METHOD AND APPARATUS FOR IMPACT DRILLING OF OVERBURDEN

Filed June 19, 1961

7 Sheets-Sheet 1

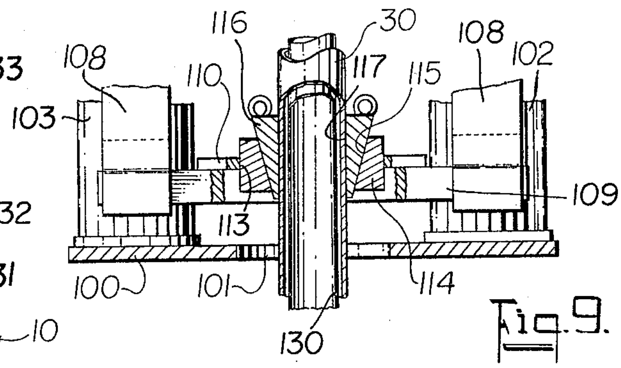

Fig. 9.

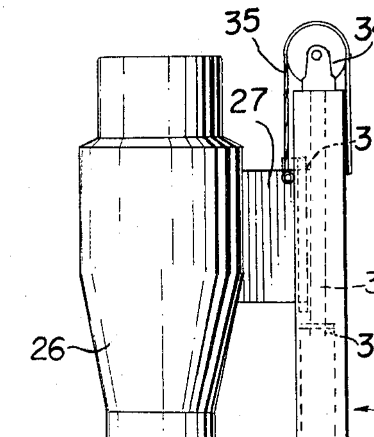
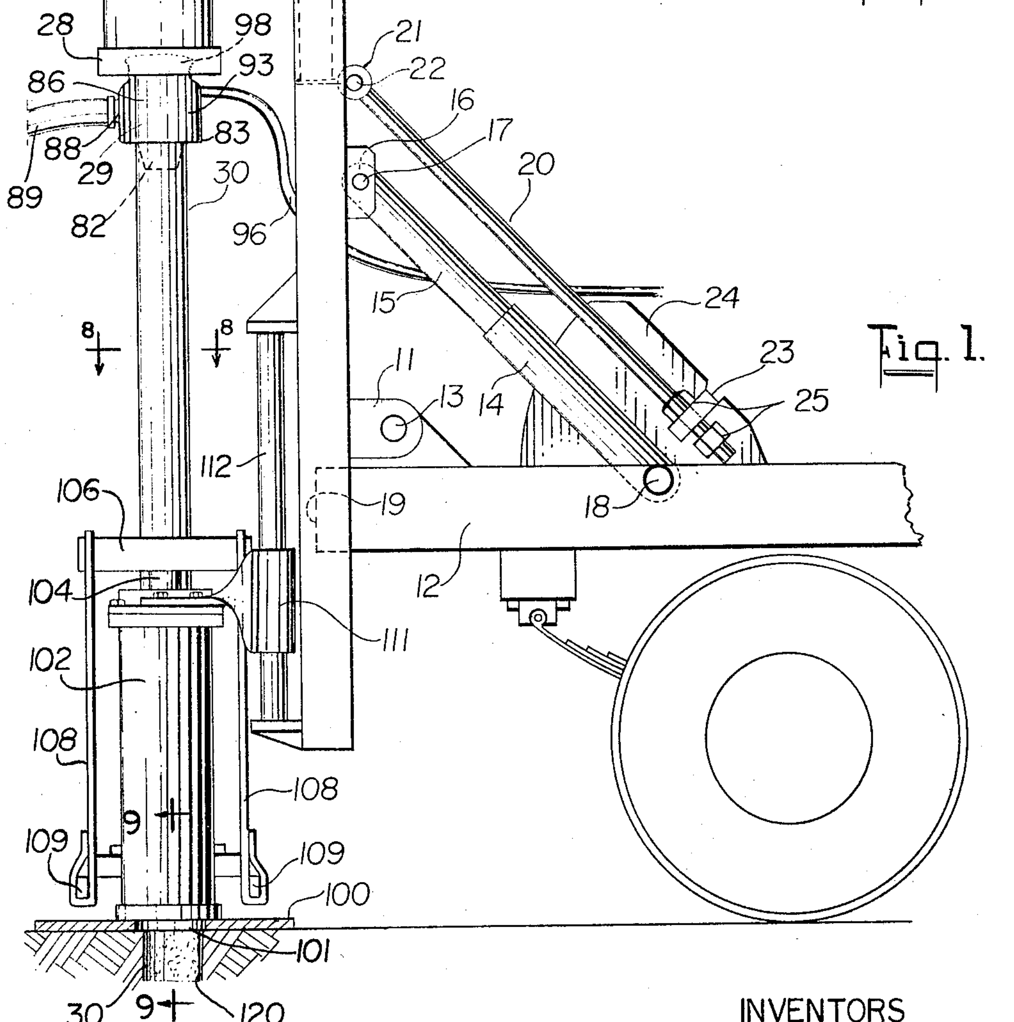

Fig. 1.

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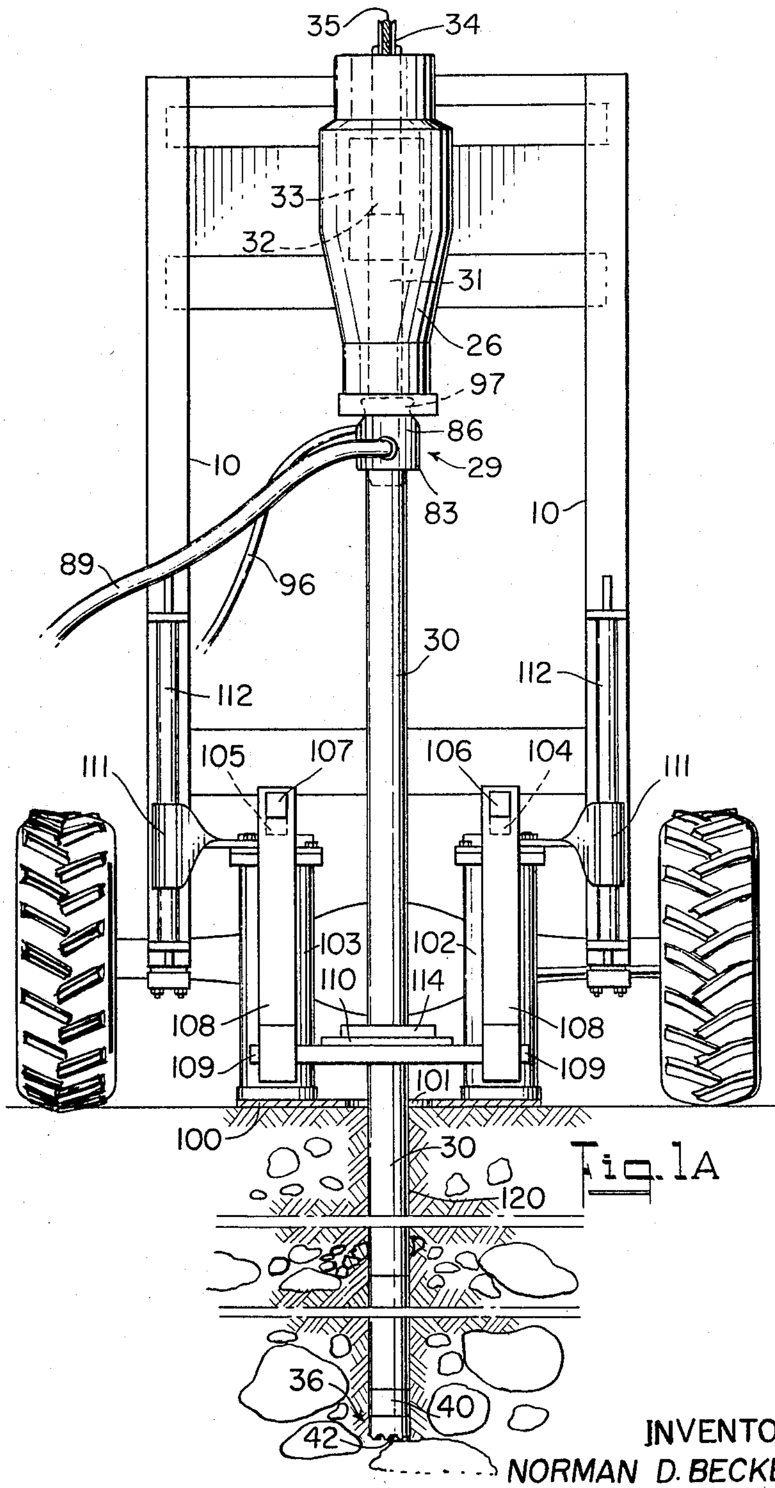

Fig. 1A

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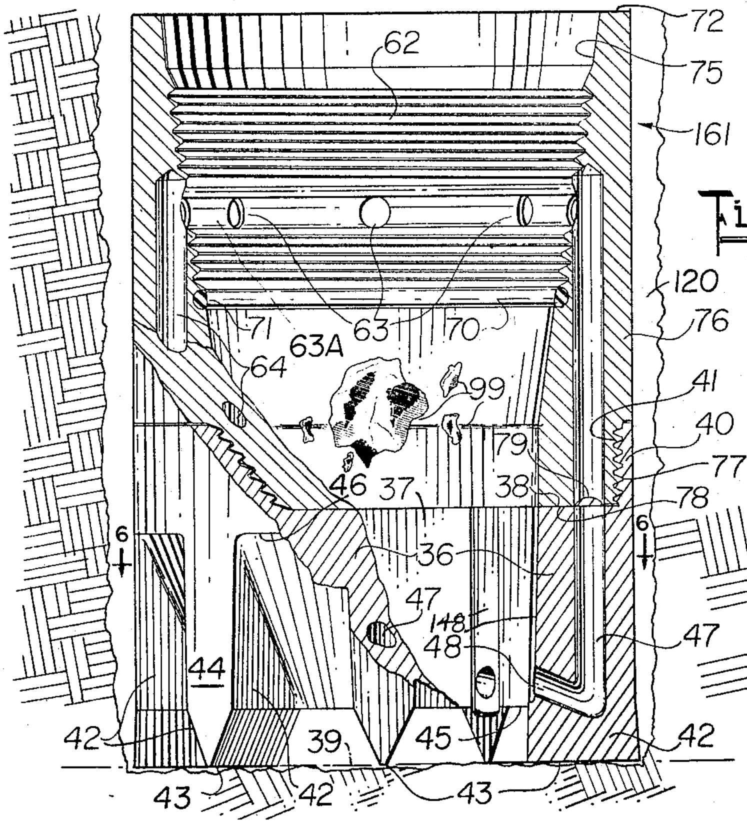

Fig. 2.

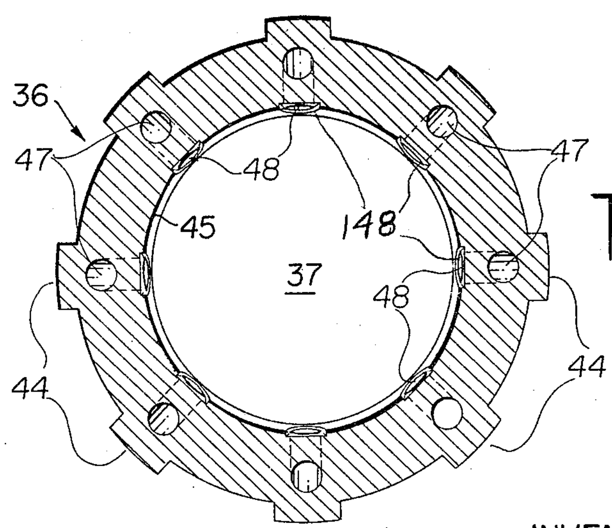

Fig. 6.

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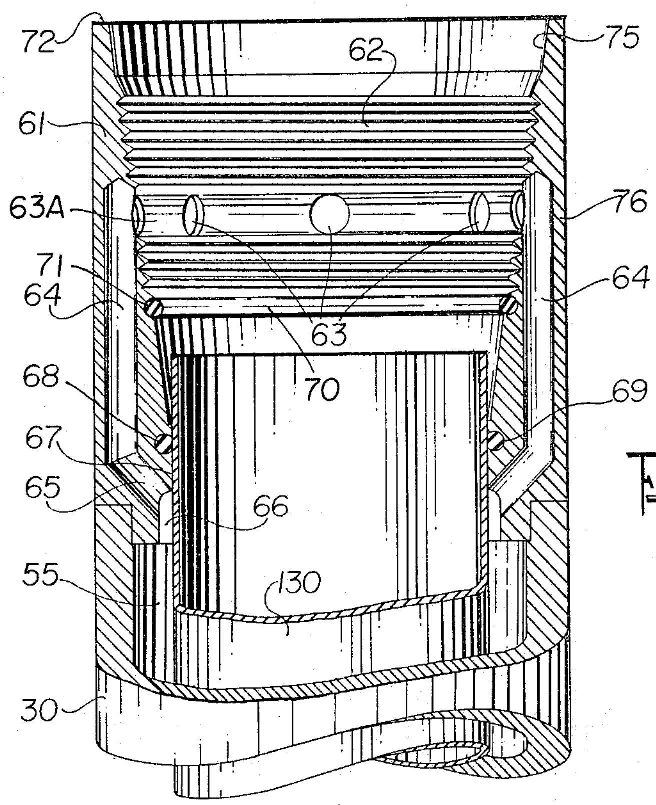

Fig. 4.

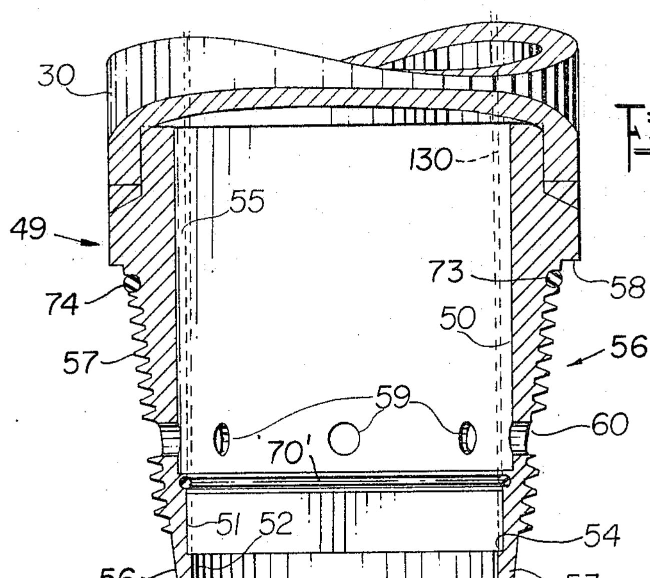

Fig. 3.

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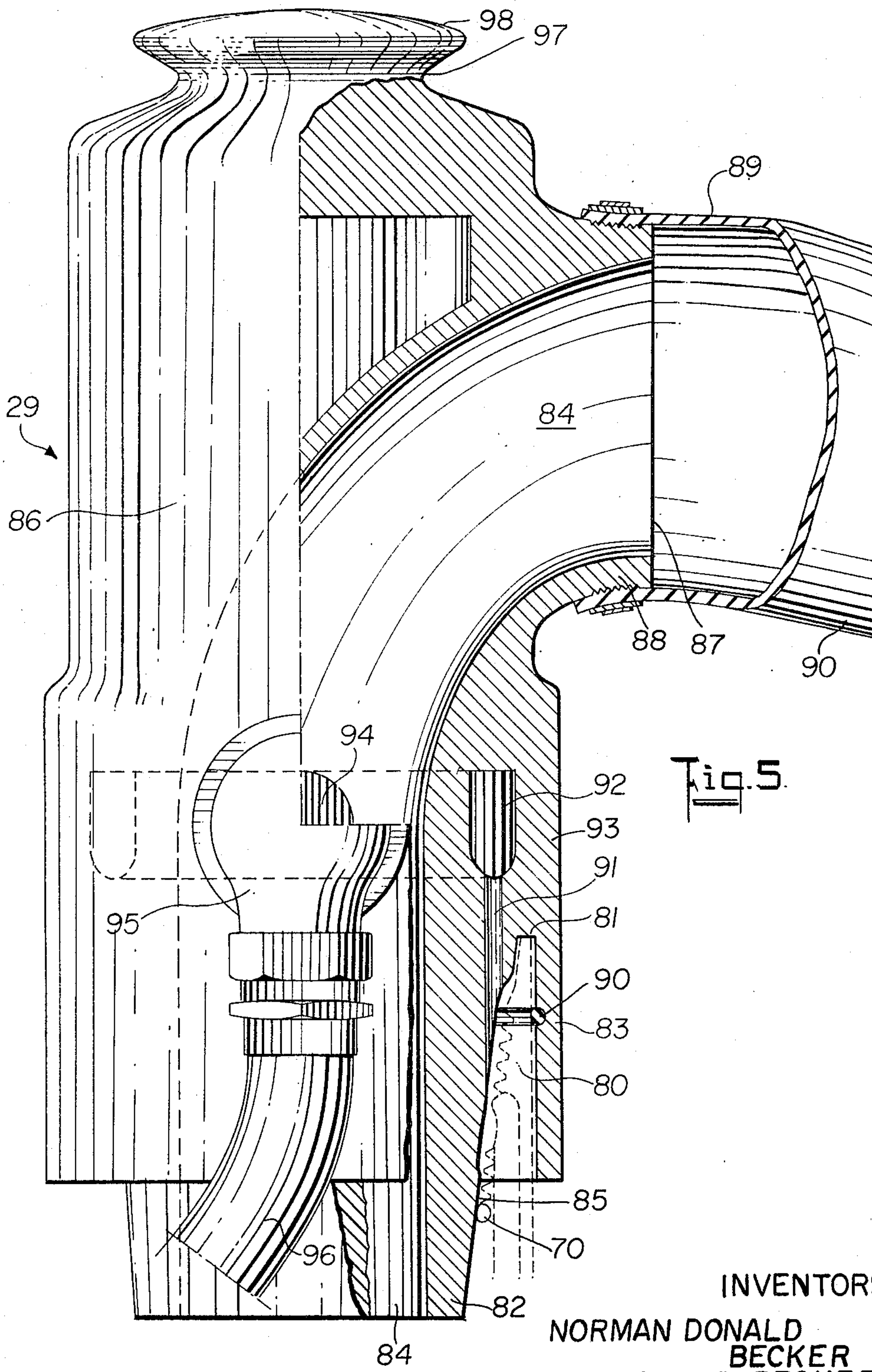

Fig.5

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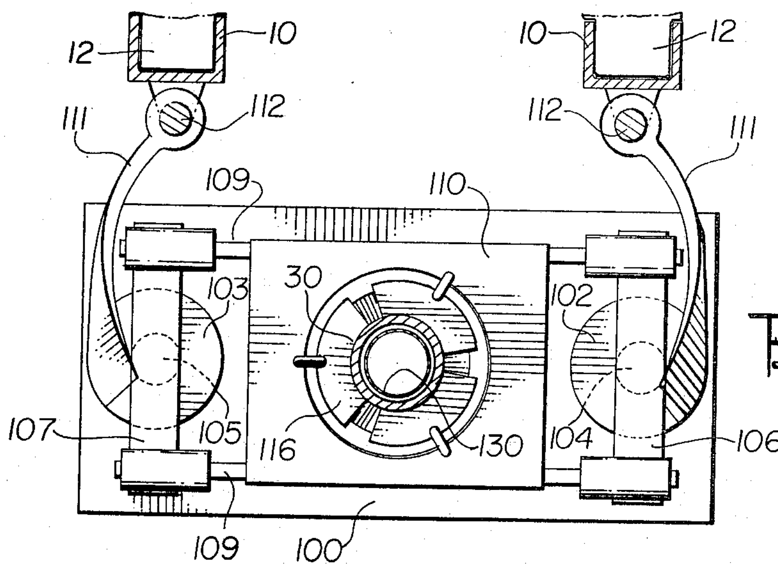


Fig. 8.

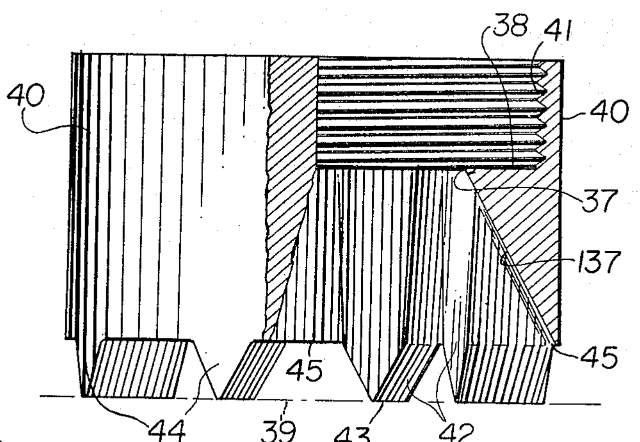
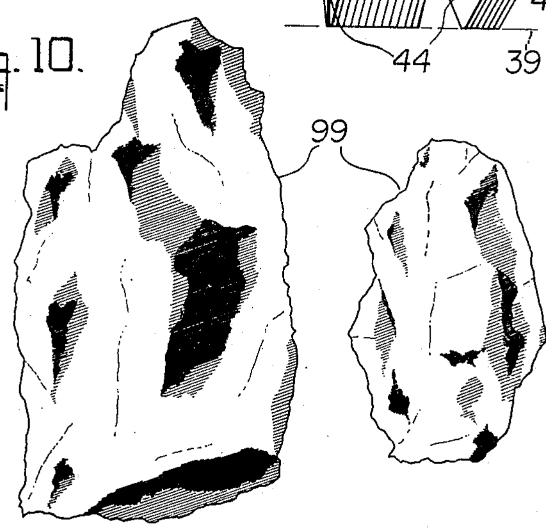


Fig. 7.

Fig. 10.



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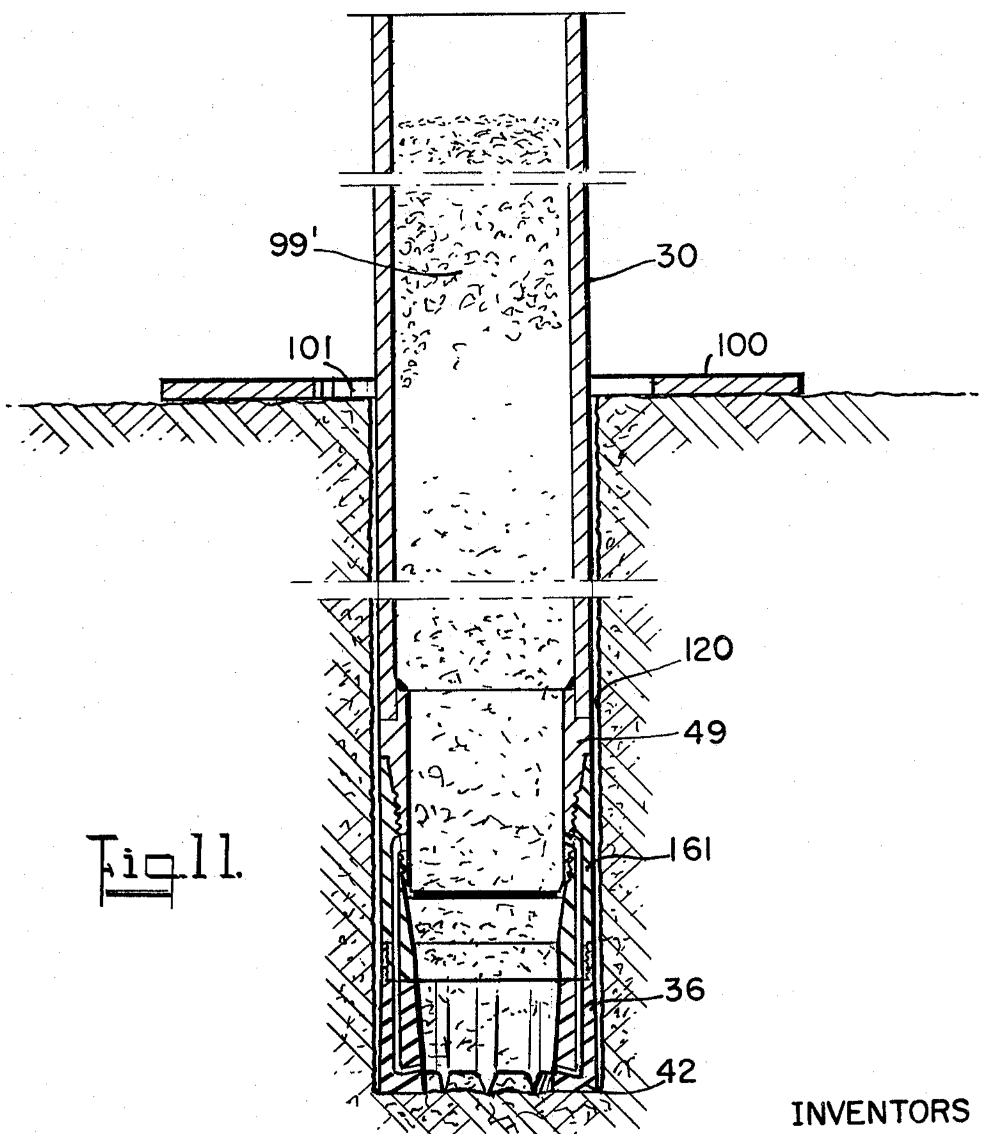

Fig. 11.

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United States Patent Office

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METHOD AND APPARATUS FOR IMPACT DRILLING OF OVERBURDEN

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32 Claims. (Cl. 175—58)

This invention is in the art of piercing earth formations, and more particularly is embodied in apparatus for sinking a borehole by percussive drilling and for immediate collection of fragments of earth formations penetrated as the fragments are loosened, to enable continuous monitoring and exact logging of the borehole.

Heretofore the recovery of formation samples in a borehole has required drilling by core bits to penetrate the formations and produce a concentric cylindrical core which is removed from the borehole at intervals to permit examination.

Such prior art methods are costly in that they require large amounts of power expenditure per unit volume of earth formation removed, and because of the limited wear life of rock cutting bits, which are costly. The rate of drilling is moreover relatively low and there is an inherent delay in the determination of what formations have been pierced until the core is brought to the surface. The operation is particularly troublesome in drilling coarse gravels, requiring costly rotary bits which produce no core. The investigation of earth structure by such methods has therefore proved economically unattractive, for such specific purposes as determining soil profiles, water tables and porosity, and assaying for mineral values.

The present invention is an arrangement of a novel earth boring and casing withdrawal apparatus for rapid penetration of earth formations and continuous immediate recovery of fragments as they are loosened, wherein an annular, axially apertured toothed bit is driven by high energy driving engine means down through the earth formations by means of a drill pipe structure comprising a rigid, elongate tubing which transmits the force of blows delivered by the driving engine; the tubing preferably has concentric double walls and the bit has passages for conveying a fluid such as air or water applied under pressure to the space between the double walls to bit apertures opening into a central duct of the drill pipe, for carrying fragments to the surface by energy of the fluid streams. The invention moreover includes clamp and hoist structure for holding and controllably raising the drill pipe, which is made separable in convenient lengths so that any desired depth of borehole may be drilled.

The invention also includes an arrangement which omits the use of a second wall for the drill pipe and a flushing fluid, whereby the central duct serves as a receptacle for fragments produced as the bit is forced downwards, the pipe being thereafter emptied or opened along a longitudinal axial plane to recover the fragments which lie in the same order as that in which they were encountered.

In the penetration of unconsolidated deposits such as river bed gravels or agglomerates including boulders such as glacial till, the resistance offered to different parts of the bit varies greatly depending on the degree of consolidation of fragments forming the structure traversed and on the size of larger masses. In order to maintain straightness of hole, which neither rotary bit devices or single point impact drills of known type can achieve in such deposits, a special form of annular, coaxially apertured bit has been found to be most effective. Such bit form is made with peripherally spaced teeth extending parallel with the longitudinal axis of the drill pipe and having a radial extent such that the side faces lie inside a circle just larger than the body of the bit and the drill

pipe. The central aperture receives earth formation fragments loosened or broken from larger rock masses lying in the path of the drill bit, and the fragments lying in the vertical cylindrical zone registered on the bit aperture are forced upward into the drill pipe. The cross-section being known, collected fragments either removed to the surface immediately by fluid jets, or accumulated loosely in the central duct of the drill pipe, provide a continuous sequential relation enabling reconstruction and identification of components of the formations.

When water bearing formations are encountered, the nature of the borehole produced and its relation to the drillpipe provides effective sealing of formations traversed so that recovery of water by use of a gaseous flushing fluid is an accurate index of the porosity and flow potential of strata in which the drill bit has entered.

The expenditure of work in piercing earth formations by apparatus according to the invention has been found to be very much less than for any known method of earth boring; since the impact energy imparted to the bit causes fracture and shattering of rock only in an annular zone, and since the fragments do not require to be ground to dust particle size but may instead have cross sections as large as will allow passage through the bit's central aperture, very much higher speed of penetration is achieved for a fraction of the work required by other drilling methods. As a specific but non-limiting example, the boring of holes by rotary bit rigs in coarse river bed gravels was found to take 90 hours when by comparison the apparatus of the present invention required about one hour to attain the same depth of borehole. The gravel ranged in size from about half inch to boulders of several hundredweight.

The construction, purposes, and uses of practical and preferred embodiments of the invention may be understood from the accompanying figures of the drawing, wherein,

FIG. 1 shows in elevation side view, a transportable earth boring apparatus constructed according to the invention;

FIG. 1A shows an elevation end view of the apparatus of FIG. 1 viewed from the left side thereof;

FIG. 2 shows in vertical diametral section, a detachable drill bit and a connector body for connection with a drill pipe of FIG. 1;

FIG. 3 shows a vertical diametral section of a male connector for attaching a double walled drill pipe with the bit of FIG. 2;

FIG. 4 shows a vertical diametral section of a double walled drill pipe and a female connector for joining with the connector of FIG. 3;

FIG. 5 shows a partial transverse vertical cross section of an anvil cap fitting of FIG. 1 with fluid supply and exhaust ducts for driving a single or double walled drill pipe;

FIG. 6 shows a horizontal section taken on line 6—6 of FIG. 2 through a drill bit, showing fluid passages;

FIG. 7 shows a side elevation view in partial section of an alternative form of drill bit;

FIG. 8 shows apparatus for withdrawing drill pipe from a borehole in plan view, on a section taken along line 8—8 of FIG. 1, the section having been turned 90°;

FIG. 9 shows in vertical diametral partial section, taken on line 9—9 of FIG. 1, part of the apparatus of FIG. 8;

FIG. 10 shows, outlines of rock fragments actually recovered by the earth boring apparatus of FIG. 1 in the same scale representation as FIG. 6, and

FIGURE 11 shows a vertical diametral section of an alternative embodiment with a single wall drill pipe serving as receptacle for earth materials.

A transportable earth boring apparatus as shown by FIG. 1 comprises an erectible derrick frame **10** pivotably supported as by brackets **11** from a horizontally extending vehicle frame **12**, to rotate about a transverse horizontal axis in bearing pins **13**. The derrick frame is arranged to be erected and lowered by linear motor means **14**, such as a hydraulic or pneumatic piston and cylinder supplied by fluid under pressure through suitable control valves and lines (not shown). One end of a piston rod **15** is pivotally secured to bracket **16** fixed to the derrick, rotating about pin **17** in the bracket, while the cylinder has its lower end pivotably supported in the vehicle frame as by pivot pin **18**. In the erected position, a prolongation **19** of the rear part of the vehicle frame serves as a stop to limit backward swing of the upper part of the derrick frame. The derrick is braced in erected position by a strut **20** secured pivotably at its upper end in derrick bracket **21** by pin **22**, and held adjacent its lower end in slotted lug **23** of vehicle bracket **24**, the lug being interposed between stop nuts **25** spaced adjustably along the strut.

A percussion motor **26** such as an internal combustion engine, which may be a diesel pile hammer of known type having a reciprocating hammer as manufactured by Syntron Company is adjustably supported by a sub-frame **27** in the derrick frame **10**, and having a downwardly facing cupped striking part **28** adapted to deliver blows against an anvil cap **29** carried on the upper end of drill pipe **30**. To effect controlled raising and lowering of the hammer, an elevating motor means **31** such as a hydraulic or pneumatic piston and cylinder is supported in the derrick frame and has its driven member, for example a piston rod **32**, arranged to reciprocate vertically to raise or lower a transverse carrier slide **33**. A pulley wheel **34** fixed on the upper end of the carrier has a cable **35** passing over it, one end of the cable being suitably secured in derrick frame **10** and the other end being attached to the sub frame **27**. When the elevating motor **31** is suitably actuated by control means (not shown) the sub-frame **27** will be raised or lowered twice the distance traveled by the carrier, as will be readily understood from the prior art of elevating devices. Consequently the position of striker **28** may be adjusted with respect to ground level, and the weight of the motor **26** may be rested with steady pressure entirely upon the drill pipe, whose lower end is fitted with a suitable drill bit, as will be described more particularly hereinafter.

Referring additionally to FIGS. 2 and 6, a preferred form of drill bit for attachment to a drill pipe comprises an annular bit body **36** having an axial bore **37** and upper and lower faces **38** and **39** respectively lying in planes spaced parallel with each other. To the upper side **38** is attached, as by welding, an integral cylindrical connector flange **40** having an internal thread **41**. The lower side, designated by the dashed line **39**, is recessed axially to form a plurality of teeth **42**, for example eight in number, uniformly spaced angularly with respect to the axis of the body. Each tooth **42** has a rectangular cross-section and has a cutting edge **43** of wedge or chisel shape lying in the common plane **39** transverse to the bit axis, and each edge also being aligned with a radius and of substantially equal length. The outer side faces **44** lie along the surface of a cylinder slightly larger than the outside diameter of the connector flange **40** of annulus **36** so that the latter may pass readily through an aperture formed by the action of the bit teeth.

The annular body **36** is formed, between the teeth **42** with intervening sectoral portions having a conic taper, the body having a diameter at the lower edge **45** of the tapered portion which is substantially that of the axial bore **37**, and a diameter at the crown **46** substantially that of the bounding cylinder which encloses the teeth. The lower margin **45** of the conic portion is spaced above the plane **39** of the tooth edges, and preferably lies at the level of the upper ends of the bevelled surfaces of the chisel portions. The bit may be formed of any suitable material, such as a hardened alloy steel capable of transmitting impact energy to rock without itself breaking and having satisfactory wear life. In one practical embodiment capable of drilling about 1800 feet of hole through granitic gravel before replacement, the body had a diameter of 5.75 inches, a tooth radial width of 1.3 inch, a tooth length of 2.6 inches, and a tooth thickness of 0.75 inch maximum at the root. The minimum diameter of the axial bore was 3.05 inches.

Each tooth is preferably provided with a passage **47** for directing fluid through the bit body **36** to flow into the axial bore **37**, the passage extending downwardly from face **38** parallel with the bit axis and turning radially inward and slightly upward adjacent the tooth edge **43**, opening at **48** at a point slightly above the lower conic margin **45** into the bore **37**.

The lower end of the drill pipe **30**, shown best in FIG. 3, comprises a permanently attached male connector **49**, having an axial passage defined in descending order by the bores **50**, **51**, and **52**, which are of respectively decreasing diameters and lengths. The flange **53** which terminates the lower end of the connector is provided with a laterally inwardly extending shoulder **54** on which the lower end of an inner tubing wall **130** is supported, the outline of the tubing wall being shown by dashed lines. The bore **51** is made to be a free fit for the outside of the tubing wall **130**, while a substantially annular passage **55** is provided between the outer surface of tube **130** and the bore **50**, of connector **49** or the interior surface the drill pipe **30**.

The exterior face **56** of connector **49** is tapered and partly externally pipe-threaded as indicated at **57**, the thread commencing a short distance from the lower end of the connector, and a shoulder **58** facing downward being provided above the threading to form a thrust face for transmitting driving force to a further length of drill pipe (not shown) which may be joined below the connector or to the bit body by a connector to be described hereinafter.

A plurality of lateral apertures **59** formed in the connector **49** near the lower end of bore **50** communicate with a peripheral groove **60** recessed in the threaded face **57**, providing ducts connected with the annular passage **55**.

As may be understood more readily from FIGS. 2 and 4, a connector **49** is adapted to be screw-threadedly engaged to form a conventional pipe joint with a female coupling **61** for joining with a length of drill pipe, or alternatively with a female coupling **161** for joining with drill bits, either of which coupling forms has a tapering interruptedly pipe-threaded bore **62** for receiving threaded face **57**. Such couplings each have a plurality of ports **63** registered on groove **63A** recessed intermediate the threaded length **62** extending radially outwardly partway through the body of the coupling, and communicating with the upper ends of axially extending passages **64** whose lower ends terminate short of the lower end of the coupling, and in turn are connected with short inturned passages **65**. In coupling **61**, these open into the stepped bore **66** at the lower end of the coupling, whereas in coupling **161** the axial passages **64** extend to the annular groove **79** recessed in the bottom face of the coupling.

Bore **67** in coupling **61** has a diameter which is a free fit for the inner tube wall **130** and is the narrowest part of the female pipe coupling body. A rounded groove **68** is provided in the bore wall just above the passages **65** to receive an O-ring **69**, the latter making a fluid-tight seal with the upper part of tubing **130** to close the upper end of annular space **55** so that gas or liquid may not pass between bore **62** and space **55** except by way of the passages **63**, **64**, and **65**.

Coupling **61** is provided with a further O-ring **70** seated in rounded groove **71**, the latter being located intermediate the vertical length of coupling **61** below the lower end of the thread which is formed along tapered bore **62**. The diameter of the seated O-ring **70** is such that when the unthreaded lower end of the tapered surface **56** of connector **49** is received therein, a fluid-tight seal is formed between the parts, and the ports **63** in groove **63A** and the apertures **59** of peripheral groove **60** are then registered in a common transverse plane, permitting flow of fluid from annular space **55** in one length of drill pipe to the corresponding space **55** in a connected length of pipe. Compression and impact loads are applied by shoulder **58** which is seated on the upper end **72** of coupling **61**, so that the threaded mating parts of the joint are relieved of the loads due to percussive blows.

To ensure fluid tightness, a peripheral groove **73** for an O-ring **74** is recessed adjacent shoulder **58** of connector **49** between the shoulder and threading **57**. When the joint is made, ring **74** engages the smooth tapered bore **75** formed in the upper end of either of couplings **61** or **161**, the seal preventing loss of fluid through the mating threading in bore **62** and threading **57**.

In coupling **161**, the groove **68** and O-ring **69** may be omitted, as shown, since any fluid escaping into the space adjoining axial bore **37** is not wasted but serves a useful flushing function as will become apparent hereinafter.

The lower portion of the cylindrical outer surface **76** of coupling **161** has a reduced diameter at **77** and this reduced diameter portion is threaded, to permit screw engagement with threading **41** of bit flange **40**. When the coupling **161** and bit **36** are firmly joined, the lower broadened face **78** of the coupling is seated against upper face **38** of the annular part of bit **36** to transmit forces thereto. The semi-toroidal channel **79**, in face **78** is in communication with the ends of axially extending passages **64** and **47** of the coupling **161** and bit **36** respectively.

Referring to FIG. 5, the anvil cap **29** is formed to be received into the coupling **61** of the upper end of a drill string by axial insertion, the lower portion of the cap **29** being annularly recessed at **80** and the recess having a bottom wall **81** lying in a transverse plane, and adapted to bear against face **72** of the female coupling **61**. An elongate boss **82** projects downwardly coaxially to define one side wall of the recess **80** while a depending cylindrical sleeve **83** extends along the outside surface **76**, to loosely confine the coupling in the recess. A central passage **84** within the boss **82** has a diameter which is fractionally greater than the inner diameter of the inner tube **130**. The lower end of boss **82** has a tapered exterior face **85** which passes through and forms a seal with O-ring **70** when the cap is resting on the coupling, while a sufficient clearance is provided between the exterior of the remaining part of boss **82** and the tapered bore **62** of the female coupling to allow fluid to move freely therebetween toward ports **63**. Loss of fluid between surface **76** and the inner face of sleeve **83** is prevented by an O-ring **90** recessed in the sleeve.

The central passage **84** continues upward within an axially extended thrust column **86** forming the upper portion of the anvil cap, and curves laterally without decrease of diameter to connect with aperture **87** of exhaust nipple **88** protruding from the side of the column. A flexible conduit **89** attached to the exhaust nipple leads to a suitable catcher (not shown), which preferably is an elongate porous-walled cylindriform container of suitable dimensions.

The recess wall **81** has a radial breadth somewhat greater than the radial breadth of thrust face **72** of the coupling, and a plurality of axially extending passages **91** are formed therein, being disposed at a lesser radius than the shoulder **81**. These communicate at their upward ends with a toroidal channel **92** formed within the thickened basal portion **93** of anvil cap **29**, and the channel is connected by a short, relatively large diameter passage **94** in a fluid inlet nipple **95**. To the latter is connected as by a suitable flexible high pressure conduit **96**, a supply of fluid, which may be gaseous or liquid. In most applications compressed air at a pressure of from about 45 to about 100 pounds per square inch may be supplied from a source such as a motor-driven compressor. For the system described a compressor having a free air delivery rate of about 400 cubic feet per minute was found suitable for drilling holes down to about 250 foot depth. Such compressor unit may conveniently be carried by the same vehicle as supports derrick **10** and hammer **26**, and arranged to be driven by the drive engine which powers the vehicle.

Depending upon the shape of the striker **28** of the hammer employed, the upper end **97** of the anvil cap will be suitably shaped, for transfer of impact energy and preferably is formed with a slightly rounded striker-engaging upper face **98**.

In the operation of the apparatus described, a length of drill pipe **30** having the inner pipe **130** in place and connected at its lower end with bit coupling **161** and a drill bit body **36**, has its upper coupling **61** received within the lower part of anvil cap **29** and the weight of the hammer **26** is rested upon the drill pipe. With fluid such as air supplied to the conduit **96** and thereby led down annular spaces **55** to flow as high velocity jets from apertures **48** into the interior of pipe **130**, the hammer motor is operated to cause teeth **42** to be driven downward into the earth strata. The scouring action of the jets above the lower margin **45** of the conic portion of the annulus **36** causes entrainment of particles and fragments **99** of any size loosened within the axial bore **37**. These loosened fragments are carried upward along the drill string within pipes **130** at a high velocity to be exhausted above ground by way of conduit **89** and thereupon to be suitably collected. Any water present is rapidly and continuously pumped away as a commingled spray and air stream. The loss of fluid into the space surrounding the drill pipe **30** within borehole **120** is negligible due to the effective seal made by margin **45** which is forced against the hole bottom by a large static load. Such axial loading is considerable, because the total weight of the drill string and hammer is carried by the bit annulus.

The rate of striking is not critical, and for most applications a rate of from **50** to **150** blows per minute provides rapid penetration of gravels, typical drilling rates experienced being from **5** to **10** feet per minute. Suitable gross weights of hammers and energy yields per blow may be readily determined by trial for each application; in one practical installation for sinking a 5¾ inch borehole in unconsolidated placer gravels a hammer weight of 3600 pounds with an indicated energy yield of about 7500 foot pounds per blow proved satisfactory. Expressed otherwise in terms of energy input, effective driving of an annular bit body as described may be achieved by delivering impact energy at the rate of about 500 foot pounds per blow per inch of bit diameter, or any higher energy rate within the strength limitations of the drill pipe and bit body. The steady pressure exerted on the bit annulus due to the gravity load of the drill string, hammer, and its mounting structure, assists in the penetration of ground and shattering and displacement of boulders. The loading will generally exceed at least 1000 pounds per inch of borehole diameter as may be understood from the foregoing data. Fragments as depicted in FIG. 10 having lengths in one direction up to 5 inches and cross-sections passing through a three inch pipe were broken out of the formations penetrated and freely ejected.

As the bit and drill pipe are driven down into the ground, it becomes necessary to attach a new length of drill pipe. This is accomplished by first elevating the hammer, after the air supply has been shut off, removing the anvil cap **29**, and then raising a new length of drill pipe with the inner pipe **130** already in place, with its bottom margin resting on the shouder **54** of flange **52**, and its upper end extending into coupling **61** to a point just below the O-ring 70. The added length of drill pipe is screwed into place by conventional means for making the joint which, being very well known, need not be described in detail here. When the length of pipe is securely in position, the anvil fitting is brought into position upon the upper end of its coupling 61, as by use of a pulley block and tackle (not shown) and the hammer is rested upon the anvil cap. Alternatively, the anvil cap may be suitably attached to the hammer to be raised jointly with it. The fluid supply is then admitted to the inlet of conduit 96, and any water which has risen in the borehole is rapidly pumped out, the exhaust spray being shunted away from the fragment collector means so as not to flush valuable mineral particles from collected fragments if the purpose of the drilling is to assay earth formations for mineral values. Thereafter the hammer is put into operation until the added length has been driven down. Each additional length is similarly put into place, and the operation is continued to the desired depth, being limited eventually by friction of the drill pipe against the sides of the borehole, particularly where the ground is unconsolidated.

When the drill bit requires to be replaced or a new hole driven, the drill pipe is removed by ancillary apparatus forming part of the invention, as will now be described. The apparatus for withdrawing the drill pipe from the borehole is required to develop a very considerable lifting force to overcome the large frictional and gravity loads of a drill pipe of considerable length, particularly in formations which cave readily. In those applications where fluid pressure is not applied, as where the entire contents of the borehole are to be collected within the drill pipe, this additional weight must be raised. Starting pulls in excess of 30 tons have been experienced, requiring robust equipment of considerable power. Since the drilling operation described is carried out at relatively high speed, it is imperative that the withdrawal operations be speeded up comparably to gain the highest efficiency.

Referring to FIGS, 1, 1A, 8, and 9, an apparatus for guiding and grabbing the drill pipe comprises a platform 100 in the form of a rectangular, rigid plate member, disposed in the horizontal plane to be supported upon the ground surface and having a circular aperture 101 registered over the borehole 120. The platform supports a pair of upright hydraulic motors 102, 103, of the piston and cylinder type whereof the driven elements, for example piston rods 104, 105 are vertically driven with respect to the platform. Fixed upon the upper ends of the piston rods are transverse beams 106, 107, from the ends of which depend tension members 108 of such length that in the fully retracted position of the pistons, the lower ends of the tension members reach almost to the platform surface. A cradle structure is carried by the lower ends of members 108, including transverse beams 109 and a strong plate 110 supported upon beams 109.

The assembly of platform 100 and cylinders 102, 103 is supported from derrick 10 by braces 111 including sleeve parts received on guides 112 fixed to the derrick.

Plate 110 is apertured at 113, the aperture registering in vertical spaced coaxial relation with aperture 101, and supporting a thrust block 114 which is coaxially apertured at 115, the aperture being of conic form opening upwardly. The minor diameter of aperture 115 is slightly larger than the outside diameter of the drill pipe 30, and a set of wedges or slips 116 having hardened, milled inner faces 117 of cylindric form and conic outer faces complementary to the form of bore 115 are receivable between the latter and the drill pipe.

As the piston rods 104, 105 are caused to be raised, as by applying fluid under pressure through suitable conduits and control valves (not shown) to motors 102, 103, the cradle structure with plate 110 and thrust block 114 is raised, causing wedges or slips 116 to clamp against pipe 30, and to grip it tightly as lifting force is applied. When the upward limit of motion of the rods 104, 105 has been reached, the motors are then operated to drive their piston rods down, thereby lowering the cradle structure and thrust block 114. The wedges or slips 116 disengage, and the pipe remains standing in its raised position in most instances, due to earth friction. In the event that such frictional holding is insufficient, resort may be had to conventional drill pipe clamps to prevent lowering, such devices (not shown) being conveniently located at the platform aperture 101.

The raising and lowering operation is repeated as quickly as desired, the hydraulic fluid pumps being chosen preferably of such size that the withdrawal of a length of pipe is less than the driving time. The drill pipe 30 is caused to be pulled out of the hole by increments, until a length is clear. The free length is unscrewed and removed by conventional methods, and succeeding lengths are similarly brought up until all have been removed. A catcher or stop (not shown) may be employed to cover the aperture 115 when the last length is lifted clear.

To dismantle the apparatus for transport, the frame 27 is suitably connected, as by chain and hook means, with the platform 100, and the hammer and lifting apparatus raised together. The derrick is then lowered upon the vehicle frame by releasing the strut 20 and retracting piston rod 15.

While the foregoing description has set forth a practical embodiment preferred for use in sampling gravels and the like, the earth boring apparatus according to the invention is not limited to unconsolidated formations, but may be used to make boreholes in strong ground and consolidated rock formations such as limestones, shales, sandstones, coal, and even igneous rock. For such drilling a different bit form as shown by FIG. 7 is necessary. The bit form resembles in most respects that illustrated by FIGS. 2 and 6, except that a tapered axial bore 137 is formed, as a cone coaxial with the bit axis and narrowing upwardly to the diameter of the annular body aperture 37, with the outer faces 44 of the teeth and the side wall of the bit being of identical diameter. The lower terminal margin of the cone extension of the bit body 36 is the edge 45 which has a diameter substantially that of side faces 44.

The breaking action of the bit of FIG. 7 in rock is somewhat different than that of the bit of FIG. 2; in the latter, fragments not lying along the axial bore 37 but in the path of body 36, are forced laterally outwards into the earth formations, which yield, or the shattering of fragments so deflected permits them to be expelled into the bore and removed. In the alternative bit form of FIG. 7 the teeth 42 break an annular zone of rock into fragments, which move inwardly and are forced up the central pipe 130 or up the pipe 30 if a double-walled drill pipe is not used. Due to the fact that rather more rock material must be shattered, a greater expenditure of work and hence a slower drilling rate is achieved. Such alternative bit forms prove to be able to drill a straight borehole, in many respects superior to a borehole drilled by rotary or reciprocating bits. Bit nozzles 48 shown in FIGURE 2 and FIGURE 6 are preferably radially recessed in the wall of bore 37, as shown, so that they open into the central passage of annulus 36 slightly outward of the inner ends of teeth 42. This is accomplished as illustrated by providing vertical grooves 148 extending along the wall of bore 37 between end face 38 and terminating a short distance below each nozzle 48, at, or just above, the level of the circular edge 45.

The vertical grooves serve to admit air freely into the central passage 130 of the drill string whenever bit bore 37 may become largely blocked by fragments or clay plugs which have not separated from the bottom of the borehole, thereby ensuring maintenance at all times of a vigorous upward current.

In FIGURE 11, a single-wall drill pipe 30 is shown in a borehole 120 carrying a bit 42 such as is illustrated in FIGURE 2, the drill pipe serving as a receptacle for earth materials forced into the bore 37 as the pipe descends.

Because the entire assembly of bit and drill pipe is subjected to strong shock at each impact of the hammer, and as each increment of penetrative progress commences and stops abruptly, it is found that the generally pulverulent contents 99' move upward freely within the drill pipe. The natural cohesion and friction of the materials with the drill pipe when at rest prevents the column from dropping therein as the drill pipe is raised. As each length is brought above ground level, the contents may be removed in any desired manner, assisted if necessary by striking the exterior of the drill pipe.

We claim:

1. The combination of a thick-walled drill pipe having a bit end and a drive end, a bit carried by said bit end, said bit having a circular opening extending through the bit along the axis of said pipe, a second pipe contained within and coextensive with said thick-walled pipe and spaced therefrom to provide an annular space between said pipes, separable anvil cap means closing said annular space at the drive end of said thick-walled tube, sport means in said bit providing passages communicating with said circular opening and with said annular space, said bit being toothed and said teeth extending in an axial direction from said pipes and being radially spaced about said bit axis, fluid supply duct means formed in the wall of said anvil cap means communicating with said annular space, and exhaust duct means in said anvil cap connecting with the interior of said second pipe and extending through a side wall of said cap for conveying fluid and fragments therefrom.

2. The combination claimed in claim 1 wherein said port means in said bit comprise a passage within each tooth extending in an axial direction from said annular space, said passage being curved inwardly adjacent the cutting end of each tooth to open into said circular opening.

3. The combination claimed in claim 2 wherein the wall of said circular opening is grooved and each groove extends to a corresponding passage for guiding fluid flow upwardly.

4. The combination claimed in claim 1 wherein said bit has sectoral outer portions disposed between said teeth, said portions having conic form thickening upwardly and having curved lower margins spaced above the tooth edges.

5. The method of making a straight borehole in overburden which consists in continuously subjecting an annular toothed bit body carried at the lower end of a rigid drill pipe to axially directed loading of at least 1000 pounds per inch of borehole diameter while intermittently delivering impact energy to the upper end of said drill pipe at a rate in excess of about 500 foot pounds per blow per inch of borehole diameter to effect displacement and shattering of boulders occluded in said overburden along said bore and to force overburden materials upward into said drill pipe, and raising said drill pipe with its contents out of said borehole.

6. The method of making a stragiht borehole in overburden comprising subjecting an annular bit body secured to the lower end of a rigid drill pipe and having a lower conic wall portion terminating in a marginal circumferential edge portion intersected at spaced intervals by radial cutting teeth extending below the marginal edge to a steady axially directed force of at least 1000 pounds per inch of borehole diameter while transmitting impact energy by repeated blows on the drill pipe at a rate in excess of 500 foot pounds per blow per inch of borehole diameter to effect displacement and shattering of boulders occluded in said overburden along said bore and to force overburden materials upwardly into said drill pipe, and withdrawing the drill pipe and bit from the overburden.

7. The method of making a straight borehole in overburden comprising, subjecting an annular toothed bit body carried at the lower end of a rigid drill pipe to a force of at least 1000 pounds per inch of borehole diameter while transmitting impact energy along said drill pipe to said bit body by repeated blows delivered to said drill pipe at a rate in excess of about 500 foot pounds per blow per inch of borehole diameter to effect displacement and shattering of boulders impeding progress of said bit body, while flowing a fluid inwardly of said bit body at a rate sufficient to continuously convey fragments of said overburden materials passed through said annular bit body along said drill pipe and to eject said materials above ground level.

8. The method of claim 7 wherein the fluid is compressed gas.

9. The method of making a straight borehole in overburden which comprises impressing an annular bit body having a central passage and a plurality of radially aligned cutting edges depending from said body into the ground under a steady pressure applied to a rigid drill pipe fixed to said body such that each inch of tooth edge supports at least 400 pounds dead weight while delivering energy of impact to said bit body by repeatedly impacting a heavy mass axially on the upper end of said drill pipe to abruptly increase the stress in the contact zones adjacent said tooth edges, said energy being sufficient to fracture brittle objects encountered by said bit body and to displace fragments axially and laterally of said annulus, and being at least 500 foot pounds per blow per inch of borehole diameter.

10. Apparatus for making straight boreholes in overburden comprising, a rigid tubular drill pipe having double walls defining a central bore and an annular chamber between said walls, an annular peripherally toothed bit body having depending teeth and having an axial bore registered with said central bore carried by one end of said drill pipe, conduits in said bit extending axially within said teeth and communicating with said chamber and opening into said axial bore, and an anvil cap closing the end of said annular chamber remote from said bit body, said cap being adapted to receive impact energy to drive said bit through said overburden, and having an inlet duct for admitting gaseous fluid to said chamber under pressure and having an exhaust duct for leading fluids and fragments of overburden out from said central bore laterally of said cap.

11. Apparatus as set forth by claim 10 wherein said anvil cap supports a superposed impact engine which contributes a gravity load on said bit body such that the total load is significantly greater than about 1000 pounds per inch of borehole diameter.

12. The apparatus set forth by claim 10 in combination with an impact engine capable of delivering impact energy to said anvil cap by repeated blows at an energy input rate exceeding about 500 foot pounds per blow per inch of borehole diameter.

13. The apparatus set forth by claim 10, wherein said teeth have chisel cutting edges and said edges are radially aligned and circumferentially spaced, and have a radial extent such that said edges project respectively radially inwardly of said central bore and radially outwardly beyond said drillpipe.

14. The apparatus of claim 13 wherein the radial breadth of portions of said bit body annulus between said teeth decreases downwardly to a lower peripheral edge spaced above said tooth edges.

15. In a drilling apparatus for making a borehole in overburden, the combination of a thick-walled outer drill pipe having a bit end and an impact-receiving end, a cutting bit of annular cross-section carried by said bit end, said bit comprising an annulus having a central passage therethrough coaxial with the pipe axis, a second pipe contained within said outer pipe and defining a chamber between said pipes, the interior cross-section of said second pipe being at least as large as the least cross-section of said central passage and providing a conduit for guiding therealong fragments capable of moving through said central passage, a weighted anvil cap re-

movably received on said impact receiving end in closing relation with said outer pipe, said cap having a fluid inlet duct and a fluid exhaust duct respectively communicating with an end of said annular chamber and with an end of said conduit when said cap is received on said impact-receiving end, said chamber being closed at said bit end by said bit, and passages in said annulus communicating with said chamber and opening into said central passage.

16. Apparatus set forth by claim **15** wherein said passages comprise an axial portion extending parallel with said axis within each tooth and opening upwardly into said chamber and a lateral portion extending inwardly adjacent the cutting edge of the tooth and terminating in a nozzle opening into said central passage.

17. Apparatus set forth by claim **16** wherein the wall of said central passage has a like plurality of grooves extending upwardly to said conduit and communicating with said nozzles.

18. Apparatus set forth by claim **16** wherein said central passage and said conduit are substantially cylindrical and said bit body comprises sectoral portions constituting thickened root ends of said teeth disposed between and integrally joined with intervening sectoral portions formed with an outer conic surface, said intervening sectoral portions having cutting edges curving in a plane which is transverse to the pipe axis and which lies intermediate said chisel cutting edges and the upper face of said annulus.

19. Drilling apparatus for extracting a fragmented core from a borehole as said borehole is produced in overburden and conglomerates comprising a rigid tubular drill pipe having double walls defining a central conduit and an annular chamber between said walls, an annular peripherally toothed bit body detachably secured at the lower end of said drill pipe and having a central passage coaxial with and substantially not larger than said conduit and a plurality of axially-extending, peripherally spaced teeth integral with said bit, each tooth having a passage formed therein connecting with said annular chamber and with said central passage for jetting fluid into said conduit from said chamber, an anvil cap adapted to receive impact energy to drive said bit body intermittently through said overburden and conglomerates removably secured on the upper end of said drill pipe, fluid supply means connected with said anvil cap effective to supply fluid under pressure to said annular chamber, and central curved duct means having a diameter not less than the diameter of said conduit communicating with said conduit for ejecting fluid and fragments of said formation entrained by jetting fluid above the surface.

20. In impact drilling apparatus for sinking a straight borehole in unconsolidated overburden and gravels, the combination with a double-walled drill pipe having inner and outer pipes defining central and annular passageways, and an annular drill bit carried at the lower end of said drill pipe and having a ring array of depending teeth and having a central bore registered on said central passageway, of an anvil cap removably supported on the upper end of said drill pipe for receiving hammer blows and for transmitting impact energy axially of said drill pipe to cause said bit to shatter and displace boulders obstructing penetration by said bit, said cap comprising an elongate rigid body having an upper impact receiving anvil face and a lower tubular seating portion, said seating portion having an upwardly extending annular recess, said outer drill pipe having a tapering internally pipe-threaded female coupling end adapted to be freely received in said recess and to seat against a bottom wall of said recess in load bearing and impact transfer relation thereagainst, and having axial passages opening into a peripheral internal groove intermediate the ends of said threading, a central passage in said anvil cap opening downwardly and registering on said central passageway of said drill pipe and curving upwardly laterally and opening outwardly through the side of said cap above said seating portion, an annular chamber having passages communicating with said recess, a fluid supply duct extending through a side of said cap and communicating with said chamber, and a depending conic boss defining a common wall between said central passage and said recess adapted to be received within said female coupling and to effect a fluid-tight seal between said boss and the interior of said female coupling.

21. A double-walled drill pipe comprising inner and outer pipes coaxially disposed to form an annular chamber, said outer pipe having respective tapered ends formed as a male connector and a female coupling for disconnectably joining with mating connectors and couplings of other lengths of said outer pipe, the male connector having a threaded tapering portion and a progressively stepped bore including a first bore formed in the narrow end having a diameter substantially equal to the inner diameter of said inner pipe, a second bore being substantially a free fit for said inner pipe, and a third larger bore having a diameter intermediate the inner diameter of said outer pipe and the outer diameter of said inner pipe, a peripheral groove and transverse apertures formed in said threaded portion communicating with said third bore and the exterior of said male connector, the female coupling having an interior thread reducing in diameter in the axial inward direction and a fourth bore formed in said female coupling spaced axially inwardly from said interior threading having an inner diameter which is a free fit for said inner pipe, said inner pipe extending from a seating in said second bore upwardly into said female coupling beyond said fourth bore, and said female coupling having an internal groove communicating with axially formed passages registering with said peripheral groove and said transverse apertures to connect annular chambers of joined lengths of said drill pipe.

22. In an earth boring apparatus, the combination comprising an annular drill bit having an axial bore and a plurality of peripherally spaced teeth extending axially from one side, fluid guiding passages extending axially within each tooth toward the tooth points and bending radially inwardly to communicate with said bore, an integral axially extending flange projecting from an end face of said bit on a side opposite said teeth formed as a cylindrical shell-walled tube having an internal thread and an external diameter slightly less than the maximum diameter of said bit, a double-walled drill pipe comprising inner and outer pipes coaxially disposed to form therebetween an annular fluid-guiding chamber and having a coaxial passage coextensive with said inner pipe, the outer pipe having male and female pipe-threaded ends, a tubular internally pipe-threaded fitting connecting with the lower end of said drill pipe, said fitting having its lower end face formed with an annular groove, said lower end having a stepped diameter threaded to engage said flange, axially recessed passages communicating with said groove and connecting said annular chamber with said passages in said drill bit, said end face lying in a plane and being disposed to bear against said drill bit for transfer of impact energy thereto.

23. A double wall drill pipe having inner and outer pipes defining central and annular passages and having joint means for joining lengths of drill pipe in end-to-end relation whereby to provide continuous separate passageways between said central passages and between said annular passages along a drill string, said joint means comprising a tubular end fitting secured to the lower end of said outer pipe and having a shoulder, a conic outer face tapering away from said end to a diameter less than the internal diameter of said outer pipe, the end of the fitting remote from said outer pipe having a radially inturned flange and a cylindrical bore, said bore being a free fit for said inner cylindrical pipe and said flange having an inner diameter substantially equal to the inner diameter of said inner pipe, and said fitting having a second bore disposed intermediate said cylindrical bore and an end of said outer pipe which is intermediate the inner diameter of said outer pipe and the outer diameter of said inner pipe, and peripherally spaced apertures piercing said end fitting wall and opening into said second bore to communicate with said annular passage; and a second fitting on the other end of said tubular body having an internal thread complementary with said outer thread for receiving an end fitting of another length of drill pipe, said other fitting having apertures extending axially between said annular passage and a plurality of connecting radial apertures opening inwardly, said other fitting having an internal bore adjacent said tubular body which is a clearance fit for said second pipe, said inner pipe having a length greater than that of the outer pipe whereby when one end of said inner pipe is supported on said flange, the other end extends within said second fitting.

24. In impact drilling apparatus for sinking a straight borehole in unconsolidated ground the combination with a rigid drill pipe having a central passageway for receiving earth material and fragments and carrying at its lower end an annular drill bit having depending teeth and an axial bore registered on said central passageway, of an anvil cap removably supported on the upper end of said drill pipe for receiving hammer blows and for transmitting impact energy axially of said drill pipe to cause said bit to shatter and displace brittle obstructions, said cap comprising a stout rigid body having an upper unapertured impact receiving anvil face and a lower tubular seating portion, said seating portion having a downwardly extending sleeve and a depending conic guiding boss coaxial with said sleeve and extending below said sleeve, said boss being inwardly spaced from said sleeve to define a recess adapted to freely receive the upper end of said drill pipe and to guidedly seat said upper end against a lateral shoulder terminating said recess.

25. Apparatus for earth boring of water-pervious gravels comprising, a rigid tubular drill pipe having relatively fixed inner and outer pipes defining central and annular passages, an annular peripherally toothed bit body having an axial bore registered with said central passage fixed to the lower end of said outer pipe, passages in said bit extending axially within said teeth and opening into said axial bore and into said annular passage, impact-receiving cap means supported on the outer pipe, said cap means being engaged by power hammer means of high energy yield per blow effective to strike said cap to drive said bit downwardly through said gravels and being subjected to a gravity load effective to close the upper end of said annular passage, said cap means comprising a freely detachable fitting having an upper end fact formed as an unapertured anvil surface and a lower end formed as a hollow depending boss insertable into said inner pipe, said fitting having a cylindrical depending sleeve coaxial with said boss adapted to enclose the upper end of said drill pipe freely received between said sleeve and said boss in gas sealing relation, said fitting having a laterally projecting exhaust duct communicating with said central passage for discharging material conveyed up said central passage by flow of said fluid, and having a fluid inlet entering said fitting between said sleeve and said upper end face and communicating with said annular passage.

26. A drill bit for impact drilling a substantially straight borehole in overburden earth materials comprising an annular body adapted to be carried at the lower end of a driving pipe, said body having a planar upper end face, a central aperture for passing fragments upwardly therethrough into said pipe as said bit penetrates said earth materials, having its side walls respectively of cylindrical and conic form and intersecting in a sectorally interrupted lower circular marginal edge, and having a plurality of circumferentially spaced depending teeth extending parallel with the bit axis below said circular marginal edge, said teeth having nearly constant radial width and nearly constant tooth thickness along their length and terminating in chisel edges disposed radially about said axis, said edges extending in plan slightly beyond said end face and slightly inside of said central aperture.

27. A drill bit as claimed in claim **26** wherein said bit body has a cylindrical outer side wall and said central aperture narrows upwardly from the lower marginal edge.

28. A drill bit as claimed in claim **26** wherein said bit body has a cylindrical bore and a conic outer side wall, said teeth have fluid-guiding passages opening into said end face and opening into said central aperture adjacently above the plane of said circular marginal edge.

29. A drill bit as claimed in claim **28** wherein said bore is vertically grooved between said end face and the inward openings of said passages.

30. A drill bit for impact drilling a substantially straight borehole in overburden comprising an annular body adapted to be carried at the end of a driving pipe, said body having an axial bore, a planar upper face, a lower circular marginal edge, and a conic outer surface widening upwardly from said marginal edge and having a plurality of circumferentially spaced depending integral teeth projecting from said conic surface and extending parallel with the bit axis below said circular marginal edge, said teeth having a uniform radial width and constant tooth thickness alon gtheir length and terminating in chisel edges disposed radially about said axis, said edges extending slightly beyond the outer diameter of said body and slightly within the diameter of said axial bore, fiuid guiding passages in said teeth opening upwardly into said planar face, and opening into said axial bore adjacent said tooth edges for jetting fiuid into said bore above said circular marginal edge, and grooves extending between each inward passage opening into said annular face.

31. A drill bit as set forth in claim **30** further including an integral cylindrical coaxial flange projecting from said upper face, said flange having an internal thread and having an external diameter slightly less than the maximum diameter of said bit.

32. A drill bit as set forth in claim **31** in combination with a detachable hollow fitting for separable attachment with an end of a double-walled drill pipe comprising inner and outer pipes coaxially disposed to form therebetween an annular fluid-guiding chamber and a coaxial passage coextensive with said inner pipe, said outer pipe having male and female pipe-threaded ends, wherein said fitting comprises a tubular member having a thick wall, an upper portion formed with an internal pipe thread connectable removably with a male pipe-threaded lower end of said drill pipe, said fitting having an end portion of reduced external diameter remote from said pipe-threaded portion threaded for engagement with said flange, and having an end face adjacent said reduced diameter portion formed with an annular recess and being disposed to bear against said planar upper face of said drill bit for transfer of impact energy thereto, a peripheral groove formed in said internal pipe thread, and ports opening into said groove and communicating with axial passages formed in said wall and opening into said recess in said end face for connecting said annular chamber with said fluid-guiding passages in said drill bit.

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