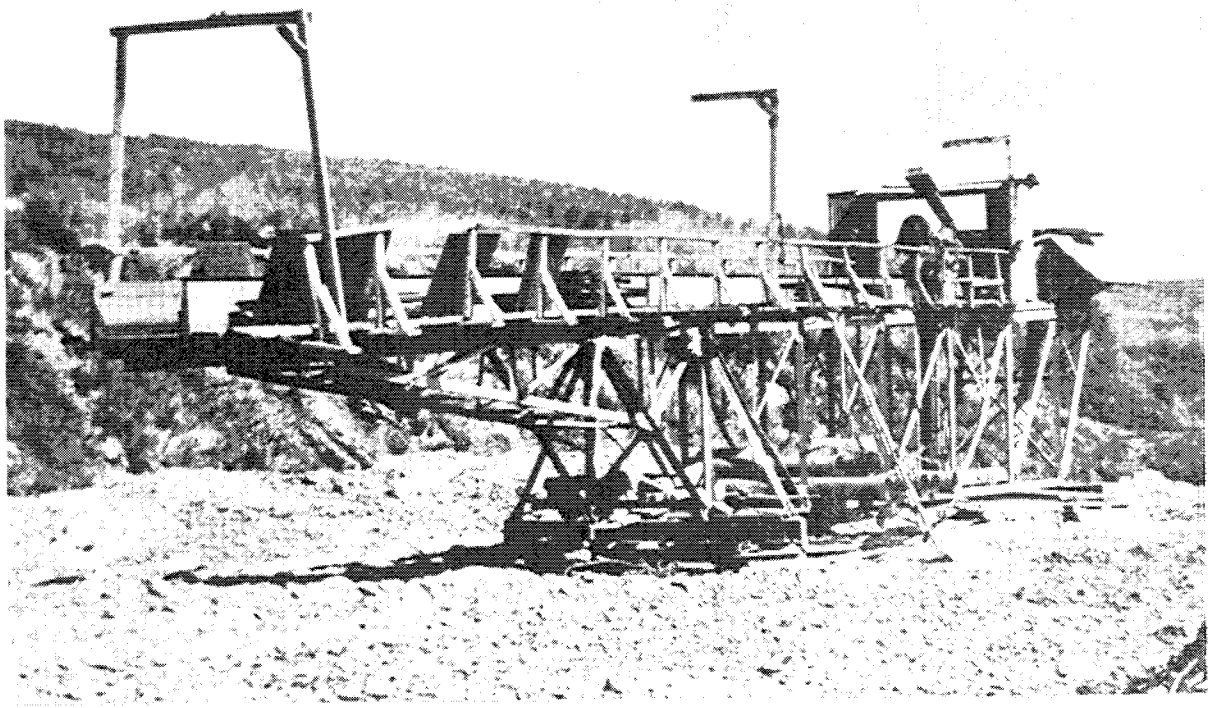

FIGURE 6.—Sluice Elevated on Steel Trestle.

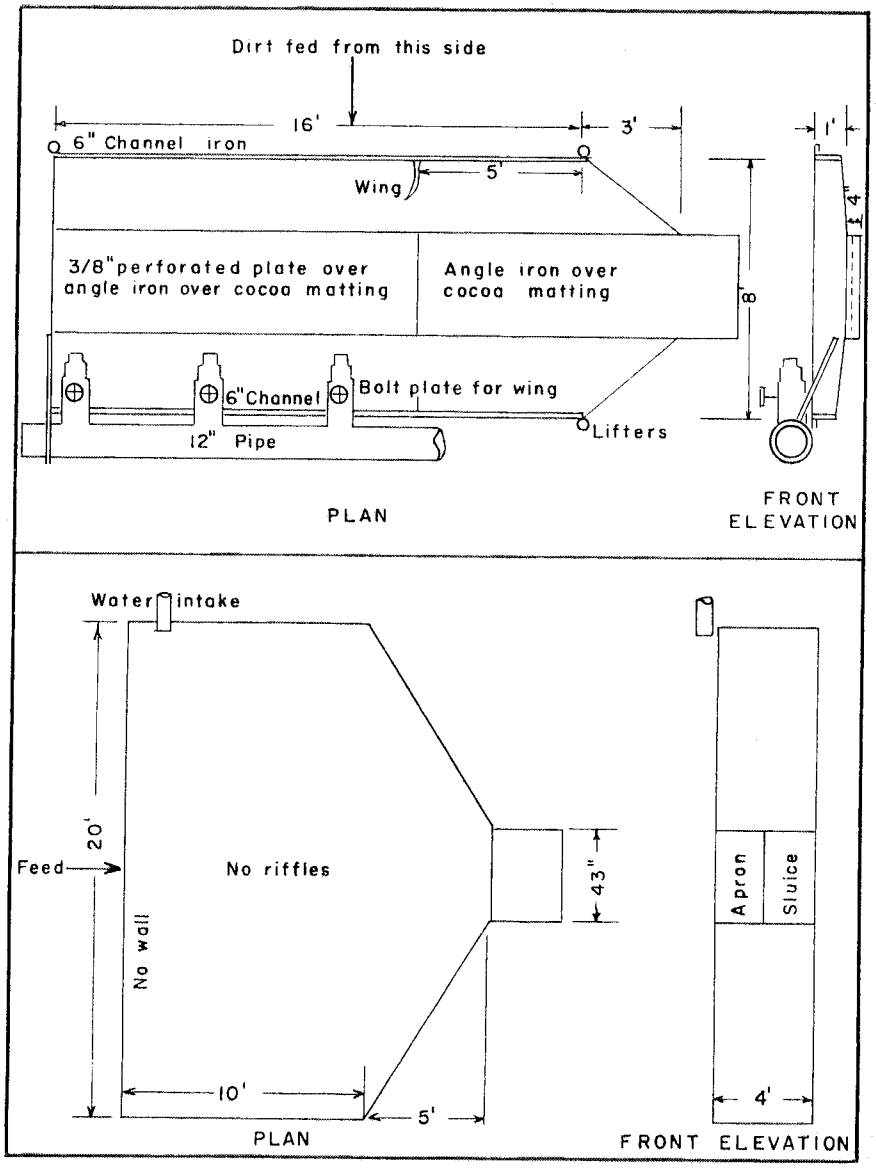

FIGURE 7.—Sluiceplates.

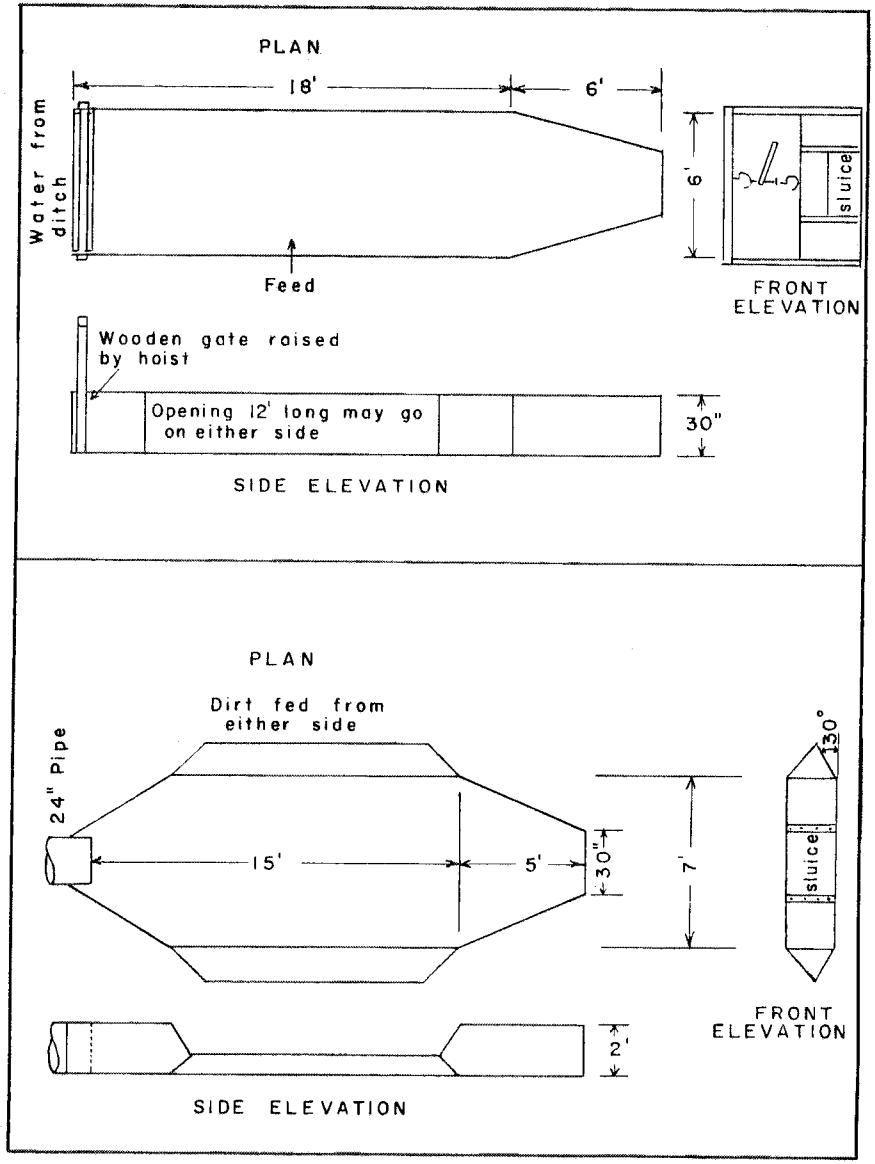

FIGURE 8.—Sluiceplates.

FIGURE 9.—Sluiceplate Fed From Head End.

FIGURE 10.—Sluiceplate Fed From Side.

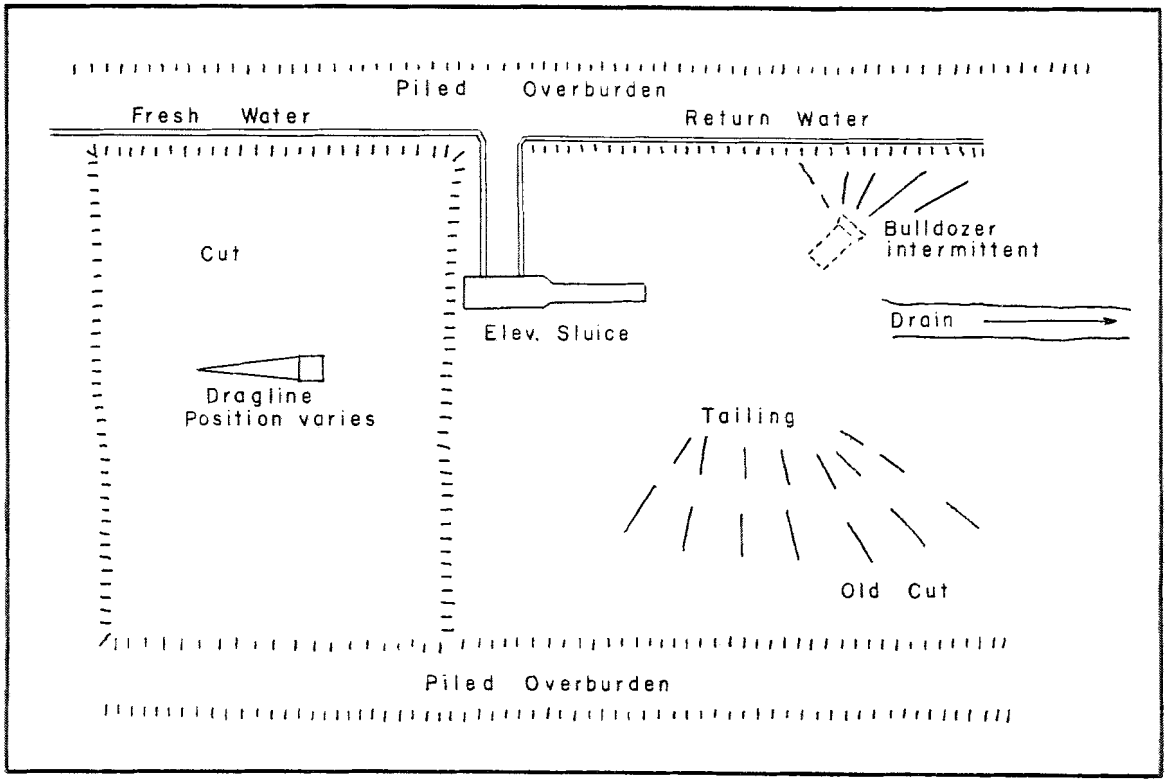

FIGURE 11.—Mining Arrangement Using Sluice Elevated on Trestle.

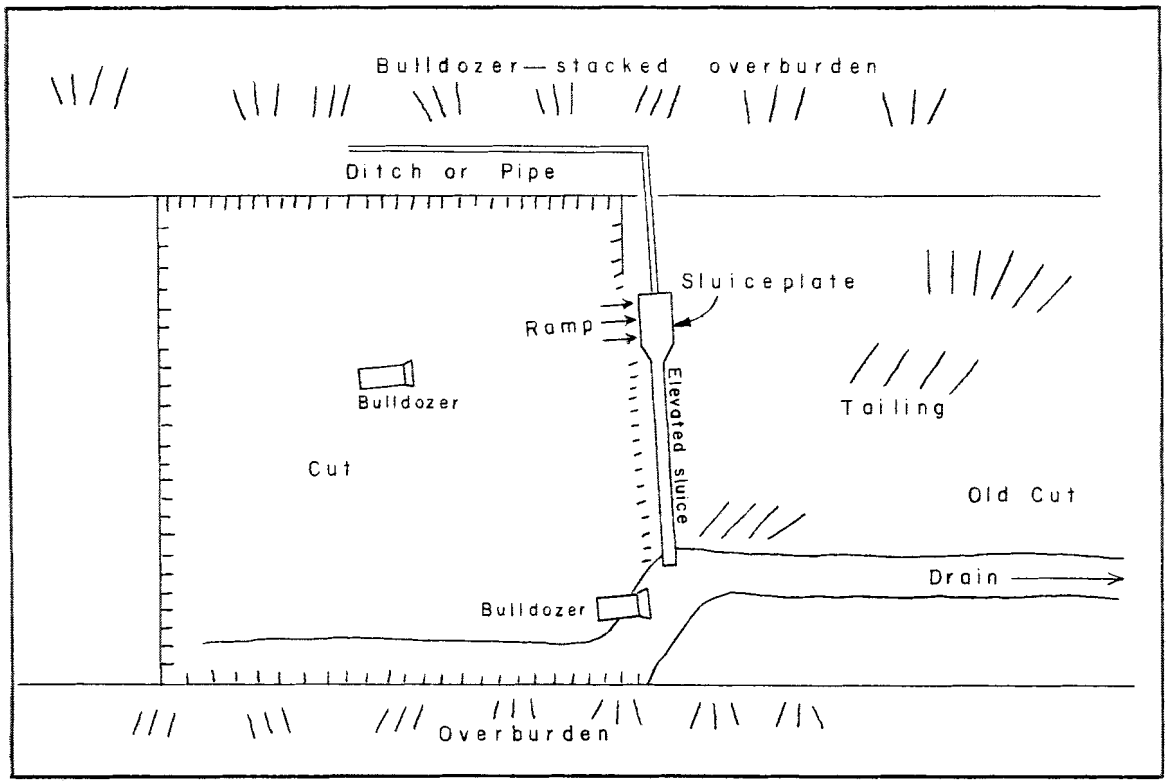

FIGURE 12.—Mining Arrangement Using Bulldozer and Sluiceplate.

FIGURE 13.—Pay Gravel Being Washed in Sluiceplate.

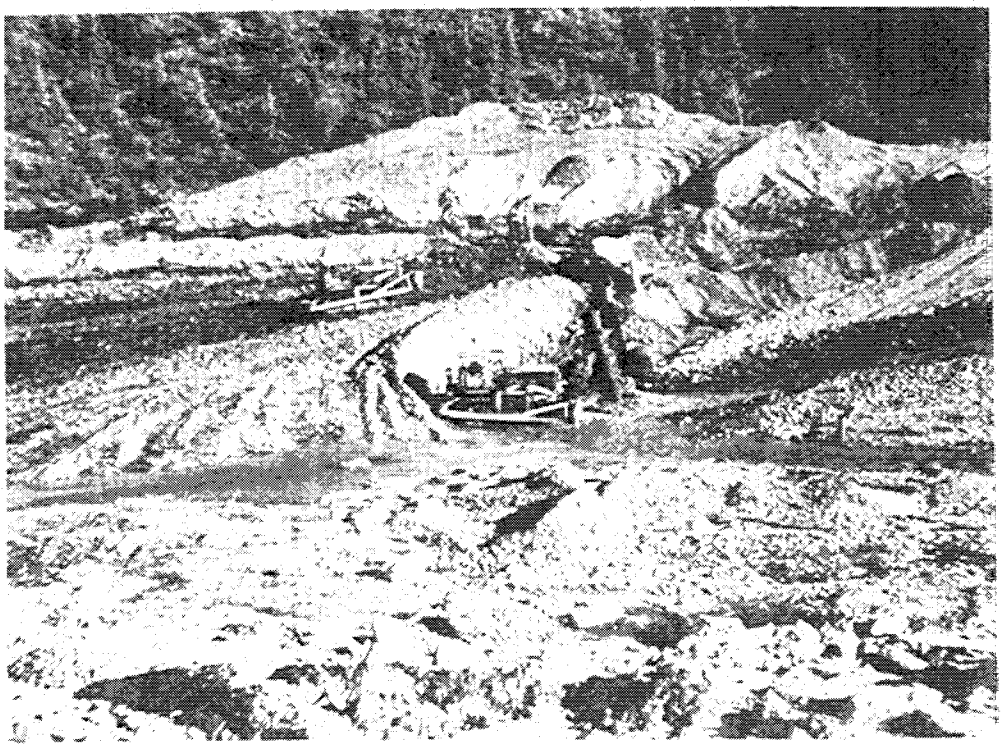

FIGURE 14.—Tailing Removal at a Bulldozer Sluiceplate Operation.

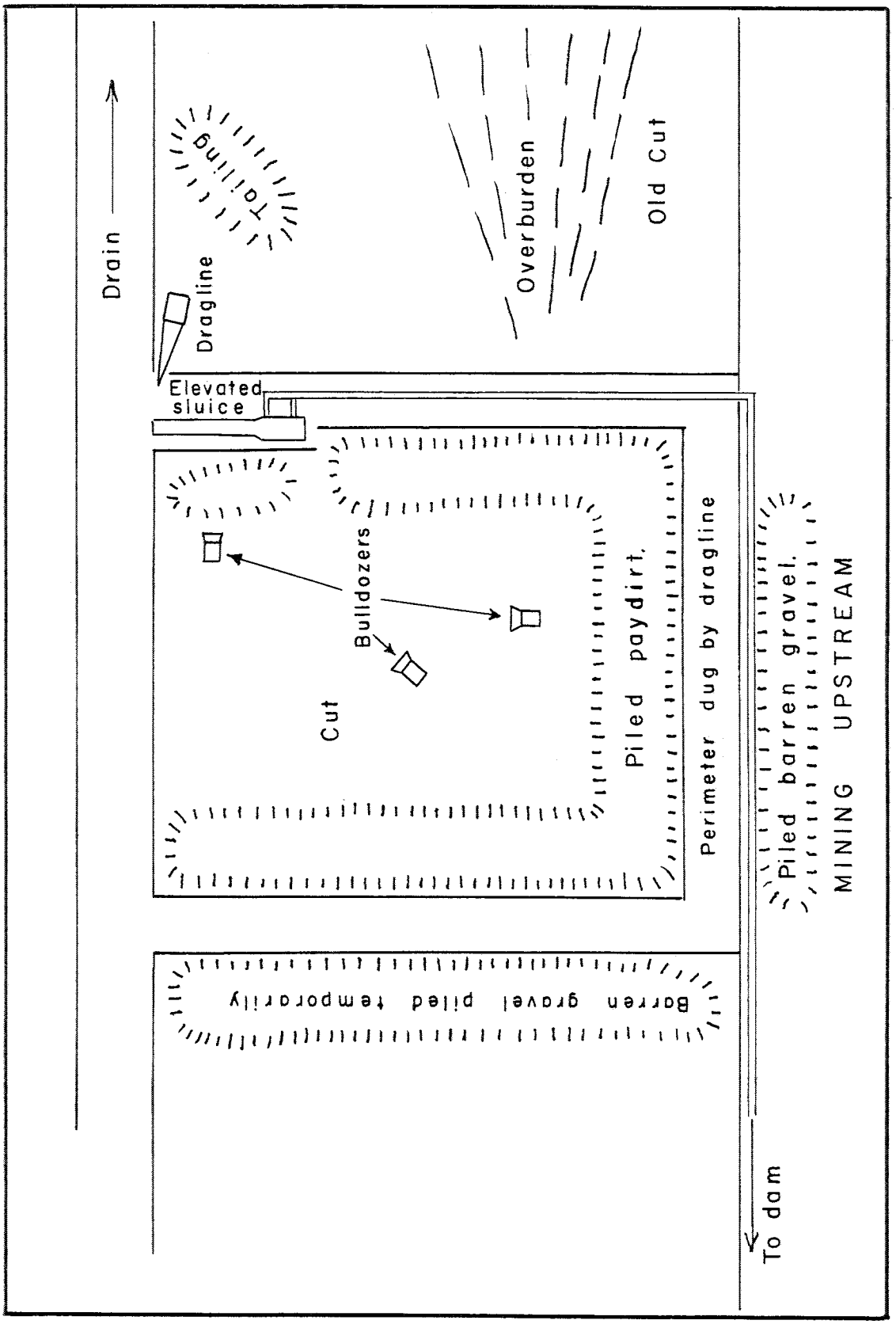

FIGURE 15.—Bulldozer-Dragline-Sluiceplate Mining Plan.

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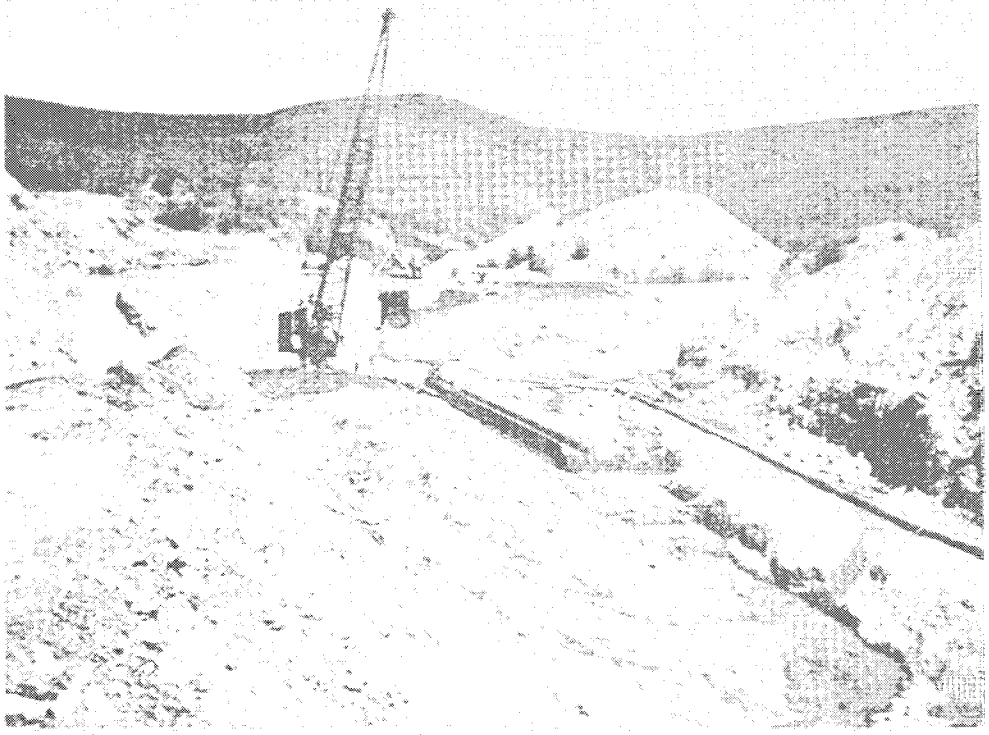

FIGURE 16.—Dragline Removing Tailing From Sump.

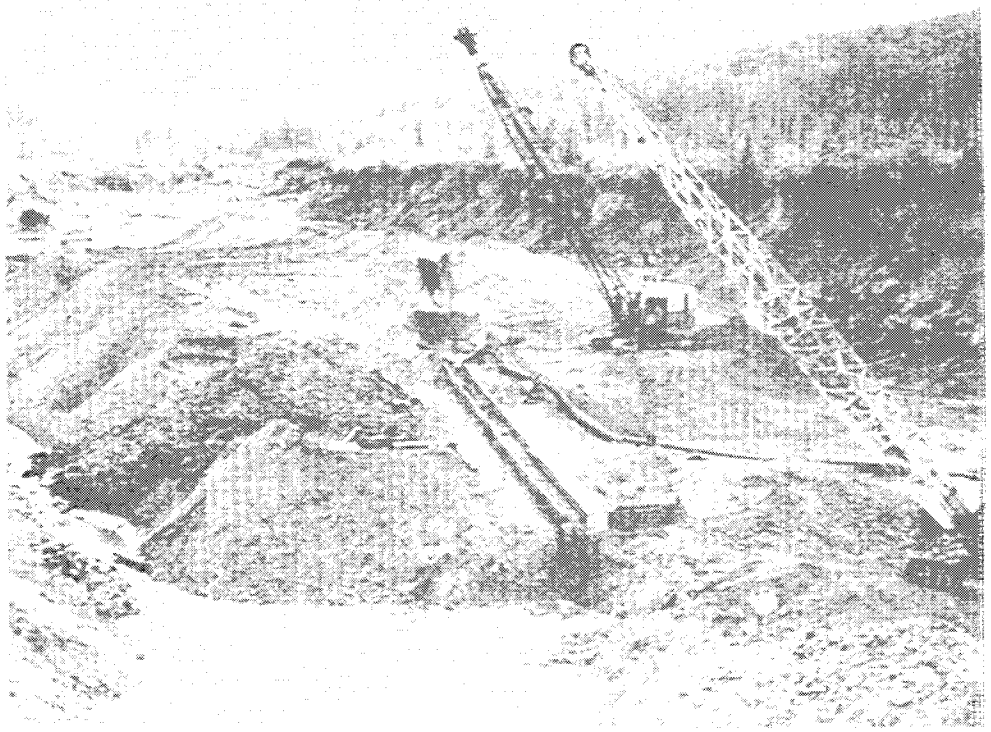

FIGURE 17.—Double Dragline Sluice Mining.

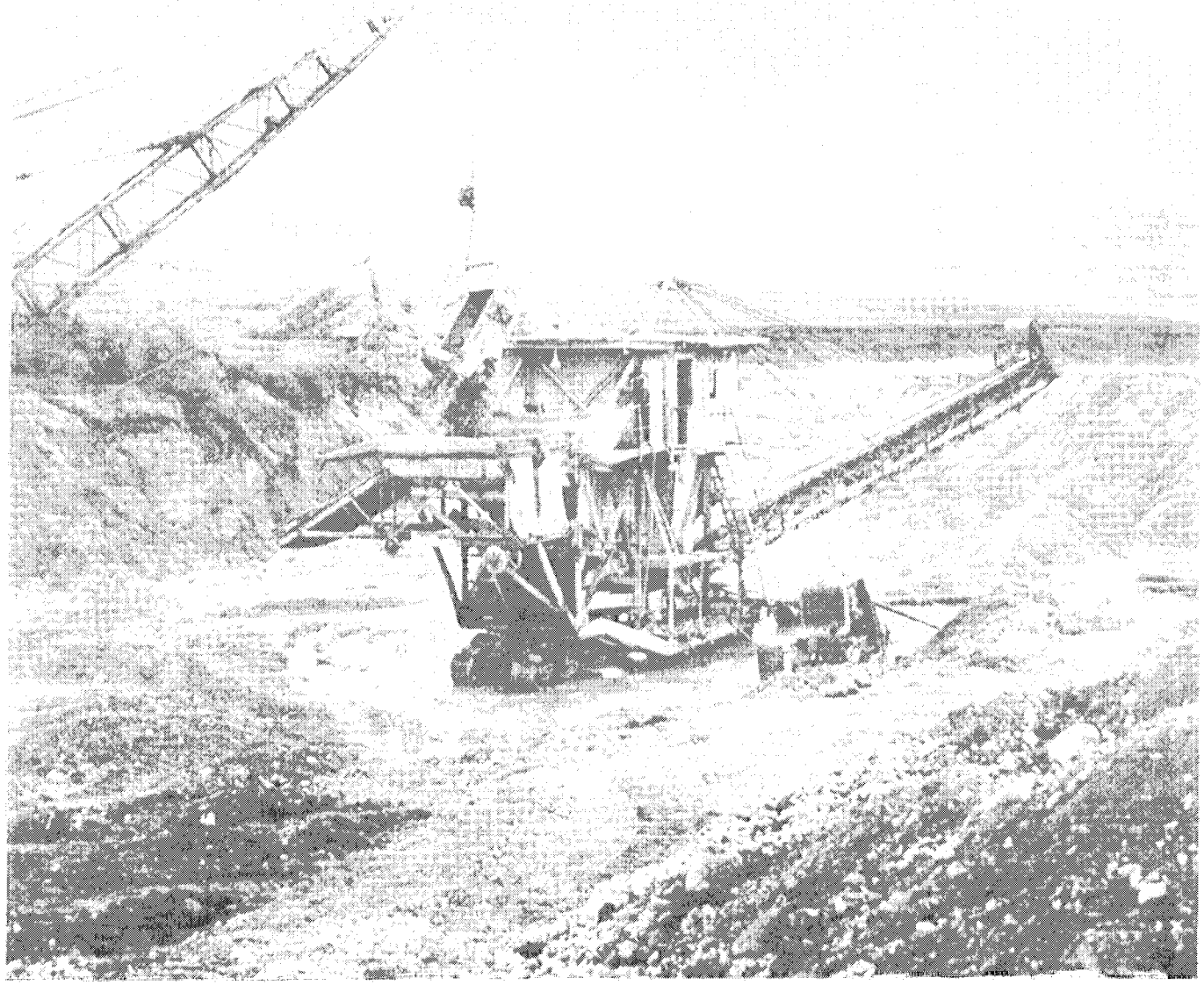

Figure 18.—Dryland Washing Plant Being Fed With Dragline.

WATER SUPPLY

As previously noted, the source, amount, and method of water supply are important factors in determining the mining equipment and arrangement most suitable for economic operation. Water for both stripping and sluicing commonly is transported by pipelines in which pressure is obtained by centrifugal pumps or, in some instances, by high head ditches. Where water is scarce, it may be recirculated from settling ponds (fig. 19) or impounded in reservoirs (fig. 21). Where the topography is favorable, water may be conveyed direct to the sluiceplate by diversion ditches (fig. 20).

EXAMPLES OF MINING METHODS AND COSTS

The 14 mines described are typical of the various placer operations that use mechanical excavation equipment. These mines were selected from the most active mining districts (fig. 22); their identity has been withheld at the request of the operators. Five mines were selected to illustrate sluice-on-bedrock operation using hydraulic-bulldozer arrangements. The remaining mines employ sluices elevated above bedrock. Examples are given of bulldozer-dragline-hopper, bulldozer-sluiceplate, bulldozer-dragline-sluiceplate, and double dragline-sluiceplate arrangements. Detailed description has been limited to that necessary to adequately present the procedures used at the various operations and to point out those procedures that are peculiar to certain operations.

The unit cost figures reflect direct operating costs and were computed from total expenditures, as reported by individual operators, for handling a given volume of material during a certain period. Unless otherwise noted, this is for a full operating season. At certain properties the only labor performed is that of working partners; therefore, allowances have been made for their wages before computing a final cost figure so that all unit costs could be presented on a comparative basis.

SLUICES ON BEDROCK

HYDRAULIC-BULLDOZER OPERATION

MINE 1—CIRCLE DISTRICT

At this mine the deposit is a stream and bench placer composed of gravel 8 feet deep, containing some boulders and resting on a low gradient bedrock. Two partners operate the property under a lease agreement that includes the use of a ditch, penstock, pipeline, and camp buildings. Equipment includes two No. 2 monitors, a No. 1 monitor, a medium-size diesel-powered bulldozer, and a ¾-yard cableway bucket scraper run by a double drum hoist powered by a 4-cylinder gasoline engine.

The plant setup is shown in figure 23. Two parallel cuts are worked alternately; each cut is 75 feet wide and 100 feet long. The bulldozer is used to strip 4 feet of barren gravel from the pay section, and the pay gravel is washed into the sluice boxes by the three giants (fig. 24). Because water supply is limited, it is necessary to use a splash system (intermittent use) during most of the season. Sluicing continues for about 2 hours, the time of one splash; the time between splashes is utilized to remove boulders from the cut and to stack tailing with the bucket scraper. One of the giants is placed so that it may be used to flatten tailing piles as well as to move gravel to the sluiceboxes.

During a 1-month period one cut was mined; 2,220 cu. yd. of material was stripped and sluiced from 7,500 sq. ft. of bedrock. The bulldozer was operated 42 hours; 68 hours were spent sluicing, and 68 hours stacking tailing. The summary of approximate operating expenditures for this 1-month period is as follows:

Gasoline (135 gal. @ 41½ cents)	$56
Diesel fuel (74 gal. @ 33¾ cents)	25
Lubricants	10
Repairs to equipment	200
Board and lodging (2 men, 30 days)	150
Total	441

Cost of mining, not including labor, was 20 cents per cubic yard. The partners worked 520 man-hours. Wages of $700 per month for each partner would raise the cost of mining to 83 cents per cubic yard.

MINE 2—CIRCLE DISTRICT

Two partners operate this mine under a lease agreement. The deposit is a permanently frozen bench placer that averages 27 feet in depth and is covered by 1 to 2 feet of muck overburden. The gold is fairly coarse and is concentrated just above the schist bedrock; about 22 feet of overlying gravel is barren.

The operators have invested approximately $27,000 in equipment which includes two bulldozers; four No. 2 giants; five sections of wooden sluices each 12 feet long, 28 inches

wide, and 22 inches high and equipped with transverse and longitudinal [illegible] [illegible] by 12-inch diesel-powered centrifugal pump; an arc welder; a light plant; and [illegible] cellaneous hand tools.

Water for stripping and mining is obtained from a nearby creek and is supplied by gravity to the bench through a ditch. Additional water is pumped from a small reservoir that is downstream from the bench ground.

Fig. 10.—Pump Recirculating Water From Settling Pond Below Sluicing Operation.

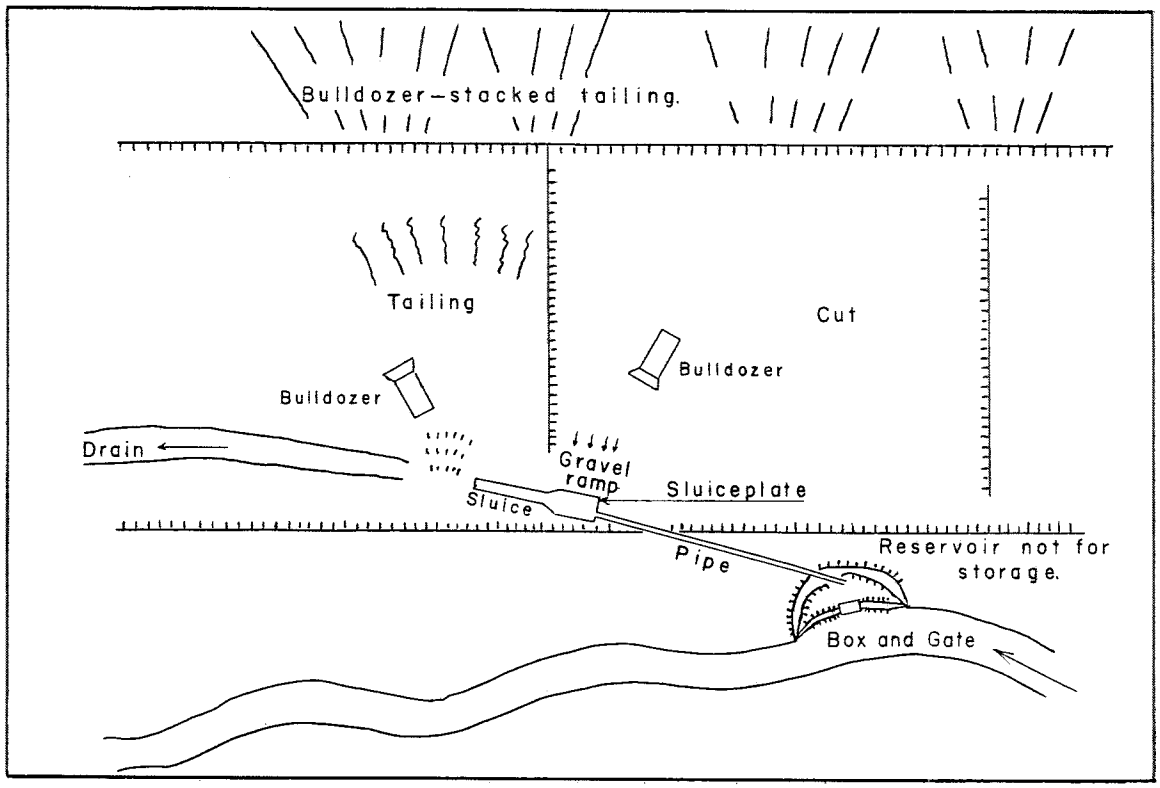

FIGURE 20.—A Method of Conveying Water Direct to Sluiceplate.

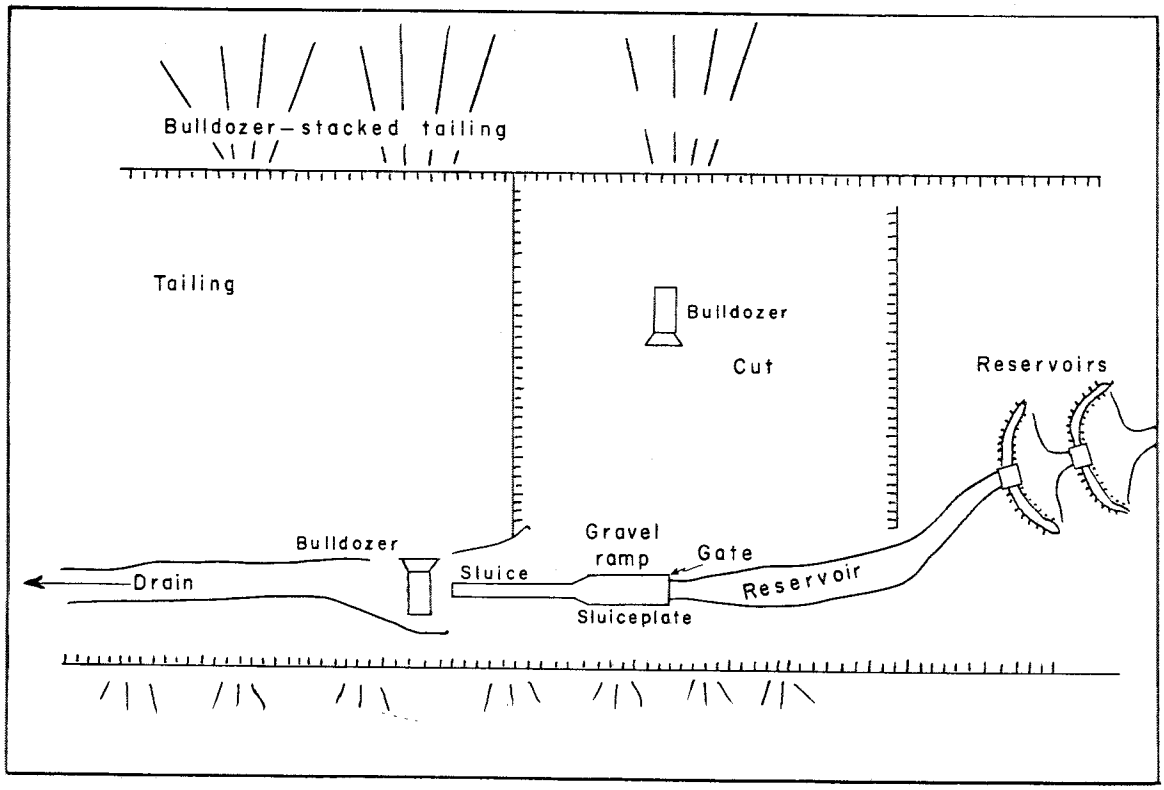

FIGURE 21.—A Method of Storing Water When the Supply Is Limited.

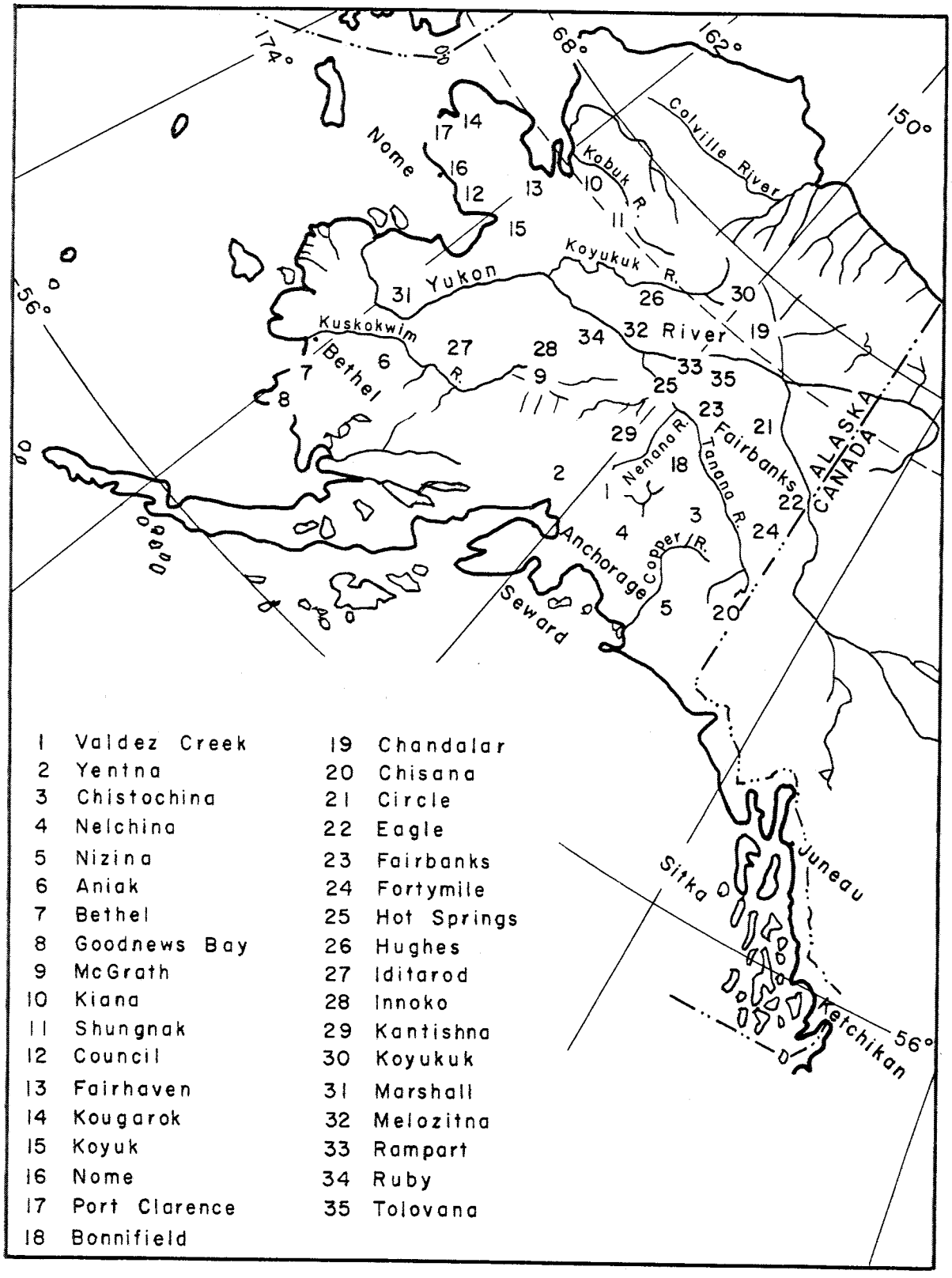

FIGURE 22.—Placer Mining Districts of Alaska.

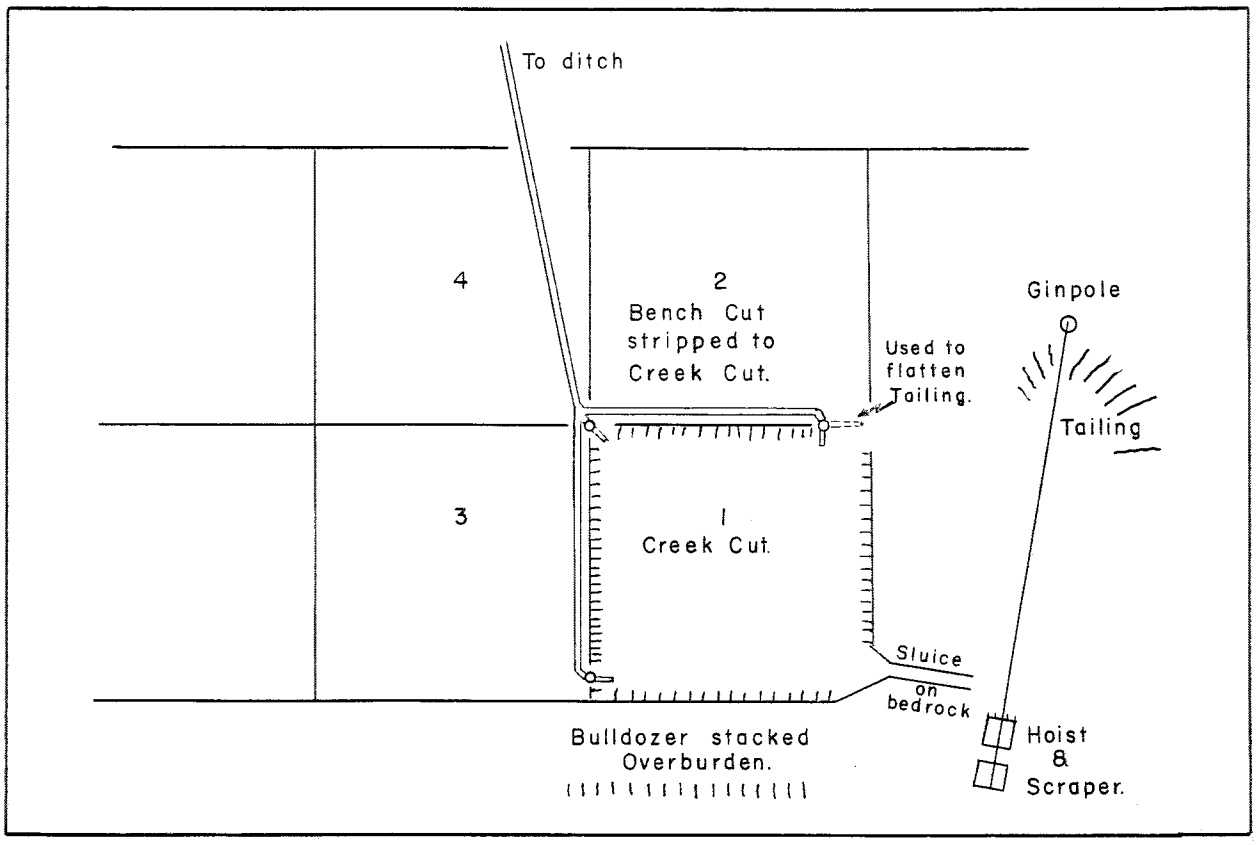

FIGURE 23.—Plan View of Mine 1.

Water from hydraulic giants thaws the muck overburden and upper 22 feet of barren gravel. As the gravel thaws, it is piled into windrows by the giants, and the bulldozer moves it into worked-out areas or beyond the pay limits. The gold-bearing gravels of the lower 5 feet of the deposit and enough bedrock (about 2 feet) to assure recovering the gold that penetrates into joint fractures are mined and conveyed to the sluiceboxes by hydraulic giants. During the sluicing periods, one partner operates the giants while the other stacks tailing with the bulldozer. Approximately 6,000 cu. yd. of gravel was sluiced during 151 9-hour days of the 1953 mining season, the first year of operation on the bench.

The following summarizes approximate expenditures for the 1953 season:

Repair parts for mining equipment	$3,320
Fuel	1,695
Freight (not including oil and gas)	593
Board and lodging	400
Trucks	400
Miscellaneous	500
Total	6,908

The repair costs were excessive because of a major breakdown that required the installation of a new crankshaft, pistons, and liners in a tractor. Because breakdowns of this type seldom occur, the normal repair cost averages $1,300 per year. The average total annual operating cost is $4,900, excluding wage allowance, for the treatment of 6,000 cu. yd. of gravel, or an average cost of 82 cents per cu. yd. If the wages of the partners totaled $8,000, the unit cost would be $2.15 per cu. yd.

MINE 3—FAIRBANKS DISTRICT

The deposit at this mine is frozen, covered with brush, and consists of about 10 feet of slide rock and muck covering 10 feet of clay-bearing gravel, which is sticky and hard to wash. All the gold is found in the lower 5 feet of gravel.

Approximately $40,000 is invested in equipment, camp buildings, and other facilities. The hydraulic plant consists of one-quarter mile of ditch, 3,000 feet of slip-joint hydraulic pipe, two No. 2 giants, and a diesel-driven 12- by 10-inch centrifugal pump. The washing plant includes a steel sluice 72 feet long by 30 inches

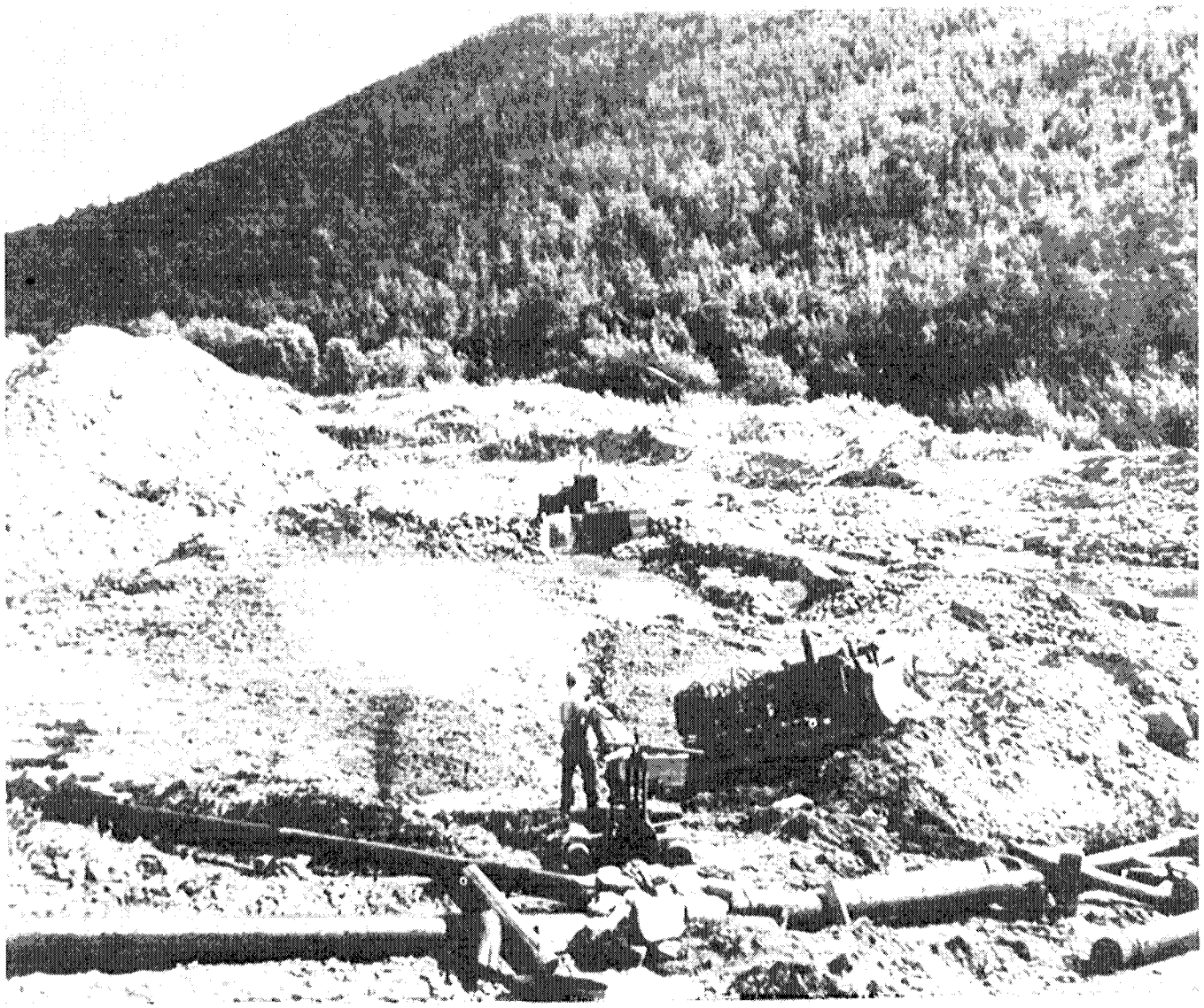

FIGURE 21.—Hydraulicking Toward Sluice Boxes, Mine 1.

wide fitted with a steel mouthpiece and angle-iron riffles. The final 16 feet of sluicebox is covered with cocoa matting overlaid with punched steel plate. Arc and gas welding outfits and miscellaneous handtools comprise the shop equipment. A 1½-ton truck, a pickup, and two "go devils" are used for freighting and general hauling. Camp accommodations consist of a messhouse and a bunkhouse.

Bulldozers strip brush, muck and slide overburden, and barren gravel from the pay streak as thawing by natural means allows. The pay streak is about 5 feet thick and 100 feet wide. It is mined across its entire width by advancing upstream making successive cuts 100 to 120 feet long. A bulldozer pushes gravel to the mouthpiece where it is fed to the sluicebox by water from a No. 2 giant (fig. 25). The sluiceboxes are set on bedrock. The second bulldozer stacks the tailing.

The water supply is limited, and it is necessary to collect the sluice water in a settling pond and recirculate it by pump. Makeup water comes from the nearby creek and from a more distant tributary by ditch and pipeline. The owner and two employees moved about 16,000 cu. yd. of material in 150 days of each season in both 1947 and 1948. This included 8,000 cu. yd. of muck and slide overburden, 4,800 cu. yd. of barren gravel, and 3,200 cu. yd. of pay gravel that was sluiced. The average cost of seasonal operation was as follows:

Repair parts	$2,500
Fuel and lubricants	950
Labor	4,200
Board and lodging	1,200
Miscellaneous	500
Total	9,350

The unit cost approximated 58 cents per cu. yd.; a $4,000 wage per season for the owner would raise the cost to 84 cents per cu. yd.

HYDRAULIC-BULLDOZER-DRAGLINE OPERATION

MINE 4—IDITAROD DISTRICT

A creek placer deposit, most of which had been mined previously by other opencut methods, was worked using an hydraulic-bulldozer-dragline arrangement. The deposit consists of 12 to 14 feet of gravel composed of quartz, monzonite and basalt and some sandstone and shale; there is no muck overburden. Although the deposit contains a few boulders, most of the material is well-worn gravel of medium size. When mining in old opencut workings, all the gravel is sluiced; when virgin ground is worked, some barren gravel is stripped before sluicing. In places it is necessary to dig 3 to 4 feet of blocky monzonite bedrock to recover gold from depressions and crevices. The bedrock grade is almost flat, which makes drainage a major problem.

Approximately $175,000 has been invested in mining machinery and various equipment, camp structures, and general improvements to the property. The equipment includes two large bulldozers, a lighter tractor for hauling, a dragline with a 1½-yard bucket, an excavator with a 1½-yard back hoe, a 280-hp. water-driven turbine connected to a 16- by 14-inch turbine pump having a rated capacity of 5,000 g.p.m. and a 30-kw. generator, three sets of sluiceboxes, eight hydraulic giants, 2 miles of hydraulic pipe, four hydraulic elevators, and gold-processing equipment including retort and amalgamation barrel. The plant and buildings include a complete machine shop with lathe, drill press, electric welder, and other tools; a well-equipped messhall with electric stove, refrigerator, deep freeze, and washing machine; and bunkhouses for employees.

A ditch system, 5 miles long, delivers a water supply more than adequate for mining operations. Water drops 33 feet through a 36-inch penstock to operate the turbine. The turbine by means of linked chain drives turns both the centrifugal pump that supplies water for sluicing operations and the generator that furnishes electricity for all the needs of the camp and shop.

The gold-recovery system consists of five steel sluiceboxes, each 12 feet long, with a head box and wings. These sluiceboxes are 34 inches wide and are set on a grade of 1 inch per foot. Patented angle-iron transverse riffles are underlaid with cocoa matting for the entire length of the sluice. No amalgamation is attempted during the sluicing, but some mercury is picked up from old workings.

At this operation the mining method depends a great deal on the conditions in each cut. Because it is not always possible to maintain natural drainage, it often is necessary to modify the mining method and layout. In addition, the changing character of the material from virgin ground with barren overburden to old tailings containing gold throughout precludes the adoption of a standardized mining method. The arrangement employed usually includes a combination of dragline, bulldozer, and hydraulicking or hydraulic elevator.

The gentle gradient of the creek does not allow natural drainage if the sluiceboxes are placed on bedrock; therefore, a special placement technique is used. Before setting up the sluiceboxes, a trench is dug in pay dirt and backfilled with barren gravel. This trenching

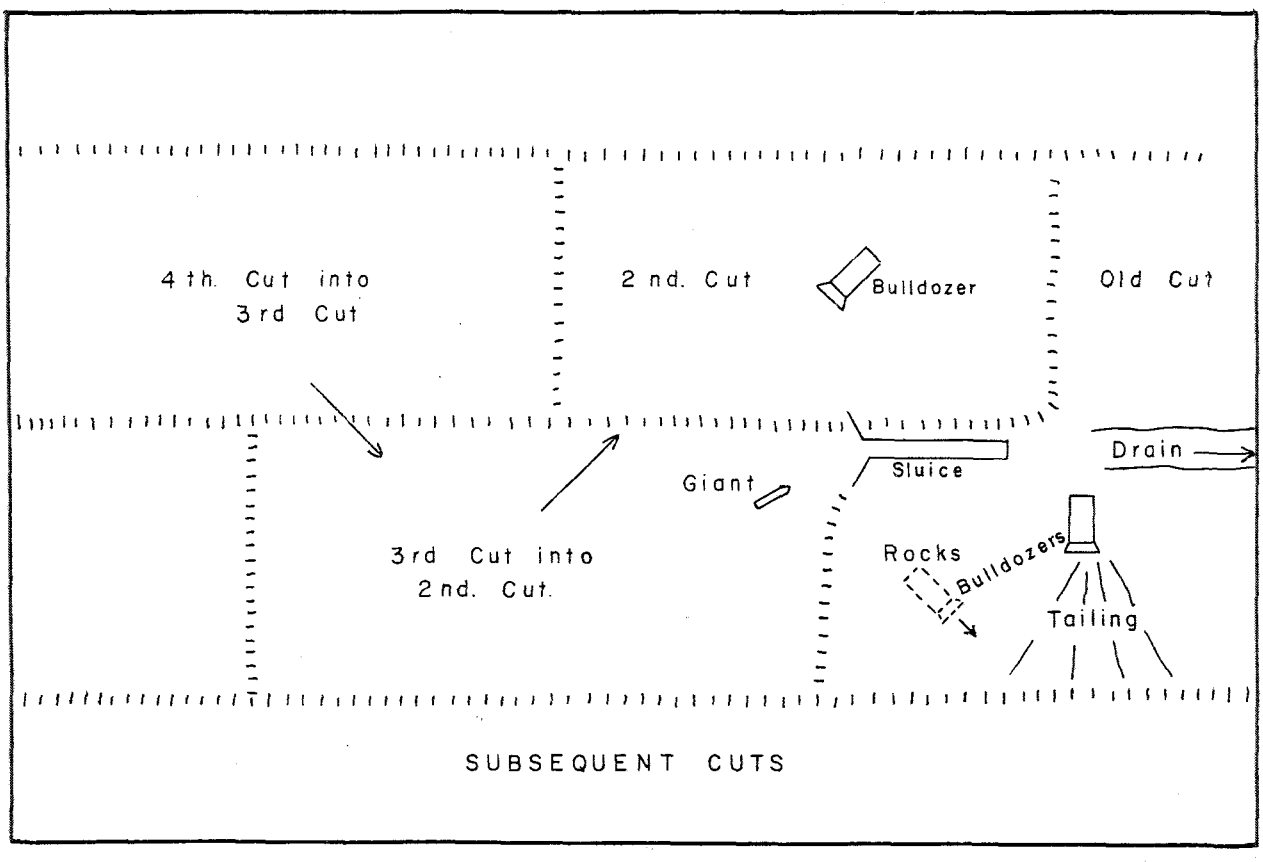

FIGURE 25.—Plan View of Mine 3.

and backfilling is done by a 1½-yard back hoe. The back hoe also is utilized to move the sluice-boxes.

A No. 2 hydraulic giant is placed at the head of the sluice to wash and sluice the gravels pushed to it by two bulldozers. The back hoe is used for squaring up the cut and digging the hard rocky bedrock. It also is used periodically for removing large boulders. The hydraulic lift usually is used to keep the cut dry. A 1½-cubic-yard bucket dragline stacks the tailing. In certain cuts the boxes are so high on the ramp that it is necessary to use a hydraulic elevator to lift the gold-bearing gravel to the sluice; under these conditions the giant nozzling into the elevator is fed by the bulldozer, and the back hoe is used to square up the cut and handle the boulders. At other places the back hoe lifts pay dirt to the bulldozers working on the level of the giant.

During a recent season when only old tailings were worked, the two partners and their six employees (three dozer operators, one nozzle man, one cook and one general laborer) treated approximately 160,000 cu. yd. of gravel in 120 10-hour days. Operating expenses, not including wages for the two partners, were reported as follows:

Repair parts	$10,200
Fuel and lubrication	5,710
Freight	4,765
Board and lodging	5,500
Labor	12,000
Miscellaneous	1,000
Total	40,175

The direct cost per cu. yd. was approximately 25 cents. Wages of $8,000 for the two partners would raise the operating cost per cu. yd. to about 30 cents.

MINE 5—FAIRBANKS DISTRICT

A permanently frozen ancient buried channel in this district is being reworked by modern placer methods. The ground was drift-mined in the early days, and much ice is found filling the old drifts and rooms. The depth of the deposit varies considerably; however, the average depth was 45 feet over an area mined in a recent season. A typical section mined contained 20 feet of muck, 20 feet of slide rock, 4 feet of gravel and 1 foot of bedrock.

Approximately $58,000 is invested in machinery and equipment, consisting principally of the following items: 2,000 feet of slipjoint hydraulic pipe, three No. 2 giants; one steel sluice, 34 inches wide by 75 feet long with angle-iron riffles, mouth piece, and wings; one diesel-powered 12- by 10-inch centrifugal pump; two large bulldozers; one 1½-yard dragline; two pickup trucks and one truck with tandem rear end and front-wheel drive.

The camp consists of two cabins and a small shop equipped with arc and acetylene welders and small handtools.

Stripping was started 3 years in advance of mining and is continued yearly so that enough gravel can be exposed each season for work the next summer. The muck and slide overburden is broken by a bulldozer, and the fine material removed hydraulically. A dragline side-casts the accumulated slide rock from the cut.

Gravel is mined in successive cuts, 150 feet wide by 400 feet long, advancing upstream. The sluice is set in bedrock along the center line of the previous cut, and the wings and mouthpiece adjoin the virgin ground. Bulldozers push gravel to the mouthpiece, where a giant feeds it to the sluice; the dragline stacks the tailing. A pump recirculates water to the giant; sluice water comes directly from the creek.

Three partners working 9 hours per day operate this property; occasionally, they trade work with neighboring miners. The following are expenses for a recent season:

Repair parts	$4,000
Fuel and lubricants	3,500
Board and lodging	1,500
Total	9,000

Freight costs are included. During the season a total of about 104,400 cu. yd. of material was moved, of which 91,000 cu. yd. was muck and slide and 13,400 cu yd. was gravel. The unit cost was 8.6 cents per cu. yd. for stripping and sluicing; $12,000 for the wages of the partners would raise the unit cost to 20 cents per cu. yd. The unit cost is relatively low for a small operation because a large percentage of the material handled is muck, readily stripped by hydraulicking.

SLUICES ELEVATED ABOVE BEDROCK

BULLDOZER-DRAGLINE-HOPPER OPERATION

MINE 6—FAIRBANKS DISTRICT

An elevated sluice setup with dragline-bulldozer-hopper arrangement is used for mining a permanently frozen creek deposit composed of 40 feet of muck covering 10 feet of medium gravel. Two partners do all the preparatory work at this operation, but they are assisted by three employees during the sluicing season.

Approximately $65,000 is invested in earth-moving, hydraulic, plant, and accessory equipment and camp facilities. The equipment includes one elevated sluice 34 inches wide by 70 feet long with hopper and automatic giant, 3,000 feet of hydraulic pipe, seven No. 2 giants, a diesel-powered 12- by 10-inch centrifugal pump, a 10- by 10-inch centrifugal pump, one large bulldozer, one 1½-yard dragline, one smaller tractor for hauling, and a shop complete with small tools and electric and gas welding equipment.

The gravel deposit thaws readily when exposed to solar heat. If the muck overburden is removed at least 1 year before mining, the gravel can be dug with little interference from frost. Water delivered to hydraulic giants under gravity head is used to strip the muck. Pumps supply pressure when gravity water is scarce.

Barren gravel 2 to 4 feet thick covers the pay streak. As soon as the exposed barren gravel thaws 6 inches or more, a bulldozer removes it and the dragline casts it beyond the pay limits. Pay gravel is mined from cuts covering areas 40,000 to 50,000 sq. ft. The elevated sluice, fed by dragline, is moved parallel to the cut on a road built on side-cast barren gravel. The end of the sluice is angled so that the tailings drop in the worked-out areas (fig. 26). A pump recirculates water for sluicing from a settling pond built downstream from the mining area.

Operating expenses for sluicing and for a small amount of gravel stripping in a recent season were as follows:

General labor	$840
Cook	1,500
Fuel and lubricants	1,800
Board and lodging	1,600
Freight	467
Repair parts	5,423
Accounting and legal	503
Miscellaneous	867
Total	13,000

Deferred muck stripping costing $19,000 increases operating expenses to $32,000 per year. For this expenditure 267,000 yards of muck was stripped from 66,000 cu. yd. of gravel and bedrock. Approximately 14,000 cu. yd. of gravel was side-cast and about 52,000 cu. yd. was sluiced. The cost for moving muck was 7.1 cents per cu. yd.; for sluicing and side casting gravel the cost was 19.5 cents per cu. yd. The cost for sluicing only was slightly higher—about 23 cents per cu. yd. The two

partners drew a total of $10,000 as salaries. If this cost were divided evenly between the stripping and thawing operations, the cost per cu. yd. would be 9 to 10 cents for stripping muck and 27 cents for sluicing and stripping gravel. The average cost for all material moved is about 13 cents per cu. yd.

BULLDOZER-SLUICEPLATE OPERATION

MINE 7--CIRCLE DISTRICT

The placer deposit at this mine is about 2 miles long and from 10 to 12 feet deep; it is overlain by a small amount of muck. The gravel is unsorted, angular to subangular, and contains considerable sand and a lesser amount of clay. Gold is concentrated in the lower 6 feet of gravel on top of the schist bedrock, and in places penetrates 2 to 3 feet into the joints and fractures of the bedrock.

The property is worked by three members of the same family under a lease agreement, which includes the use of hydraulic pipe and giants. The operators have invested about $18,000 in a large bulldozer, sluiceboxes, and sluiceplate. The sluice consists of five boxes, each 10 feet long, 32 inches wide, and 20 inches deep. The first 30-foot section contains longitudinal iron-rail riffles; the remaining sections have transverse iron riffles with notched upper surfaces. The notched riffles are reported to increase the recovery of fine gold when heavy sand is encountered (fig. 27). The sluiceplate is 24 feet long by 6 feet wide and has sides 3 feet high (fig. 28).

A bulldozer strips, mines, feeds the sluiceplate, and removes the tailing. Sluicing is intermittent; water is scarce and is accumulated in an upstream reservoir between splashes. In this manner, cuts 150 by 200 by 10 feet are mined in fifteen 9-hour shifts.

Expenditures for one season were reported to be:

Repair parts	$2,600
Fuel and lubricants	1,947
Board and lodging	1,000
Freight	400
Total	5,947

About 6,000 cu. yd. of muck and gravel was stripped, and about 12,000 cu. yd. sluiced during the season. The 18,000 cu. yd. was moved at a unit cost of 33 cents per cu. yd. Wages of $10,000 for the owners would raise the unit cost to 89 cents per cu. yd.

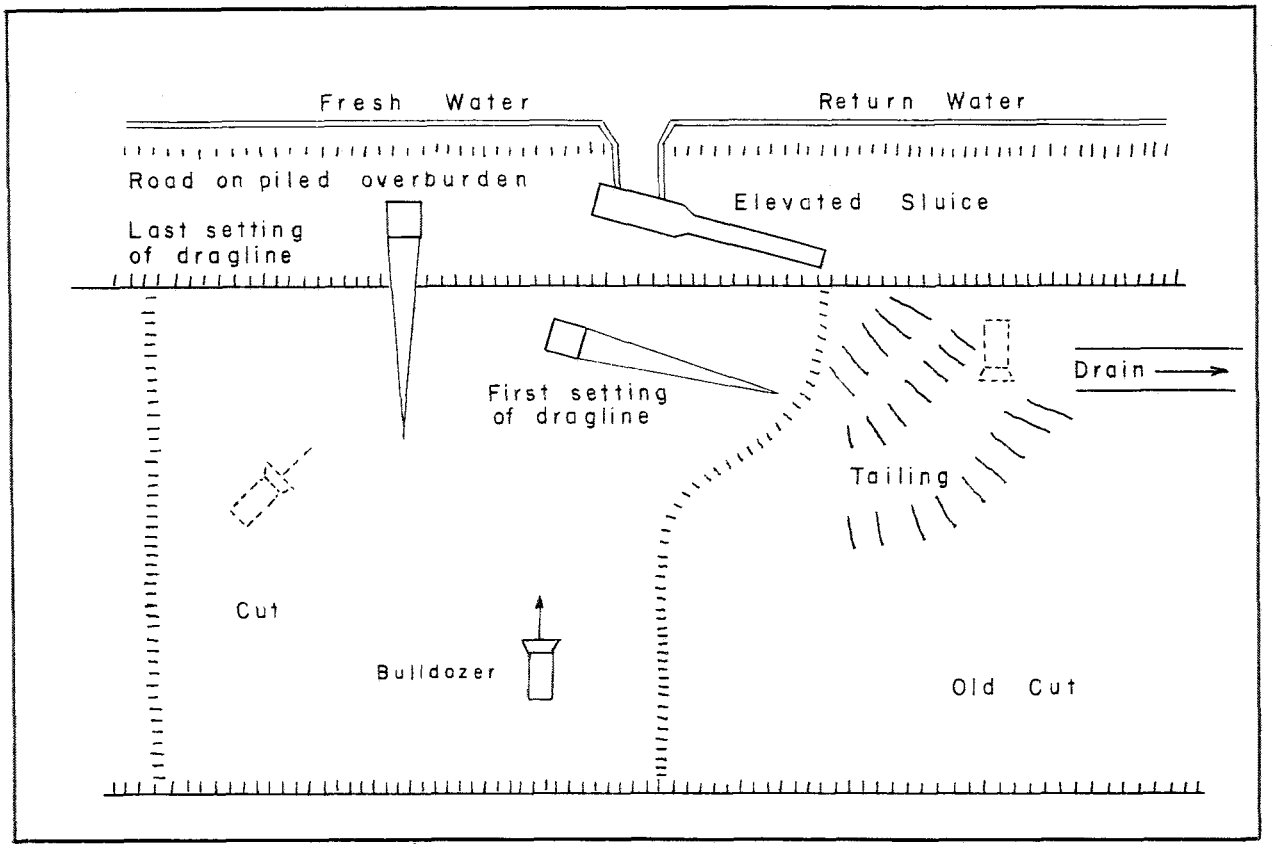

FIGURE 26.—Plan View of Mine 6.

MINE 6.—FAIRBANKS DISTRICT

The bulldozer-sluiceplate method is used to mine a shallow-creek placer deposit in the Fairbanks district. The deposit is composed of small- to medium-sized thawed gravel, 6 to 7 feet deep, overlain by 1 foot of soil and moss. The bedrock is a fractured and jointed soft schist. Gold is found in the lower 18 inches of gravel and penetrates the joints and fractures of bedrock to a depth of 3½ feet.

About $21,000 is invested in a medium-sized bulldozer, a 12- by 10-inch centrifugal pump powered by a diesel engine, 400 feet of slip-joint hydraulic pipe, one No. 2 giant, a sluiceplate, sluiceboxes and riffles, a ½-ton pickup truck, a shop building with an electric acetylene welding outfit and miscellaneous tools, and living quarters.

A bulldozer strips barren top soil and gravel. Pay gravels are mined and delivered to the sluiceplate by bulldozer; the tailing is removed and stacked by hydraulic giant.

The owner and one employee, who work 13 hours a day during the sluicing season, operate the property. During 140 operating days in 1953, about 13,000 cu. yd. of overburden was stripped, and about 25,000 cu. yd. of gravel sluiced. The operating expenditures for the season were:

Repair parts	$1,800
Fuel and lubricants	1,967
Labor	3,850
Board and lodging	1,360
Travel, freight, and miscellaneous	1,023
Total	10,000

A total of 38,000 cu. yd. of material was moved for 26 cents per cu. yd. A $4,000 wage for the owner would raise the unit cost to 37 cents per cu. yd.

MINE 8.—FORTYMILE DISTRICT

This property is a permanently frozen creek placer consisting of 8 feet of gravel covered by 12 feet of muck. The gravel lies on a decomposed acidic igneous rock that decomposes to a clayey mass when in contact with water. The creek is small and during the dry part of the summer water is scarce. By impounding it in a reservoir above the site of operations, enough water is collected for 15 minutes of sluicing during a 3-hour period.

Approximately $25,000 has been invested in a large bulldozer, a sluiceplate, a 2- by 40-foot steel sluice with Hungarian riffles, four giants, 1,500 feet of hydraulic pipe, and two trucks.

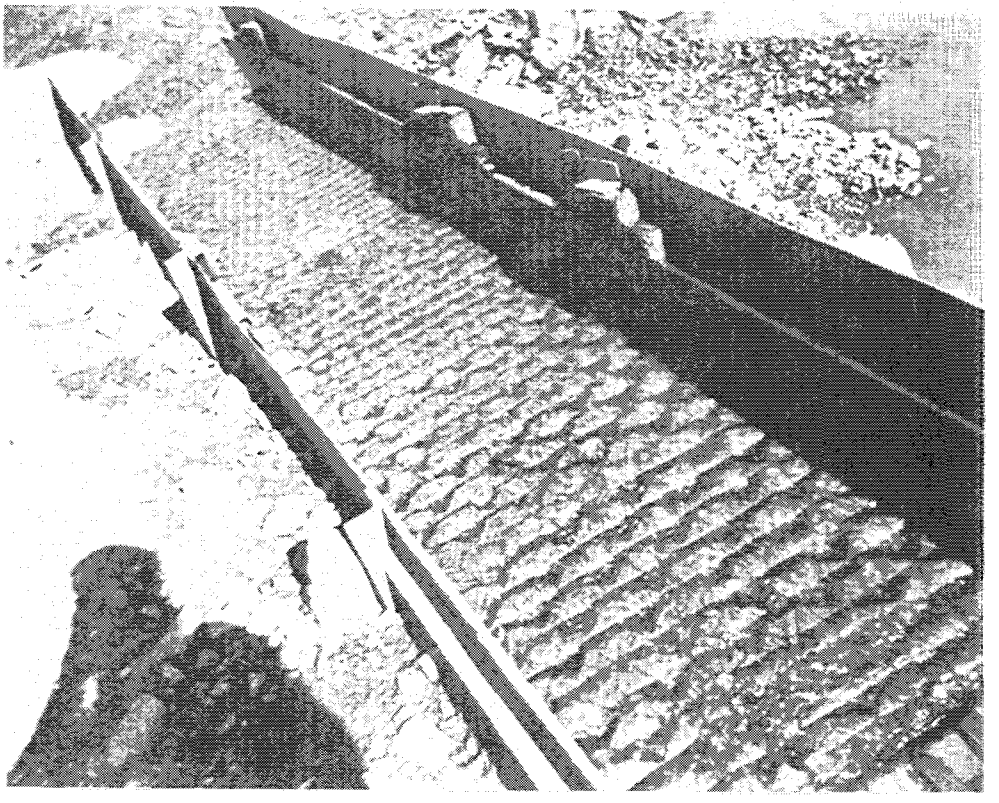

FIGURE 27.—Notched Riffles for Recovering Fine Gold, Mine 7.

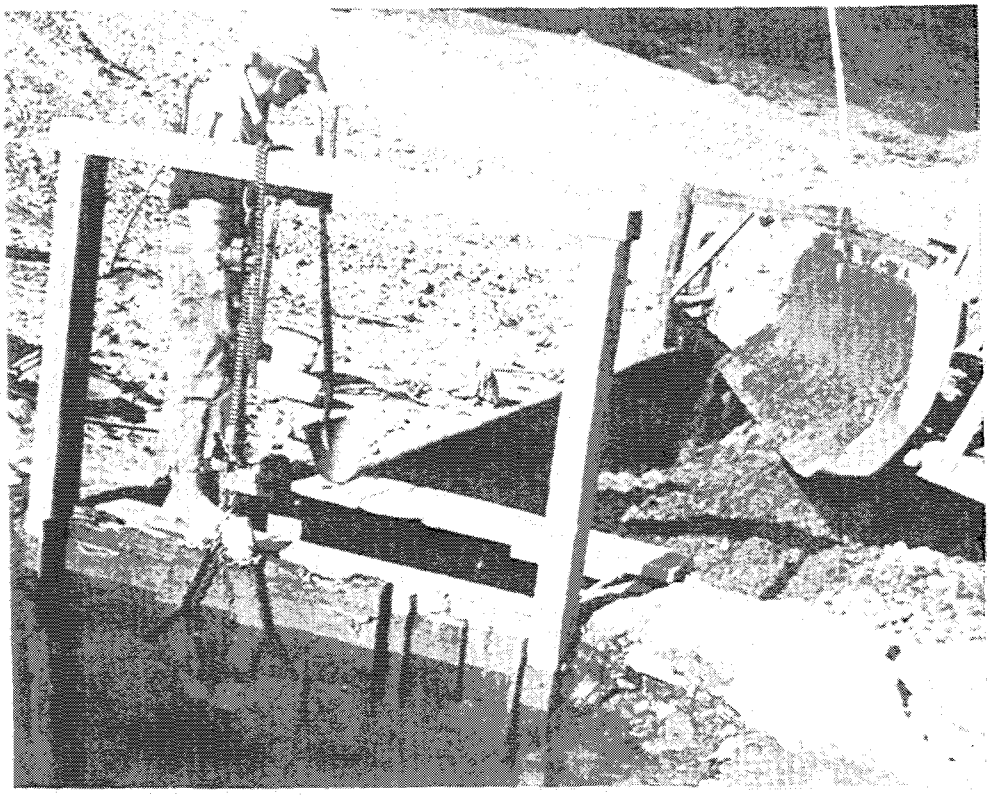

FIGURE 28.—Bulldozer Feeding Sluiceplate, Mine 7.

When water is available, muck is stripped by hydraulic giants; otherwise it is removed by bulldozer. The bulldozer also removes barren gravel from the pay section. Sluicing is done intermittently or by splashes. The owner, mining alone, operates the bulldozer and pushes the pay dirt to the sluiceplate before and during each splash. Between splashes he stacks tailing and strips on the next cut. Expenditures for one season approximated the following:

Repair parts	$1,825
Fuel and lubricants	1,065
Board and lodging	600
Freight	100
Miscellaneous	100
Total	3,690

During the year, 8,000 cu. yd. of muck and gravel was moved at a cost of $1.20 per cu. yd. Wages of $1,000 would raise the cost of moving the dirt to $2.54 per cu. yd.

BULLDOZER-DRAGLINE-SLUICEPLATE OPERATION

MINE 10—INNOKO DISTRICT

A streng placer is mined by a bulldozer-dragline-sluiceplate method to recover gold from permanently frozen medium-size gravels, 12 feet deep and covered by 6 feet of muck. The upper half of the gravel section is barren and contains many large boulders. Bedrock is composed of soft schist, decomposed sandstone, and slate; it has an even surface and a slight gradient. The gold is in the lower 6 feet of the gravel section, and the greatest concentration is on top of the bedrock; in places it is as much as 2 to 3 feet down in joints and fractures of the weathered bedrock. The gold is medium to fine, and the individual particles are rounded and polished.

The equipment consists of four large bulldozers (three used in mining operations and one as a standby), one smaller tractor for hauling, one excavator with a 60-foot boom and a 2-cubic-yard bucket, one 12- by 10-inch diesel-driven centrifugal pump, one 60-kv.-a. power-plant, and one smaller auxiliary powerplant for standby. All heavy equipment is standardized, and one model diesel engine facilitates ordering and replacing parts. Additional facilities include a complete machine shop, a small portable machine shop on skids, a sawmill, a complete carpenter shop including power tools, a warehouse, and adequate boarding and housing accommodations.

Ground preparation is relatively simple; muck is removed by groundsluicing, and barren upper gravels are stripped to a depth of 6 feet by bulldozers. Individual mining blocks or cuts cover 80,000 to 100,000 sq. ft. of bedrock, and each block is mined successively in a downstream direction. Before sluicing, a drainage ditch is dug to bedrock around the perimeter of each cut. This ditch serves to drain the cuts during their excavation. Sluiceboxes and the sluiceplate are set on a gravel ramp that is built up with barren gravel by backfilling a trench excavated to bedrock in virgin ground. The sluiceboxes are on the upstream side of the cuts and discharge into a drain (fig. 29). Two bulldozers convey gravel in front of the sluiceplate, where it is fed by a third bulldozer. A dragline stacks the tailing. Water for sluicing is impounded upstream from the cuts and conveyed by pipeline under pressure from a centrifugal pump at the rate of 3,500 g.p.m.

The recovery system consists of four 12-foot sluiceboxes and 20 feet of riffles in the sluiceplate. The sluiceboxes are 36 inches wide by 18 inches deep and constructed of 3/16-inch steel plate and 1/8-inch steel for inside liners. The upper box has longitudinal riffles covered by punch plates with 3/8-inch perforations; two boxes have longitudinal riffles of cocoa matting, and the last box has punch plate above cocoa matting. The gold amalgamates readily; for each pound of gold recovered 1¼ to 1½ pounds of mercury is used.

Two owners and four employees at this operation work 12-hour shifts during a mining season of 120 days. A breakdown of the costs of this operation is not available, but it is reported that material is moved for about 23 cents per cu. yd.

MINE 11—CIRCLE DISTRICT

The unfrozen creek placer at this mine consists of 4 to 7 feet of fairly coarse angular gravel overlain by 1 to 5 feet of moss and muck. Fine-grained gold is concentrated in the lower 2 feet of gravel and the top 3 feet of intensely weathered schist bedrock.

The operators are working under a lease agreement that permits the use of certain hydraulic equipment and buildings on the property. About $29,000 has been invested in additional equipment, which consists of a medium-sized bulldozer, a ¾-yard dragline, an 11- by 9-inch diesel-powered centrifugal pump, a 200-ampere arc welder, a pickup truck, hydraulic pipe, sluiceboxes, riffles, and a sluiceplate.

The moss cover is stripped by bulldozer and muck overburden is removed by hydraulicking. The dragline side-casts barren upper gravels moved into position by the bulldozer. Pay gravels and bedrock are hydraulicked to the sluiceplate, where they are fed by bulldozer; the dragline stacks the tailing (fig. 30). This unusual method of mining is employed because transporting the pay dirt to the sluiceplate with water (fig. 31) breaks down the clayey bedrock so that enclosed gold particles are released to permit their free settling in the riffles, which results in more efficient recovery.

The recovery system consists of three sluiceboxes, 30 inches wide by 10 feet long. The first two sluiceboxes have two layers of transverse T-iron riffles, and the last box has one layer of transverse T-iron riffles covered with ½-inch perforated plate, which serves as an undercurrent. There are also 14 feet of transverse T-iron riffles in the sluiceplate. Water for stripping and sluicing is supplied by gravity from a ditch that has its intake about 1 mile upstream from the operations. Water from the creek below the intake is channeled directly to the sluiceplate. When water is plentiful, two No. 2 giants convey gravel and bedrock up to the sluiceplate, but when the supply diminishes, one giant shoots water into the sluicewater channel. When water is scarce, it is necessary to recirculate it to the sluice by pumping from a settling pond downstream from the cut.

One of the two partners, two hired miners, and a cook operate this property. During a recent season of 150 days, this crew worked 10 hours per shift. The expenditures were about as follows:

Repair parts	$2,500
Labor	9,520
Fuel and lubricants	2,890
Board and lodging	2,500
Freight	1,500
Miscellaneous	2,090
Total	21,000

Approximately 20,000 cu. yd. of overburden was stripped, and 20,000 cu. yd. of pay dirt sluiced at a cost of 52 cents per cu. yd. Wages of $4,000 for the working partner would raise the cost per cu. yd. to 63 cents.

MINE 12—FAIRBANKS DISTRICT

This mine is a permanently frozen narrow-creek placer in a readily accessible area about 50 miles from the city of Fairbanks. The deposit is 30 to 35 feet deep and consists of gravel containing layers of clay and many small boulders. The gold is very fine and is distributed throughout the lower 20 feet of the gravel section.

About $100,000 is invested in equipment and buildings. Equipment includes two large bull-

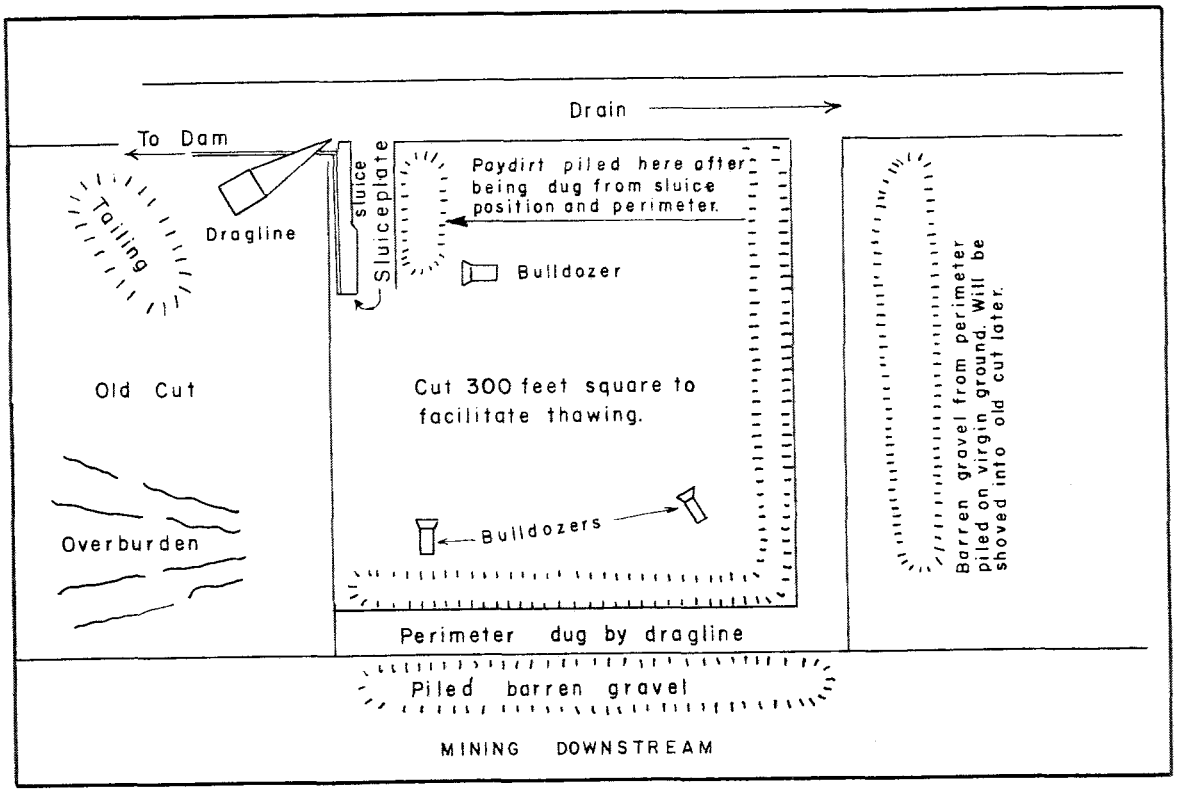

FIGURE 29.—Plan View of Mine 10.

dozers, a 1¾-cubic-yard dragline, a 10- by 10-inch centrifugal trash pump powered by a diesel engine, 800 feet of slip-joint hydraulic pipe, 80 feet of steel sluiceboxes (43 inches wide by 21 inches high), and a 20-foot square sluiceplate with 4-foot sides. Three camp buildings and a shop completely equipped with electric and gas welding outfits, overhead crane, diesel-electric powerplant, lathe, grinders, and miscellaneous handtools complement the mining operation.

Before sluicing, bulldozers and a dragline remove 10 to 15 feet of barren gravel. In the mining process two bulldozers push pay gravel to the upper end of the sluiceplate and the dragline stacks the tailing (fig. 32). Water is scarce, but enough for sluicing is assured by using a reservoir and recirculating the water by a centrifugal pump.

Sticky clay with the fine gold makes recovery difficult. To facilitate breakdown of the clay before its entry into the sluiceplate, a small amount of water is added to the gravel in the cut so that the clay becomes a semifluid mass. The sluiceboxes are set on a grade of 16 inches to 10 feet. The first box has punched plate over heavy canvas, the next four sections angle-iron riffles, and the last three sections punched plate above cocoa matting.

The crew consists of two bulldozer operators, a dragline operator, a sluice tender, and the owner. Operating expenses for a recent season were approximately as follows:

Repair parts	$7,200
Labor	13,700
Fuel and lubricants	4,300
Taxes, board and lodging and miscellaneous	8,200
Total	33,400

About 20,000 cu. yd. of barren gravel was stripped and 63,000 cu. yd. sluiced. The cost per cu. yd. was slightly over 40 cents. Depreciation, depletion, taxes, and royalties are included in the total expense; therefore, this figure should be reduced somewhat when comparing costs with other operations. It is believed that by substituting an allowance for the wages of the owner for depreciation, depletion, taxes, and royalties the unit cost would remain at about 40 cents per cu. yd.

MINE 13—FAIRBANKS DISTRICT

A bulldozer-sluiceplate-dragline plant is used for mining an ancient, permanently frozen, buried, bench placer deposit adjacent to a wide pay streak, which had been mined by dredging. The deposit contains 10 feet of gravel resting on a schist bedrock and is covered by 60 feet of muck, which is about one-third ice.

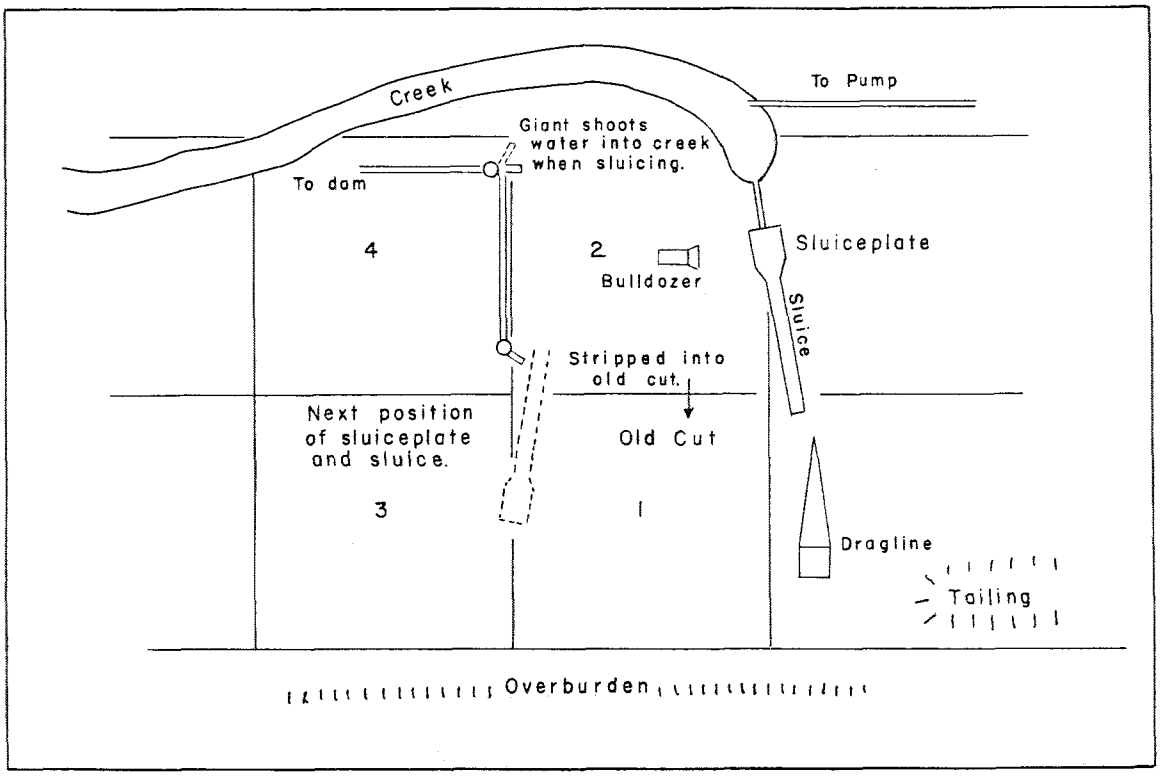

FIGURE 30.—Plan View of Mine 11.

The entire plant represents an investment of $52,000 and includes one 1½-cu.-yd. dragline, two bulldozers (one large and one medium-sized), a 1½-ton flatbed truck, six giants, 4,000 feet of slip-joint hydraulic pipe, one diesel-powered 12- by 10-inch centrifugal pump, a string of four sluiceboxes, and a specially designed sluiceplate 8 feet wide by 20 feet long with riffles down the center and three built-in adjustable nozzles.

Muck stripping is accomplished by first removing the moss cover with bulldozers and then using a combination of hydraulicking and ground sluicing.

Ground sluicing is carried on by controlling the water from a creek that had been channeled against the toe of a high muck bank exposed during ground preparations for the previous dredging operation. Before hydraulicking, the muck is shattered and broken into large blocks by blasting. This is accomplished by making two horizontal, 5-inch-diameter toe holes, one 60 feet long and the other 90. They are spaced 20 feet apart at the collar and are cut by an auger, one in a direction normal to the face of the muck bank and the other at an angle of 45° to the face. The holes are loaded with cordite (11 cases in each hole) and discharged separately. The effective radius of each blast is approximately 100 feet. These blasts break the frozen muck into large blocks and shatter and fracture muck in place. The resultant parting planes develop air and water courses within the muck and hasten the thawing process. Hydraulic removal is accomplished by pumping to giants near the toe of the blasted area.

Gravel is mined from three cuts, each 150 feet wide and 100 feet long. Bulldozers push the gravel to the sluiceplate, and the dragline stacks the tailing. Water for sluicing is supplied under pressure to the sluiceplate by centrifugal pump.

The crew consists of a foreman-tractor operator, a second tractor operator, a dragline operator, and a laborer. In 120 days (1,200 hours) about 75,000 cu. yd. of muck was stripped, and about 17,400 cu. yd. of gravel and bedrock sluiced. The operating expenses are itemized as follows:

Repair parts	$3,094
Fuel and lubricants	3,195
Labor	12,877
Supplies including powder	513
Miscellaneous	1,048
Total	20,727

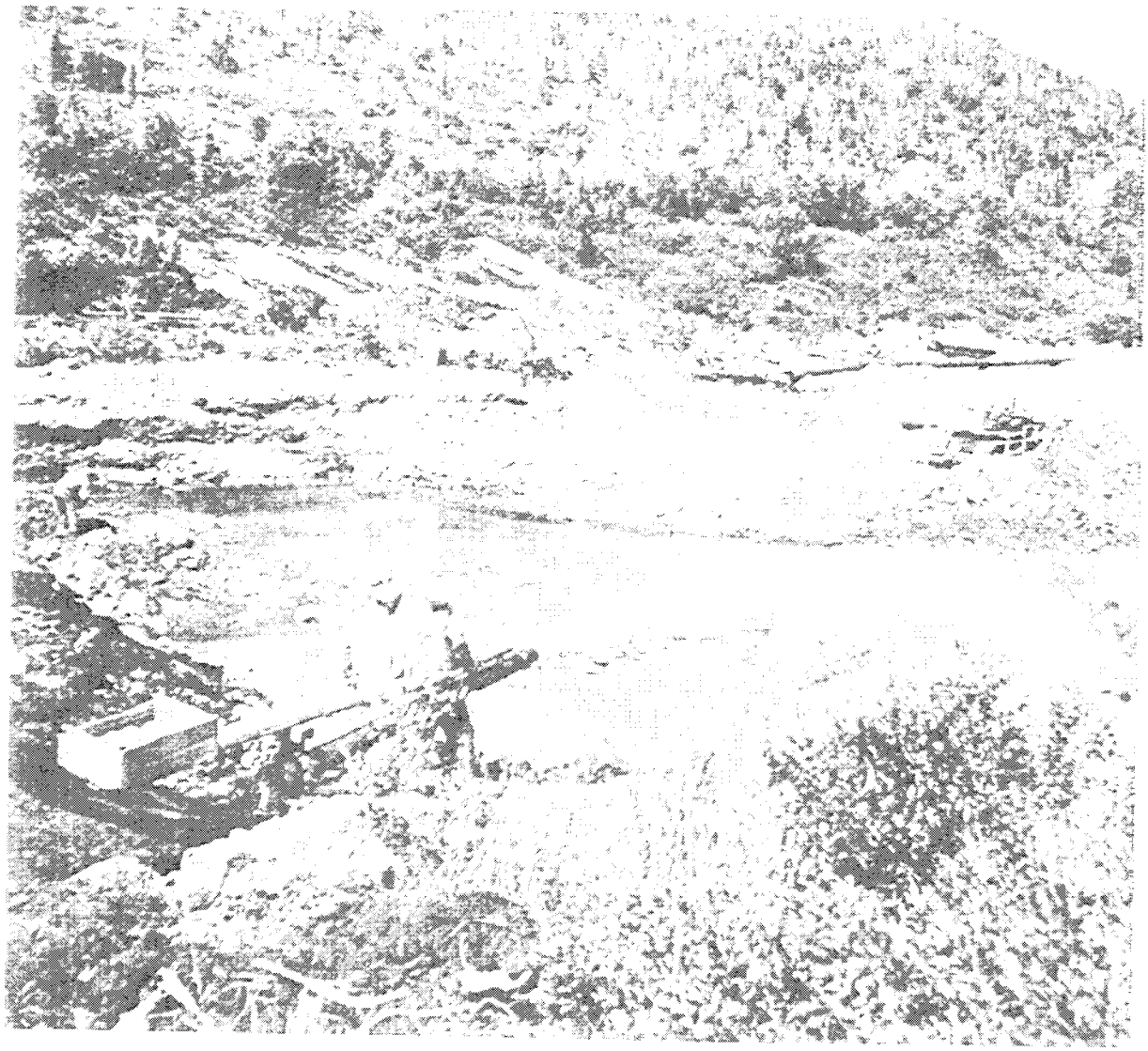

Figure 31. [illegible]

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DOUBLE DRAGLINE SLUICEPLATE OPERATION

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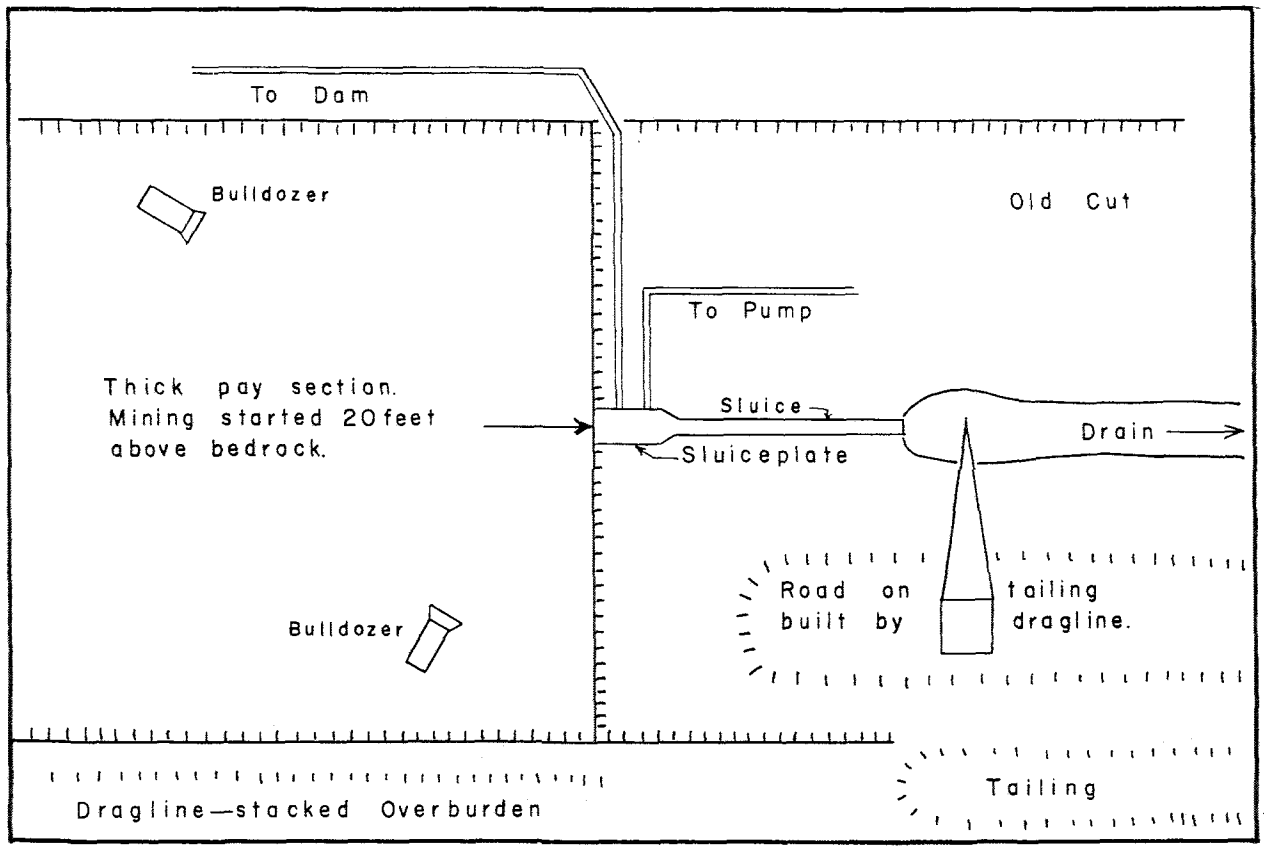


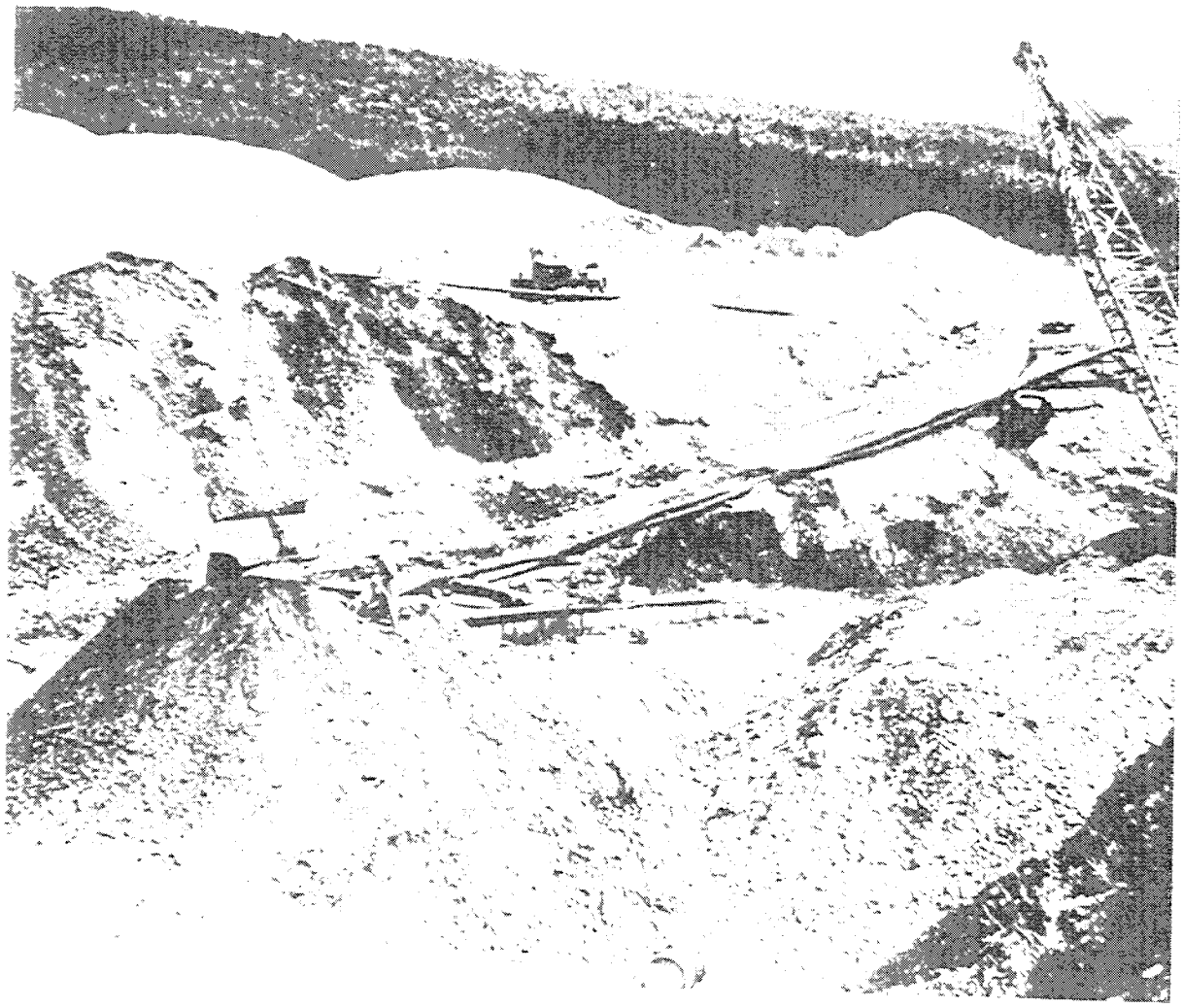
FIGURE 32.—Plan View of Mine 12.

doned because of its bulk and weight, and a sluiceplate arrangement substituted. The sluiceplate and boxes are on a ramp made by excavating a trench to bedrock in virgin ground, and then backfilling it with barren gravel. A dragline is used to feed the sluiceplate with gravel pushed into position by bulldozers; the tailing is stacked by another dragline (fig. 33). Water for stripping is furnished by gravity from a ditch, and sluice water is recirculated by pumping.

The operating crew consists of two dragline operators, two bulldozers operators, one pump tender, one nozzleman, and three working partners. The approximate expenditures for a full season are listed below:

Repair parts	$7,000
Diesel oil, gasoline, and lubricants	4,000
Labor	10,000
Board and lodging	3,500
Miscellaneous	500
Total	25,000

About 200,000 cu. yd. of muck and gravel was moved at a unit cost of 12.5 cents per cu. yd. Wages of $12,000 for the partners would raise the unit cost to 18.5 cents per cu. yd.



SUMMARY OF COSTS

For purposes of comparison, costs of operations at these mines are summarized and tabulated in table 2.

TABLE 2.—*Summary of costs*

Mine No.	Total volume of material sluiced and stripped, cubic yards	Total expenditures	Unit costs per cubic yard, cents	Total expenditures including allowance for wages of operators	Unit costs per cubic yard, including allowance for wages of operators, cents
1	2,200	$441	20	$1,841	83
2	6,000	4,900	82	12,900	215
3	16,000	9,350	58	13,350	84
4	160,000	40,175	25	48,175	30
5	104,400	9,000	9	21,000	20
6	333,000	32,000	10	42,000	13
7	18,000	5,947	33	15,947	89
8	38,000	10,000	26	14,000	37
9	3,000	3,630	130	7,630	254
11	40,000	21,000	52	25,000	63
12	83,000	33,400	40	83,000	40
13	92,400	20,727	22		
14	200,000	25,000	13	37,000	19

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