United States Patent [19]

Dane, Jr.

[11] **3,811,730**

[45] **May 21, 1974**

[54] **DEEP SEA MINING SYSTEM**

[76] Inventor: **Ernest Blaney Dane, Jr.**, 57 Tyler Rd., Belmont, Mass. 02178

[22] Filed: **Aug. 29, 1972**

[21] Appl. No.: **284,606**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 148,853, June 1, 1971, abandoned, and a continuation-in-part of Ser. No. 754,191, Aug. 21, 1958.

[52] **U.S. Cl.** **299/8**, 37/58, 37/72, 37/DIG. 8

[51] **Int. Cl.** **E02f 7/00**

[58] **Field of Search** 299/8, 9; 37/DIG. 8, 58, 37/72

[56] **References Cited**

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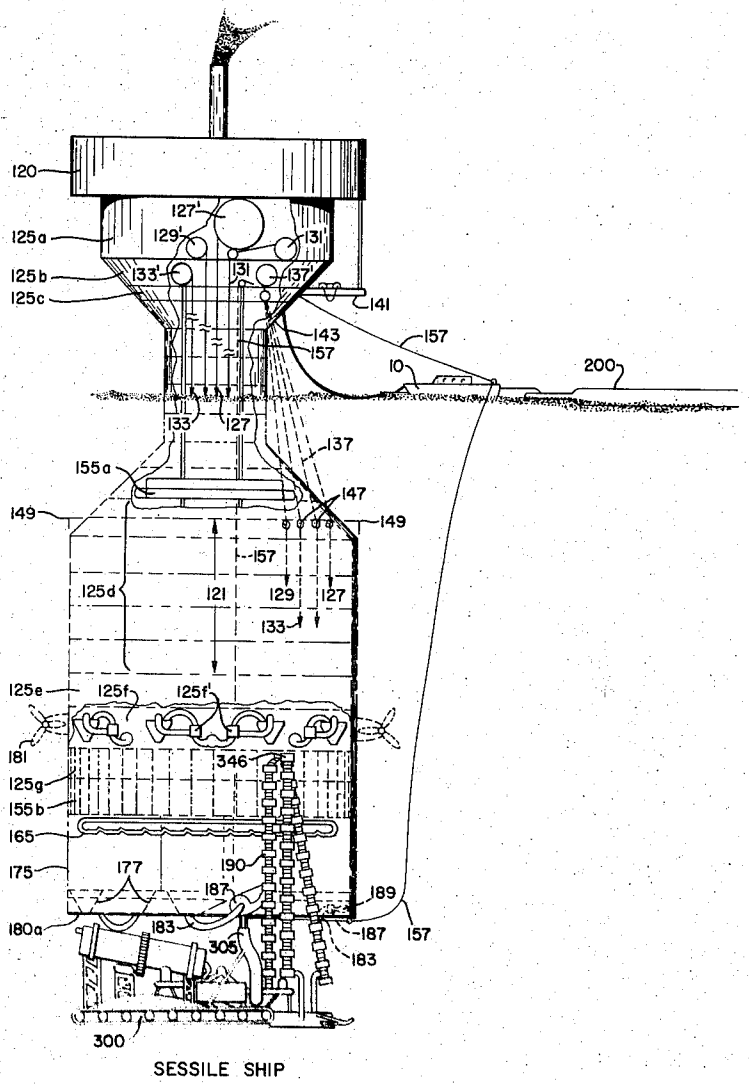
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Primary Examiner—Ernest R. Purser

[57] **ABSTRACT**

A deep sea mining system for mining ore from the surface of an ocean bed using a mining plant that travels the bed, a Sessile ship, and an interconnecting hoist pipe circuit. The system is transported to the mining site by a ship with streamline and structural strengthening sections which are later detached and reassembled into an auxiliary vessel. The hoist pipe circuit is towed to the mining site in sections which, during assembly of the hoist pipe circuit, are used to lower the plant to the ocean bed. After being lowered, the plant covers the bottom, the Sessile ship following the course of the plant, continually hovering over it. A scraper bucket system mounted on arms incorporated by the plant scrape ore nodules from the surface of the bed. The plant cleans the nodules of valueless mud, crushes them to particle size and couples the ore particles to the hoist pipe circuit where they are lifted as slurry and deposited in bins of the hovering Sessile ship.

20 Claims, 27 Drawing Figures



SESSILE SHIP

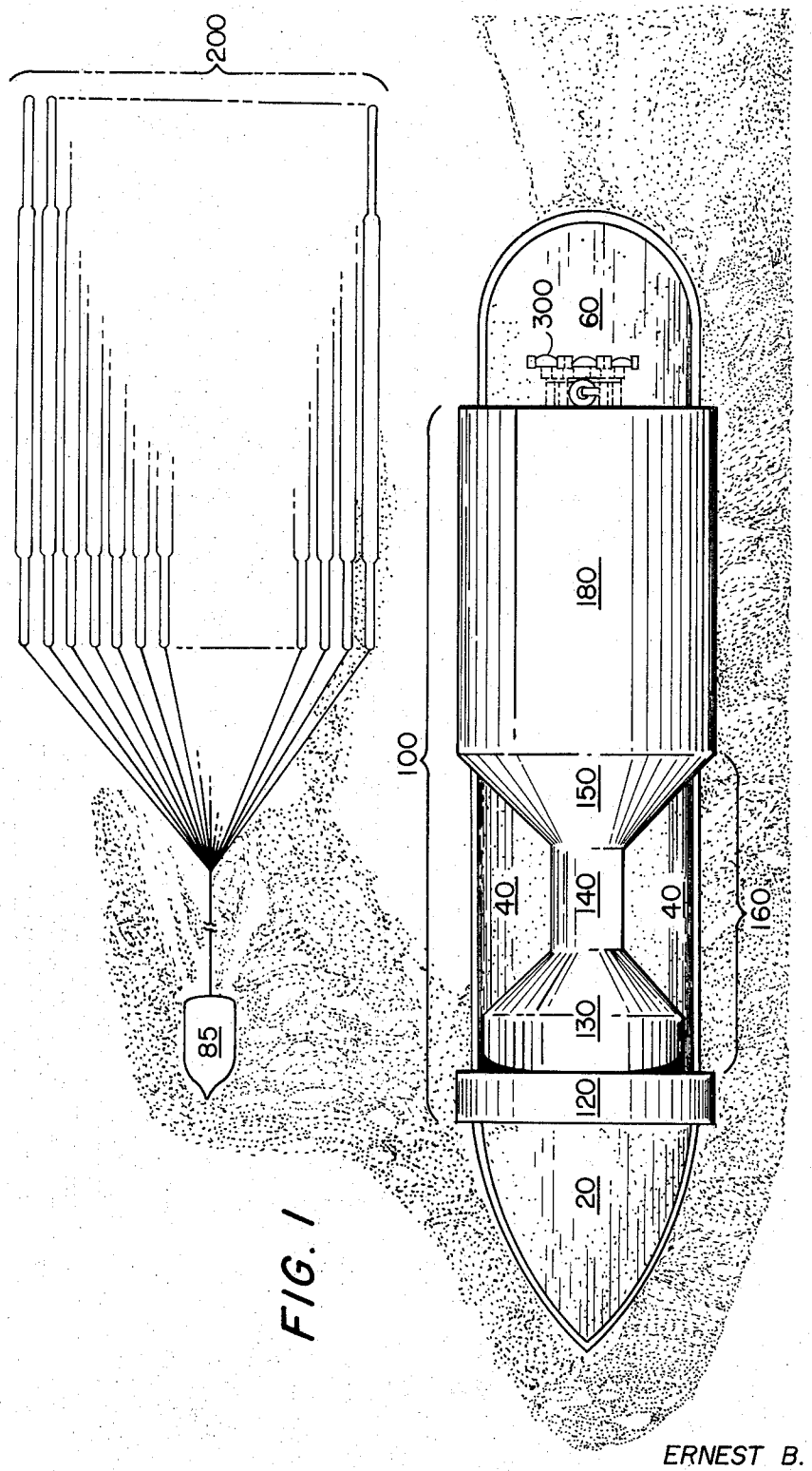
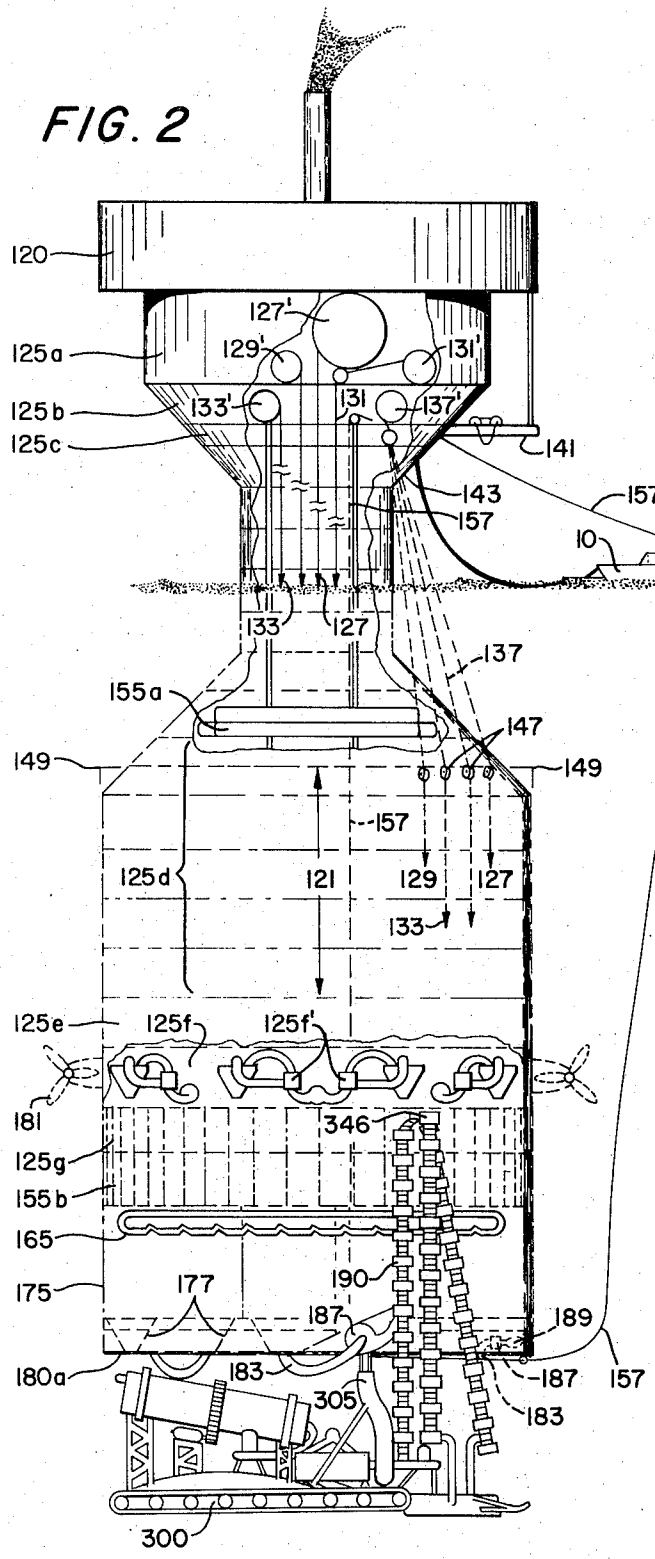


FIG. 1

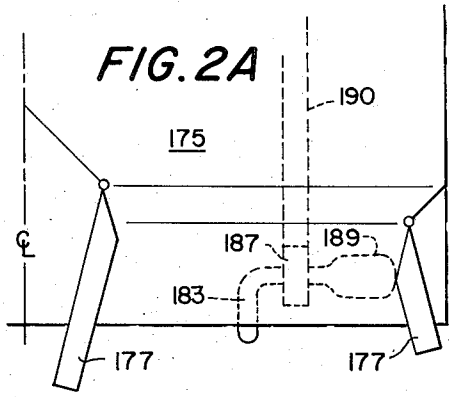
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FIG. 2



SESSILE SHIP

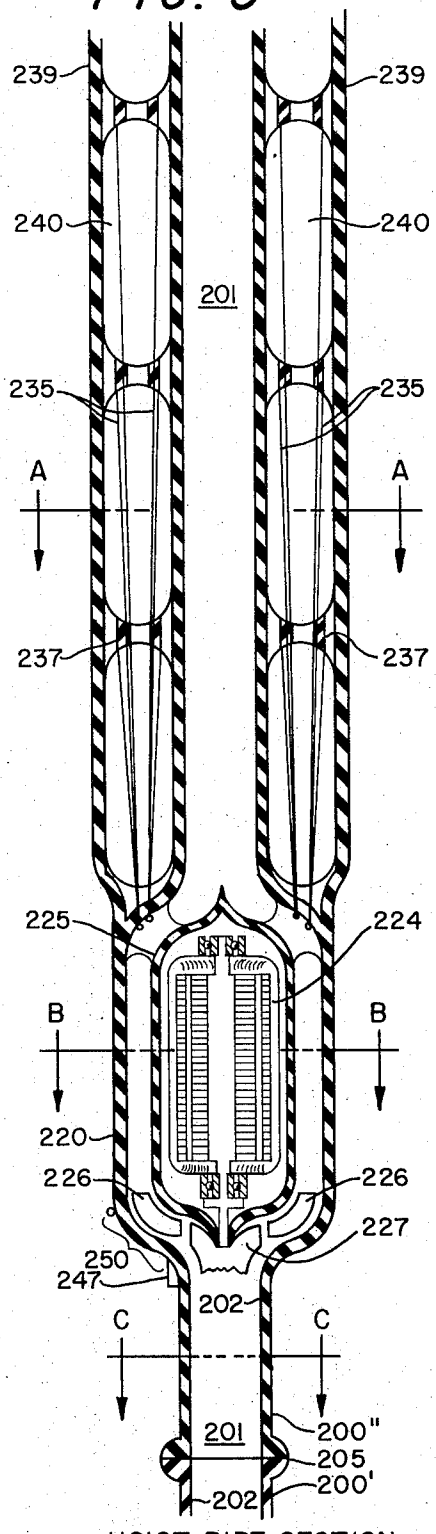
FIG. 2A



ORE BIN HATCH

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FIG. 3



HOIST PIPE SECTION

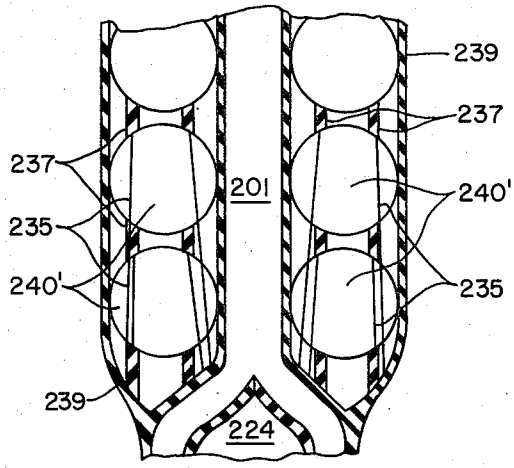


FIG. 3D

FIG. 3A

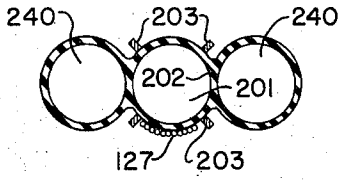


FIG. 3B

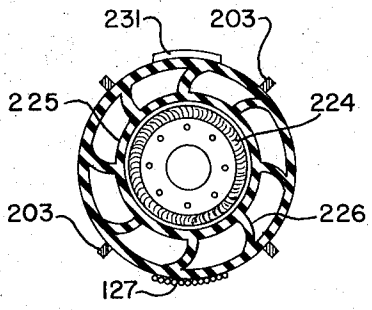
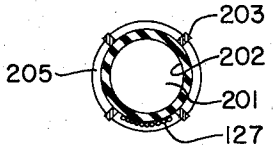


FIG. 3C



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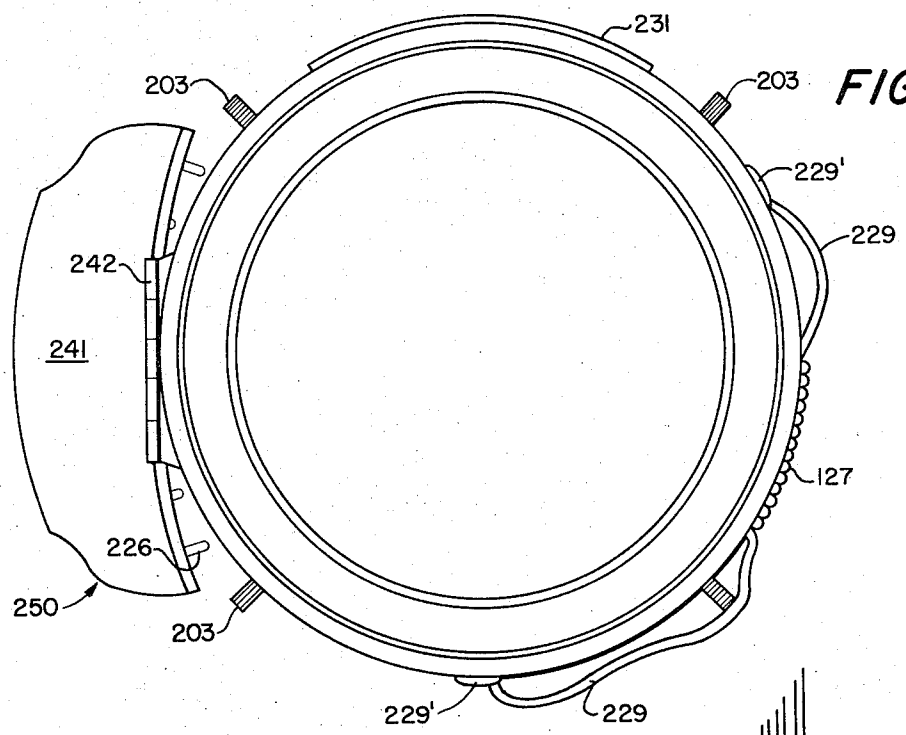


FIG. 4A

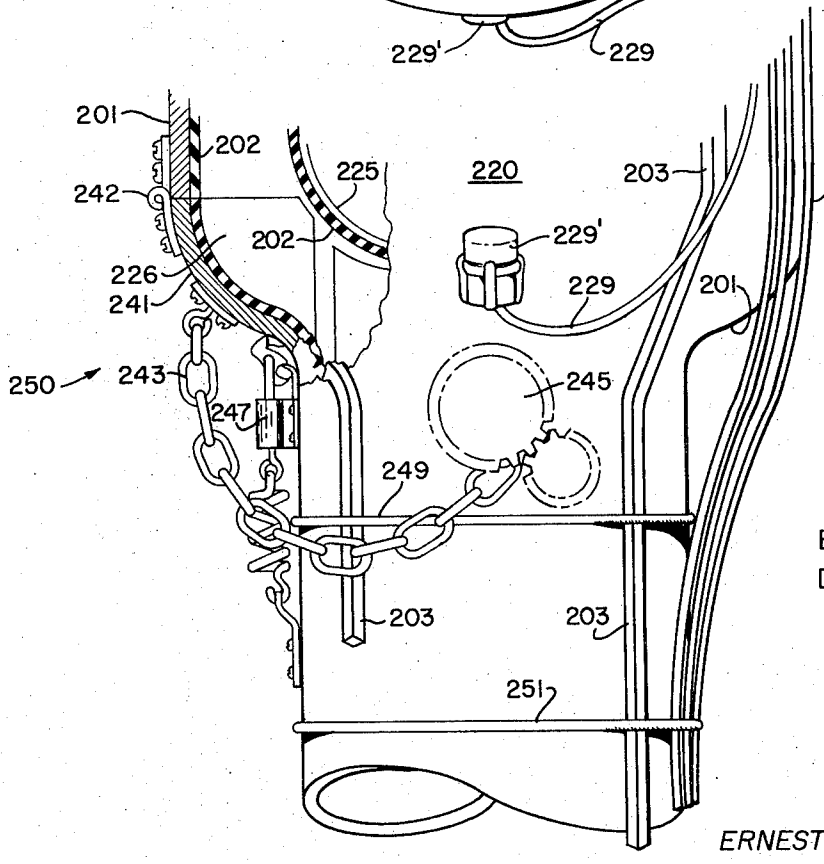
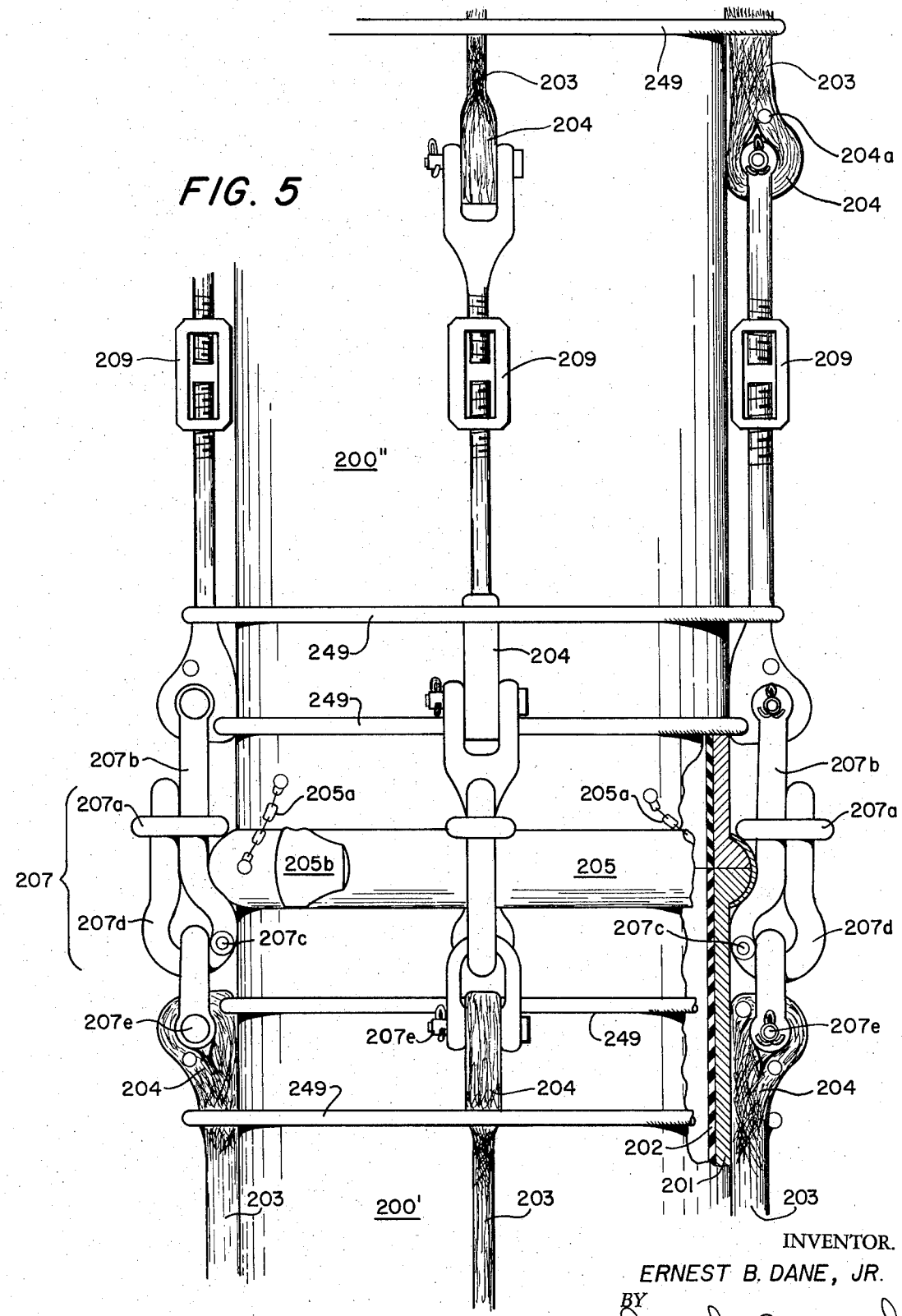


FIG. 4

EMERGENCY
DUMP VALVE

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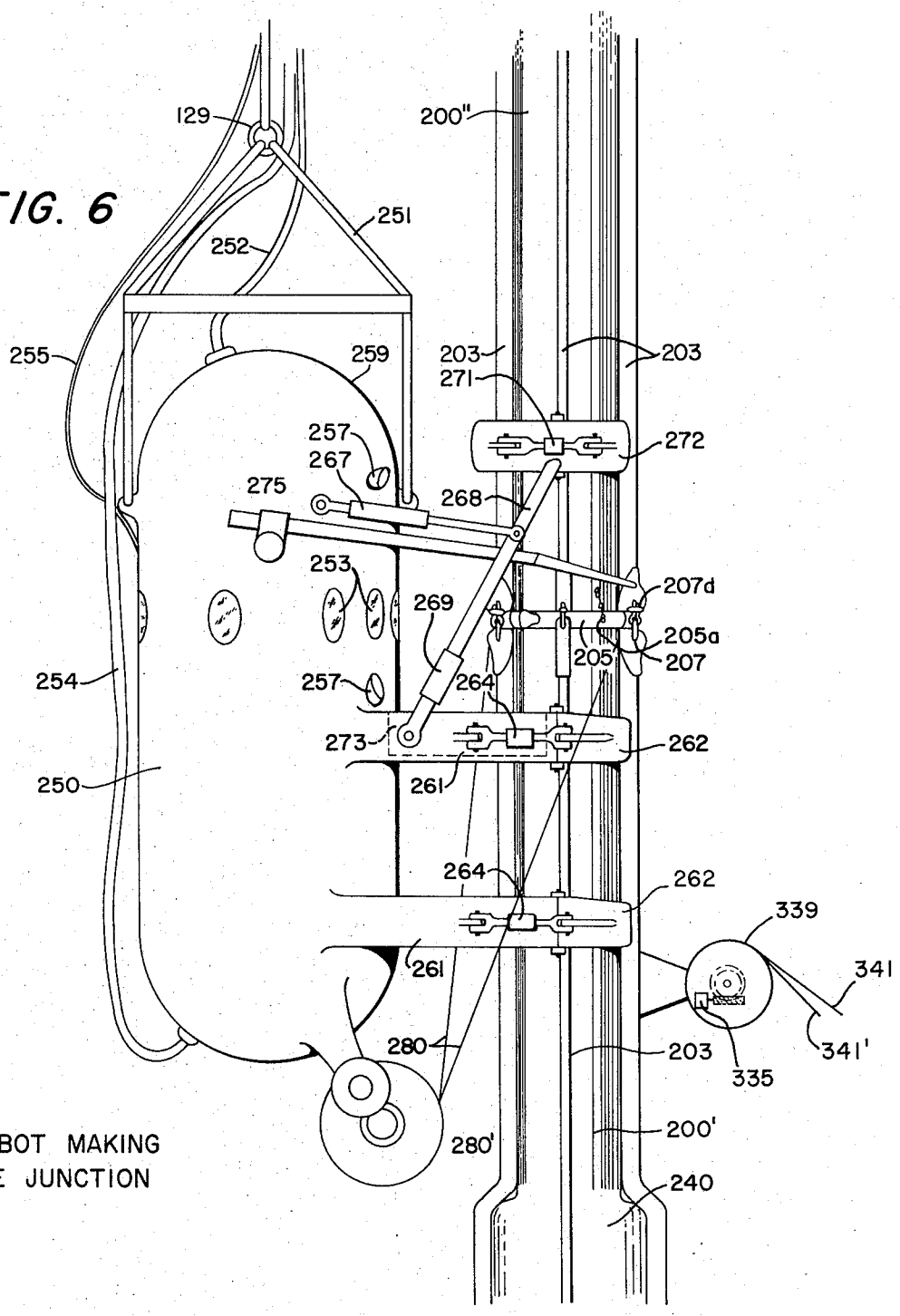
FIG. 5



ADJOINING END OF PIPE SECTIONS

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FIG. 6



MANBOT MAKING
PIPE JUNCTION

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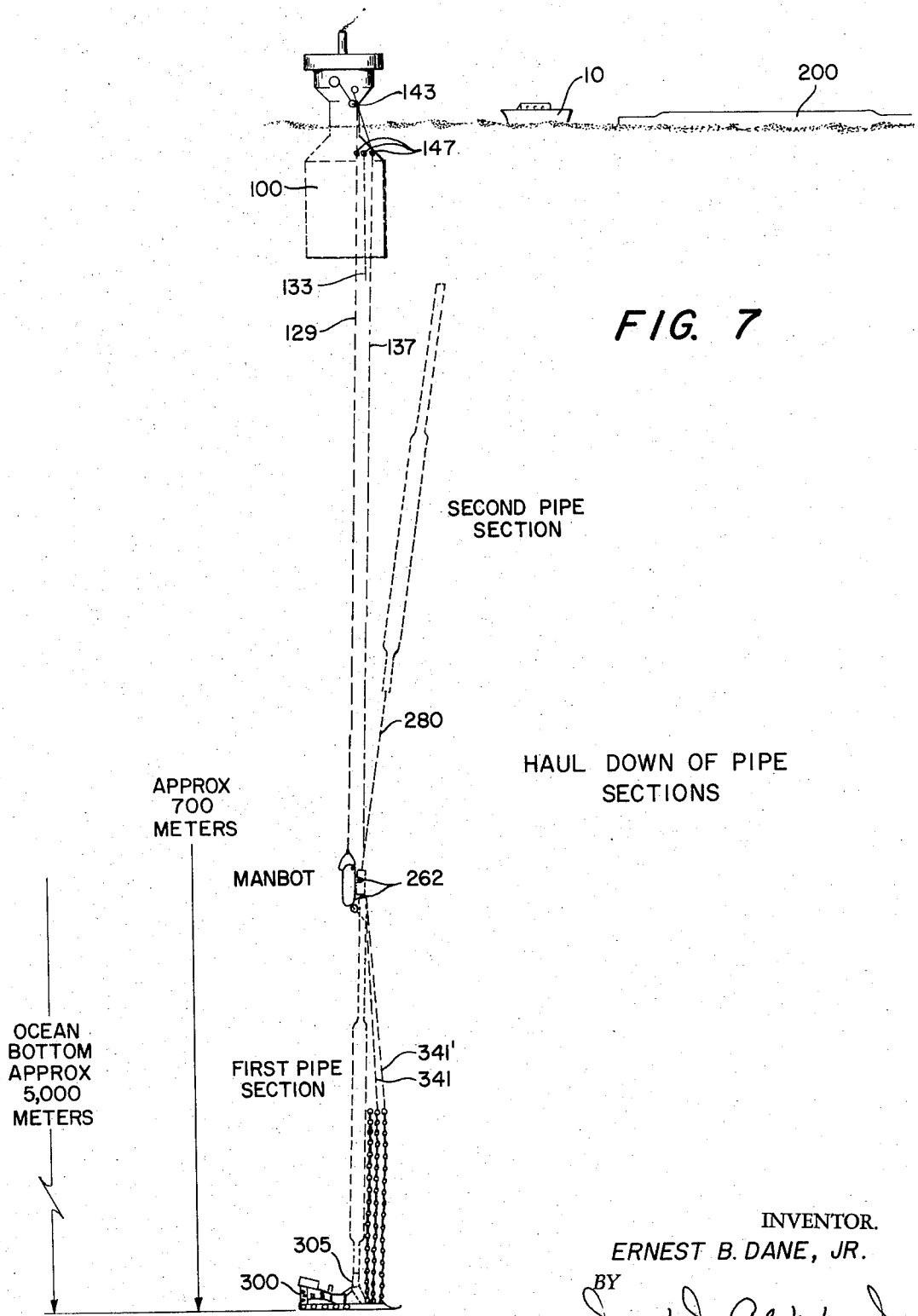


FIG. 7

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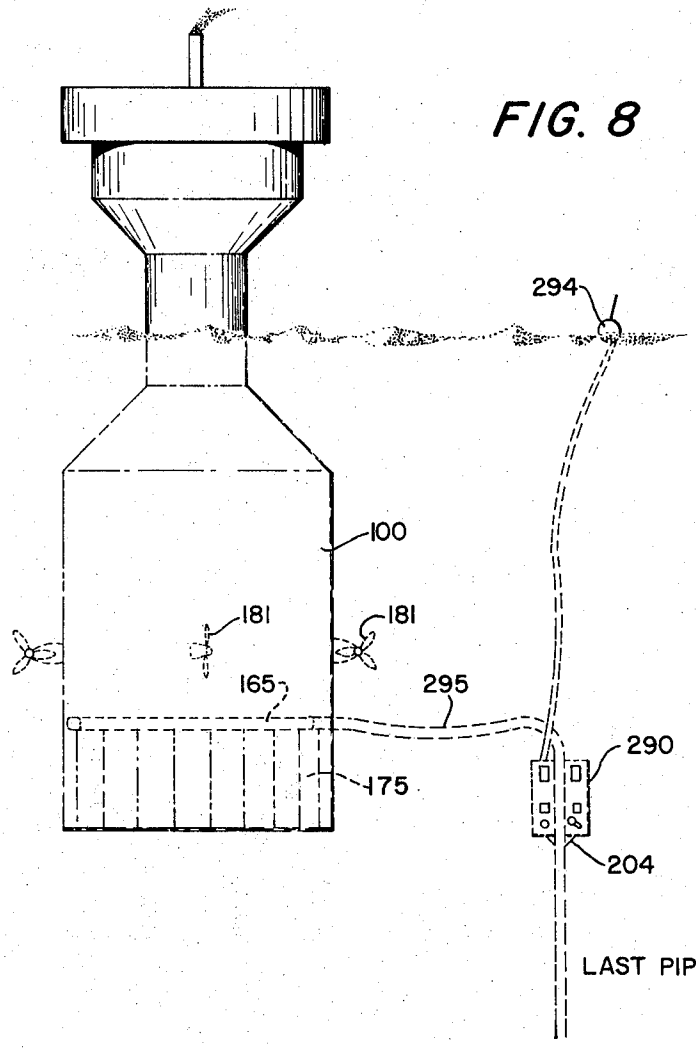
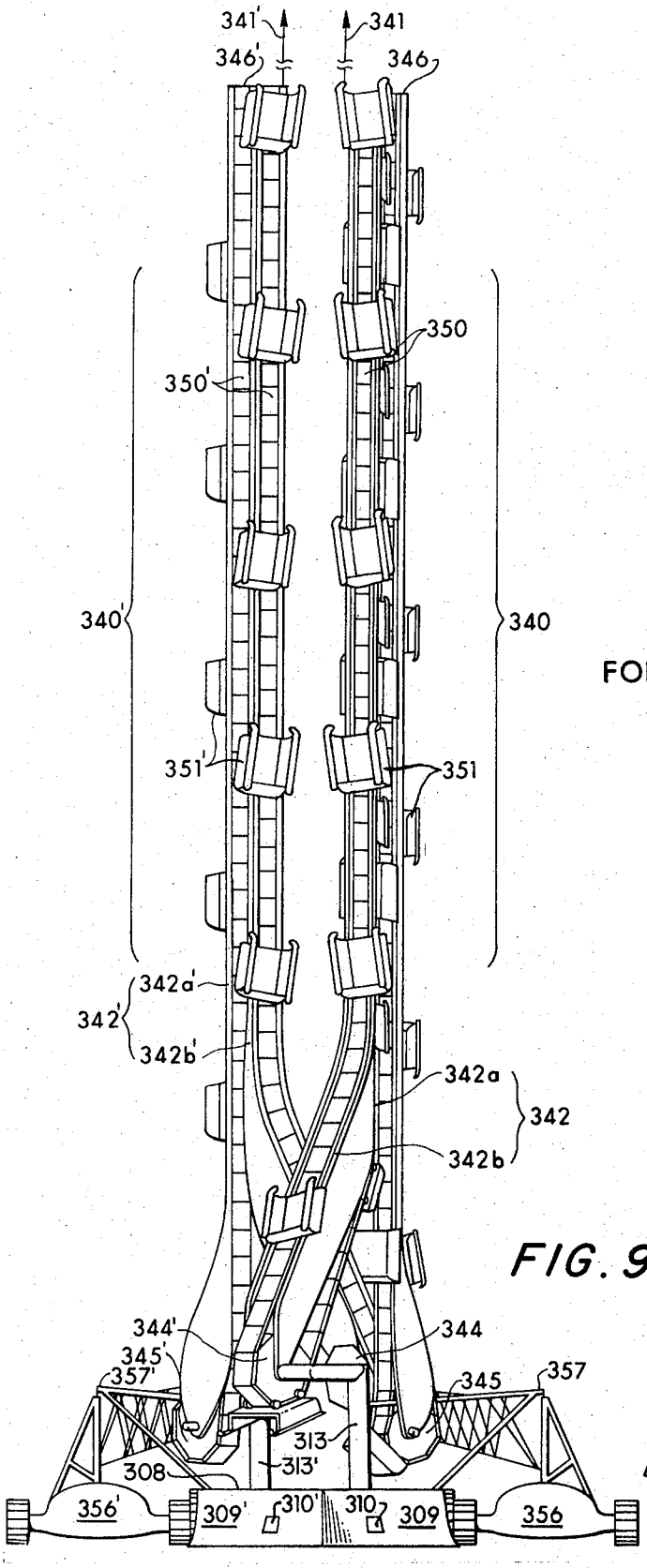


FIG. 8

TERMINATION OF LAST PIPE SECTION

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FOLDED ARMS

FIG. 9

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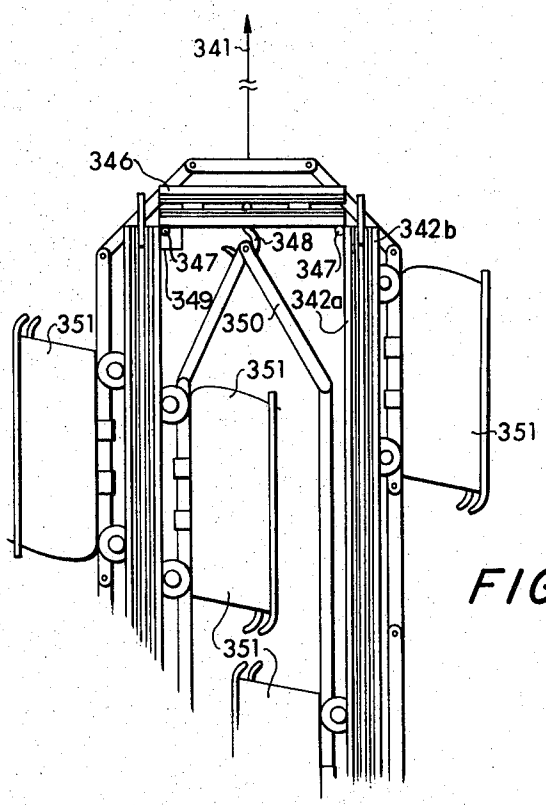
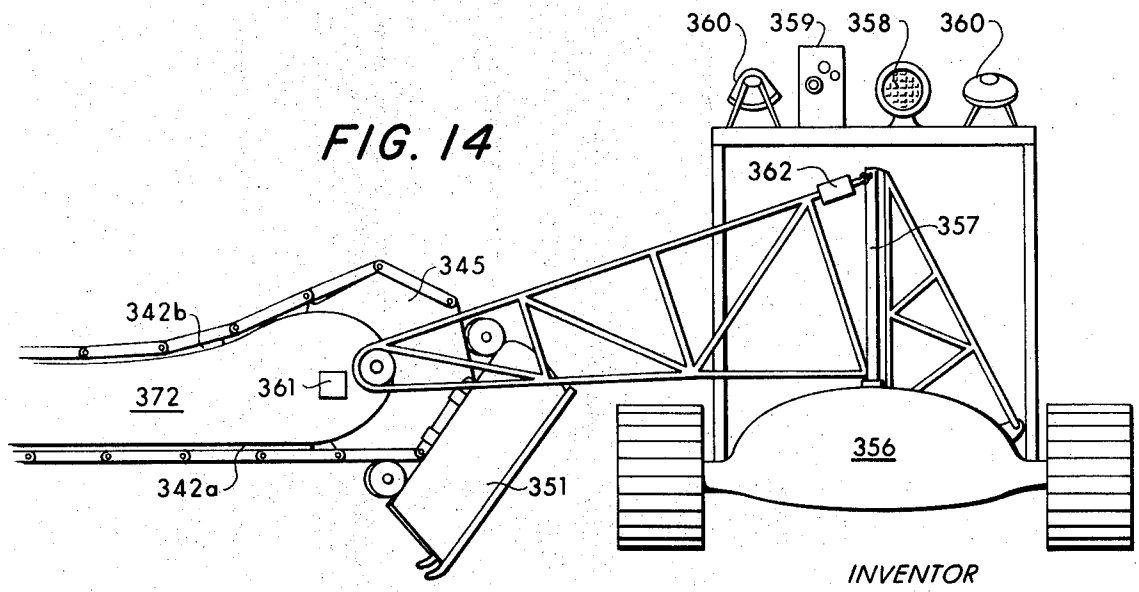


FIG. 10

DOUBLE JOINT AT MID LENGTH OF ARM
SHOWN IN FOLDED POSITION AS WHILE LOWERING

FIG. 14



FAR END TERMINAL OF ARM

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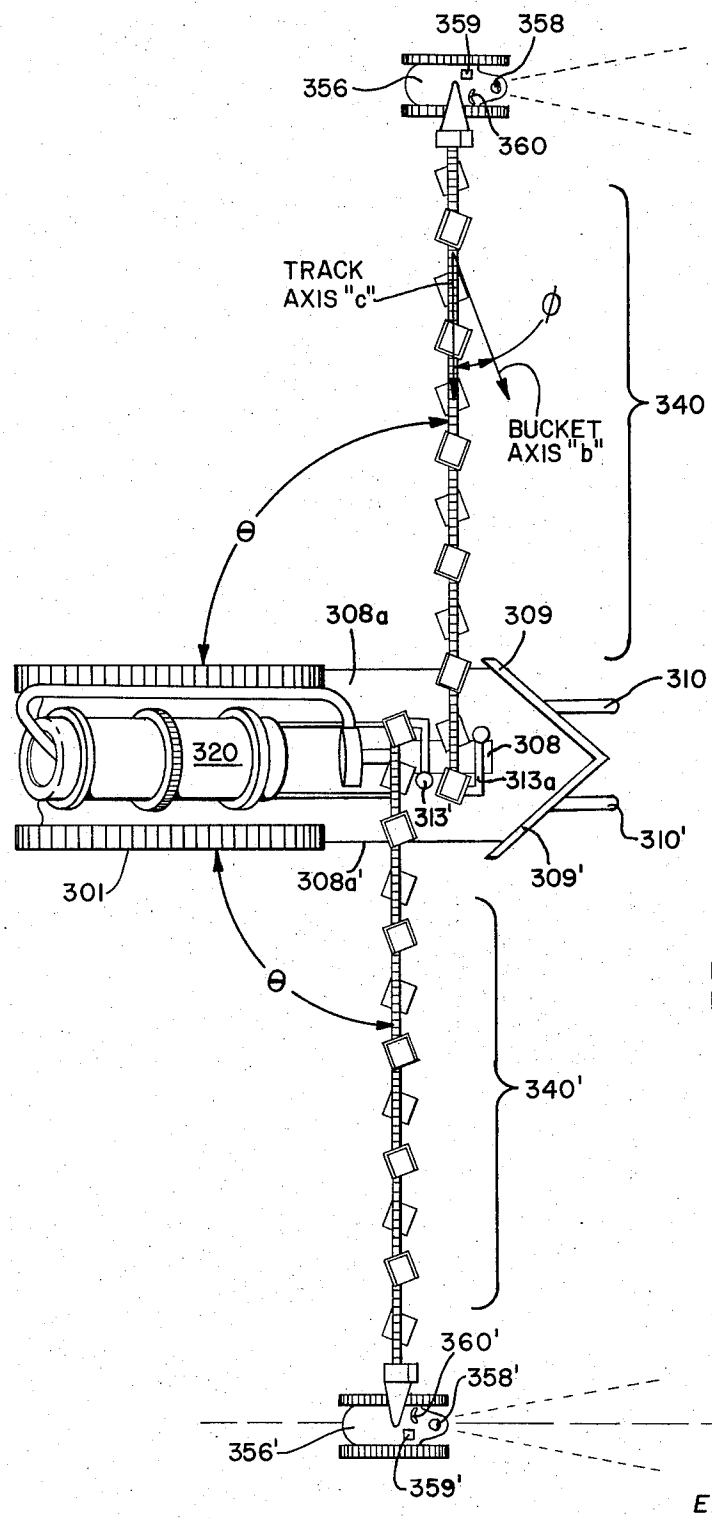
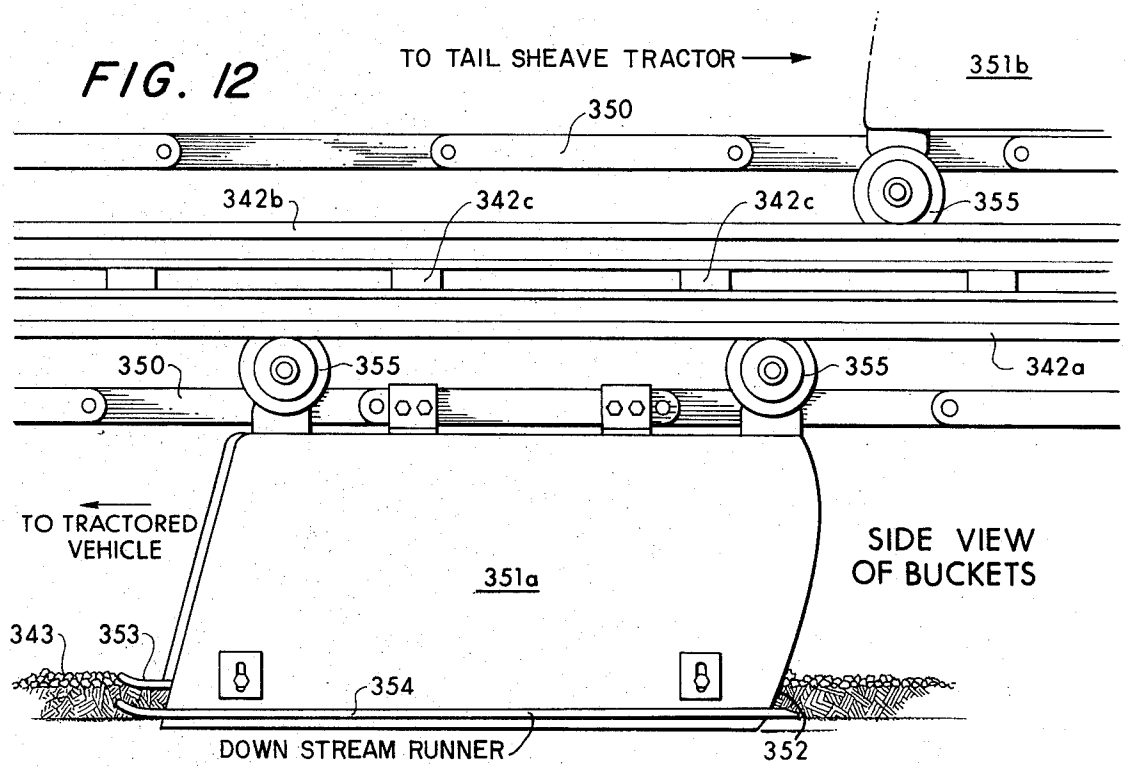


FIG. 11

MINER WITH
EXTENDED ARMS

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FIG. 12



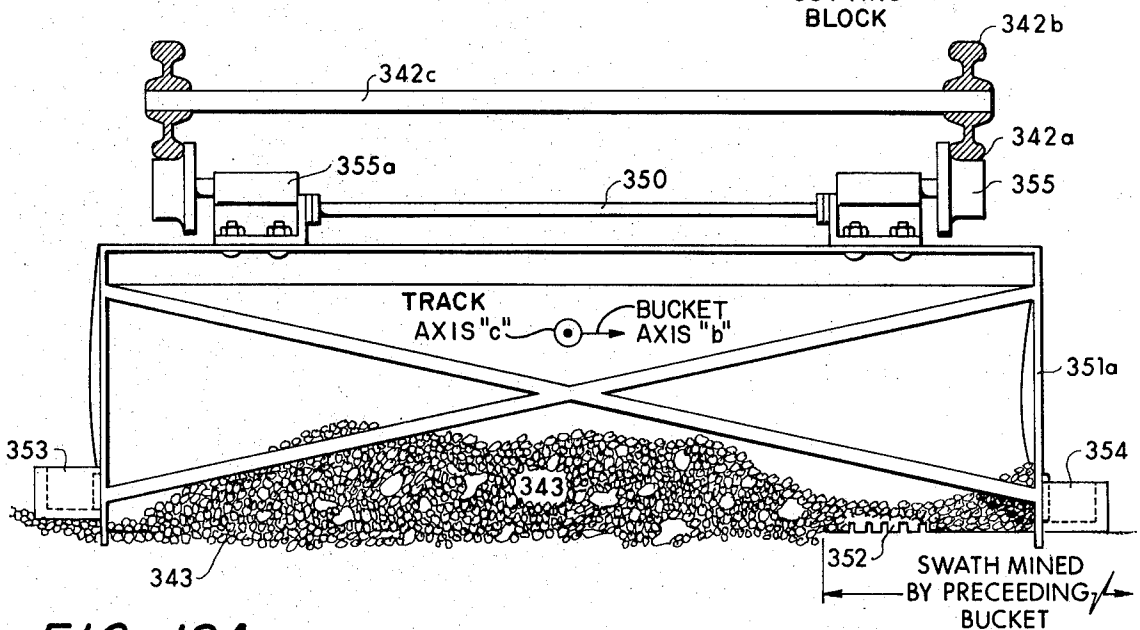


FIG. 12A FRONT VIEW OF BUCKETS

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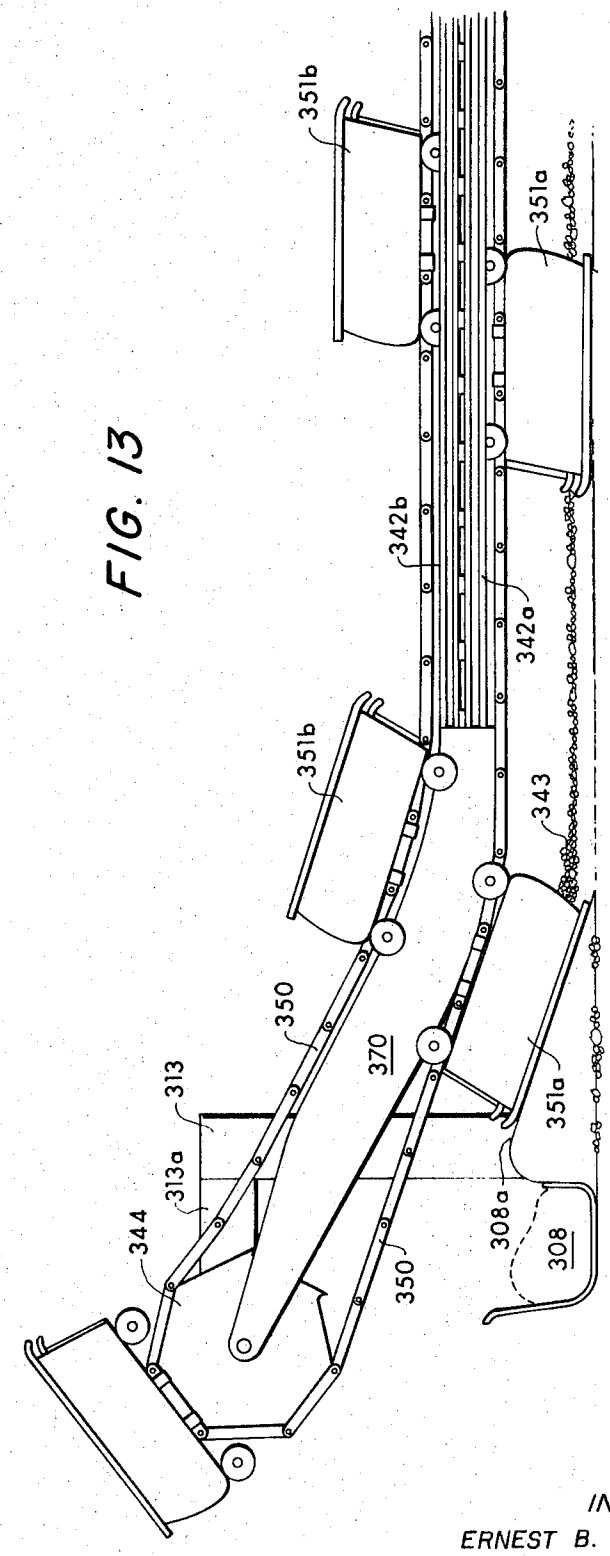


FIG. 13

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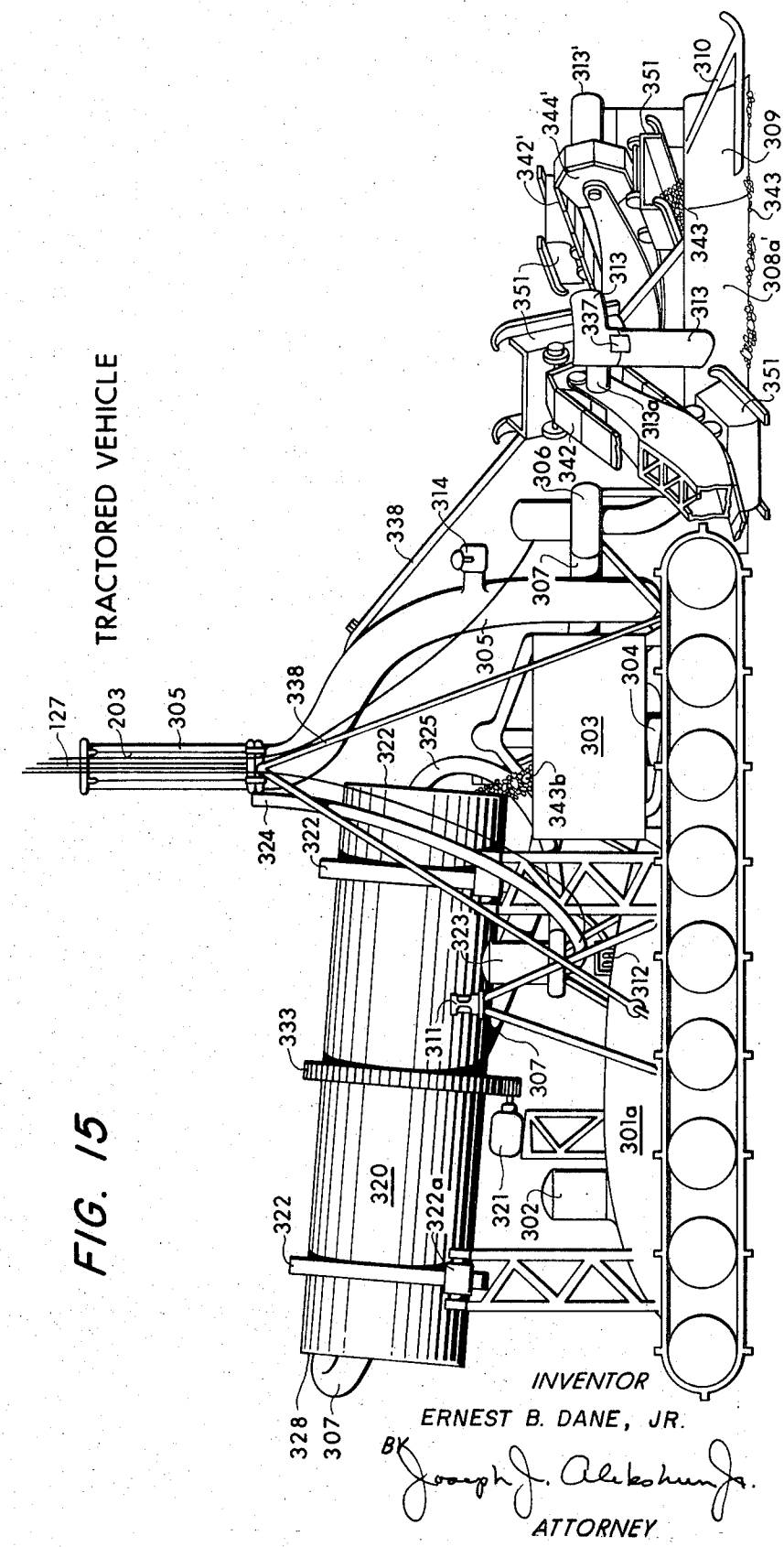
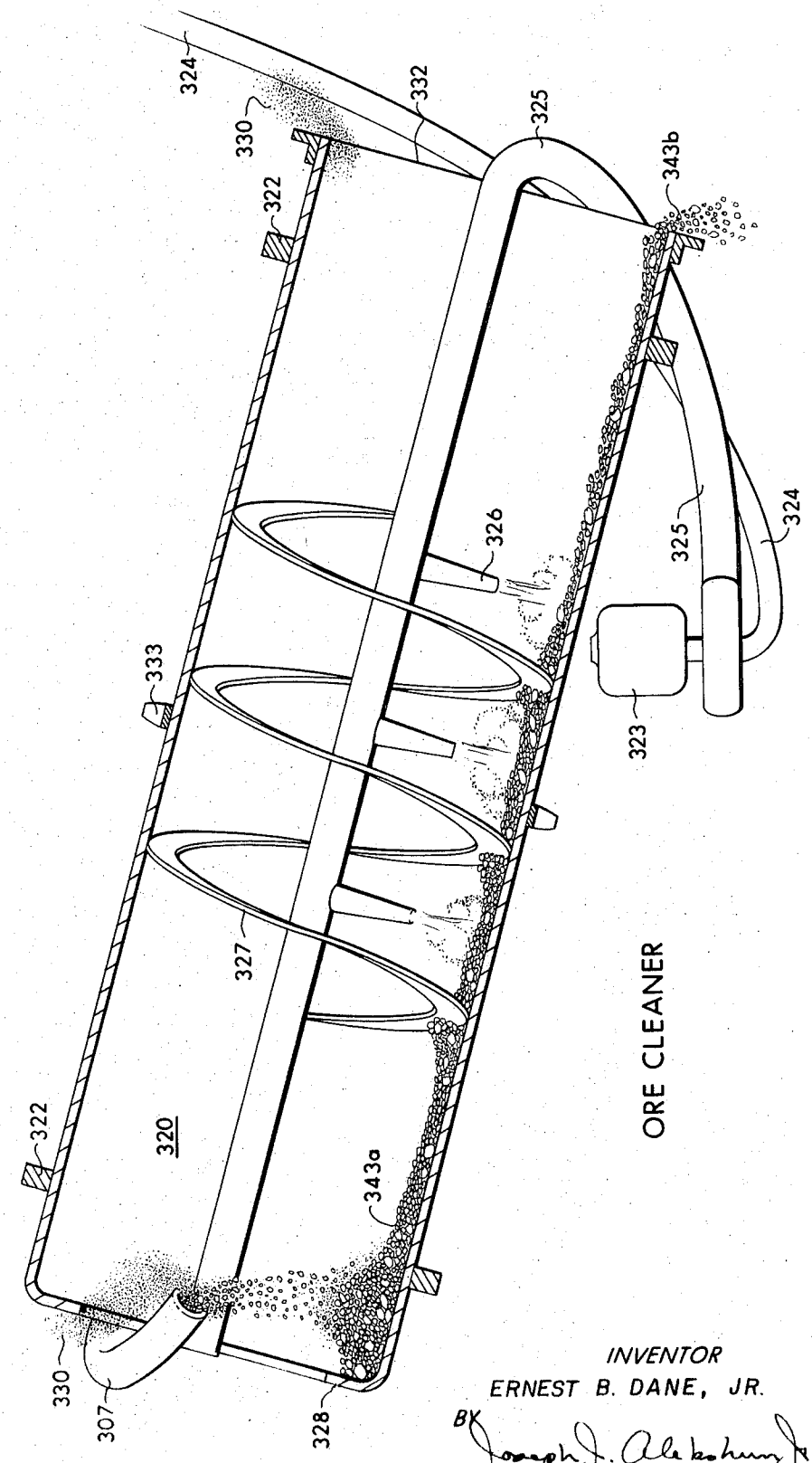


FIG. 15

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FIG. 16



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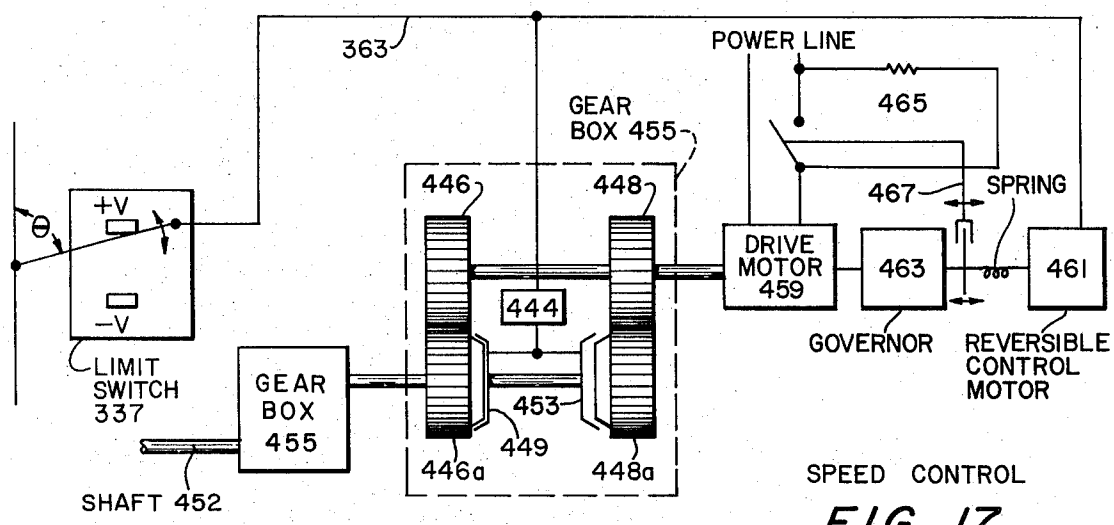


FIG. 17

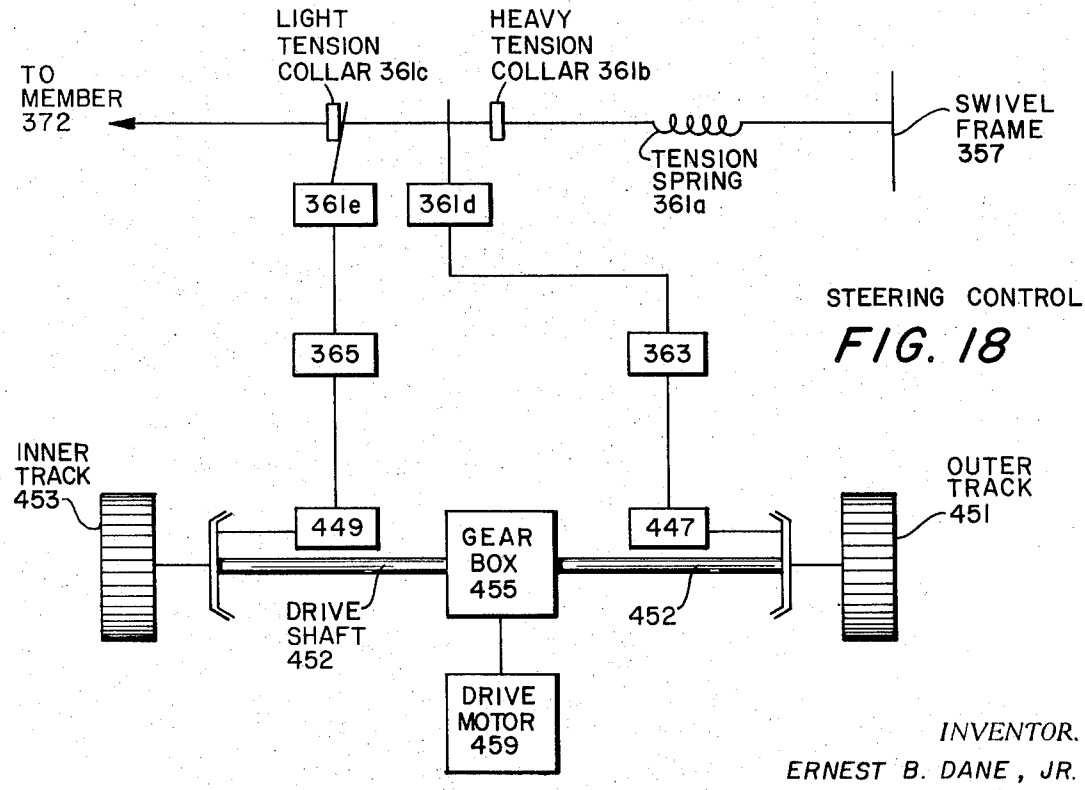
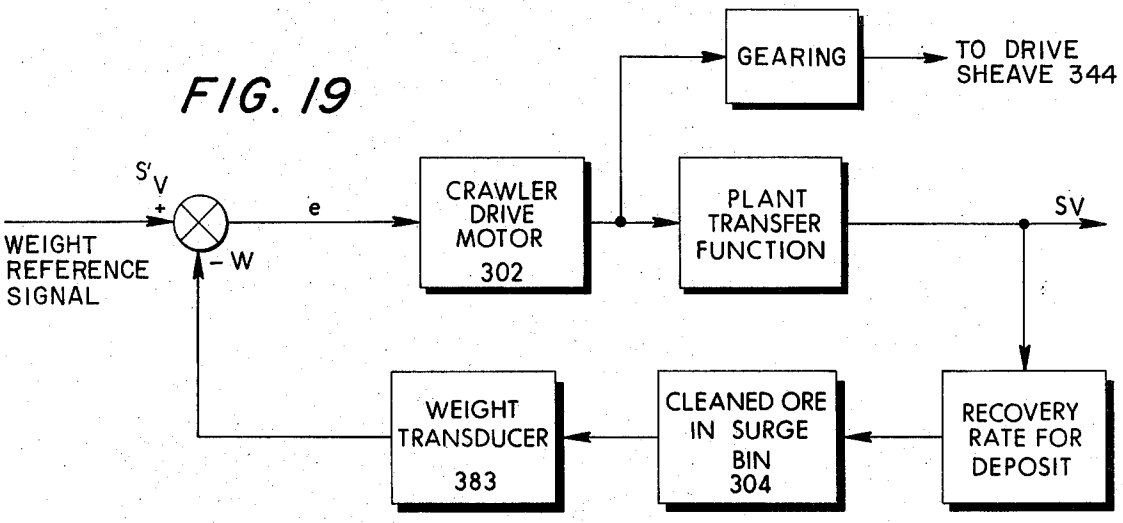


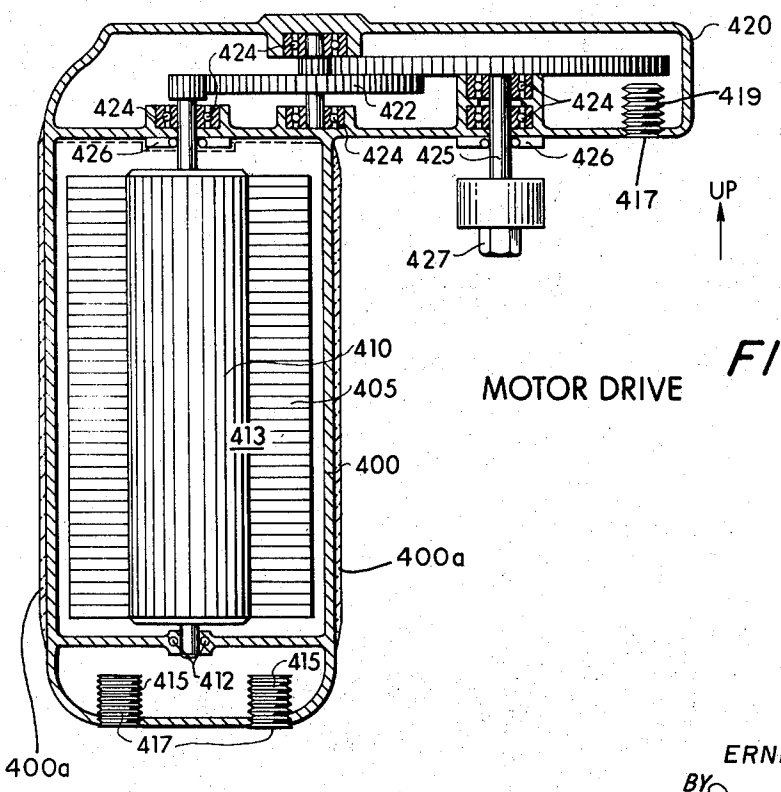
FIG. 18

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FIG. 19



FUNCTIONAL BLOCK DIAGRAM



MOTOR DRIVE

FIG. 20

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DEEP SEA MINING SYSTEM

This application is a continuation-in-part of my copending U.S. Pat. application Serial No. 148,853 which is now abandoned and is a continuation-in-part of U.S. Pat. application Ser. No. 754,191 filed Aug. 21, 1958 and subject to a requirement for restriction.

This invention relates generally to ocean mining systems and particularly to systems for retrieving loose ore sediment from deep sea floors.

INTRODUCTION

The mineral resources of deep ocean beds though long recognized have yet to be fully exploited. Sufficient quantities of minerals lie loosely in the sediment of deep sea oozes to make their recovery in scale attractive. Of particular interest are manganese nodules that are found in ocean sediments formed under oxidizing conditions, and are especially widespread in the southeast Pacific Ocean. They are shaped like potatoes, mammilated cannon balls, marbles and also assume less identifiable forms. They range in size with diameters of between 0.5 to 25 cm, however, the majority of nodules recovered from deep sea dredging probes have not exceeded 10 cm in diameter. Numerous photographs taken of the ocean floor indicate that they average about 3 cm in diameter (See The Mineral Resources of the Sea, by John L. Mero, Elsevier Publishing Company (1964)).

In addition to manganese, the nodules contain a number of other minerals in adequate quantities, for example, iron, silicon, aluminum, copper and nickel, to make them an attractive source of these as well. Mineral content is regional with comparatively high concentrations of iron in nodules near the western coasts of North and South America and the eastern coast of Asia, while nodules distant from Pacific islands and continental bodies possess relatively high nickel and copper content.

Most deposits are covered by between 2,000 and 6,000 meters of ocean. They are within the range of some deep submersible vehicles and sampling probes but the feasibility of mining them depends on the capability of recovery in scale, at the rate of many tons per day.

PRIOR ART

Most ocean-mining systems of the prior art are directed toward recovery at comparatively shallow depths and at small scale. Drag dredges, for instance, are of limited capacity and involve considerable turnaround times when used at great depths. Lengthly ladder dredges tend to become massive. When extended from the side of conventional ships wave-induced oscillations of the ship may rupture the interface with the ladder or embed it in the ocean floor. Suction dredges have also been employed. Often in these, however, much power is expended in raising valueless mud. Moreover, systems such as these and others that are stationary may recover insufficient quantities of ore to make them economically unfeasible. In particular U.S. Pat. No. 3,522,670 granted Aug. 4, 1970 to J. E. Flipse et al. discloses apparatus for harvesting nodules with a gathering means which is arranged to crawl around the bottom under control of T.V. cameras and the like, but the gathering of nodules at any instant must be from the immediate locality of the expensive and complex gathering means. U.S. Pat. No. 3,433,531 to Koot recognizes the need to harvest from a substantial area around the lifting apparatus, and the desirability of crushing and treating the gathered material befor lifting it, but does not provide these features with the means hereindisclosed to move the plant rapidly, systematically, and in operating condition from place to place over the ocean floor, so that economic tonnages can be handled in regions where the nodules are of only moderate concentration.

SUMMARY OF INVENTION

In view of the cited limitations in the art of ocean mining, applicant has as the primary object of his invention to provide a system for gathering loosely embedded minerals form deep ocean beds in quantity.

It is another object of his invention to provide an efficient system for mining minerals from deep ocean floors.

It is a further object of his invention to provide a system for mining at ocean depths of 100 fathoms or more.

These and other objects are met by a system comprising a tractored central mining plant and a "Sessile" ship interconnected by a string of buoyant hoist-pipe sections. Except for the pipe sections which are carried in tow, the system is transported to the mining site in the Sessile ship. To reduce drag and provide structural strengthening, the ship is equipped with streamlining, strengthening and propulsion sections that are detatchable at sea and may be reassembled into an auxiliary vessel. Upon reaching the mining site, the sections are separated and the Sessile ship is erected. The mining plant is lowered by linking it up with the first and succeeding pipe sections one at a time. The hoist pipe circuit so formed is completed when the miner reaches the bottom and rests on the ocean floor.

The miner incorporates a tractored vehicle with a pair of arms projecting from its sides. Each arm carries a series of scraper buckets that ride on an endless chain that circulates along the length of the arm. As the vehicle travels the bottom linked with the hovering Sessile ship by the hoist pipe circuit, the circulating buckets scrape nodules on either side of the vehicle cutting a wide swath in the deposit. Gathered nodules are cleaned of valueless mud and crushed into particle size by apparatus on the vehicle. They enter the hoist pipe circuit as slurry and are pumped to temporary storage bins in the ship to await subsequent transfer to an ore freighter.

Because the system is capable of sweeping large areas, it recovers ore at a high rate. The system is efficient as the ore is cleaned of mud prior to transport thereby reducing power consumption. Operation is continuous and involves no turn-around time except for initial deployment and final recovery of the miner which may be some weeks apart. The system is self-contained, all necessary power, equipment, and facilities being supplied by the Sessile ship. These and other features of the system will become apparent from the following detailed description; but this description should not be taken as a representation that the whole system or any parts of it have been actually constructed or actually observed and tested by me to operate in the manner described. This specification is to be read in conjunction with the drawings of the above-mentioned application Serial 148,853 about to be abandoned

which are to be transferred and made a part of this application to the extent that they may be of which:

DRAWINGS

FIG. 1 is a sistant bird's eye view of the system in transport to the mining site.

FIG. 2 is a side cut-away view of the freed Sessile ship of FIG. 1 in a vertical orientation.

FIG. 2A illustrates the bottom dump hatches of the ore bins in the ship.

FIG. 3 is a partial cross-sectional side view of two joined pipe sections of FIG. 1 illustrating the principal features of a typical pipe.

FIGS. 3A, 3B, and 3C are top cross-sectional views of the pipe of FIG. 3 along cutting planes A—A, B—B, and C—C, respectively, while FIG. 3D is a cross-sectional view of the spherical tanks used in the lower pipe sections.

FIGS. 4 and 4A are side and vertical views, respectively, of the dump valve in the pipe section of FIG. 3.

FIG. 5 is a detailed side view of the secured junction of FIG. 3.

FIG. 6 is a side view of the Manbot used to construct the hoist pipe circuit and its operation in securing the pipe junction of FIGS. 3 and 5.

FIG. 7 illustrates the haul-down of pipe sections of FIG. 1 in the construction of the hoist pipe circuit.

FIG. 8 illustrates the terminal junction between the hoist pipe circuit and the Sessile ship of FIG. 3.

FIG. 9 is a front view of the folded arms of the miner of FIG. 8.

FIG. 10 is a side view of the double-joint fold of the arms of FIG. 9.

FIG. 11 is a distant vertical view of the miner of FIG. 2 with arms extended.

FIGS. 12 and 12A are side and front views, respectively, of the ore-gathering buckets mounted on the miner's arms.

FIGS. 13 and 14 are side views of the near and far ends, respectively, of the miner's arms.

FIG. 15 is a side view of the tractored vehicle of the miner.

FIG. 16 is a cut-away view of the ore cleaner in the vehicle of FIG. 15.

FIG. 17 is a diagram of a speed-control system for the tail-sheave tractor of FIG. 14.

FIG. 18 illustrates a steering control system for the tail sheave tractor of FIG. 14.

FIG. 19 is a functional block diagram of a system for controlling the advance rate of the tractored vehicle of FIG. 15.

FIG. 20 illustrates a geared-motor drive for use in deep sea apparatus.

PREFERRED EMBODIMENT

The surface components of the mining system are provided by a tender that performs a mumber of functions to sustain the venture, including the following;

a. transports the miner to a distant mining site,

b. supplies power to the miner and hoist pipe circuit,

c. provides a control facility for all apparatus in the system,

d. stores ore mined from the ocean bed temporarily pending transfer to another ship,

e. provides living accommodations for the crew and holds enough commissaries and fuel for at least a month's work,

f. provides a sufficiently stable and suitable base for lowering the miner and construction of the lengthly hoist pipe circuit therewith, for retrieving them upon conclusion of operations, and for receiving ore as it hovers over the miner working the ocean floor.

While conventional ships are adequate in some of the above respects, they may be troublesome with regard to the provision of a stable base in rough seas. During construction, the miner is lowered from the ship attached to the hoist pipe circuit as the latter is assembled from the floating pipe sections. The accumulating load may develop a mass of over 1,000 tons before the miner reaches the bottom. A large component of the static load is compensated by buoyancy tanks built into the respective pipe sections. However, the dynamic load produced by the massive ship as it rolls, pitches and heaves in the waves, some of which are in the order of 20 feet or more in height, is imposed fully on the construction hoists and the uppermost sections of the pipe circuit. Such dynamic loads could damage the pipe circuit or cause it to break away from the ship altogether.

The sensitivity of the hoist circuit to unwanted motion characteristic of conventional ships may be reduced by using complex compensating equipment in the pipe circuit. Alternatively, the surface terminal may be supplied by a semi-submerged catamaran, like those used on oil-drilling sea rigs. However, the preferred embodiment of the present system features a simpler and less expensive approach by incorporating a surface ship whose ratio of displacement change to total displacement as a function of depth from an assigned water-line is small compared to that of a conventional ship. Such features are realized in a "Sessile" or "Flip" type ship illustrated in later FIG. 2 which has a relatively thin stem section and an assigned water-line midway up the stem. The section comprises a relatively narrow cylindrical steel shell bounded by two widening conical shells, with a slope of about 45°. The upper conical shell merges into a cylindrically shaped double decked top while the lower conical shell is bounded by a long and wide cylindrical shell that is submerged when the ship is erected along the vertical. The cross-sectional area of the bottom cylinder is much greater than that of the stem section which is at the ocean surface. Consequently, changes in displacement due to wave action is significantly less than that of a conventional ship. Moreover, the massive ship's submerged bottom provides substantial damping to motion, particularly heave, caused by waves.

The Sessile ship has a draft of about 85 meters, which makes her too deep to float in many harbors. Therefore, she is conveyed from port to deeper water in a horizontal orientation. Because of the flatness of her top deck, she develops considerable drag or resistance to passage in the sea. Her velocity is accordingly limited to a few knots in this orientation. With the aid of special power drives adapted to propel the ship at inclined attitudes, say with her top deck a few feet or so above the surface, the ship with miner attached may be transported to a mining site at restricted speeds. As surface conditions change from calm to rough, the inclination of the ship may be varied by internal ballasting so

the top deck clears the waves. However, due to the slow speeds of such self-propelling modes, mining sites attempted are limited to short distances from port.

Since many of the productive mining areas may be some thousands of kilometers from port, it is desirable to provide for more expeditious transport to the distant sites. Accordingly, the Sessile ship is supplied with special sections that reduce her resistance to motion, provide propulsion, and add structural strengthening to her weak stem section. A Sessile ship so adapted is shown in the distant vertical view of FIG. **1**, and more fully described in applicant's copending application "Ship Sections Adapted for Disassembly and Reassembly at Sea," U.S. Pat. Ser. No. 97,484 also subject to the above requirement for restriction. As illustrated in FIG. **1**, Sessile ship **100**, with miner **300** clamped through an opening in ship bottom **180**, has her top deck covered by streamlining bow section **20**, her stem section strengthened by midships section **40**, and is propelled by powered stern section **60**. Upon reaching the mining site, the sections are detatched in the manner described in the above referenced copending application. The ship is then erected along the vertical by controlled flooding of its internal ballast tanks, eventually assuming the vertical orientation shown in FIG. **2**.

Referring now to FIG. **2**, the Sessile ship contains multiple levels of decks **125***a* through **125***g*, and bottom ore bins **175**. Decks **125***a* through **125***c* have single and double drum winches **127**; **129**; **131**; **133**; **137**; respectively. The winches hold cables **127**, **129**, **131**, **133**, and **137** extending down central well **121** or out hatchway **143** and through a series of snatch blocks **147**, some of the latter resting on flat landing **149**. Cable **127** is a sheet cable of light-weight electrical conductors for carrying power and control signals from a control room on deck **125***e* to miner **300** and pipes **200**. Appropriate lines of cable **127** are connected to the various terminals of miner **300** and pipes **200** during construction of the hoist circuit. Cable **131** has a pair of electrical wires that convey temporary power for initially operating the two top winches of the first pipe section. Cable **129** is an elevator cable for manipulating the position of a manned submersible as will be described. Cables **133** and **137** are hoist cables each having two lines with a load capacity greater than the weight of miner **300**, which may be in the order of 100 tons. Two lines of cable **133** are attached to eyelets at the top of outlet pipe **305** of miner **300**, and each pays-out from one of the interconnected drums of winch **133'**. A line of cable **137** from coupled drums **137'** is attached to each of folding joints **346** of the miners arms. Hoist cables **133** and **137** serve to lower the miner and forming hoist circuit.

Decks **125***d* contain personnel facilities and space for a number of functions in support of mining operations. Fuel cells **125***f'* on deck **125***f* supply electrical power to the system and to drive propellers **181** to station the ship. Ballast tanks **155***b* on deck **125***g* cooperate with blow tanks **155***a* to perform ballasting action. Circular pipe **165** is designed to receive mined ore from the mining plant **300** after it starts mining the ocean floor. Ore slurry from pipe **165** is released into funnel shaped bins **175**. As shown in FIG. **2A**, a typical bin is equipped with dump hatches **177** (shown open) and pumping apparatus **187** and **189** between feedline **183** and external discharge pipe **190**. Affixed to bottom **180** is powered stern section **60**. All equipment for the mining operation is stored on board except for buoyant hoist pipes **200** that are towed as a raft by sea-going tug **85**. As discussed in detail in the above referenced parent application, ship sections **20**, **40** and **60** are specially adapted to detach at sea and recombine into an auxiliary vessel for further utilization.

Once over the intended mining site, the special sections are detached and the Sessile ship is raised along the vertical by controlled flooding of its ballast tanks. The erected ship appears in the cut-away side view of FIG. **2** with pipe sections **200** stationed nearby tended by motored launch **10**. Details of the ship are next outlined.

SUGGESTED DIMENSIONS FOR THE SHIP

The following general dimensions are recommended for the ship.

Vertical Heights or Lengths
- Upper to lower decks of the Top: 2.5 meters
- Lower deck to cylindrical shell in stem section: 9 meters
- Cylindrical shell in stem section: 16 meters
- Vertical length of lower conic in stem section: 9 meters
- Bottom: 42 meters

Radii
- Top radius (r): 12.5 meters
- Radius (s') of top cylindrical shell in stem section: 10 meters
- Radius (s) of central cylindrical shell of stem section: 3.5 meters
- Radius of bottom: 12.5 meters

HOIST PIPE CIRCUIT

The hoist pipe circuit used to transfer ore from central miner **300** to Sessile ship **100** is constructed from the several hoist pipe sections **200** of FIGS. **1** and **2** towed to the mining site. The pipes are serially connected between the miner and pipe **165** of ore bins **175**. Each pipe section includes a pump for raising the slurry through its length and an emergency valve to permit rapid dumping of the slurry in the event that there is a serious failure in the system. The pipes are made of strong buoyant material and further equipped with buouancy tanks. They are designed so that the resulting buouancy is sufficient to support most of the total weight of the loaded pipe sections including that of its pump, pipe and about 8 tons of ore slurry. The pipes have sufficient radial strength to withstand the internal pressure of the slurry. They are also provided with enough longitudinal reinforcement to withstand both the stresses caused by subsurface sea forces and to support the weight of the mining plant. The pipes are used to transport the plant between the Sessile ship and sea bottom both during the initial deployment of the system and upon termination of the mining operation. The pipes are also equipped with water-tight electrical connectors that receive lines of cable system **127** supplying electrical power for the pumps and auxiliary equipment. One pair of power lines is assigned to each pipe and the performance of the corresponding pump is monitored by measuring the power it consumes.

PIPE SECTIONS

The principal features of each pipe section **200** are illustrated in FIGS. **3–6**. FIG. **3** shows two pipe sections

200′ and 200″ as they appear after being joined in the construction of the hoist pipe circuit. The top of pipe section 200′ is joined to a succeeding pipe 200″ by toggle ring binder 205 and other fastenings to be later described in conjunction with FIG. 5. Pipe section 200″ is representative of the lower portion of each pipe section. It comprises plastic pipe 201 having an internal diameter of about 40 cm. except near pump section 220 where it widens out to a diameter of 3 to 4 meters. Located above pump section 220 is about 100 meters in length of floatation gear in the form of hollow tanks 240. Above the tanks each pipe 200 assumes the form of a simple pipe 200′.

Since it is difficult to extrude pipes in 300 meter sections, each pipe section is fabricated on shore in parts that are joined lengthwise by molding or otherwise. Pipe 201 is made of strong, non-porous buoyant material having a compressibility approximating or preferably less than that of water. These properties are aimed at preventing the pipes from sinking gradually when exposed to the sea pressures along the length of the pipe circuit over considerable periods of time. Polypropylene and polyethylene plastics possess the sought characteristics. Pipe walls are about 2.5cm. thick and are internally lined with materials 202 that resists the abrasion of moving slurry, for example, are lined with about 0.5 cm. of rubber. Each pipe is equipped with four or more I-bars 203 that improve the natural tensile strength of the pipe. The I-bars are of plastic potted fiberglass and secured to the pipe with the aid of wrapping straps disposed around each pipe. The rubber lining and I-bars are shown in FIGS. 3A, 3B, and 3C which are cross-sectional views of the areas cut by planes A—A, B—B and C—C, respectively.

Pump section 220 houses a pump with motor 224 within casing 225 capable of pumping 500 metric tons of slurry per hour at a moderate head. Motor 224 is coupled downward to rotor 227 having many vanes located at the bottom of pump section 220. A modified version of the radial flow type used on hydraulic dredges is employed in the pump. The modification resides in building an upward curvature in the stator's guide vanes.

Specifically, in a conventional rotary pump, the rotor vanes impart tangential motion on the fluid. The fluid is collected by a stator surrounding the rotor and is redirected out the pump's discharge terminal. However, in the modified pump shown in FIGS. 3 and 3B, stator guide vanes 226 are mounted on the inside wall of pump section 220. The surfaces at the input side of guide vanes 226 are shaped to receive the tangential flow while the surfaces at the output side are co-directional with the axis of the rotor or that of the pipe. The intervening surfaces of the vanes have a gradual twist that provide a smooth directional transition. Stator vanes 226 thus transform ore slurry leaving rotor vanes 227 from a tangential flow into an axial flow upward through the spacing between casing 225 and the internal wall of pump section 220. To reduce wear in this area, the rotor and stator vanes and casing 225 are rubber lined.

To avoid brush wear, pump motors are three phase *a–c* motors. Cable system 127, shown in FIGS. 3A, 3B and 3C is a sheet cable which is added to the pipe section. The individual lines of cable 127 tap-off the sheet at points along its length and carry two phases of the three phase supply. Two such tap-off lines 229 are illustrated in the area of the dump valve of FIG. 4A to which reference is shortly made. Plate 231 mounted on the pump section provides the third terminal of the supply. It has enough area to provide a good electrical circuit through seawater between the pipe and the ship's structure that supplies the other ground terminal. For maximum efficiency, rotor vanes 227 are run at about 960 rpm. For operating minimum weight motors at maximum efficiency, high speeds of about 1,700 rpm are advisable. To gain this advantage, the coupling between rotor vanes 227 and the pump motor may have a single-step reduction gear (not shown) to reduce speed.

Still referring to FIG. 3, just above pump section 220 is about 100 meters of serially arranged tanks 240 affixed to the outside of pipe 201. These supply about three-fourths of the buoyancy for a section filled with ore slurry. Tanks used at greater depth, say below 3,000 meters, require greater strength than ones used at lesser depths. Upper seas tanks are cylindrical with hemispherical tops and bottoms as in FIGS. 3 and 3A, and are made of fiberglass, plastic or aluminum. Lower seas tanks 240′ of FIG. 3D, are preferably spherical and made of more expensive hollow glass. Tanks 240 and 240′ are filled with air or another gas. The tanks are covered by a thick plastic cover or tube 239 that makes them easier to tow on the surface and protects them from abrasion during construction of the pipe circuit to be described subsequently. The tank floatation gear is further secured to pipes 201 by bands that extend around both tanks and pipes.

The tanks are serially disposed along the length of a pipe with collar-like cushions 237 interposed between the opposing curved surfaces of adjacent tanks. Cushions 237 are of solid propylene reinforced with fiberglass and are designed to prevent high direct contact pressures from occuring between the curved surfaces of the tanks. As is seen in FIGS. 3 and 3D, a pair of cables is linked between each of padded collars 237 and the heavy pump section 220 to distribute the load between tanks, preferably so that they each support about the same weight.

Near the bottom of pump section 220 is emergency dump valve 250. Valve 250 provides an exit by-passing the pump's rotor and stator for releasing the column of ore slurry in the event of an emergency and also affords for repairing the pump in the event it is necessary. Valve 250 is positioned to allow the pipe to release most if not all of its slurry without backing-up in the pump. FIG. 4 offers a cut-away side view with details of valves 250 shown in a closed condition, while FIG. 4A is a top view of the valve when opened. Referring to FIG. 4, dump valve 250 comprises door 241 mounted on hinge 242. Door 241 is closed by the pull of chain 243 when winch 245 is energized. When door 241 is shut, solenoid catch 247 is activated causing it to force up against the door, locking it in place. Winch 245 is then reversed allowing slack in chain 243, this state being shown in FIG. 4. Commands for operating the mechanisms are provided by lines 229 of cable system 127 coupled into pump section 220 by connectors 229′. Lines 229 carry power to both the pump motor and solenoid catch 247. In the event the pump is shut down due to a power failure or intentionally because of a malfunction, catch 247 is automatically released. Door 241 swings open by the force of the slurry to the position of FIG. 4A and the ore is dumped. Lines 229

also include a line for controlling winch **245** so that it takes up or releases chain **243** when desired.

FIGS. **4** and **4A** also illustrate other features of the area near pump section **220.** Rubber lining **202** is shown covering the internal wall of pipe **201** and casing **225** of the pump motor. One of the series of straps **249** wraps around longitudinally extending strengthening I-bars **203** and pipe **201** holding the former in place. One of the series of binding cable **251** holds those lines of cable system **127** continuing down to a lower pipe section. Top view **4A** shows stator guide vanes **226** fixed to the inside wall of the pump section.

Connectors, such as connector **229'**, employed to connect cable system **127** to various points in the mining system are oil filled and of the kind typically used to couple power into submarines or other submersibles. They point downward and have an oil-filled chamber that protects the internal sockets from the sea water. A tape seal across the mouth of the chamber helps to retain oil and exclude the sea water. To resist corrosion, cable pins and connector sockets are made of solid copper or are copper plated. Once an electrical connection is made, it is sealed by rubber tape or other suitable material and secured by a strong spring fixture to prevent it from being shaken free by pump or other vibrations.

FIG. **5** is a detailed view of the junction of pipe section **200'** and **200''** of FIG. **3.** To stablize their registration the ends of each pipe section are flanged. Strengthening I-bars terminate into eye splices **204** at both ends of a pipe which have extra holes **204***a* for receiving hoisting or haul-down cables. The bottom of each pipe section is equipped with pelican hooks **207** having a safety ring **207***a*, ring binder **205** held by chain **205***a*, while the eye splice at the top of each pipe is provided with shackle **207***e*.

The pipes are joined by aligning their ends so that the flanges are in smooth registration and both sets of eye splices **204** are aligned, with mechanical operations worked by the "Manbot" of later FIG. **6.** Ringbinder **205** is fitted crosswise over the joint. Toggle levers **205***b* are used to clamp the ring in place and pelican hooks **207** are then secured. Hook **207** has ring **207***a* and member **207***b* joined at one to rotatable arm **207***d* by pin **207***c*. The opposite end of member **207***b* has jaws bolted to short turnbuckle **209.** Each arm **207***d* is arranged to fit through shackle **207***e* fixed to an eye splice at the top of a lower pipe **200'** and to fold back on member **207***b*. Turnbuckle **209** is is located below the end of I-bar **203.** Once a pelican hook is fitted through its shackle **207***e* and folded over member **207***b* and locked by ring **207***a*, the clamping action is firmed by adjustment of turnbuckle **209.**

Each of the pipe section is as just described except the first one that has one or a pair of winches near its top that help support folded joints **346** of the miner's arms. The winch is illustrated in FIG. **6** where the pipe sections are assumed to be the first and second. The winch has drum **339** holding cables **341** and **341'** linked with joints **346** and **346'** of the arms. The drum is operated by motor **335** initially energized by cable **131** and finally by sheet cable **127.**

THE MANBOT ASSEMBLER

Construction operations occur in quiet water with the aid of one or more manned submersible machines, here termed a "Manbot," which is a variant of the kind described in "*The Deep Submersible*," by Richard D. Terry, published by Weston Periodicals Co. (1966), at page 169. It consists of a water-tight chamber capable of providing a shirt-sleeve environment to an operator at depths of at least 400 meters. The Manbot is shown in FIG. **6** making a junction between the first and second pipe sections. It has chamber **250** linked by suspension member **251** to the ship's elevator cable **129.** It has a telephone to the ship's control room and is ventilated by hoses **252** and **254.** Power is furnished through cable **255.** Anchoring clasps **262** are provided to secure it along positions on the pipe. Saddles **261** on the inside of clasps **262** fit the sides of a pipe. Clasps **262** are opened and closed by cylinders **264.** A similar member, upper clasp **272,** extends upward through support **268** and is operated by cylinder **271.** Angular adjustment cylinder **267** connected to support **268** controls the angular position of clasp **272,** while support **268** manipulates its height. One or more cylinder-operated manipulator arms **275** are included to perform manual functions. In FIG. **6** one is shown closing a pelican hook at the bottom of pipe **200''.** Tool crib **273** installed in the clasp is within easy reach of arms **275.** At the bottom of chamber **250** is a pair of interconnected drums **280'** each containing over 400 meters of haul-down cable **280** with enough strength to haul 10 tons of load. These are used to haul-down pipe sections **200** during construction of the hoist pipe circuit.

LOWERING THE MINER AND PIPE SECTIONS, PROCEDURE

Referring now back to FIG. **2,** hoist cables **133** and **137** are connected to miner **300** when the system is prepared for deployment. Pipe sections **200** and motored launch **10** are brought in the proximity of the ship, and an endless wire **157** with an attached hook ring is run down central well **121,** to the launch and back to the ship through an opening made by the removal of plate **143.** Lowering of the miner **300** begins by releasing its clamps with ship **100** so that it is supported entirely by cables **133** and **137.** Winches **133'** and **137'** then pay-out cable at the same rate so miner **300** descends levelly until it reaches a depth of a little more than one pipe length, say about 400 meters. The Manbot, which is linked with cable **129,** may clamp itself to outlet pipe **305** or be lowered after the miner reaches its station. Before descending, haul-down cables **280** are hooked to the ring on endless wire **157** so that the Manbot may release cable upon its descent. When the Manbot is firmly clamped to outlet pipe **305,** it so informs the ship and the first pipe section is prepared for lowering. Personnel in launch **10** draw on endless wire **157** holdng the ends of cables **280** and connect them up with the bottom of the first pipe section.

With the assistance of personnel in the launch, the first pipe section is hauled-down until it is about 5 cm. above the top of the miner's outlet pipe **305.** Using upper clasp **272,** the Manbot draws the two pipes into alignment and firms the junction as was discussed earlier. Elevated by cable **129,** the Manbot again links cable **280** to the endless wire and then returns to the top of the first pipe section. Temporary electrical cable **131** is drawn down and connected to the winches of the first pipe section. Cables **341** and **341'** of the winches are connected to joints **346** and **346'.** They assume the load of lines **137** which are returned to the ship and led

down its side through snatch block **147** along the course of dashed line **137** of FIG. **2.** Cable **280** is then used to haul down cables **137** whereupon they are connected to the top of the first pipe section. With cables **137** assuming the load along the outboard side of ship **100,** cables **133** are released. Simultaneously, ballast tanks **155***b* on the opposite side of the ship take in enough water to counter the off-center load. Cables **133** are retrieved and led outboard of the ship along dashed line **133** of FIG. **2.** Next, elevator cable **129** and the Manbot are drawn up and led over the side of the ship along dashed line **129** of FIG. **2** as is electrical sheet cable **127.** The latter is linked to the endless wire whereupon it is received by the Manbot that connects it up with all electrical apparatus including the pump and winches of the first pipe section, and control and monitoring equipment in the tractored vehicle and the tail sheave tractors.

The Manbot ascends, connects its cables **280** to the endless wire and returns to the top of the first hoist pipe. Cables **280** are connected to the bottom of the second pipe section. Lines **137** are lowered one pipe length, the Manbot paying-out cable **280** as it rides down with the pipe. The second pipe section is subsequently hauled-down, which operation is illustrated in FIG. **7,** but not to scale, and where sheet cable **127** is omitted for clarity. The second pipe section is aligned and registered with the first. After making electrical connections between lines of cable **127** and electrical terminals in the second pipe, the Manbot is raised by elevator cable **129** toward the endless wire to which it attaches haul-down cable **280.** Previously freed hoist cable **133** is linked with cable **280** near the ocean surface. Releasing cable **280,** the Manbot then descends to the top of the second pipe where it anchors itself, and then draws cable **133** down with winch **280'** and connects it up with eye splices at the top of the pipe.

The Manbot is next lowered by elevator cable **129** to the top of the first pipe section. Upon instructions from the Manbot the load is gradually shifted from cable **137** to cable **133.** The Manbot frees cable **137** and returns toward the surface to connect haul-down cable **280** to the endless wire. After the Manbot returns to a station on the top of the second pipe section, winch **133'** lowers the miner to a third depth, the Manbot riding down to the construction depth. Cable **280** is then attached to the bottom of the third pipe section and it is prepared for transport to the forming pipe circuit.

The above sequence of operations performed by the Manbot is repeated until the miner reaches the bottom. Hoist cables **137** are used to secure the top of odd-numbered pipe sections and assume the suspended load when even-numbered sections are hauled-down by the Manbot with cable **280** and linked therewith. Similarly, hoist cables **133** are utilized to hold the load at the tops of even-numbered pipe sections when odd-numbered ones are hauled-down. More generally, miner **300** is lowered to the *k*th depth, where *k* is an integer ($k=1, 2, \ldots n$), and the *k*th pipe section is hauled-down by the Manbot clamped to the top of the $(k-1)$th pipe section. After the junction is secured, sheet cable **127** is connected to electrical apparatus in the pipe. The Manbot is then raised by cable **129** to attach its haul-down cable **280** to endless wire **157** for transfer to the free hoist cable of cables **133** and **137.** The free cable is then drawn down and linked with the kth pipe section and assumes the suspended load. The alternative hoist cable is freed and the Manbot elevated to attach cable **280** to the endless wire for transfer to the $(k+1)$th pipe. The Manbot then stations itself on the top of the *k*th pipe section whereupon the miner is lowered to the $(k+1)$th depth, the Manbot rinding down to the construction depth in preparation for the lowering of the $(k+1)$th pipe section.

During formation of the hoist pipe circuit, the remaining distance to bottom is estimated by comparing the known length of the circuit with the depth indicated on the ship's fathometer. Scanning sonars on tail sheave tractors **356** offer a more precise indication of the distance to bottom. When the miner reaches the ocean floor, the load on cables **133** or **137** holding the last pipe section lightens abruptly.

Once the miner is solidly on the bottom, the *n*th pipe section is hauled-down and joined the the $(n-1)$th section. The *n*th section may be shorter than the others in order to locate the upper end of the hoist circuit within a short distance of the surface, say 50 to 100 meters depth. Next, a large float containing a special power and control line with the ship, buoyancy tanks, two or three winched lines, one end of a flexible pipe and other equipment is guided to a point over the *n*th pipe. The lines are connected-up with the Manbot's haul-down cables. The Manbot is then stated on the top of the *n*th pipe section. It draws the lines down and links them up with auxiliary eye-splices at the top of the *n*th pipe section. The winches are next activated and reel-up the lines connected to the *n*th pipe as the float is drawn toward the top of the pipe. The Manbot guides the float into alignment so that the pipe threads a central aperture in the float and then secures it with pelican hooks and suitable fastenings.

Referring now to FIG. **8,** after float **290** is secured, one end of flexible pipe **295** temporarily fastened to the float is engaged with the top of the *n*th pipe. The other end of pipe **295** is already joined to distribution pipe **165** over the ore bins in the ship. Flexible pipe **295** is supported by a cable connected to the ship, and sheet cable **127** is fastened to pipe **295.**

Ballast tanks in the float are pumped out to offer a buoyancy slightly more than the uncompensated weight of the hoist circuit. It is recalled that buoyancy tanks in the pipes provide an upward force of about three-fourths the weight of each pipe loaded with ore. For example, assuming each pipe section has a capacity of 8 tons of ore, a section is 5 tons "light" when empty and 3 tons "heavy" when filled. For neutral buoyancy in a circuit of 17 sections, float **290** provides a vertical force of 51 tons.

Float **290** is linked with small surface buoy **294** containing radio tracking equipment and flashing lights. The buoy is small enough to offer little drag to the pipe circuit even in a typhoon. In the event of a serious storm, the ship is detached from the circuit and driven to a safe location. Buoy **294** provides a reference to the returning ship. Float **290** is located deep enough below the surface to be unaffected by storms.

EXTENDING THE ARMS

The arms are unfolded one at a time by the coordination of winches **339** of the first pipe section of FIG. **6** and maneuvers performed by each tail sheave tractor **356.** Tractors **356** are initially secured to vehicle **301** by electrically actuated davits **311** of latter FIG. **15** and

other remotely controlled catches transmitted from the ship through cable **127.** Tractors **356** are slightly elevated by a few centimeters, and are lowered to the floor prior to their release. Running gear within the tractors is tripped by relays to afford direct or manual control from the ship. Scanning sonars, lights and the closed circuit t.v. system are turned on. Upon receipt of a manual control command from the ship, tail sheave tractors **356** turn sharply outward and travel away from vehicle **301.** A t.v. camera is directed to scan astern of tractors **356** to assure that their course is approximately at right angles to the heading direction of vehicle **301.** As the tractors move outward, winches **339** of the first pipe are activated and pay-out cable. Angle transducers **349** at joints **346** indicate the angular disposition of the folds. The outputs of transducers are monitored shipboard and signify appropriate signals to be transmitted to speed control equipment in tractors **356.** When transducers **349** indicate the joints to be substantially opened, say at about 160°, the outbound tractors **356** are slowed-down progressively until they are just crawling, for instance at a speed of 10 cm/min., when the arms are completely outstretched.

CENTRAL ORE MINER

Ore is gathered from the bottom surface by central ore mining plant **300.** The plant incorporates a tractored vehicle with a pair of foldable arms at its port and starboard sides, each being coupled to the vehicle by a rotatable mast. The opposite end of each arm is supported by a tail sheave tractor that is driven parallel to the vehicle. The arms carry a circulating endless chain with attached buckets or hoes that scrape nodules along successive paths and deliver them to the vehicle as it proceeds along the bottom. The nodules are dumped into a trough mounted on the front of the vehicle. A pair of slanting plates shaped like a snow plow is mounted on the front of the vehicle. These force ore sediment to either side where it is gathered up by the incoming buckets. The The plant thus clears a strip which is spanned by the vehicle and its two extended arms.

The sediment delivered by the buckets is transferred from the trough to a washing cylinder where the mud is separated from the nodules. The process of removing valueless mud saves the large amount of valuable energy and plant capacity that would otherwise be required to lift it through the hoist pipe circuit. The cleaned nodules are then fed into a crusher where they are reduced to particles of about 1 cm maximum diameter. The particles are transferred to a surge bin coupled to the suction feed of the first hoist pipe where they enter as slurry. The slurry is pumped up through the hoist pipe circuit and to circular pipe **165** of hovering Sessile ship **100** into ore bins **175.** The gathering, processing and transfer of ore to the surface ship in this manner is continuous as the plant sweeps the bottom.

The operation of the ore cleaner and the scraper buckets in many situations stirs up the mud so that visual observations may be impossible, however, hulks of sunken ships are widespread, and there may be other hazards to avoid, accordingly television camera **359,** sonar systems **360** and high-intensity lights **358** are provided at the front of the sheave tractors **356,** where visibility may be best. Power for this electrical apparatus is supplied by lines of cable system **127** that runs down the pipe string and out along each of the arms. Information signals return to the control system in the control room **125***e* of the ship through the same cable system.

As the miner operates, the edge of the strip that has been mined will be distinctively marked by the tracks of the tail sheave tractor **356** and by the bites of the scraper buckets. Both of these marks are periodic in nature. This periodicity is unnatural and will distinguish sonar echoes from these periodic artifacts from echoes from naturally occurring features of the bottom. It follows, therefore that the sonar system **360** may be provided with a mode of operation wherein it may seek out and follow these distinctive markings even though individual bucket and track marks may be indistinct.

By causing one of the tail-sheave tractors to follow the edge of a previously mined strip, the means of efficient and accurate control of the collection is at hand. The miner may be lowered to the top of a hill, and follow a spiral path around it. After one turn under direct control, the uphill tractor's sonar acquires and follows the track made by the down-hill tractor on the previous circuit. Thereafter the equipment will systematically mine a circular area of steadily increasing diameter.

For flat areas, the tractor may follow a compass heading until the deposits become too lean, then double back along the track, until the whole area is mined in parallel strips, the tracking preventing the overlapping of the mining strips.

Since the ship is physically linked to the plant by a fixed length of hoist piping, there must be minimum lateral motion of the ship relative to the plant. Personnel in control room **125***e* maneuver the ship to hover continually over the plant. Motion is made very slow to avoid high drag forces on the extensive length of pipe. In addition to drag, other factors limit the advance rate. First is the amount of power required to drive a vehicle at such great depths. Secondly, an excessive speed tends to develop a catenary in the pipe and poses the need for additional piping. To maintain drive power within reasonable limits and to avoid unnecessary complications in the hoist circuit, the maximum advance rate of the plant is limited to 0.5 m/sec. Within this limit, the average speed of the vehicle is servo controlled to deliver a constant flow of about 500 tons of ore per hour.

The speed of the vehicle is modified by monitoring the weight of ore particles in the surge bin. The hoist pipe circuit is withdrawing slurry at its capacity of about 500 tons per hour. If the bin does not receive enough ore to support this rate, the total weight of the bin varies. A decrease in total weight indicates that the vehicle should be speeded-up, whereas an increase in weight indicates that it should be slowed-down. A weight transducer monitors the weight of the bin and generates an electrical signal the amplitude of which is modulated by the weight. This signal is used to control the advance rate of the vehicle.

These and other features of the plant are illustrated in FIGS. **9** and through **19** and related auxiliary views. FIG. **9** is a front view of the plant emphasizing port and starboard arms **340** and **340'** prior to their extension. The arms are maintained in this folded condition by tension in lines **341** and **341'** between joints **346** and **346'** and winches at the top of the first pipe section. Both arms are of the same construction. Consequently,

further reference is made to the port-side arm in unprimed notation.

Again referring to FIG. **9**, arm **340** comprises a double-tiered track **342** carrying sprocketed chain **350** that circulates between drive sprocket **344** and tail sheave **345**. Attached to chain **350** are a series of buckets **351** preferably skewed to reduce crabbing. Tail sheave **345** is connected to tail sheave tractor **356** by swiveling support frame **357**, while drive sprocket **344** is mounted on rotatable mast **313** above ore receiving trough **308**.

FIG. **10** shows details of the double-hinged joint **346** of the track. Hinges **347** are set inboard of the rails with their axes just below the head of the inverted rail. Hook **348** is remotely controlled to connect-up with the lower branch of chain **350** and release it when the chain becomes operative. Once the arms are unfolded, outbound buckets of upper track **342***b* are inverted while inbound buckets on lower track **342***a* are righted and contact the bed.

FIG. **11** shows vehicle **301** with extended arms scraping a strip bounding edge **380** of a previously cut strip. Arms **340** and **340'** are disposed from masts **313** and **313'**, respectively, at an angle θ relative to the negative of the vehicle's velocity vector $\overline{S_v}$. To reduce crabbing, axes "*b*" of inbound buckets are skewed in the direction of the vehicle's motion by angle ϕ relative to axis "*c*" of the track **342**. Generally, angle ϕ is in accordance with the relation

$$\phi = \theta - \tan^{-1}(S_c \sin \phi / S_v + S_c \cos \phi)$$

where S_c and S_v are the scalar speed of the buckets and of the vehicle, respectively. To maximize the width of the strip, angle θ is maintained at 90° so the angle $\phi = 90° - \tan^{-1}(S_c/S_v)$. By appropriate gearing between the crawler drive-motor of vehicle **301** and drive sheave **344**, speeds S_c and S_v are proportional so that the ratio (S_c/S_v) and the proposed skewness ϕ of bucket axes "*b*" are essentially constant.

Still referring to FIG. **11**, lights **358** and **358'** illuminate areas in front of sheave tractors **356** and television cameras **359** display the terrain on monitors in control room **125***e* of the ship. Camera **359** displays edge **380** of the preceeding strip so that an operator in the control room may steer behicle **301** to clear an abutting strip. Scanning sonars **360** mounted on tractors **356** scan the surface to warn of impending obstacles and hazardous terrain, penetrating cloudy water that may obscure television images.

THE BUCKETS

FIG. **12** is a close side view of two representative buckets, outbound inverted bucket **351***b* riding upper track **342***b* and inbound righted bucket **351***a* riding lower track **342***a*. FIG. **12A** is a front view of righted bucket **351***a* and shows the relation between bucket input axis "*b*" and track axis "*c*." Buckets **351** have an open front and bottom, a partially closed top, fully closed sides and back. Each bucket slides on a pair of broad ski-like runners **353** and **354** the height of each being adjusted by means of slotted fasteners attached to each side of a bucket. Downstream runner **354** is flush with the bottom of the back of the bucket while upstream runner **353** is adjusted to a height equal to the thickness of the layer **343** to be cut as judged by samples previously taken of the bed. The disparity in runner heights enables the bucket to ride level with runner **353** gliding along undisturbed ground while runner **354** rides on a previously scraped surface. Both bucket sides extend slightly below the runners. Fastened to the back of the bucket is a cutting block with a toothed edge **352**. The cutting edge of the block scrapes the surface causing nodules to accumulate in the bucket and the teeth permit some of the unwanted clay and mud to escape.

The buckets have a paritally closed top for the attachment of four flanged wheels **355** and fasteners that link the top with the chain. As is more clearly detailed in FIG. **12A**, upper track **342***b* and lower track **342***a* each comprise a pair of light railway rails. Flanged wheels **355** ride along the heads of a rail. The support of the inbound buckets help hold the track structure in the vertical plane.

THE TRACK

The track structure is thin to make it limber in the vertical plane so that the system of buckets can follow gentle irregularities in the bottom topography. Transverse stiffness to keep the buckets in line is supplied by a series of ties and cross bars **342***c* shown in FIGS. **12** and **12A** that extend orthogonally and diagonally between the rails of each track.

The two ends of the track are illustrated in FIGS. **13** and **14**. Track rails terminate in rigid supporting members at both ends. At the near end of FIG. **13**, lower track **342***b* bends upward so that incoming buckets may be elevated to deposit their loads in trough **308**. The upward bend starts over the point where inclined plate **308***a* of the vehicle of later FIG. **15** emerges from the ground. Lower and upper tracks **342***a* and **342***b* terminate in supporting member **370** which bends upward over the point where buckets **351***a* meet plate **308***a*.

The distant end of the track is shown in FIG. **14**. Upper track **342***b* bends upward while lower track **342***a* remains horizontal and in close proximity to the chain. Both tracks terminate into support member **372** rigidly connected by swivel frame structure **357** to tractor **356**. The terminal points of the tracks are close to tail sheave **345**. The terminal point for lower track **342***a* is as close as possible to where the rounding buckets assume a righted position. A hydraulic actuator **362** is provided in structure **357** to raise the outer end of the track when tractors **356** are maneuvering into position or the miner is moving to a new area.

For support additional to that provided by the buckets and to provide stability at its center, each arm is provided with a pair of wheels (not shown) that are wide enough to avoid sinking into the clay. These are mounted in the vicinity of the midpoint of the arm, one to the front of the track and the other to its rear. They are separated by about three or four meters and prevent the arms from tipping.

Endless chain **350** is composed of many long links that mate with the flats of drive sprocket **344** and tail sheave **345**. Drive sprocket **344** is coupled by gearing to the output of the crawler drive motor of vehicle **301**. Buckets **351** are mounted at points on the chain of each arm so that there is no interference between the two sets of buckets over trough **308**.

Servo units in the miner maintain angle θ at 90°. Limit switch **337** linked to each mast **313**, as shown in FIG. **15**, senses angle θ and issues appropriate speed adjustment command signals to sheave tractors **356** and **356'**. As is discussed again subsequently, a de-

creasing angle θ causes switch **337** to provide a signal for increasing the speed of tail sheave tractors **356** and **356'**, whereas an increasing θ causes switch **337** to slow down the tail sheave tractors. Tension transducer **361** of earlier FIG. **14** measures the tension of each track along its longitudinal axis. It generates steering signals for constraining the movement of tractor **356** along a path parallel to tractor **301.** If tail sheave tractor **356** deviates from a parallel course, corrective commands are sent to a steering mechanism in tractor **356.** Both control systems are described in conjunction with later FIGS. **17** and **18.**

PARAMETERS OF THE ARMS

To utilize the buckets efficiently, they should be spaced so that the swath of any bucket overlaps somewhat that made by the preceeding one. The following specifications for the arms suppose an average advance rate S_v of 0.2 m/sec. which should be reasonably sufficient to mine ore over a typical deposit at a rate of 500 tons/hr. Exemplary specifications are:

Extended length of each arm — 50 meters
Height of the arms including mounted buckets and two tiers of tracks — 1.05 meters.
Scraper chain speed, S_c, — 1 meter/sec.
Length of each chain link — 0.5 meters.
Bucket capacity — 0.5 meters^3.
Bucket width — 1 meter.
Width over outside of bucket runners — 1.7 meters.

Angle θ of 90° and angle ϕ of 11°.

The nodule-gathering apparatus as just described is a vital part of the system; and the success of the system requires that it operate reliably, and unattended, for long periods of time. It is, however, not necessary that details of this apparatus be as described and shown in the drawings to fall within the spirit of this invention.

There are other kinds of gathering apparatus which may effectively span a wide mining strip.

It is necessary that the gathering apparatus extend out a substantial distance, of the order of 100 meters, from the vehicle where the ore is collected in a trough or other receiving means. It is further a feature of my invention that the gathering be accomplished by a mechanical conveyor which scrapes the ocean floor along a path extending from its proximal end at the vehicle to its distal end at the edge of the strip. It may be that a screw conveyor or the like may be used; but one or another form of endless belt or chain of buckets is contemplated to be preferred depending on various design factors. In these the endless scraper scrapes along the distance from a tail sheave at the edge of the strip inward to the vehicle. The invention further requires that propulsion means be provided to move the collecting means with the vehicle while extended to span the strip. I prefer that this be provided by a tractor carrying the tail sheave; but clearly the tail sheave might be carried by a sled which would be towed by a tractor and kept at its distance by the angle of its runners.

I prefer that the position of the buckets be positively controlled by indexing their wheels to a track with vertical flexibility, and that they be propelled by a chain; but they might be drawn like so many skiers on a rope tow.

On their return to the tail sheave, I prefer that the buckets be carried on the track out of contact with the ocean floor, but the scraper means might well be supported on this return trip by passing over one or more sheaves held off the ground by floats; or might be pulled back over the ground in a reversed non-scraping orientation.

While I believe that a chain of buckets or scrapers is preferred, it is possible that the nodules may be scraped up and carried by an endless belt, weighted at its lower edge by a steel cable, and bouyant at its other edge. This may have angles cleats along the heavy edge to urge it against and into the material to be recovered.

Generally the collecting apparatus will extend laterally from the vehicle that is in a direction, preferably and generally normal to the velocity vector of the vehicle, and being flexible will not necessarily extend in a straight line, but rather adopt some optimum curve, and may angle considerably forward or backward while extending laterally.

THE TRACTORED VEHICLE

Referring again to FIG. **15,** tractored vehicle **301** comprises an ore-delivery component followed by cleaning and crushing apparatus mounted on a tractored chassis. With the aid of FIG. **11,** it is observed that plow blades **309** and **309'** are followed by inclined plates **308***a* and **308***a'*. The blades push ore directly in front of the vehicle to its sides where it is gathered up by the incoming buckets. The inclined plates terminate sharply into trough **308.** The plow and inclined plates ride on a pair of flat runners **310** and **310'** that, though only partly shown, extend back and end just short of the vehicle's tracks. The runners control the cutting depth of the plow blades. Mounted on each inclined plate is a telescoping rotary mast **313** or **313'** supporting driving sprocket **344** and the prozimal end of the corresponding arm. The masts are located at points on the inclined plates to permit them to swing about 180° without interference. As better shown in FIGS. **11** and **13,** the masts are connected to the drive sprockets through an inward pointing member **313***a* so as to reduce the slope at which the buckets must climb the plates before depositing their loads in trough **308.** Masts **313** and **313'** telescope and swivel by operation of motors mounted under plates **308***a* and **308***a'*.

Base **301***a* of the vehicle houses the mechanisms that drive the tractored wheels. The mechanisms are actuated by crawler drive motor **302.** Because of the softness of the bed, the tracks are sufficiently wide to support the vehicle. The necessary width for the tracks is determined from samplings taken of the bed prior to the lowering of the plant.

Mounted on base **301***a* is cylindrical nodule cleaner **320** and ore crusher **303.** Cleaner **320** is slightly inclined with its output end tipped toward the inlet of crusher **303.** Nestled in the base underneath ore crusher **303** is surge bin **304.** This bin is carried by a weighing transducer **389,** (not shown) illustrated in later FIG. **19,** that provides electrical feed back signals to the servo loop that controls crawler drive motor **302** and the advance rate of the vehicle. At its bottom, surge bin **304** is emptied by outlet pipe **305** which was rigidly coupled to the first hoist pipe at the beginning of the lowering sequence. Rods **338** support the outlying portions of the miner during the long trip to the bottom, when all its weight is supported by outlet pipe **305.**

Cylindrical cleaner **320** slowly rotates about its longitudinal axis. The rotary drive is provided by interaction of gear **333** installed on the outer rim of the cylinder and drive motor **321.** The cylinder is supported by a pair of trunion rings **322** which ride on rollers **322***a* fixed to the base.

Feedline **307** extends from the bottom of trough **308** through pump **306** and freely projects into cleaner **320** through a large aperture in its elevated input end **328.** Feedline **307** has a tap-off valve that couples into a large ballast bin with a capacity of at least 20 tons and a bottom dumping hatch (all of which are not shown). The initial load of sediment composed of mud and nodules deposited in trough **308** is fed into the ballast bin until it is filled whereupon the valve is shut and the rest of the sediment is fed into the cleaner. After the removal of clay and mud, cleaned ore **343***b* escapes from the cleaner at output end **322** and falls into crusher **303** where it is reduced to particles of 1 cm. or less in diameter. Ore processed by the crusher falls from its bottom into outlet pipe **305** where, by action of a pump in outlet pipe **305** or the pump of the first hoist pipe, it is transported into the hoist pipe circuit up to the hovering Sessile ship. Servo-controlled valve **314** admits sea water to mix with the rising slurry to keep the concentration constant. Manifold **312** mounted on the base distributes clean water to the many water-lubricated bearings used in vehicle **301.**

ORE CLEANER

Details of the ore cleaner **320** are illustrated in the cross-sectional side view of FIG. **16.** It comprises a cylindrical chamber about 2 meters in diameter and 6–9 meters in length. Elevated input end **328** has a large aperture whereas output end **332** is fully open. Midway through the chamber is a helical baffle **327** open at the center. The helix is fastened to the cylinder and revolving with it. The helix controls the stream of nodules and fine ore particles **343***a* sliding down the incline of the clinder and prevents their escape while being stirred and washed. A water pipe **325** passes through the open center and has several output nozzles **326** that discharge cleaning water on the ore. The output of these nozzles is sufficiently close to the stream of nodules to reduce frictional losses between the jets and the surrounding water. The pipe is made rigid enough to withstand the reaction of the downward pointing jets even though it is only supported at its ends.

Clean water for pipe **325** is derived from intake pipe **324** which extends to a clear zone a distance of between 200 and 300 meters vertically from the cleaner. The intake pipe passes through pump **323** and coupled into central pipe **325** at the output end of the cleaner.

A combination of the tumbling motion induced by the rotating helix and the agitation of the water jets separates the fine mud from the ore particles. The fine mud rises in cloud **330** and escapes out the openings in the two ends of the cylinder. The heavier ore particles and nodules **343***a* remain at the bottom of the cylinder while the finer particles are prevented from escaping by the helix. The ore finally moves down to output end **322** and falls into ore crusher **303.**

ORE CRUSHER

Ore crushers are common in mining. A number of commercial units may perform the function presently contemplated, so a description of the structural and operational details of crushers is though unnecessary. However, certain considerations enter into the design of a preferred embodiment for crusher **303.**

As is mentioned at the outset of the specification, the average diameter of nodules on the ocean floor is about 3 cm. So few may be expected to exceed a diameter of 10cm that the inlet of crusher **303** may be restricted to 10 cm without incurring a significant economic penalty. A "secondary" type crusher (one with intake limited to small sized solids) is preferred for this application. Although they have a restrictive inlet, they have a larger hourly capacity. The latter feature is more important and fortunately imposes little if any operational penalty.

To avoid the high drag that accompanies the high speed flywheels of the Blake type, the "secondary" crusher is of the gyrator type. The opposing ore crushing surfaces are lined with a "hard" substance that is corrosion and wear resistant, such as alumina blocks. The bearing of mechanically interacting members, such as that of the eccentric drive cones and surrounding pressure cones, are water lubricated. As water has a much lower viscosity than the oil used in gyratory rushers, the bearings are designed with a larger diameter than that adopted in conventional units. Bearing clearances are reduced to compensate for the lower viscosity of the water lubricant. High stiffness and minimum friction is sought for the bearings. They are made of very thin rubber, for example, in the order of 1 mm on a conical bearing of 60–80 cm. diameter.

SERVO CONTROLS

Illustrated in FIGS. **17** and **18** are two systems for controlling the direction and speed of tail sheave tractors **356.** FIG. **18** illustrates a steering control system functioning with the command signals of tension transducer **361** of FIG. **14,** and FIG. **17** shows a proposed speed control system utilizing the command signals of limit switch **337** of FIG. **15.** Referring first to the steering control system of FIG. **18,** tension transducer **61** comprising spring **361***a* in series with a pair of collars **361***b*–**361***c* is connected between the frame of mast **357** and structural member **372.** Collars **361***b* and **361***c* cooperate respectively with heavy and light tension switches **361***d* and **361***e.* When triggered by movement of the collars, switches **361***d* and **361***e* activate recycling timers **363** and **365,** respectively. The timers energize one of clutch solenoids **447** or **449** to disengage briefly one track from drive shaft **452** for purposes of turning the tail sheave tractor in the appropriate direction by a small angle, say 1°. If the turn is insufficient to release the switch, the timers re-cycle after a short period, for example 30 seconds, to cause successively small turns in the same direction. Thus, an inward deviation of tractor **356** compresses spring **361***a* and declutches the drive to outer track **451,** while elongation of the spring declutches track **453.** The corrective action of the steering control to unwanted deviations of tractors **356** and **356'** keeps them within maximum and minimum angular limits and on an average course essentially parallel to the travel of tractored vehicle **301.**

A speed control system for maintaining angle θ approximately constant on the average is illustrated in FIG. **17.** Limit switch **337** coupled to mast **313** is connected electrically by line **363** to gearbox **455.** The

gearbox has two sets of gears, one set of which is operative at any time to couple drive motor **459** of tail sheave tractor **356** to drive shaft **452**. The two gear sets provide an incremental step in the drive speed, say a 1 percent change, of shaft **452**. For example, gear set **446–446***a* may have a tooth ratio of 201/200, and gear set **448–448***a* the inverse. The gears are coupled to shaft **452** by action of bi-state solenoid **444** which operates clutches **449** and **453**. The state of solenoid **444** depends on which of the two limiting signals of switch **337** is carried by line **363**. When angle θ exceeds 90° by a specified angular limit, solenoid **444** is energized to engage step-up gear pair **446–446***a* to decrease the speed of the tractor by 1 percent. Similarly, when angle θ reaches a lower specified limit, step-down gear pair **448–448***a* is engaged with shaft **452** imposing a 1 percent increase in speed.

While gearbox **455** provides an immediate but small adjustment in speed, a requirement for gradual and greater variations is satisfied by adjusting a governor regulating the speed of drive motor **459**. Still referring to FIG. **17**, limit switch **337** is parallel connected to reversible control motor **461** which is coupled to governor **463** through a large step-down gearbox (not shown). The step-down gearing affords a slow adjustment in the governor's setting, say 1 percent per minute, in response to signals from switch **337**. Governor **463** regulates motor speed in the usual way with spring actuated switch **467** sorting series winding resistor **465** when motor speed is less than that ordered by the governor, and reinserting the resistor when the motor speed is excessive. Thus, when angle θ of the scraper bucket arm attains its maximum specified limit, reversible motor **461** gradually increases the governor setting, and conversely decreases the setting when angle θ reaches its minimum specified limit.

The effect of such variations in the operating speed of motor **459** complements step speed changes produced by gearbox **455**. If the speed required of the tail sheave tractor is not within the 1 percent adjustment capability of the gear change, one of the contacts of switch **337** will be operative for a longer period than the other and the net change in the governor's setting is in the direction required to achieve orthogonality in the scraper bucket arm. The speed adjustment will continue at a slow rate until the tractor is running at a speed very close to that desired. The intervals of high and low speed operation of the gearbox will become equal and no further net change in governor setting will occur.

The advance rate of the plant is regulated by the speed control for the crawler drive motor **302** of vehicle **301** appearing in the functional block diagram of FIG. **19**. Surge bin **304** of earlier FIG. **15** offers a measure of the difference of the flow rate of ore processed by the vehicle and the rate of ore hoisted by the pipe circuit. Controls, including servo control valve **314** maintain the desired flow rate and ore concentration in the pipe circuit, here about 500 tons/hr. The crawler speed control of FIG. **19** adjusts the advance rate S_v to keep the two rates equal. The initial rate of speed for the control is set according to the ore density of the field previously determined from a sampling tube. However, as the field is mined, weight transducer **383** for surge bin **304** provides a control signal W. Weight reference signal S'_v transmitted from the control room of the Sessile ship corresponds with a specfied quantity or weight of ore to be maintained in bin **304**, preferably the weight of the bin when half-filled with ore. Output W of transducer **383** is compared with weight reference signal S_v' and error signal "*e*" results to vary the speed of crawler drive motor **302** appropriately until the vehicle's speed S_v is such to hold the reservoir of ore in bin **304** as specified (half-filled). A scraper bucket chain drive proportional to speed S_v derived through gearing between the output of crawler drive motor **302** and drive sheave **344**. This coupling allows a chain speed S_c proportional to vehicular speed S_v and the ratio (S_c/S_v) to be maintained reasonably constant, as was discussed above.

MOTOR DRIVES

The several motor drives used throughout the lower portion of the system and miner **300** are specially designed to avoid the need for tightly sealed and expensive cashings ordinarily required in a high pressure environment. Referring now to FIG. **20**, a typical motor drive comprises a motor housed in casing **400** located below gear box **420**. The chamber of casing **400** is filled with distilled water **413** that is electrically insulating and immiscible with the oil in gear box **420** and has a specific gravity greater than that of the oil. Water **413** fills casing **400** from "O" ring seal **426** at the junction of the casing and gear box **420** to the bottom where it envelops the closed surfaces of expansion bellows **415**. As with a similar bellow **419** located in the shell of gear box **420**, bellows **415** have outward facing openings that receive sea water. Immersed in the distilled water is the stator **405** and a rotor **410** that is mounted on the shaft **409**. The bottom of shaft **409** rests on rubber-lined, fluid-lubricated bearing **412**, wiile the top of the shaft is mounted on ball bearings **424**. The drive of shaft **409** is coupled to the motor's output shaft **425** and its rubber-lined, water-lubricated bearing **427** through meshed gearing **422** in box **420**. Gear box **420** is filled with lubricating oil of light density and high viscosity, say with a specific gravity of 0.89 and a viscosity of about 90cs. The gearbox is sealed from the sea by "O" ring seal **426**. The outer surface of casing **400** has a thin layer of insulation **400***a* but with enough leakage to allow some of the heat generated inside the motor to dissipate. Solid material, such as alumina oxide, high melting point wax paints or plastics, are suitable insulators.

Functionally, the chilling temperature of the deep sea environment contracts the oil and water inside the motor causing bellows **415** and **419** to adjust in volume until the pressure differential across the motor's housing is substantially reduced. Through action of "O" seal **426**, the pressures of distilled water **413** and the lubricating oil tend to equalize. These adjustments in the pressure differentials both internal and external, and the natural segregation of the oil above the water in casing **400**, tend to simplify the sealing problem and allow the use of "O" seals **426** instead of more expensive tighter ones at mechanical junctions.

MINING PLAN AND SYSTEM RETRIEVAL

In mining an ocean bed, flat areas are covered in a straight strip while abyssmal hills are worked along a spiral path. When an area is sufficiently covered and the plant is to be transferred to a new site, arms **340** and **340'** are rotated forward of vehicle **301** ($\theta\Delta 180°$) and tail sheave tractors **356** and **356'** are aligned with

the vehicle. Alternatively, the arms may be folded again with the aid of winch **339** and the plant moved in the orientation of FIG. **9.**

The retrival procedure basically is the reverse of the assembly process. The miner and pipe sections dump their loads and the arms are folded into the arrangement of FIG. **9.** Upon being lowered from the ship, the Manbot connects one hoist cable, say cable **133,** to the $(n-1)$th pipe section. The cable gradually assumes the load of the system while flexible pipe **295** and float **290** are de-coupled from the nth pipe section by scuba divers. After electrical cable **127** is disconnected from terminals of the nth pipe, the junction between that and the $(n-1)$ th pipe section is disengaged by the Manbot. The nth pipe is guided to the surface with the aid of a line between it and motor launch **10.** The system is then elevated one pipe length by cable **133** and the Manbot next connects the second hoist cable **137** to the $(n-2)$th pipe. Cable **137** then assumes the load while the $(n-1)$th pipe is disconnected by the Manbot and guided to the surface. The remaining pipe sections are disengaged in the same manner, the system being raised one pipe length at a time with the top most pipe guided to the surface after being freed.

Finally, when only the first pipe section remains, one of the hoist cables is run down central well **121** and linked-up with outlet pipe **35.** The load is then transferred gradually to the axis of the ship. The free cable is likewise run down well **121** and the Manbot one of the lines with each of joints **346** of the arms. The top winches of the first pipe section are disconnected from joints **346** whereupon the pipe is freed of outlet pipe **305** and guided to the surface. The miner is centrally positioned along the axis of the ship for its final return and clamping to the ship's bottom as in FIG. **2.**

Having thus described a preferred embodiment of his mining system, applicant now defines his invention in the appended claims.

What is claimed is:

1. In a deep sea mining plant for collecting and processing ore nodules on the ocean floor for delivery to a pipe circuit for hoisting to the ocean surface, the combination of;

a vehicle adapted to travel said floor with a velocity S_v and including receiving means for receiving collected nodules, an ore cleaner for removing unwanted mud from said nodules, and means for transferring said cleaned nodules to said pipe,

ore gathering apparatus mounted on said vehicle and extending over a substantial distance laterally from said vehicle to span a strip and adapted to collect nodules from said ocean floor along said distance and deliver them to said receiving means of said vehicle, said ore gathering apparatus having propulsion means adapted to travel said floor laterally spaced apart from said vehicle to move said apparatus with said vehicle while so extended, thereby to clear said nodules from said strip.

2. The mining plant of claim **1** wherein said means for transporting said cleaned nodules to said pipe circuit includes a surge bin for accumulating said cleaned nodules from said cleaner, and said plant further includes first control means operatively associated with said bin adapted to vary the speed S_v of said vehicle so as to maintain the flow of said cleaned nodules into said bin essentially equal to the flow of said nodules to said pipe circuit.

3. The mining plant of claim **2** wherein said first control means comprises a crawler drive motor for driving said vehicle, a weight transducer for measuring the weight of nodules in said bin and generating signals according to said weight, means for producing a weight reference signal according to a specified weight of nodules to be accumulated in said bin, and means for comparing said signals of said weight transducer with said weight reference signal and causing said crawler drive motor to adjust said speed S_v to maintain said weight of said nodules in said bin essentially at a specified level.

4. A mining plant as set forth in claim **2** wherein said first control means is adapted to drive said vehicle at a speed S_V corresponding with maintaining a substantially constant quantity of nodules in said bin.

5. A mining plant ss set forth in claim **4** wherein said speed S_v corresponds with keeping said bin approximately half-filled with nodules.

6. The mining plant of claim **4** wherein said ore gathering apparatus includes a track with an axis "c," a series of scraper buckets circulating along the length of said track at a speed S_c with inbound buckets of said vehicle contributing to the support of said track and having open bottoms and an input axis "b" which is skewed forward of said axis "c" in the direction of said vehicle's motion by an angle ϕ, and wherein said plant further includes inclined plate means extending from said receiving means to said ocean floor for providing a riding surface for said inbound buckets from said floor to the top of said receiving means whereby said nodules collected by said inbound buckets are slideably supported by said plate means until dumped into said receiving means.

7. The mining plant of claim **6** wherein said track is extended at an angle θ relative to the negative of said velocity vector $\overline{S_v}$, and wherein ϕ is substantially according to the relation.

$$\phi = \theta - \tan^{-1} S_c \sin \theta / S_v + S_c \cos \theta.$$

8. The mining plant of claim **4** wherein said ore gathering apparatus comprises a long arm projecting from said vehicle along an axis "c" describing an angle θ of substantially 90° relative to the negative of said velocity vector, with the distal end of said arm carried by a tail-sheave tractor, and an endless scraper which scrapes nodules inwardly from said distal end to said vehicle along said arm.

9. A mining plant as set forth in claim **8** wherein said ore cleaner comprises a hollow inclined cylinder with an elevated end receiving said nodules from said receiving means, means for rotating said cylinder, a helical plate affixed to the internal surface of said cylinder along which said nodules may slide down said incline upon rotation of said cylinder, and means for directing jets of water on said sliding nodules to clean them.

10. The combination as defined by claim **2**

wherein said apparatus comprises a pair of long arms projecting from said vehicle at an angle θ of substantially 90° relative to the negative of said velocity vector $\overline{S_v}$ with the distal end of each arm carried by a tail-sheave tractor, and and endless scraper which scrapes nodules inwardly from said distal ends to said vehicle along said arms,

wherein said vehicle comprises an ore crusher for reducing said cleaned nodules to particle size, and means for mixing said particle-sized nodules with

fluid to produce ore slurry, in further combination with

a Sessile ship adapted to hover over said plant, and

a hoist pipe circuit adapted to pump ore slurry along its length, one end of said circuit connected to said ship and a second end connected to said plant and receiving said ore slurry porduced by said plant, said hoist pipe circuit comprising a series of hoist pipe sections each having a plurality of buoyancy tanks to provide a buoyant force amounting to at least half the weight of said pipe section loaded with ore, and a pump adapted to pump said ore slurry upward the length of said section.

11. The combination as set forth in claim **10** wherein said first control means comprises a crawler drive motor for driving said vehicle, a weight transducer for measuring the weight of said bin and generating signals according to said weight means for producing a speed setting signal S_v' according to a specified weight of said bin, and means for comparing said signals of said weight transducer with said speed setting signal and cooperating with said crawler drive motor to adjust said speed S_v to maintain the weight of said bin essentially as specified.

12. The combination of claim **2** wherein said vehicle comprises an ore crusher and means for mixing the resulting crushed ore with water to form an ore slurry, in combination with a hoist pipe circuit comprising a plurality of interconnected sections, each section comprising pumping means, electrical connections, and a dump valve to clear the section in case of pumping failure.

13. The combination of claim **12** having a hovering stable surface ship with ore bins for receiving said ore slurry and further including:

a submerged float joined to said hoist pipe circuit providing it with a subsurface floating support, and

a flexible, supported pipe connected between said ore bins of said ship and said hoist pipe circuit at said float for providing a flexible conduit for the flow of said slurry from said pipe circuit to said ore bins.

14. The combination of claim **13** wherein said ore bins are located at about the same depth as said submerged float so that said flexible pipe is disposed substantially horizontally.

15. The combination of claim **14** wherein said hoist pipe circuit is fabricated of buoyant material for reducing the load of said hoist circuit.

16. The combination of claim **15** wherein said stable ship is a Sessile ship in a vertical orientation incorporating a stem section with a narrow stem and an assigned water-line crossing said narrow stem, and said ore bins are located in the bottom of said Sessile ship.

17. A sea-going rig for harvesting manganese nodules and the like from the floor of the ocean, comprising,

a. a plurality of long, buoyant hoist pipe sections, each comprising, pumping means to raise an ore slurry at a designed efficient rate, electrical connections for carrying electrical power to and through said sections, interconnecting means to permit said sections to be vertically assembled into a long conduit, an emergency dump valve, and means for rafting said sections together for towing on the high seas,

b. a miner comprising (ii) a vehicle adapted to move across the floor of the ocean with a velocity $\overline{S_v}$ and including receiving means for receiving collected nodules, an ore cleaner for removing unwanted mud from said nodules, and means for mixing said cleaned nodules with sea water for introduction into said conduit as a slurry, and (ii) ore gathering apparatus mounted on said vehicle and extending over a substantial distance laterally from said vehicle to span a strip and adapted to collect nodules from said ocean floor along said distance and deliver them to said receiving means, comprising propulsion means adapted to move said apparatus with said vehicle while so extended thereby to clean said nodules from said strip,

c. a first control means for controlling the amount of water in said slurry responsive to the lowermost of said pumping means in operation,

d. second control means for operating said dump valves,

e. third control means for controlling said velocity to maintain a steady adequate supply of ore from said apparatus to said means for mixing, and

f. a tender adapted to transport said miner from port to its operations area, to carry the equipment required to assemble said miner to the lowermost of said sections while in said operating area, and to lower said miner so attached to the ocean floor, and adapted to hover over said miner as it is in operation gathering and conveying said ore and to provide the electrical power for it its operation.

18. The rig as defined by claim **17** wherein said tender is a flip ship adapted to navigate in a horizontal orientation, and to hover in a vertical orientation over said miner in operation.

19. In the art of recovering ores comprising manganese nodules and the like from the ocean floor wherein the ore is elevated from the bottom of the ocean in a slurry carried by pumps through a very long conduit, said pumps and conduit being designed to deliver ore to the surface at a sufficiently high rate to be commercially economical, the method of harvesting comprising the steps of:

a. carrying the lower end of said conduit along the floor of the ocean along a predetermined initial path at a controlled velocity, while gathering to said lower end nodules laterally across a wide strip bounded by a first edge and a second edge,

b. gathering ore deposits on the ocean's floor to said lower end from a substantial distance laterally and transverse to said path thereby clearing a strip having a first edge and a second edge, at least one of said edges being distinctively marked by said gathering step,

c. cleaning the gathered ore by water jets at said lower end,

d. mixing said ore with water in an amount controlled to achieve constant maximum efficiency of said conduit and pumps in raising said ore to the surface, and

e. controlling the magnitude of said velocity so that the amount of ore gathered at said lower end is sufficient to supply ore for mixing in the required quantity to achieve constant maximum efficiency of said conduit and pumps in raising said ore to the surface,

f. monitoring the ground at an edge of said strip at said distance to detect an edge previously distinctively marked, and

g. controlling the direction of said velocity responsive to the detection of a previously marked edge to prevent overlapping of said strip.

20. The method of claim **19** with the further step of crushing said ore prior to mixing.

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