March 3, 1970 D. M. MATTHEWS 3,498,674

MINING METHOD AND APPARATUS

Filed Aug. 4, 1967 6 Sheets-Sheet 1

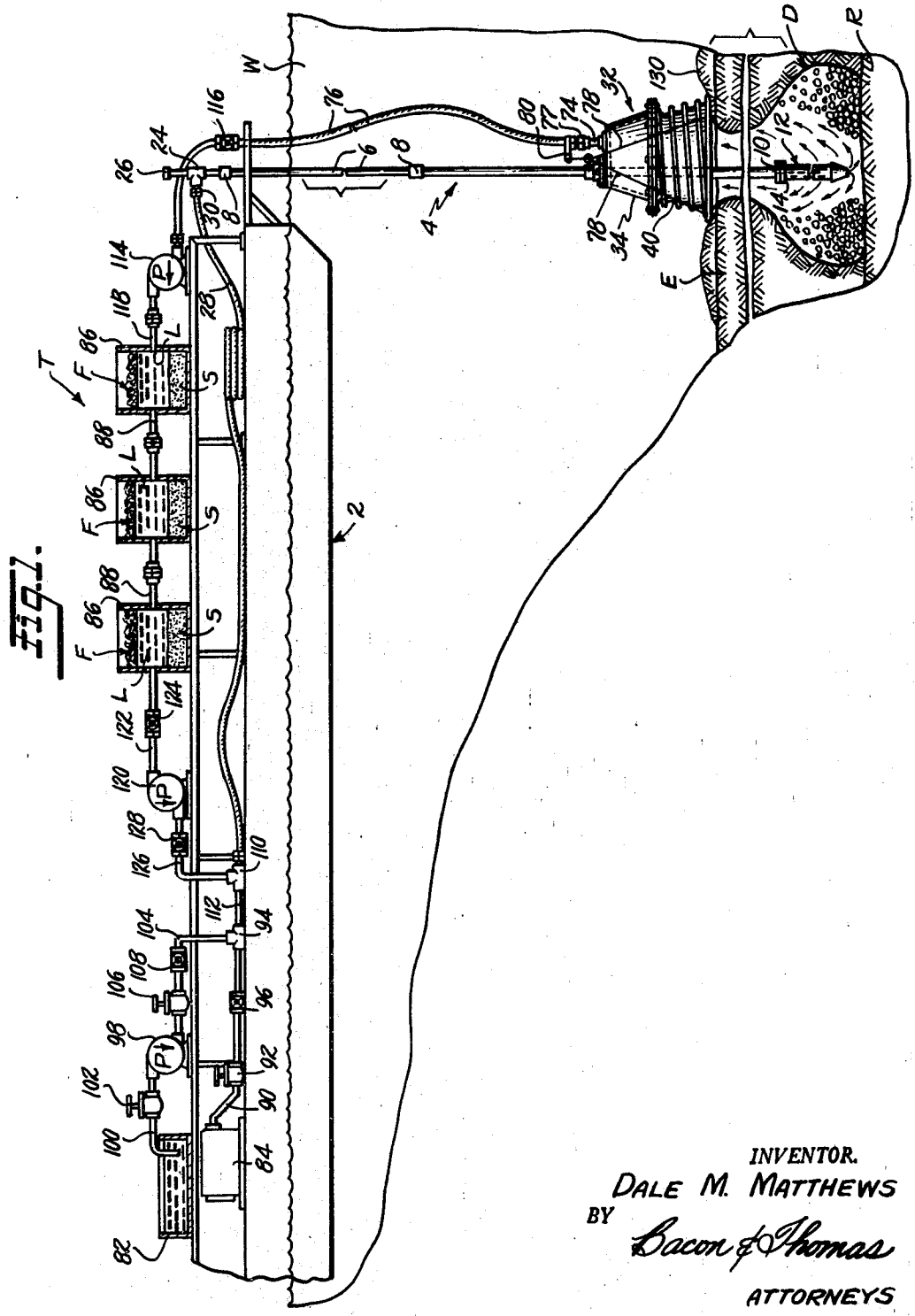


FIG. 1.

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MINING METHOD AND APPARATUS

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Fig. 2.

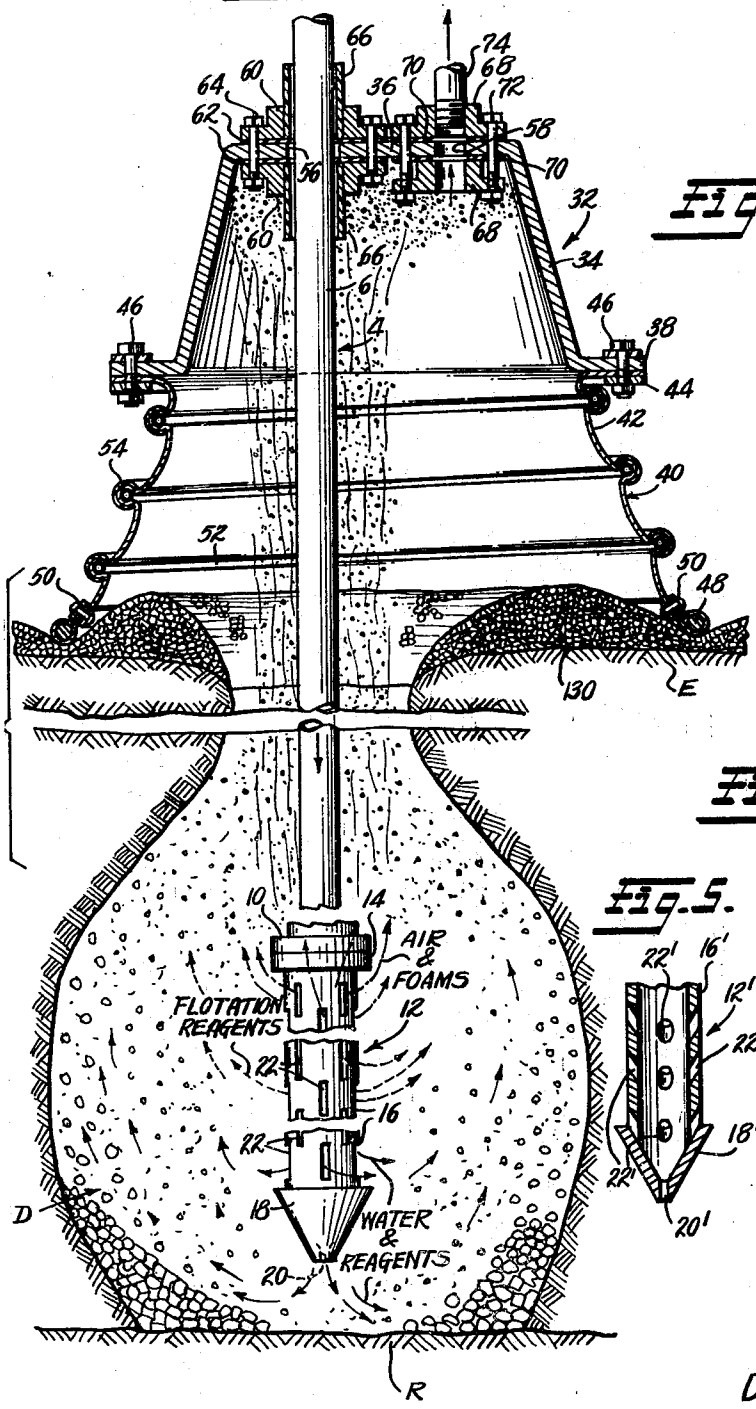


Fig. 3.

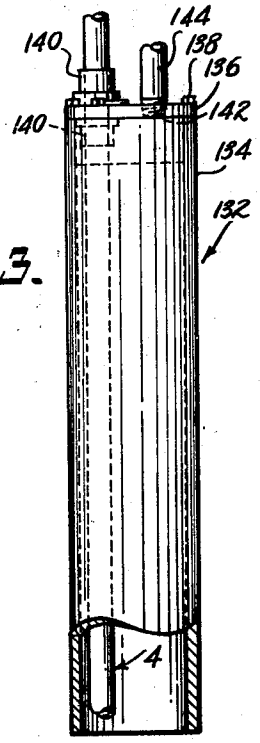


Fig. 4.

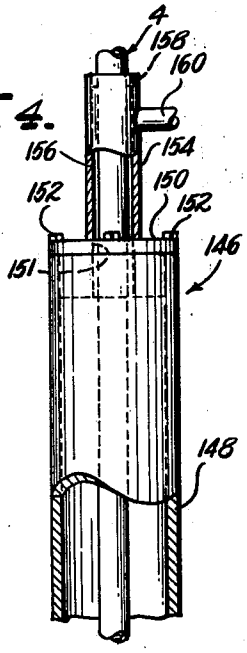


Fig. 5.

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MINING METHOD AND APPARATUS

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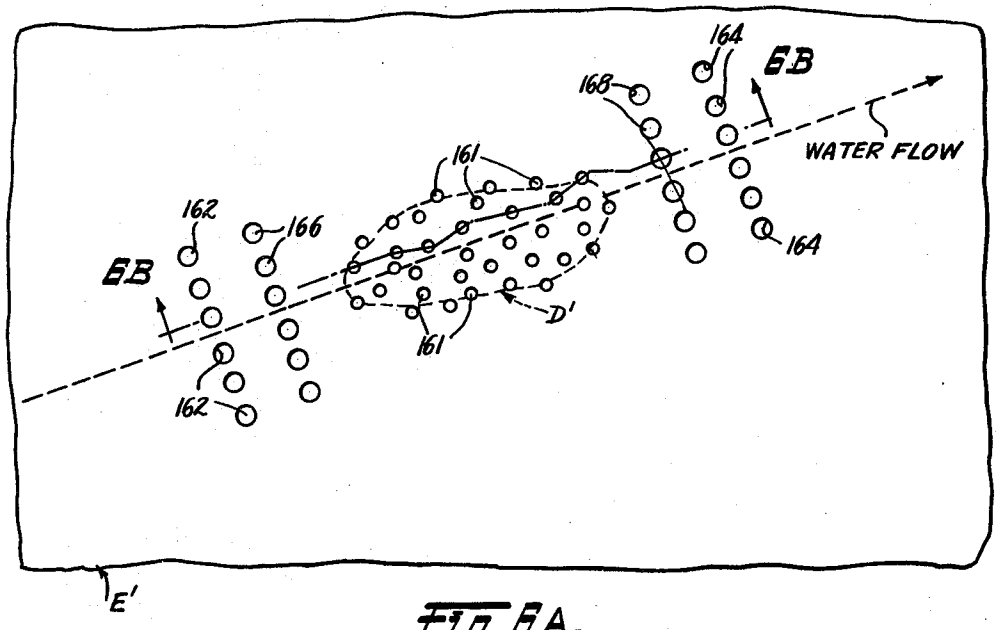


Fig. 6A.

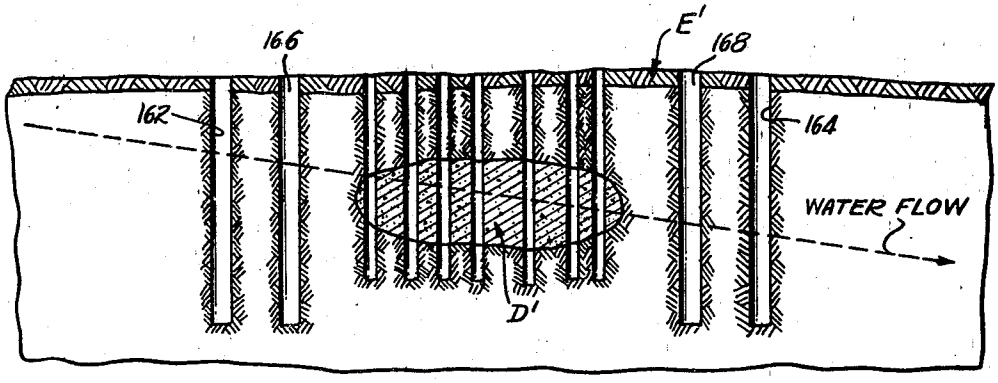


Fig. 6B.

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MINING METHOD AND APPARATUS

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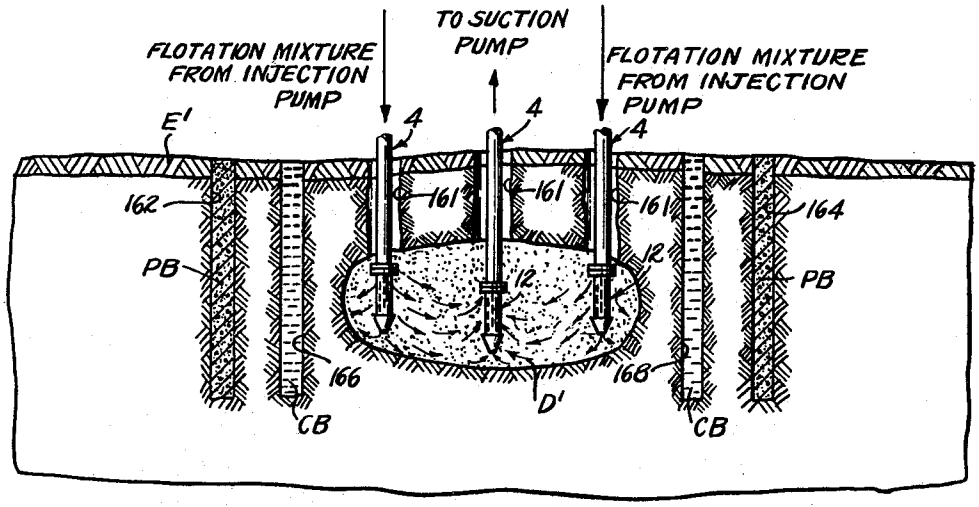


Fig. 6C.

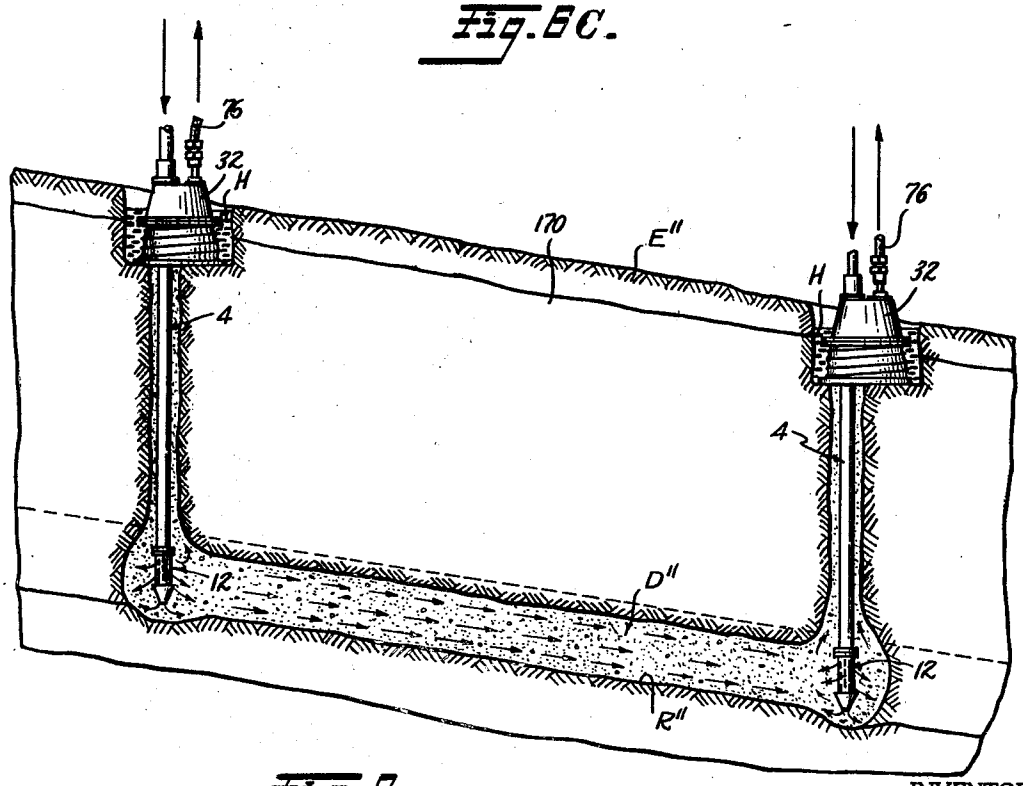


Fig. 7.

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MINING METHOD AND APPARATUS

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FLOTATION-MINING-MILLING

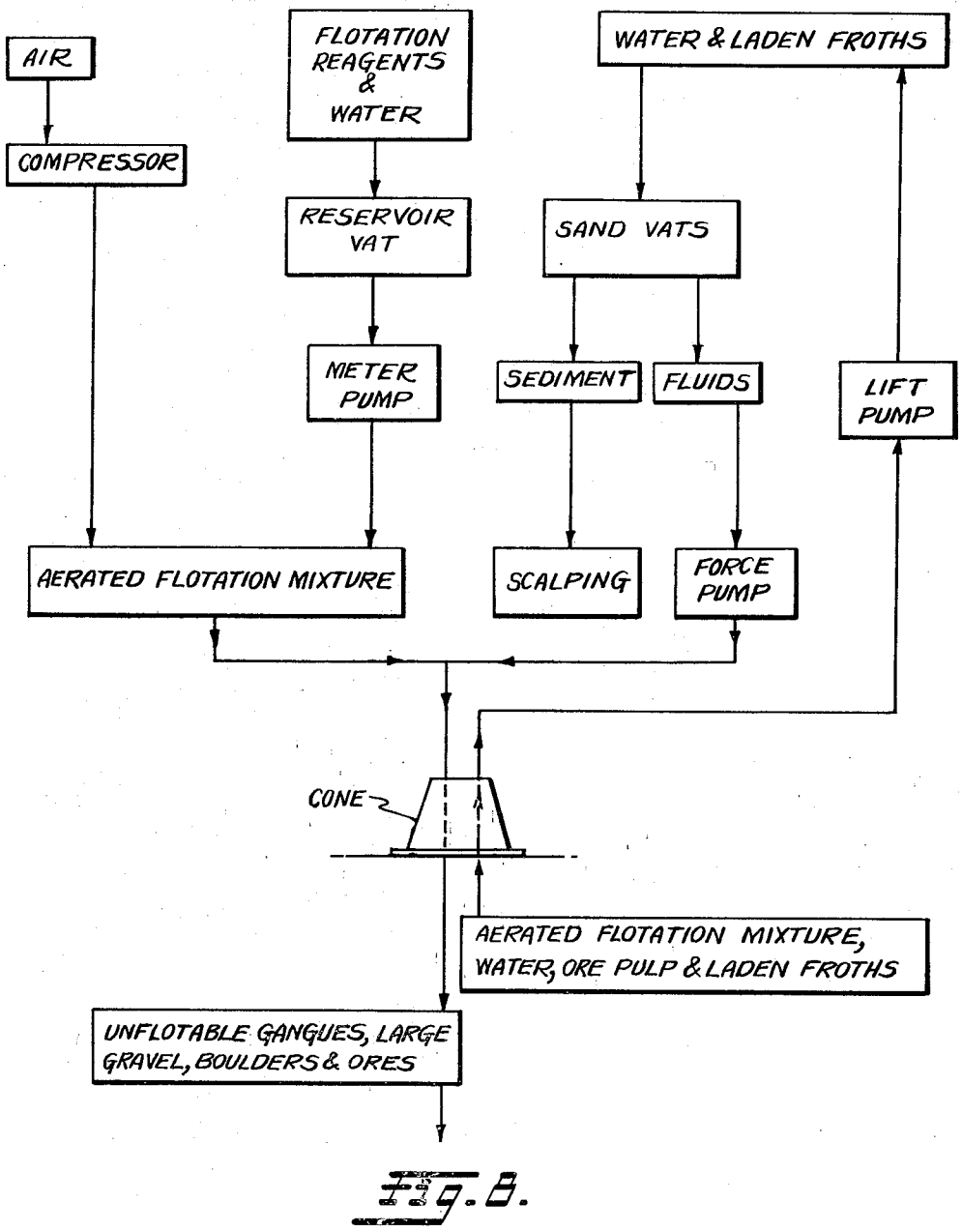


Fig. 8.

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MINING METHOD AND APPARATUS

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SCALPING OR UPGRADING OF CONCENTRATES

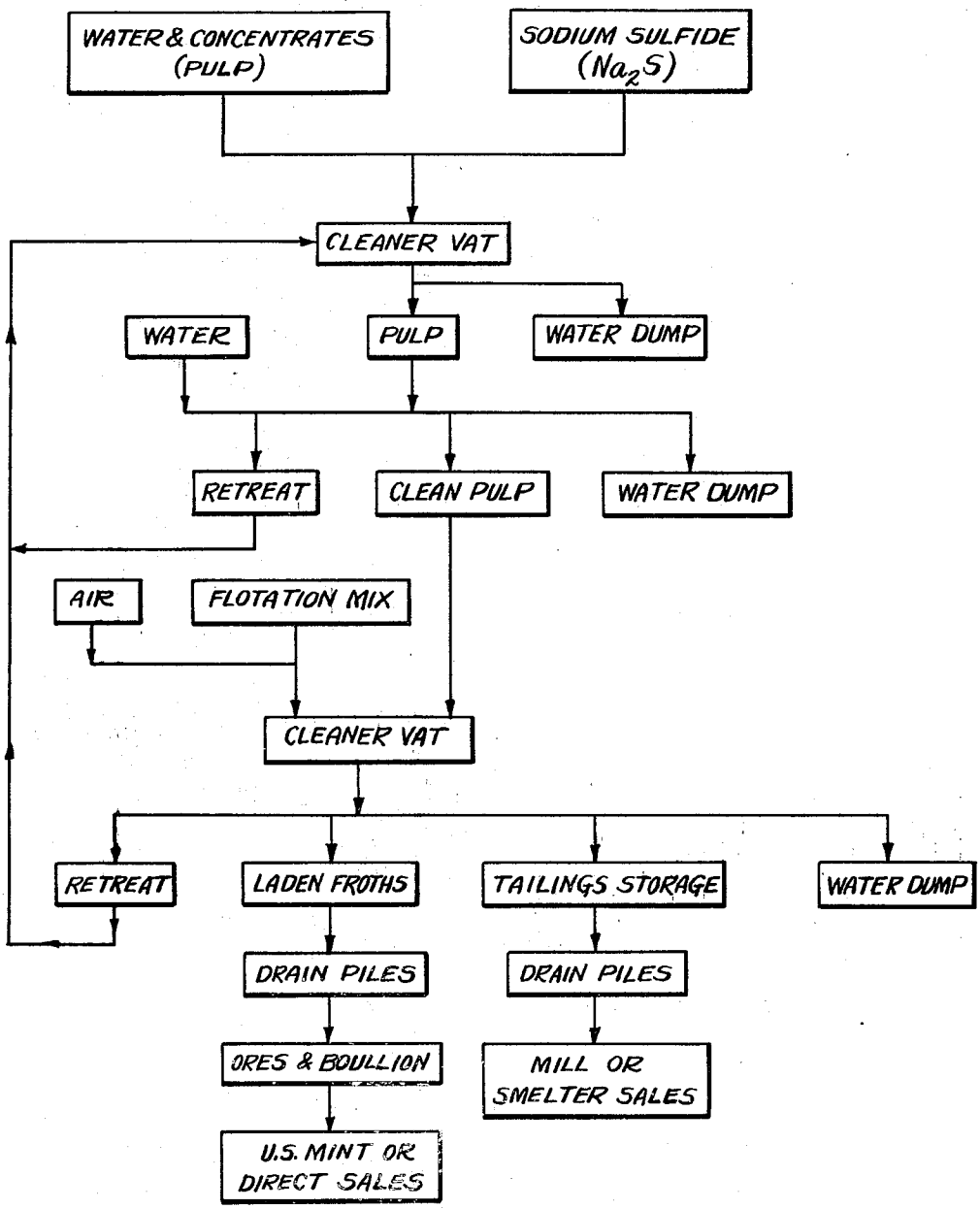


Fig. 9.

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3,498,674

Patented Mar. 3, 1970

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MINING METHOD AND APPARATUS

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Filed Aug. 4, 1967, Ser. No. 658,502
Int. Cl. E21c 37/12
U.S. Cl. 299—4 16 Claims

ABSTRACT OF THE DISCLOSURE

A method for mining or removing a selected mineral from a deposit, including the steps of forcing a probe having an injector head on the lower end thereof into the deposit, pumping through the probe to the injector head fluid containing a reagent suitable for separating the selected mineral from the deposit, removing the fluid carrying the separated mineral from the deposit to a treatment station, and treating the mineral-laden fluid to remove the selected mineral therefrom, after which the fluid can be recycled. In one embodiment of the method the fluid contains air and a selective flotation reagent to gather the selected mineral and carry it to the treatment station, the pulp, mineral-laden liquids and froths resulting in this embodiment being withdrawn from the deposit into an inverted cone around the probe at its place of entry, from which cone the mineral-laden liquid and froths are sucked and transferred to the treatment station. A preliminary step in another embodiment is to isolate the deposit, by establishing a physicial and/or a chemical barrier thereabout.

The apparatus includes a probe comprising an elongated pipe of small diameter fitted with an injector head on its lower end. The upper portion of the probe is connected through a pressure pump with a source of liquid including a suitable reagent, and in one embodiment also to a source of air pressure. The probe is forced downwardly until the injector head is positioned within a deposit, or where desired, and fluid is then pumped through the probe. An inverted suction cone about the probe at its place of entry, or another probe, is utilized to remove mineral-laden fluid from the deposit, the suction cone or the second probe being connected to a treatment station through a suction pump. The treatment station removes the mineral from the fluid, and the latter can then be recycled.

BACKGROUND OF THE INVENTION

Field of the invention

This invention relates generally to a method for mining or removing a selected mineral from a deposit, and to apparatus for carrying out the method. More specifically, the invention relates to a method and apparatus for carrying out in-place mining on any type of deposit, wherein fluid containing a suitable reagent is forced into the deposit to separate out a selected mineral, the mineral-laden fluid then being removed to a treatment station where the mineral is removed therefrom, after which the fluid can be recycled.

Description of the prior art

This invention is concerned with the mining or removal of selected minerals from any type of deposit, located anywhere. In man's quest for gold, silver and other valuable minerals many mining methods have been devised, most of which were designed to be of use with a particular kind of ore deposit. To catalog every previous

effort in this field would be difficult, but the discussion of some past developments will indicate the true novelty and scope of this invention.

An early mining process, and one still in use, requires that the deposit be physically dug out and then transported to a mill, smelter or other treatment plant where it is treated to remove the mineral therefrom, after which the tailings or slag are merely dumped and allowed to accumulate. There are many disadvantages to this conventional process, including the high cost of digging, transporting and treating the deposit material, the requirement that deposits be located where they can be dug with economy and convenience, and the unsightly and frequently dangerous mountainous piles of tailings that are accumulated near the mill or smelter. Frequently, such mounds of tailings are the source of dangerous chemicals that pollute both the ground and waterways.

Where physical digging of a deposit by mechanical shovels and the like has proved impractical, such as for deposits located under water, various types of hydraulic mining machines have been devised. In all of these both the minerals and sand, rocks, clay, and other gangues are gathered in, the gathered material then being treated much like deposits that have been mechanically dug. The cost of such mining equipment is great, and pollution and disturbance of a body of water overlying a deposit is most common.

Not all mining has been done with large machinery, of course, and the individual with his panning or a like process still exists. However, mineral recovery by this process is limited to relatively high grade ores, and much mineral is often left in the tailings. Frequently, however, a mineral deposit is so remotely located and/or is of such small size that until now only panning or a like small-scale operation has been feasible.

It is evident from this brief discussion that there is need for a mining method that can be utilized on any type of deposit, regardless of where it is located, and which can economically remove substantially all of a selected mineral from any grade-quality deposit, all without causing pollution or disturbance of the ground and waterways. The present method and apparatus meets this need, the apparatus being low in cost and designed so that it can be easily transported to even the most remote and inaccessible location.

SUMMARY OF THE INVENTION

An important feature of the present method is that it can be used to work any deposit regardless of where that deposit is located, including deposits found underwater and beneath layers of rock and boulders. Nor is the invention limited to use on natural deposits, since it can be utilized on a deposit of tailings or the like that have been accumulated in a contained area, to remove any remaining mineral therefrom.

The present apparatus includes a novel probe designed to penetrate into the selected deposit, and to inject the deposit with fluid. The probe comprises a long pipe of small diameter having an injector head on its lower end, the upper portion of the pipe being connected to the fluid source. The probe can be forced into the earth, and because of its small diameter can be worked through layers of gravel, small boulders and the like to reach a deep deposit. While the probe is designed to inject fluid containing a reagent into a deposit, it is also used in the invention to inject other fluids, and when fitted with a suc-

tion pump is utilized to withdraw mineral-laden fluid from a deposit being worked.

Essentially, the present method of mining includes the steps of forcing the probe downwardly to position the injector head within the deposit, pumping through the probe and into the deposit fluid containing a reagent suitable for separating a selected mineral from the deposit, removing the fluid carrying the separated mineral from the deposit to a treatment station; and treating the fluid to remove the extracted mineral. The fluid can be removed either with the use of an inverted suction cone fitted about the probe where it enters the ground, which cone is connected with a suction pump and removes the fluid by drawing it upwardly about the probe, or by utilizing another probe having its lower end in the deposit and its upper end connected to a suction pump.

In some instances the fluid utilized will consist basically of water having a suitable solvent therein, the solvent being chosen to extract the desired mineral from the deposit and to carry it to the treatment station. The treatment station is designed in this instance to remove the mineral from solution, after which the liquid can be recirculated.

In other instances, the fluid includes water and a suitable flotation reagent, and air under pressure is injected with the liquids through the injector head. The fluid separates the mineral from the deposit, and ore pulp and mineral-laden liquids and froths are separated in situ from the gangues, gravel and the like too large to float. The pulp and the mineral-laden liquids and froths are then withdrawn into the inverted suction cone, and the mineral-laden liquids and froths are sucked from the top of the cone to effect a further separation from gangues. The liquids and froths are then treated to remove the mineral therefrom.

The method for treating the mineral-laden froths to concentrate and then remove the minerals is also unique, and can be carried out right at the mining site utilizing conventional containers and the mining apparatus. The froths are combined with a suitable agent, such as sodium sulfide, and are passed into a vat or container. After several recyclings and the addition of air and a flotation reagent, heavily laden froths are obtained which can be dried to produce high-grade mineral.

A great concern in mining is that nature be disturbed as little as possible, so that destruction or pollution of streams, fish and wildlife is avoided. The present invention is especially adapted to ensuring that all standards for water and soil pollution control and other recognized conservation measures are rigidly observed. This occurs largely because of the closed loop operation of the invention, whereby all moving liquids and reagents are constantly isolated and prevented from disturbing areas surrounding the deposit.

In the embodiment of the invention wherein the inverted cone is utilized, the cone completely seals the place of entry of the probe. Fluids pumped into the deposit through the probe and mineral-laden fluids withdrawn through the cone are completely contained and isolated at all times. Thus, mining can be done underwater, with no possibility that the water will be disturbed or in any way polluted.

In some instances there will be geological faults in the region about a deposit, which result in the deposit not being completely isolated so that fluids injected into the deposit might flow into unwanted areas. The invention contemplates utilizing the probe to inject a suitable sealing, cementing and/or chemical agent to effect complete isolation of such a deposit, by forming a physical and/or a chemical barrier thereabout. In this way, the desired closed-loop mining conditions can be maintained.

It is the principal object of the invention to provide a method and apparatus capable of mining a selected mineral from any kind and grade of ore deposit located substantially anywhere, without in any way causing pollution or undue disturbance of natural surroundings.

A further object is to provide a mining method that can be carried out with a minimum of equipment, and which supplies high-grade mineral at a minimum cost of operation.

Another object is to provide apparatus for carrying out the flotation mining method of the invention, said apparatus being designed to be low in cost and easily portable to any desired location.

Still another object is to provide a method for scalping or upgrading mineral concentrates in the field, utilizing conventional equipment.

Yet another object is to provide a suction cone for removing froths and liquids from a deposit, designed to be low in cost, to seal effectively against the escape of fluids, and to be easily adjusted to withdraw froths at a desired location along the height of the froth column.

A further object is to provide a probe for injecting fluids into, or removing them from an underground deposit, the probe being designed so that it can be forced and manipulated to pass through overlying layers of earth, gravel, and small rocks and boulders.

Still another object is to provide an injector head for the probe of the invention, designed to eject air, liquid reagent and water at separate heights for maximum mining effectiveness.

It is also an object to provide a method for isolating a deposit by establishing a physical and/or a chemical barrier thereabout.

Still another object is to provide a method and apparatus for mining cold or frozen deposits.

Other objects and many of the attendant advantages of the invention will become readily apparent from the accompanying drawings, and the following description of the preferred embodiments.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a fragmentary diagrammatic view of one form of the mining apparatus of the present invention as applied to underwater mining, wherein the inverted suction cone is utilized to withdraw fluids from the deposit;

FIG. 2 is an enlarged sectional view through the suction cone and its flexible skirt, and shows how the injector head functions to eject air, flotation reagents and water at different levels into a deposit;

FIG. 3 is a modified form of device for use in down-the-hole, low water table situations, comprising a probe and vacuum cylinder;

FIG. 4 shows another device for down-the-hole operation;

FIG. 5 is an enlarged fragmentary vertical sectional view of a modified form of injector head;

FIGS. 6A, 6B and 6C are a topograhic and two profile diagrammatic views, respectively, showing the method of confining a deposit in a pond or lake beneath the surface of the earth by forming physical and chemical barriers, and in FIG. 6C showing the use of a plurality of probes to carry out the present mining method on the isolated deposit;

FIG. 7 is a profile diagrammatic view illustrating the use of the inverted cone and probe apparatus of FIG. 1 in plural to extract minerals from a cold-frozen deposit beneath the surface of the earth;

FIG. 8 is a flow diagram illustrating the method of closed loop flotation mining and milling; and

FIG. 9 is a flow diagram illustrating the method of scalping or up-grading the concentrates.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

While the method and apparatus of the invention can be utilized to extract many different minerals, depending upon the reagent selected, this description will concentrate on the mining of gold, and in particular placer de-

posits of gold. A typical placer deposit will lie just above bedrock, clay or some other barrier strata, and usually below one or several layers of earth, gravel, rocks and small boulders; most exposed placer deposits have long since been mined. Indeed, in some instances a deposit can lie beneath an overlaying solid rock strata, which must be dynamited or otherwise penetrated to reach the deposit. Frequently, valuable placer deposits will be found underwater, be it a small stream, a pond, or even a part of the ocean.

The particles of mineral, be it gold, silver, or some other metal, are usually found intermixed with the grains of quartz, feldspar sand, mica, clays, small rocks and other gangue materials that go to make up the placer deposit. The deposit can range from very low grade to a relatively heavy percentage of mineral, and especially in the far north can be partially or completely frozen. Present mining methods require that the overburden be removed or penetrated in some manner, after which the placer deposit is physically removed and carried to a smelter or mill. The expense of such a procedure, and the pollution and disturbance to the area that inevitably results, is all avoided by the present invention, wherein the placer deposit is mined in place.

Referring now to FIGS. 1 and 2, there is shown a first embodiment of the present mining apparatus arranged to mine a placer deposit D disposed under a body of water W and above a layer of bedrock R, the deposit D being overlain by an earth overburden E. Floating on the body of water W is a barge or boat **2**, on which is carried much of the present mining apparatus.

The mining apparatus includes a probe **4**, comprising a plurality of sections **6** of conventional pipe joined together by couplings **8** to achieve the necessary length. Typically, the pipe sections **6** will be of steel or some other rigid material, and will have an internal diameter of about 1.25 inches. A relatively small diameter for the probe **4** is important, for it makes it possible to work the probe through layers of small rocks and boulders to reach a buried deposit. Because of the reagents commonly used to recover gold and certain other minerals, no form of copper should be used in the probe **4**, or elsewhere in the apparatus.

The lower end of the bottom pipe section **6** terminates in an enlarged flange **10**, to which is secured an injector head **12** having a mating flange **14** on its upper end. The injector head **12**, as shown in FIG. 2, comprises a hollow cylindrical body **16** having a cone-shaped tip **18** secured to its lower end, said tip having an axial port **20** therethrough that communicates with the interior of the cylindrical body **16**. The dimensions of the injector head are exaggerated in FIG. 2 for clarity; typically, the cylindrical body **16** will have an internal diameter like that of the pipe sections **6**, and the port **20** will have a diameter a little less than one-half that of the body **16**.

The injector head **12** should be from about two to about three feet in length, and the side wall of the tubular body **16** has a plurality of spaced flow openings **22** therethrough. As will be explained, the elongated, small diameter injector head **12** is effective to eject air, flotation reagents and water at different vertical levels, which facilitates the mining operation. Liquid ejected through the axial port **20** is effective to drill a pathway through sand and dirt for the probe **4** as it is being forced downwardly.

The uppermost pipe section **6** has one end leg of a T-fitting **24** connected thereto by a coupler **8**, the other end leg of said fitting having a drive head **26** connected thereto. The probe **6** can be forced into the earth by exerting force on the drivehead **26**, and by manipulating the small diameter probe back and forth to maneuver the pointed injector head **12** past small rocks and boulders. Fluid is supplied to the probe **6** through a hose **28**, connected to the center leg of the T-fitting **23** by a coupler **30**.

Mounted on the probe **4** is an inverted suction cone **32**, which includes an inverted frustoconical hood or body **34** having a bottom wall **36** and an external peripheral flange **38** on its lower, open end. The hood **34** can be made of metal or plastic, and has a flexible, adjustable in length watertight skirt **40** attached thereto. The skirt **40** comprises a tubular sidewall **42** of plastic, duck or other flexible waterproof material, secured at its upper end to the flange **38** by a metallic ring **44** and bolts **46**. The bottom end of the sidewall **42** is rolled back upon itself to form an annular pocket to contain a ring weight **48**, and is secured by rivets **50**. A spirally arranged length of plastic hose **52** is positioned within a sidewall **42**, and a second, axially-split length of plastic hose **54** is snapped over the inner hose **52** to clamp portions of the sidewall **42** between the two hose sections. The two hose lengths **52** and **54** are cemented in place to the sidewall **42**, and the spiral rib formed thereby adds stability to the skirt **40**.

The bottom wall **36** of the cone body **34** has an inlet opening **56** therethrough of a diameter to easily receive the probe **4**, and an outlet opening **58**. Flanges **60** and sealing gaskets **62** are mounted on both sides of the bottom wall **36** about the inlet opening **56**, and are secured by bolts **64**. The flanges **60** are fitted with bushings **66** that fit loosely about the pipe sections **6**, the couplings **8** being sized to pass through said bushings. The flexible sealing gaskets **62** have an internal diameter somewhat less than the external diameter of the pipe sections **6**, and thus a sealed slip joint is formed between the probe **4** and the bottom wall **36**.

Flanges **68** and sealing gaskets **70** are fitted about both sides of the outlet opening **58**, and are secured by bolts **72**. The upper flange **68** is threaded to receive a nipple **74**, to which one end of a suction hose **76** (FIG. 1) is connected by a coupling **77**. The openings through the sealing gaskets **70** should be slightly larger than the internal diameter of the fitting **74**, so that no blockage of the suction hose **76** occurs.

Referring to FIG. 1, three or more ropes or cables **78** are connected at their lower end to the bottom of the skirt **40**, and are secured at their upper end to a fitting **80** clamped on the suction hose **76**. The fitting **80** is positioned on the hose **76** so that the skirt **40** can expand only to slightly less than its full length when hanging free from the hood or body **34**, so that when the suction hose **76** and the hood or body **34** is lifted above a certain height the weighted lower end of the skirt **40** will be raised from the overburden E. The height of the hood or body **34** can thus be adjusted over nearly the entire length of the skirt **40** to change the height at which froths and liquids are withdrawn from the froth column within the suction cone, as will be explained in greater detail.

Mounted on the boat or barge **2** is a vessel **82** containing water and reagent, an air compressor **84**, and a plurality of sand settling vats **86** interconnected midway their height by conduits **88**. The air compressor **84** is powered by a gasoline engine or the equivalent, and should be capable of delivering from 0 to about 125 p.s.i.g. at from 0 to about 3.6 cubic feet per minute. The air compressor is connected by a conduit **90** through a control valve **92** to one leg of a T-fitting **94**, the conduit **90** having a one-way check valve **96** therein downstream of the control valve **92** to prevent reverse flow to the compressor.

A positive displacement metering pump **98**, operated by a gasoline engine or the like, is mounted on the barge **2** near the vessel **82**, and is capable of delivering from 2 to about 20 gallons of liquid per minute at from 0 to about 500 p.s.i.g. A conduit **100**, which can be a suction hose fitted with a strainer on its intake end, leads from the vessel **82** through a control valve **102** to the inlet of the metering pump **98**, the pump outlet being connected by a conduit **104** through a control valve **106** to the center leg of the T-fitting **94**. A one-way check valve **108** is also connected in the conduit **104** downstream of the control valve **106**, to prohibit reverse flow to the metering pump.

It is thus seen that air from the compressor **84** is combined within the T-fitting **94** with liqud from the meterng pump **98**, the combined fluids being passed to a second T-fittng **110** by a conduit **112**.

Froths and liquids are withdrawn from the suction cone **32** through the suction hose **76** by a gasoline motor or like driven suction pump **114**, the suction hose **76** having an internal diameter greater than that of the probe **4** and being connected through a one-way check valve **116** with the suction pump inlet. The suction pump **114** is preferably self-priming, and can deliver from 0 to about 70 p.s.i.g. at flow rates from 2 to about 100 g.p.m. The outlet of the suction pump **114** is connected by a conduit **118** to the first of the settling vats **86** at a point about midway the vat's height.

The suction pump **114** delivers a mixture of mineral-laden froths and liquid, and floated particles of sand and other solids, to the series of settlings vats **86**. Within the vats **86** the mineral-laden froths F rise to the surface, the solids S settle to the bottom, and between the two is disposed clarified liquid L that can be recycled. The liquid L, comprised of water and reagents of somewhat less strength than the liquid in the vessel **82**, is drawn from the settling vats **86** of the treatment station T by a pressure pump **120** through a conduit **122** fitted with a one-way check valve **124**. The pressure pump **120** is identical to the suction pump **114**, and is connected by a conduit **126** through a one-way check valve **128** to the center leg of the T-fitting **110**. The outlet of the T-fitting **110** is connected to the hose **28**, so that fluids from the pumps **98** and **120** and the compressor **84** are all supplied to the probe **6**, and thence to the injector head **12**.

Obviously, the piping arrangement can be varied somewhat, and the various apparatus components alternatively can be located on a dock or on land. Further, dimensions flow characteristics and the like can all be varied, those given herein being cited by way of example and not limitation. One objective of the invention is to provide apparatus that can be easily transported, and to this end the various pumps and other components are chosen for lightness of weight so that when the apparatus is disassembled they can be carried on a person's back, if necessary.

Another feature of the invention is that it can be utilized on cold or frozen deposits, to thaw and work the same. This is accomplished simply by heating the liquids, either in the vessel **82** or in both said vessel and the vats **86**. It has been found that such heating can be accomplished merely by passing flexible steel tubing connected to the exhausts of the gasoline engines utilized to power the air compressor **84** and the pumps **98**, **114** and **120** through the vessel **82**, and if desired the vats **86**. The exhaust heat is sufficient to raise the liquid to a thawing temperature, and this is one reason why gasoline engines are preferred for power.

The injector head **12**, as has been mentioned, functions to separately eject the air, reagents and water pumped thereto. This occurs because of the length and small internal diameter of the head, and in practice it will be found that the air will for the most part eject through the ports **22** near the upper end of the head, that the reagents will eject through the middle ports **22**, and the water through the lower ports **22** and the axial port **20**, all as indicated in FIG. 2. Thus, the water tends to loosen the deposit particles and raise them up, where the flotation reagents and air can easily mix therewith. The pattern of flow separation and the ejection pattern will of course vary as the ratios of air, water and reagents are changed, and as pressures and flow rates are altered. Before beginning a mining operation the injector head **12** should be calibrated for different flow rates and pressures, so that desired separation and ejection patterns can later be easily obtained. Such calibration can be done by operating the injector head **12** while it is immersed in clear water, utilizing color dyes in the fluids discharged through the head.

The apparatus of FIGS. 1 and 2 is readied for operation by lowering the probe **4** with the suction cone **32** suspended thereon to the sand or silt overburden E, the flanges **10** and **14** being substantially larger in diameter than the bores through the flanges **60** so that the cone **32** will hang on to the flange **10** and not slip off the probe. The site to which the probe **4** is lowered may be one where it is certain a valuable deposit D lies, or it can merely be one where the presence of a worthwhile deposit is suspected. The apparatus of the invention is as well suited to prospecting or deposit exploration as to mining.

The vessel **82**, which can be an oil drum, or a plurality of interconnected drums, or any other suitable container, is then filled with reagent mixed with water. There are a great many commercially available reagent chemicals that can be utilized for flotation mining of gold, or any other selected mineral, the final selection being dependent upon the personal preferences of the operator, the peculiarities of a particular deposit, and other like factors. For example, to extract gold one may use any combination including, but not limited to, frother, collector, and selective modifier(s), plus the dispersant, flocculant, gold promoter and other(s) used upon fines, and the white (or yellow) "stick" phosphorus, carbon disulfide, ether(s), or organic solvent(s) used in cationic extraction. It is noted that tetrachlorides are also found to assist, in varying and selective manner, in the extraction of sub-colloidal or almost-dissolved gold aggregates. Use is limited to 0.5 p.p.m. at any time due to corrosive effects.

Choices for the reagent can be found in any standard text on Mining, Minerals Separation, Flotation Techniques, or the like.

One of the advantages of the invention is that it provides a way of avoiding possible pollution of surrounding areas, a purpose achieved by utilizing a closed-loop type of operation. There is always a possibility, however, that some leakage might occur from the closed loop, either through damaged or improperly handled equipment, or an unsuspected geological fault. Thus in locations where the elimination of all possibility of pollution is essential, no reagents should be used which are poisonous to surrounding vegetable or animal life or which might otherwise cause pollution. For example, petroleum-type reagents in certain areas should not be used, for they can badly pollute and foul streams and other bodies of water.

After the vessel **82** has been supplied with reagent and all is in readiness to begin mining, the suction pump **114** is started at a slow speed and circulation through the settling vats **86** and the pressure pump **120** is established and stabilized. The water W places weight on the flexible skirt **40** and seals the weighted bottom thereof against the overburden E, the cone **32** being held so that the skirt **40** is stretched to its full length. The air compressor **84**, the meter pump **98** and the pressure pump **122** are then adjusted to produce about 50 p.s.i.g., and the probe **4** is forced downwardly until the injector head **12** is in the deposit D. This can be accomplished by placing weight on the drive cap **26**, or striking it with blows from a sledge or other drive means, while wobbling, turning and otherwise manipulating the probe **4** to work it through any layers of gravel, small rocks or the like that might be present. The slip joint between the probe **4** and the cone **32**, and the flexible skirt **40**, cooperate to allow for such manipulation of the probe.

With the injector head **12** in the deposit, flow rates are set to obtain the desired patterns, as previously calibrated. The probe **4** will then begin to sink further into the deposit, at a preferred rate of 100 to 150 feet per hour with a working pressure of about 60–80 p.s.i.g.

As fluids eject from the head **12** under operating pressures, a radius of only a few feet will at first be affected. Depending upon the amount of sand, clay, and other elements in the deposit, the working radius about the probe **12** can enlarge as mining continues from a few feet up to 25 feet or more, and typically will assume the bell-

shaped configuration of FIGS. 1 and 2. At point of entry the affected area usually will be found to be 2.5 feet or more in radius, but at the higher pressures and increased flows the radius is so highly unique in each deposit and at each level in each hole, due to differential cementation and consolidation, varying matrix or fabric nature, and the amount of varying contents of muds, clays, silts, fines, sands, rocks, stones, boulders and placer particles, that no generalized statement holds. It may reach out 25 feet, and it may reach only 3.

The remaining fabric or matrix resembles washed gravels at an aggregate plant, when the extraction has been completed.

As has been explained, the injector head **12** functions to vertically separate the flows of air, water and reagent. At the injector head, deep in the deposit, the flows phenomena allows a layered effect of decreasing pressures from the top of the head down to the tip. At the first, or highest level of orifices in the sidewall **16** the air discharges at nearly the same pressure as fed into the flows at the point of supply. Below that level are discharged the foams and froths, below that the dilute reagent mixtures, and below it all the waters.

This separation allows a differential action of each, more or less "nudged" from below by the water flows. The deposit matrix is thereby raised and spread apart, and the enclosed particles are subjected to a barrage of collector in such incremental amounts as to build upon their surfaces a gradually increasing hydrophobic spot, zone, or coating, sprayed upon by air and foam-froths in a manner to substantially ensure that a satisfactory bubble-capture will ensue, given a "nudge" from below that will start them from their place in nature, and provide them with a passage or flow toward the free-water surrounding the drive pipe and the rising flows that assist their arrival at the foam column above. Any part of this effort is fully adjustable for maximum extraction.

The result is a chemical-metallurgical extraction that is in all ways superior to any present flotation, mining, or other recovery process thus far disclosed. It is so highly selective, through the choice of reagents and subtraction from the foam column, that it may be practiced upon almost any mineral values.

Adjacent and surrounding the probe **6** free water and other liquid is drawn upwardly into the cone **32** by the suction pump **114**, and the mineral-laden froth, as well as entrained ore pulp, sand and silt, move into this upward flow to form a rising foam column, leaving the rocks and other large gangues behind.

The upwardly moving foam column is a turbulent dilute pulp in which rising foams or bubbles find little barrier to their passage. The foam column, which contains ore pulp and mineral-laden liquids and froths, moves into the suction cone **32** where, due to the expanded zone area, heavier gangues and silts drop out to form a deposit ring **130** about the probe **4** that further seals the bottom of the skirt **40**. The foam column becomes increasingly dilute the nearer the top, and thus a highly selective extraction at any desired purity of concentrate can be made from the column by adjusting the height at which such extraction is done. This is done merely by slowly lowering the hood **34**, until liquids and froths of the desired quality are delivered to the settling vats **86**. It will be understood that even the thicker pulps at the bottom of the column are extremely dilute as compared with froth flotation cell practices.

Laden liquids and froths withdrawn from the deposit are fed into the settling vats **86** of the treatment station T, where gravity separation occurs. The mineral-laden froths F are periodically removed, and subjected to further treatment to remove the mineral therefrom.

By observing the liquids and froths extracted by the suction pump **114**, performance of the mining process can be evaluated. For example, if more than 50% of the concentrate delivered to the vats **86** show no sign of being anything but sand, the cone hood **34** is too low on the foam column and should be elevated. If the concentrates are all in bubble form the starch feed is too low, because the froth is not brittle enough to break sooner. And if all, or nearly all, of the froth bubbles show mineral values, the injector point **12** is sinking too rapidly through the deposit and adjustments must be made.

The mining operation is continued until no further mineral values are brought up, or until the injector point **12** bottoms on the bedrock R. The pressure pump **120** is then slowed, and the compressed air flow and the meter pump flow are increased. When the froths are nearly sterile the meter pump **98** is closed down, but aeration is continued until the froths are completely barren or until only clear water is brought up. The force pump **120** is then closed down, as is the flow of air.

With the suction pump **114** still operating, the suction cone **32** is moved while submerged to a new location a few feet away. Keeping the suction pump **114** in operation prevents rolling the natural waters, and gives clear vision. The mining process is then begun anew at the new location.

The pollution-free nature of the mining method just described is again emphasized. The suction cone **32** serves to completely seal all operating fluids from the body of water W, so that pollution and disturbance of the waters is avoided. If desired, after the minerals have been mined and before moving the suction cone to a new location the deposit can be purged or chemically neutralized merely by utilizing the probe **4** to pump liquid thereinto. Further, by moving the suction cone **32** with the suction pump **114** in operation, riling of the water W is avoided.

The apparatus of FIGS. 1 and 2 is in no sense limited to use underwater, or to use for mining a natural, buried deposit. The suction cone **32** can be utilized on dry land merely by digging a sump hole to receive the same, as shown at H in FIG. 7, which is then filled with water. Further, the apparatus can be used on a deposit made up of tailings which still contain a small amount of mineral, or any other mineral-containing material. In this instance the tailings or other material is ponded or contained in any desired manner, after which the apparatus of FIGS. 1 and 2 is utilized to carry out the method in a manner similar to that just described. One manner of containing tailings or the like is to merely deposit them in a large excavated hole fitted with a conventional plastic swimming pool liner.

The in situ flotation mining and milling process just described is shown diagrammatically in FIG. 8, and essentially includes the steps of:

(1) Forcing a probe having an injector head mounted on the lower end thereof into the deposit;

(2) Pumping through said probe into said deposit under pressure a fluid suitable for separating a selected mineral therefrom;

(3) Removing said fluid carrying the separated mineral from the deposit to a treatment station; and

(4) Treating the removed fluid to remove the separated mineral therefrom.

The fluid injected in FIGS. 1, 2 and 8 is made up of water, flotation reagents and air, and the mineral-laden liquids and froths that comprise the foam column rising vertically from the deposit are selectively extracted at a desired height on the column by the vertically adjustable suction cone **32**. Large unflotatable gangues, gravel and rocks remain in the deposit, and the smaller gangues are either dropped within the suction cone **32**, or are carried to the settling vats **86**. The accumulated sand and silt in the vats **86** can be periodically dumped, or if desired can be treated to remove any traces of mineral they might contain.

The mineral-laden froth F is periodically removed from the vats **86**, and is treated in the conventional manner to remove the mineral therefrom. The invention also contemplates a method for scalping or upgrading the mineral-

laden concentrates, at the mining location and utilizing the present apparatus. Thus, a high grade mineral product can be easily and cheaply obtained right at the mining site.

Referring to FIG. 9, the pulp concentrates from the vats **86** are diluted with water to form a 30–70% solids slurry in a separate cleaner vat, and sodium sulfide is added thereto. This treatment is continued until a clean pulp concentrate is obtained, with the dirty water being dumped after each treatment. In dumping the dirty water, as when disposing of any mining residue, care must be taken to avoid pollution of streams.

The clean pulp is then placed in the cleaner vat, and the outlet of a hose leading from the air compressor **84** and the metering pump **98** is placed in the bottom of the vat to feed air and the flotation reagent-water mix from the bottom upward into the concentrates. The resulting froths are hand dipped into a separate container, and the concentrating process is then repeated until laden froth of the desired purity and quality is obtained. This froth is then drained and dried, and mineral suitable for immediate sale is obtained.

The tailings remaining after scalping may still contain hard to recover mineral, and thus should be drained and dried for shipment to a mill or smelter. Again, in disposing of all water and other liquids care must be taken to avoid pollution.

In some instances, especially for down-the-hole operation, the suction cone **32** of FIGS. 1 and 2 is not suitable. A modification of the invention designed for down-the-hole use is shown in FIG. 3, and includes a suction cylinder **132** slidably mounted on a probe **4** identical to that shown in FIGS. 1 and 2.

The suction cylinder **132** includes a large diameter pipe section **134** closed at its upper end by a cap **136** secured in place by bolts **138**. The cap **136** has a bore therethrough for receiving the probe **4**, the bore being fitted with flanges **140** and gaskets like the opening **56** to form a sealed slip joint between the probe and the cap. A second, threaded bore **142** through the cap **136** receives a nipple **144**, which is connected to the suction hose **76**. The suction cylinder **132** operates similarly to the suction cone **32**, to extract mineral-laden froth and liquids at a desired elevation on a rising foam column.

A modification of the suction cylinder **132** is shown at **146** in FIG. 4, comprising a large diameter cylindrical body **148** closed at its upper end by a cap **150** secured with bolts **152**. The cap **150** has a centrally positioned opening **151** for loosely receiving the probe **4**, and a gland **154** is welded to the cap about said opening. The gland **154** is of larger diameter than the probe **4** to form an annular chamber **156**, and is fitted with a seal **158** at its outer end for forming a slip joint with the probe **4**. A pipe **160** is welded to the gland **154**, for connecting the chamber **156** with the suction hose **76**. Froth and liquids are sucked from the cylindrical body **148** through the chamber **156**.

A modified form of injector head, designed to impart upward thrust to fluids discharged therefrom, is shown at **12'** in FIG. 5. The head **12'** includes a cylindrical body **16'** fitted with a conical tip **18'** having an axial port **20'** therein, the sidewall of the body **16'** having a plurality of spaced, upwardly inclined ports **22'** therethrough. The inclined ports **22'** direct the air, reagents and water in an upward direction against a deposit, and thus facilitate lifting or raising of the deposit matrix to ensure proper mineral separation.

When the apparatus of the invention is utilized to work a deposit buried beneath a solid rock strata, or a solidly frozen strata, it usually will be necessary to use dynamite or the like to create a passage through the strata for the probe **4**. Once the probe **4** is past the barrier strata, the present mining method can be practiced. Thus, a relatively inexpensive manner for mining such buried deposits is provided by the invention.

To ensure that there will be no pollution of areas around a deposit, including underground streams and the like, the deposit to be worked may be isolated. Some deposits are naturally isolated, while others will be surrounded by geological faults that will leak reagent away from the deposit. The isolation of a deposit can be tested by inserting the probe **4** and pumping colored water thereinto, outcroppings of the water indicating where faults lie. Where a deposit is found to need isolation, the present invention includes as a preliminary step to the mining method a manner for effecting such isolation.

Referring to FIGS. 6A, 6B and 6C, a deposit D' is shown lying beneath an overburden E', the extent of the deposit having been determined by drilling holes **161** thereinto in the usual manner. The deposit D' has an underground water flow therethrough, which obviously must be blocked if the deposit is to be isolated. The mining method to be utilized on the deposit D' uses a conventional reagent to help separate the mineral, and thus the deposit D' should be isolated to prevent escape of the reagent.

To isolate the deposit D', holes **162** and **164** are first drilled on the upstream and downstream sides of the deposit, to extend transversely completely across the water flow. If necessary, explosives are then dropped down each of the holes **162** and **164** to shatter any rock or the like in the water flow regions. The probe **4**, without any suction cone or cylinder, is then inserted into each of the holes **162** or **164**, and a cement grout, styrofoam, hot tar, gelation agent, resin or some other liquid capable of mixing with the material in the shattered zone and hardening is injected. When the liquid has set, a physical barrier PB is created that blocks the water flow on both sides of the deposit.

To form a chemical barrier, further holes **166** and **168** are drilled between the deposit D' and the newly-created physical barriers PB, and explosives are again utilized if needed to shatter the sub-stratas. The probe **4** is then utilized in each of the holes **166** and **168** to inject a neutralizing chemical for the mineral extracting reagent into the shattered zones, thereby forming a pair of chemical barriers CB. The deposit D' is now completely isolated, and can be freely mined.

The mining process in FIG. 6C is carried out without utilizing the suction cone **32**. Instead, a plurality of probes **4** are inserted into the bores **161** about the periphery of the deposit D' and are utilized to inject the flotation reagent mixture, and another probe **4** is inserted into a centrally located hole **161** and is connected to the suction pump **134** to withdraw froth and mineral-laden liquids; the points of input and withdrawal can, of course, be reversed. The use of explosives to shatter the deposit D', may be needed, and such is done prior to beginning mining. Further, a cold or frozen deposit can utilize heated liquids to thaw the same, as described earlier.

After the mining is complete, a chemical neutralizer is pumped into the deposit D' to render it harmless, and the site is sealed off and abandoned. In this way, no possible pollution can occur.

Seldom is a placer gold deposit found that does not slope from some underground point to some lower point. In Alaska especially, where the permafrost deposit is found, a deposit usually extends from some point on an undersurface grade to another lower or higher point, forming what is in effect a gravelly muck filled ditch or valley, containing a varying percentage of boulders of various sizes and overlain by a variety of muskeg, overburden, and vegetation.

The problem is to extract the values formed by the precious metals particles from not more than five feet above bedrock or that resistant clay barrier zone that acts as bedrock, and not to thaw more of the permafrost than is absolutely necessary. If an underground water flow exists, it must be blocked off using the same technique as just described.

Such a deposit is shown at D'' in FIG. 7, lying on a sloping bedrock foundation R'' below a permafrost strata **170** and overburden E''. To mine the deposit D'', two probes **4** and suction cones **32** are utilized, one upslope and the other a distance away downslope on the deposit. Actually, a plurality of probes **4** and suction cones **32** might be utilized at each location.

Sump holes H are first dug at each location, and any bedrock or hard frozen ground is penetrated with drills or explosives. The suction cones **32** are then placed, and the probes **4** are forced into the deposit D''. Fluids are then pumped through both the upslope and the downslope probes **4**, and recovery is made from both cones **32**. The upslope probe **4**, however, is oversupplied to flood the deposit so that the distance between probes is bridged and the downslope cone **32** has excess suction to effect recovery of the excessive fluids from the upslope probe. In this way, all of the deposit D'' can be efficiently mined. If necessary, the fluids can of course be heated.

A typical use of the invention for placer mining of gold is as follows:

The probe **4** and surrounding cone **32** is placed in a stream bed or other body of water over a placer deposit to be mined. If there is no water overlying the deposit, a hole is spudded in or formed at the earth surface by use of a power-driven auger, portable post hold digger, churn drill or the like and any damming, ponding or laking, as by use of injected styrofoam, plastic sheeting, ice or natural aluminum around the hole, is used so as to trap water in the hole to give the necessary immersion of the cone.

The weighted edge of the skirt is allowed to rest upon a circular area inside which the deposit is to be penetrated. The cone is held at a maximum height that still allows full contact of the weighted lower edge of the skirt in a resting position on the earth. The suction or lift pump **114** is set at 5 gallons per minute or slow speed, as the operator desires. The air pressure, meter pump pressure, and force pump pressure are brought to approximately 50 pounds per square inch gauge.

The injector head is then forced into the deposit by the operators weight, by blows upon the drive cap **26** of the probe, by wobbling the probe, and by slight clockwise and counterclockwise turning of the probe, to help the injector head to insert itself between and through the sands, gravels, stones, and boulders of the overburden and the deposit.

The cone is adjusted to the desired point of extraction on the foam column, the pressures and feed are advanced to 80–100 p.s.i.g., and the extraction begins.

Reagents for this extraction are (placer gold only): Dowfroth 250, 0.005 lb./ton, or 2.5 p.p.m. (polypropylene glycol methyl ether), an ephemeral frother, further embrittled by the adition of: soluble starch, 0.005 lb./ton, or 2.5 p.p.m. (optionally acid or caustic, and used thereby for a minor pH control modifier, and coagulant) with sodium silicate, 0.005 lb./ton, or 2.5 p.p.m., using the liquid "N" or other forms as desired as a depressant, flocculant, and coagulant, and sodium isopropyl xanthate, 0.005 lb./ton, or 2.5 p.p.m. as a gold collector for selective collection.

These reagents are fed into the flows at "starvation rates" that allow an incremental concentration, in-the-hole, that allows a period of induction before exceeding the minimum threshold of reactive concentration, and thus act upon the minerals in a highly selective fashion. Additional items from cationic and sols and slimes extractions may be added to the recirculated liquid.

Any aqueous solution from which the gold values have not fully extracted by cationic extraction or by the recovery and drying of froths as described in the general description above is treated in the following manner:

Periodically (five gallons of each of) the following shall be prepared and used for meter pump feed, as desired:

Sodium lauryl sulfate, 0.005 lb./ton or 2.5 parts per million of the estimated contents of the foam extraction column, are fed to the aqueous solution until the slimes are deemed to be fully dispersed as desired. If no dispersion occurs regular operation is resumed until the dispersion has been dispelled by sodium silicate and starch action and the treatment is further effected by a substitution of alkyl trimethylammonium halide in the same manner. One of the two effects the desirable dispersion in most cases, but a choice of any other anionic dispersant may be made for the sulfate or the cationic dispersant halide, as the operator desires.

If the slimes are gold, a promoter is now added, at 2.5 parts per million, such as Aero promoter 208, or 404, or other, to act upon the gold particles.

A strong flocculent such as superfloc 16 is now added at 2.5 parts per million, to form discrete floc agglomerations large enough to be recovered by the device and process (above 10 microns) and operations are resumed in the customary manner.

The slimes flocs will be depressed and are subsequently flocculated by the starch and sodium silicate, while the gold flocs are, with the aid of the promoter, collected and extracted with the other gold values.

To summarize, there is first effected an anionic or cationic dispersion, then a promoter is added to treat the gold present, then a flocculant is added to form reactive flocs that react with the collector-frother as gold value agglomerations or with the starch and sodium silicate as depressed slime agglomerations. The treated waters and any spent clearing agents may be reintroduced into the closed circulating system along with additional reagent.

The invention further contemplates treating any aqueous solution containing colloidal and/or dissolved metal values with metallic phosphorus, to remove the metal values by deposition on the surface of the phosphorus. With this expedient even minute amounts of dissolved minerals, be the mineral gold, silver, platinum, palladium, or copper, can be extracted or recovered economically from aqueous solutions including those previously wasted or thought to be so low in concentration as to make further treatment useless. The application of this process to cationic and sols extraction of gold dissolved in an aqueous liquid is accomplished in the following manner:

White or yellow phosphorus metal (commonly called "stick phosphorus") is exposed to the gold-containing aqueous liquid in such manner that the phosphorus is at no time exposed to air or oxygen, or other reactive gas or liquid, but so that it is able to act upon the aqueous liquid and be acted upon by it. Contact methods for accomplishing this are well known in the art. After a suitable time of induction, the resulting phosphorus, covered with deposited metal foil, is bathed or washed in pure or distilled water until deemed clean and then heated, under water, to a temperature sufficient to melt the phosphours which may be separated from the metal encrustations, blebs, blobs, and particles that have formed thereupon.

The molten phosphorus is then poured into suitable containers and cooled to "stick" form suitable for reuse, and the metallic residue is further cleansed by treatment with carbon disulfide, ether, or any other organic phosphorus solvent, or any combination of them. At no time is the phosphorus metal, or the phosphorus containing collected materials, allowed access to oxygen or exposed to the air or other reactive material until phosphorus removal is complete. The solvent liquid is used until it is "spent", or ineffective for further digestion, and is then disposed of by adding at the rate of 0.5 part per million or 0.001 lb./ton to the reagent feed of the device and process described above.

The extraction action is due to the strong affinity phosphorus metal has for gold in any form, even in

extreme dilutions, an affinity which is also present though to a lesser extent for silver and other metals. The "stick" phosphorus (white or yellow) will be found to have formed upon its surface an encrustation of metallic gold and other metals from the aqueous solution. This extraction treatment can be practiced periodically upon the waste or recycled waters from any workable gold placer deposit (or others), in order to allow dissolved or colloidal metal values to be displaced, or it may be continuous in action.

By treating aqueous solutions according to the invention, minerals which in the past have not been recovered can be extracted at very low cost. The aqueous solution or liquid can be that resulting from pumping water and reagent into a deposit with the apparatus of the invention, or it can be liquid withdrawn from an abandoned and flooded mine, or even seawater.

The present method and apparatus thus makes it possible to recover minerals economically, to an extent not before realized. Even extremely low grade mineral values can be recovered with profit. Not only does the invention recover mineral from a placer deposit, but it also provides for recovery from tailings, and aqueous solutions from a flooded mine, a deposit, or any other source. Thus, any particular site, including both virgin locations and mines that have been previously worked but not totally exhausted, can be worked with the invention until substantially total recovery of all mineral values is achieved.

I claim:

1. The method of flotation mining for removing a selected mineral from a deposit, including the steps of: forcing a probe having an injector head mounted on the lower end thereof into said deposit until said injector head lies in the deposit; pumping through said probe to said injector head fluid containing water, air and a selective flotation reagent, said fluid being ejected under pressure from openings in said injector head into said deposit where it is effective to extract and float particles of the selected mineral from said deposit; removing fluid carrying said particles of the extracted selected mineral from the region of said deposit to a treatment station; and treating said mineral-carrying fluid to remove said extracted selected mineral thereform.

2. The method as recited in claim **1**, wherein said mineral is a metal, and said mineral-carrying fluid contains the metal in the form of sols and slimes, said step of treating including: adding to said fluid sufficient dispersing agent to fully disperse the slimes; adding a promoter for action on the metal values; and collecting and separating the metal value agglomerations.

3. The method as recited in claim **1**, wherein said selected mineral is a metal belonging to a group of metals having an affinity for phosphorus, said step of treating said mineral-carrying fluid including the steps of: contacting metallic phosphorus with said aqueous fluid in such manner that said phosphorus is not exposed to oxygen or any other reactive agent, so that said metal is deposited on the phosphorus; melting the resulting phosphorus under water to separate it from the deposited metal; and cleaning the separated metal deposit with a suitable organic solvent to remove any remaining phosphorus therefrom.

4. The method as recited in claim **1**, wherein said deposit is at least partially frozen, and including the additional step of heating said fluid before pumping the same into said probe.

5. The method as recited in claim **1**, wherein a probe is inserted into at least two separated portions of said deposit, fluid being pumped to the first of said probes at a faster rate than to the second probe, and fluid being extracted from the deposit region about said second probe faster than from the deposit region about said first probe.

6. The method of claim **1**, wherein said mineral-carrying fluid is separated in situ in the deposit from the gangues, gravels and the like too large to float, and constitutes ore pulp, mineral-laden liquids and froths that are withdrawn from the deposit into a zone around the pipe at its entry into the earth, said mineral-laden liquid and froth being sucked from a selected height within said zone to effect a further separation from gangues.

7. The method of claim **4**, wherein pulp concentrates are sucked from said zone and are upgraded at said treatment station by mixing them with water to form a 30–70% solid slurry, sodium sulfide being added to the slurry mixture to effect cleaning of the pulps, the cleaned pulps being treated with air and a selective flotation reagent to form a mineral-laden froth, said froth then being recovered.

8. The method as recited in claim **1**, including the preliminary step of isolating said deposit to prevent contamination of surrounding regions.

9. The method as recited in claim **8**, wherein said preliminary step of isolating said deposit includes: inserting a probe having an injector head thereon into the earth at various selected places spaced from the outer boundary of said deposit; and pumping through said probe into the earth at each of said places a liquid material which has the characteristic of hardening to form a physical barrier.

10. The method as recited in claim **9** wherein said preliminary step of isolating said deposit further includes: inserting a probe having an injector head thereon into the earth at various selected locations deposed between the boundary of said deposit and said physical barrier; and pumping through said probe into the earth at each of said locations a chemical capable of neutralizing said reagent, whereby to form a chemical barrier between said deposit and said physical barrier.

11. The method as recited in claim **1**, including the preliminary step of shattering said deposit with explosives.

12. Apparatus for use in mining a selected mineral from a deposit by flotation mining, comprising: probe means for injecting said deposit with fluid, said fluid being comprised of water, air and a reagent suitable for separating and floating particles of said mineral from said deposit; pump means connected with said probe means for pumping simultaneously therethrough the water, air and reagent comprising said fluid; means for withdrawing said fluid from said deposit; and treatment station means connected with said withdrawing means for treating said withdrawn fluid to remove said mineral therefrom, said probe means comprising: an elongated pipe having a small internal diameter; and an injector head mounted on the lower end of said pipe and having about the same internal diameter, said head having a pointed tip thereon with an axial port therethrough, and the side wall of said head having a plurality of axially spaced ports therein, said injector head being effective to separate and eject at different vertical levels the water, air and reagent comprising said fluid.

13. Apparatus as recited in claim **12**, wherein said injector head has an internal diameter of about 1.25 inches and is from 2 to 3 feet in length.

14. Apparatus as recited in claim **12**, wherein said sidewall ports are inclined upwardly.

15. Apparatus as recited in claim **12**, wherein said withdrawing means includes a second probe means having a suction pump connected thereto.

16. Apparatus as recited in claim **12**, wherein said withdrawing means includes an inverted cone slidably mounted on said probe means, the lower end of said cone having an adjustable in length skirt attached thereto, and the upper closed end of said cone being connected with a suction pump.

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