

[54] **SIDEWALL WELL-FORMATION FLUID SAMPLER**

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 [73] Assignee: **Gearhart-Owen Industries, Inc.**, Fort Worth, Tex.
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 [51] Int. Cl. **E21b 49/00**
 [58] Field of Search **73/155, 152; 166/264, 100**

[56] **References Cited**

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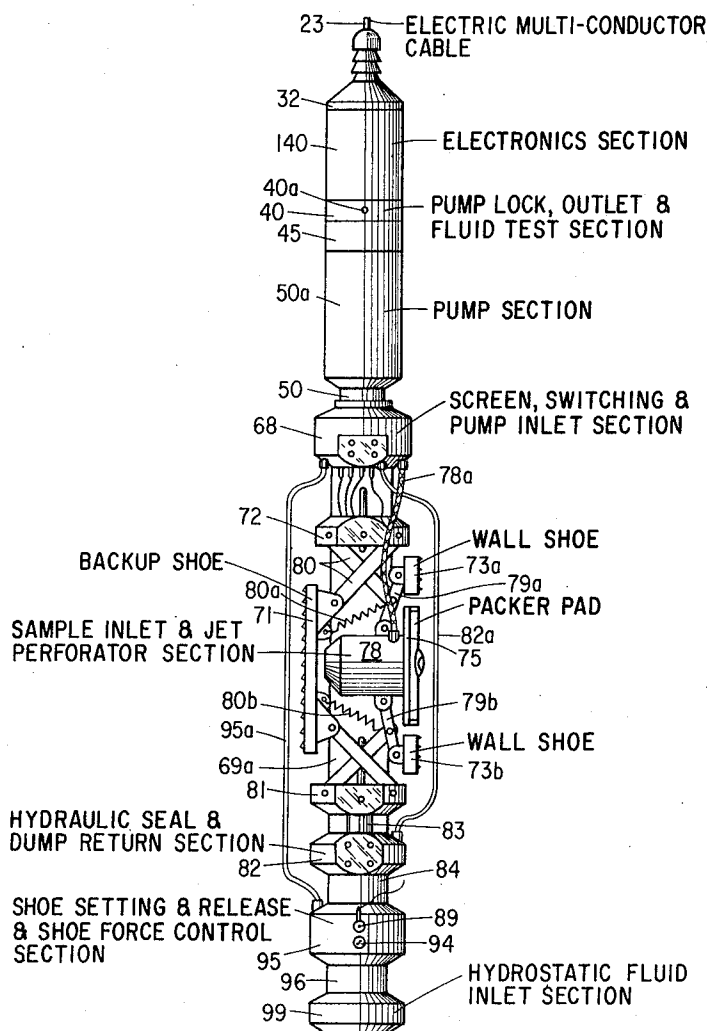
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Primary Examiner—Jerry W. Myracle
Attorney—Paul F. Hawley et al.

[57] **ABSTRACT**

A sidewall tool run on a well logging cable to obtain well-formation fluid samples incorporates a pump that is operated by reciprocating the suspending cable until a satisfactorily contamination-free sample is assured. The tool includes a number of features assuring reliable operation: shoe-setting force provided by hydrostatic pressure is regulated to be constant regardless of submergence; also, the regulated shoe-setting force is divided between large hold-down shoes and the pack-off pad so as not to overstress the mudcake or formation face; a reversible motor actuating a central control rod extending along the tool axis provides pump-locking, sample-sealing, and electrical-switching functions; alternate mechanical releasing operations are available in case of electrical malfunction; and pressure-balancing pistons prevent hydrostatic pressures from interfering with tool mechanical functions.

10 Claims, 12 Drawing Figures



SHEET 1 OF 7

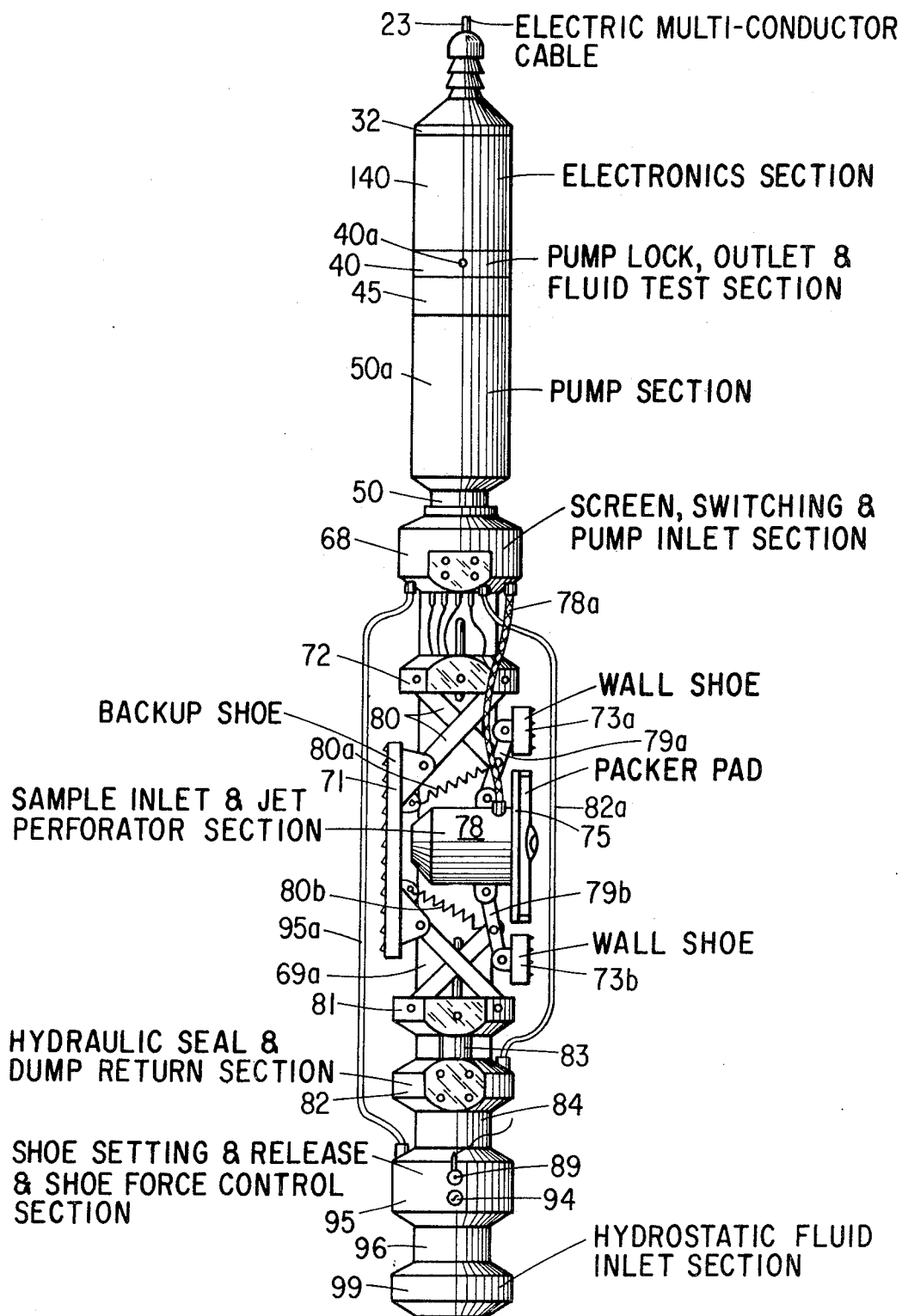


FIG. 1

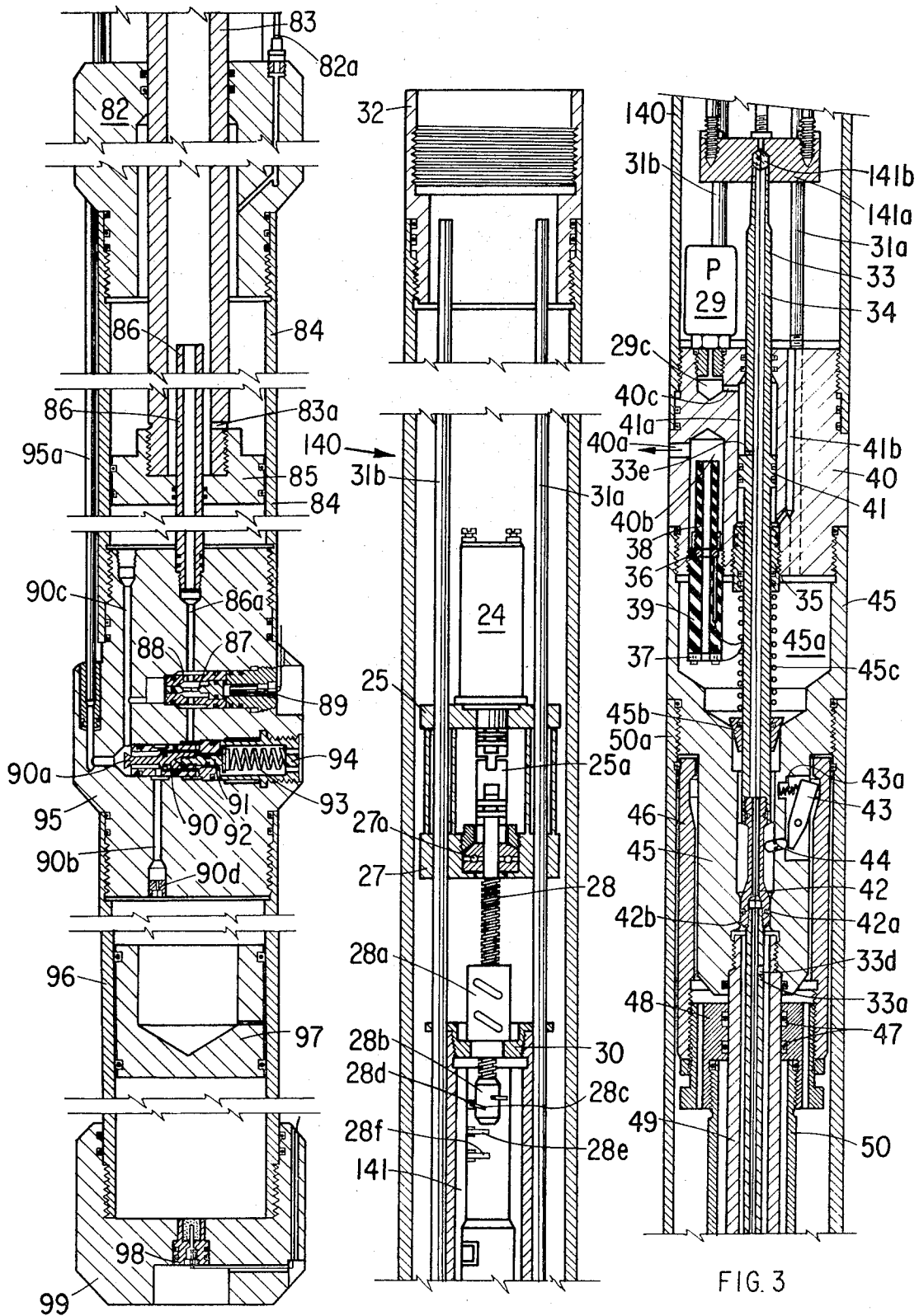


FIG. 6

FIG. 2

FIG. 3

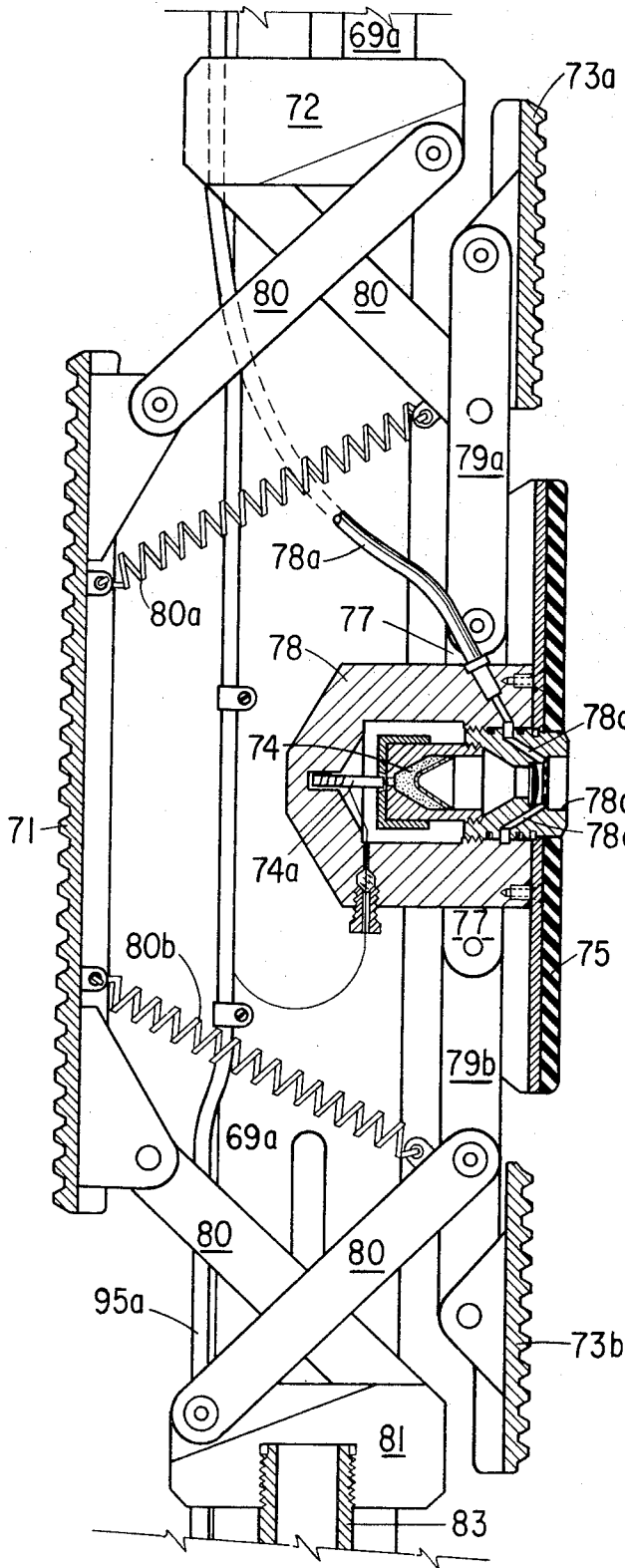


FIG. 5

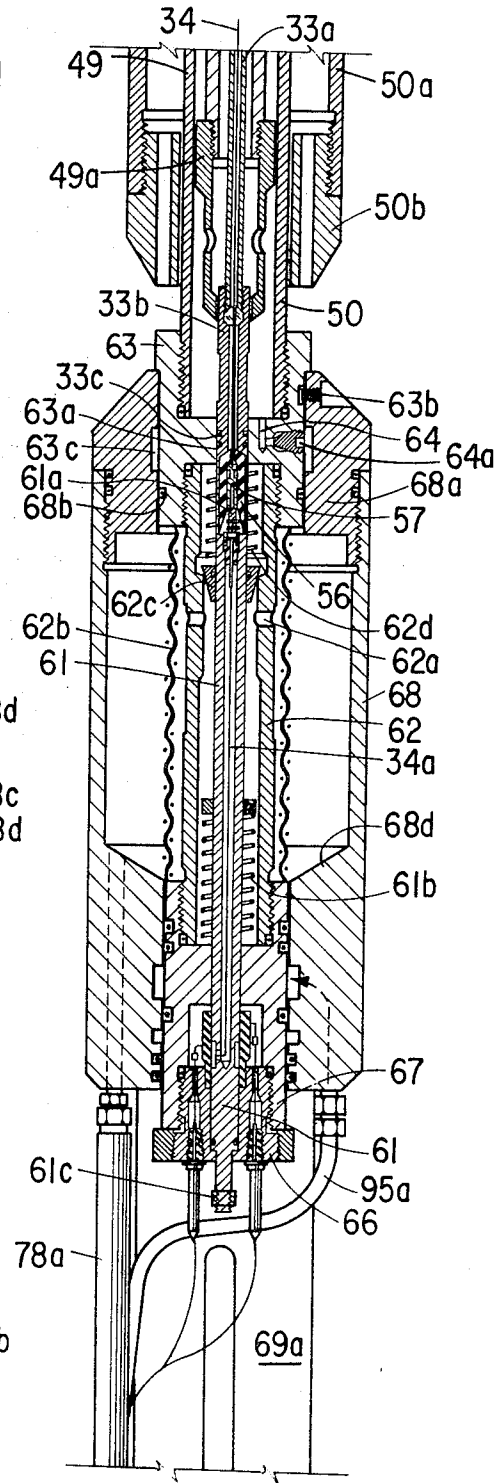
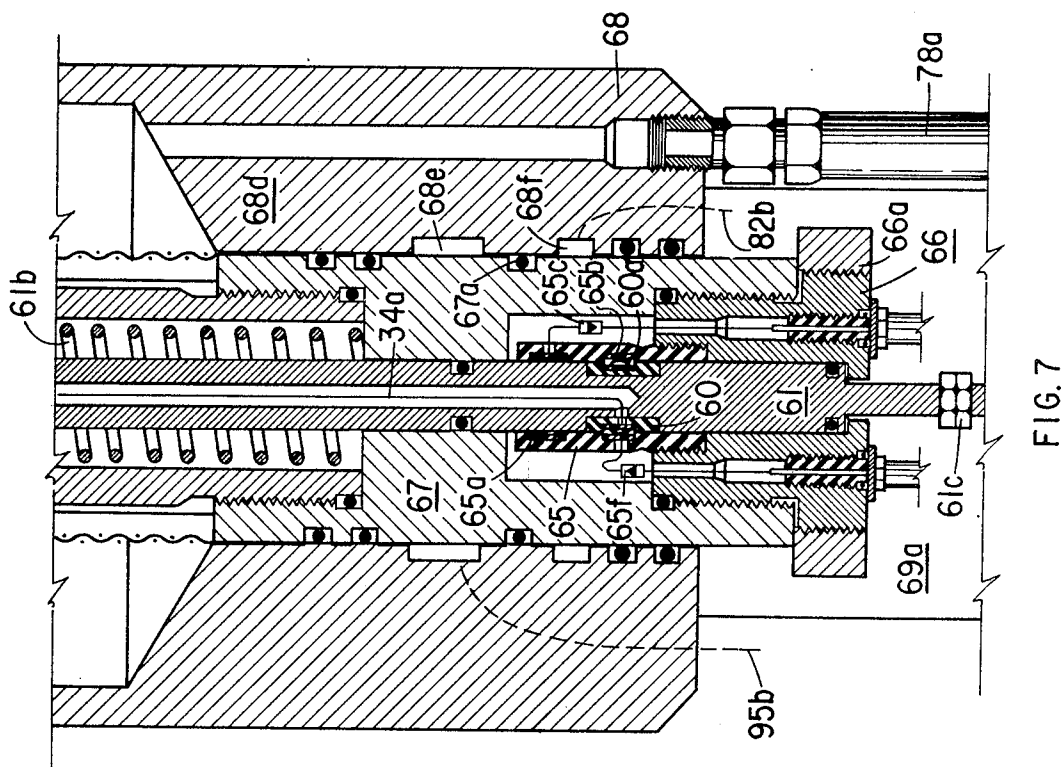
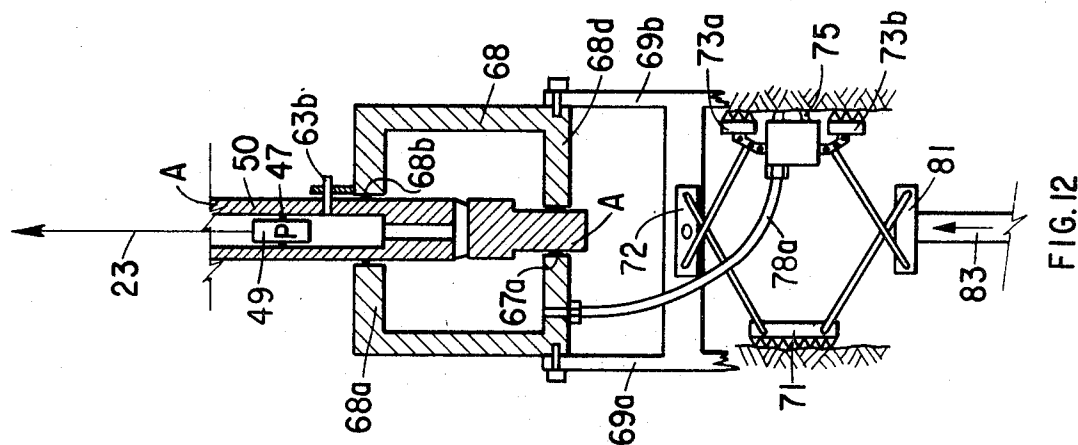


FIG. 4



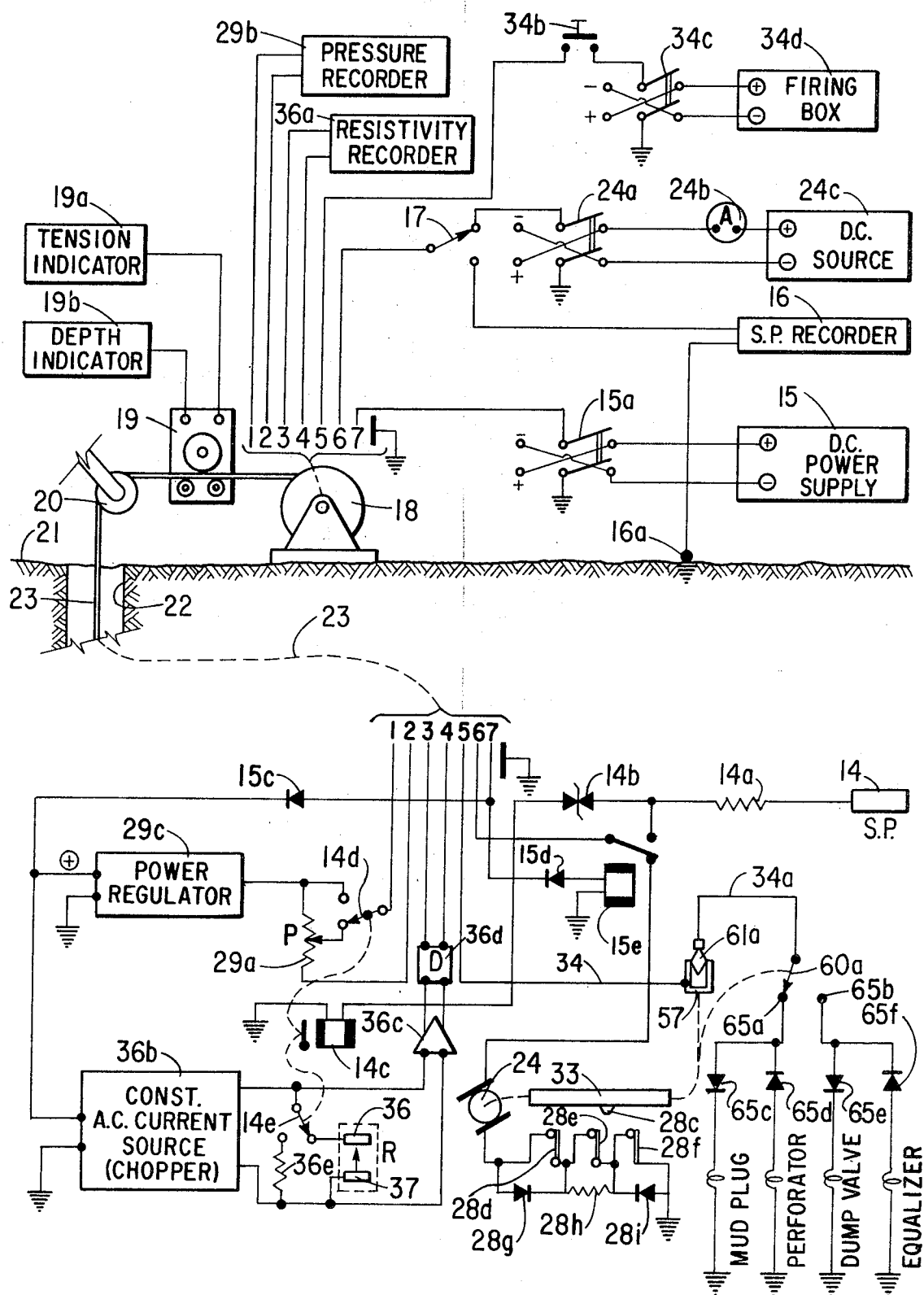


FIG. 8

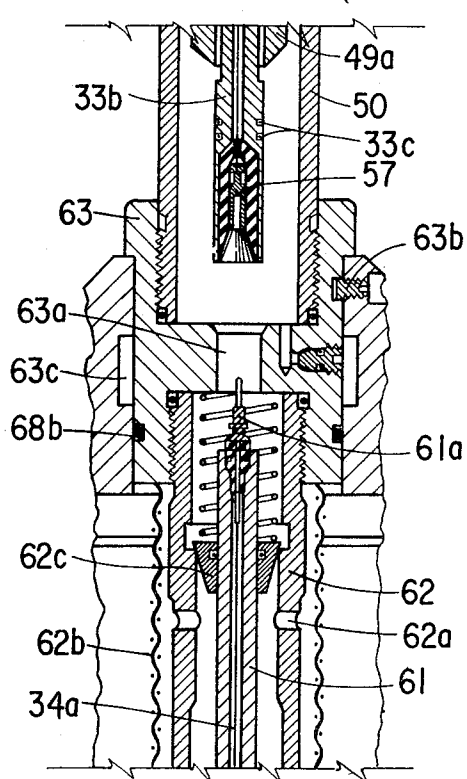
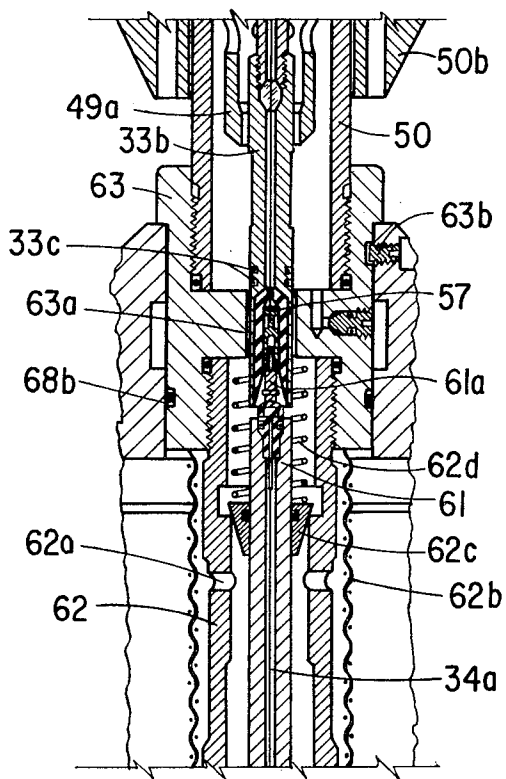
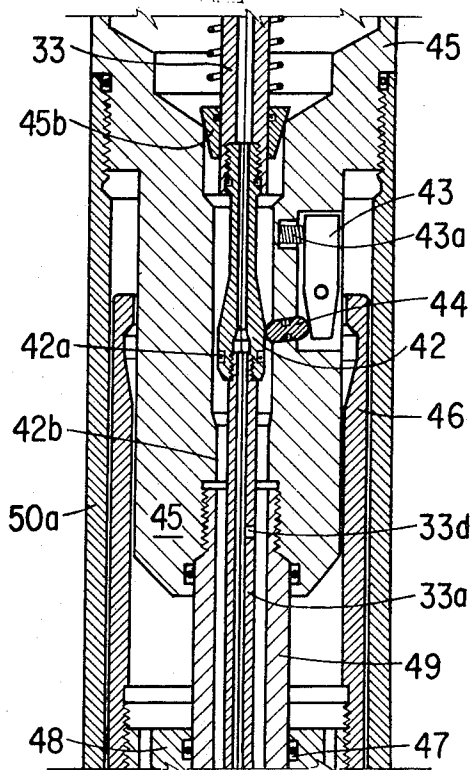
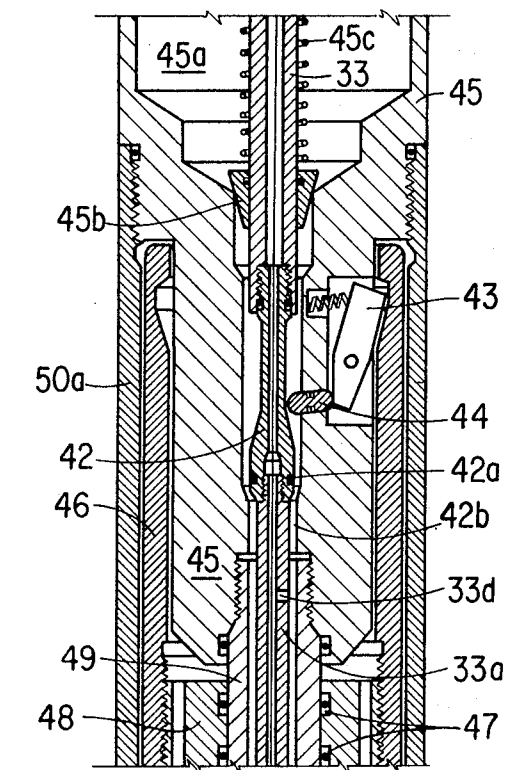
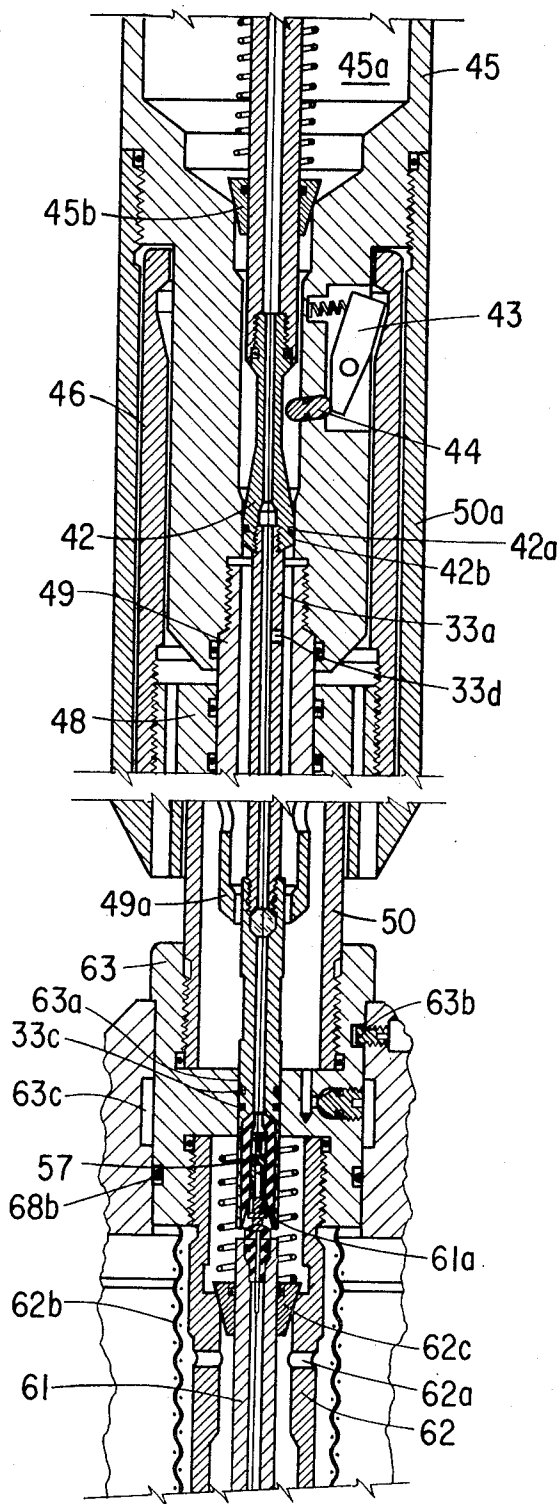


FIG. 9

FIG. 10



SIDEWALL WELL-FORMATION FLUID SAMPLER

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to formation fluid sampling and is directed to an improved formation-fluid sampler of the type that is lowered into a well on a wire line or logging cable, with pack-off means surrounding a sample inlet that is pressed against the well wall at the precise desired sampling depth. More specifically, the invention is directed to a side-wall well-formation fluid sampler with improved capabilities for obtaining contamination-free samples as compared with the commercially available samplers in the prior art.

2. Description of the Prior Art

Formation fluid testing falls generally into two categories: productivity testing and side-wall fluid sampling. In productivity testing, flow is induced into a tubing or drill pipe string in a well from more or less extensive vertical intervals of the well or from an entire pay formation, ordinarily with segregation of the test interval from the remainder of the well bore. In side-wall fluid sampling with a cable or wire-line tool, as exemplified by the present invention and by such prior-art U.S. Pat. Nos. as 2,674,313 Chambers, 2,982,130 McMahan, or 3,011,554 Desbrands, Fields, the formation fluids at essentially only a single depth point are sampled by a small-area sampling inlet pressed against the well wall and surrounded by pack-off means, such as an elastic ring. The volume of sample that can be obtained is limited due to limitations on the size and weight of tool that can be supported by the cable, which is ordinarily a logging cable having one or several insulated electrical conductors. As porous, liquid-containing formations are almost always invaded by drilling fluid filtrate to a greater or less degree, this filtrate represents contamination which is not only undesirable but for some purposes is intolerable.

Attempts to overcome or avoid this problem have involved, for example, surface monitoring of a fluid property such as resistivity while the sample is flowing to the receiving chamber, and filling multiple receiving chambers in sequence, the last filled presumably being most nearly contamination-free. It is generally recognized that the rate at which the sample is withdrawn must be so controlled as not to break the pack-off seal or to disrupt the formation. For example, to suddenly subject a small area of well wall, typically under several hundred or thousand pounds of liquid hydrostatic pressure, to the virtual vacuum of an empty sample chamber by opening a valve thereto could place such a great pressure differential across the packer and into the formation face as to cause packer leakage, bypassing of the packer seal by the well-bore fluids, or possibly breakdown of the formation material due to the large internal fluid pressure that is suddenly unbalanced. Somewhat elaborate expedients have been devised to regulate the sample flow rate, such as the use of water cushions filling the sample chamber, small orifices to prevent rapid flow, and the like.

One somewhat promising proposal that, so far as is known never became commercially available, is that shown in U.S. Pat. No. 2,511,759 Williams. There, a downhole electric motor drives a pump to draw fluids from the formation and eject them through a sample chamber into the well bore, while monitoring the fluid resistivity. Theoretically, sampling could thus be continued for an indefinitely long time, which could be as long as necessary to eliminate invasion fluid contamination from the retained sample. In practice, the sampler of Williams is faced with a number of problems, probably the greatest of which is avoided by the present invention: the amount of electrical power that can be practically transmitted over the conductors of commercial logging cables is severely limited by the conductor size and insulation. These are ordinarily designed for signal transmission involving negligible amounts of electrical power, and thus Williams could be faced with inordinately long sampling times for lack of sufficient pumping capacity. Furthermore, Williams can only indirectly ascertain the functioning of his pump by the changes noted in the fluid resistivity indication.

While contamination-free formation fluid samples are always desirable for analytical uses, they are practically essential for meaningful results when a geochemical prospecting method like that of U.S. Pat. No. 3,524,346 Schmidt is being used. There, measurements of the salinity and aromatic hydrocarbon content of well formation waters are interpreted in terms of proximity of hydrocarbon deposits that are missing from but may be located near the well being sampled. Although the present invention was initially directed to providing contamination-free water samples for use in accordance with the Schmidt prospecting method, it will be apparent that such samples, whether of water or of other fluids present in subsurface formations, are superior for all analytical uses. Accordingly, it may be considered as a primary object of the present invention to provide an improved side-wall formation-fluid sampler employing sample-pumping means at all times under direct control and monitoring from the ground surface, without the need for large-scale electric power transmission to the subsurface for pump operation.

SUMMARY OF THE INVENTION

This and other objects are accomplished in the present invention, by incorporating in the subsurface sampling unit a reciprocating pump which is stroked by raising and lowering the suspending cable. Included also are means controlled from the ground surface for locking and unlocking the pump piston, respectively to prevent or to allow pumping. At the conclusion of pumping, seals can be established near the inlet and outlet of the pump so that the space within the pump serves as the sample holder. To avoid sudden pressure differentials, the sampler can be preloaded with a liquid, preferably fresh water, and the tool opened to hydrostatic pressure. The preload liquid will be ejected into the well bore as soon as the pump withdraws liquid from the formation under test. The pressure differential across the test zone is completely controllable by the pumping rate and the length of the pump stroke. One or more fluid properties such as resistivity, temperature, and the like, are monitored over conductors of the cable; and the action of the pump as well as the response of the formation under test to the pump suction are indicated at the ground surface from an electrical pressure transducer in communication with the interior of the pump barrel.

For the electrical control of tool functions in the lower portion of the tool, an insulated electrical lead passes along the axis of the pump, and electrical contact means engagable with the pump in locked position provide continuity for the electrical circuit elements therebelow. Specifically, a hollow cylindrical rod enclosing an insulated electrical conductor and providing pressure communication to the interior of the pump extends through the pump along its longitudinal axis. A reversible electric motor actuated and controlled from the ground surface shifts the rod longitudinally to various positions, respectively to accomplish locking or unlocking of the pump mechanism, opening or sealing of the pump as a sample container, and electrical switching of the enclosed insulated lead to each of a plurality of explosive electrical igniters in the bottom portion of the tool and controlling various tool functions. Alternate electrical and mechanical procedures for releasing the tool from wall engagement are provided, including pressure-balancing of certain mechanical elements to prevent adverse effects from the hydrostatic or the pump-suction pressure acting thereon.

BRIEF DESCRIPTION OF THE DRAWINGS

This will be better understood by reference to the accompanying drawings forming a part of this application. In these drawings,

FIG. 1 is a schematic elevation view of the general form and arrangement of the invention;

FIGS. 2 through 6 respectively correspond to cross-section views of a prototype model of the invention taken from the top down;

FIG. 7 is a detailed cross-sectional view of the switching section;

FIG. 8 is a schematic wiring diagram;

FIGS. 9, 10 and 11 are detailed cross-section views of parts of the tool in different positions during different portions of the sampling operation; and

FIG. 12 is a simplified diagrammatic drawing of a portion of the tool illustrating one mode of its operation.

DETAILED DESCRIPTION OF THE DRAWINGS

Referring now to the drawings and in particular to FIG. 1, this figure shows schematically in elevation the form and arrangement of the major components of the downhole sampling tool. Beginning at the top of the figure, the multi-conductor cable 23 enters a cable head 32 of conventional form to which the cable is fastened and in which the separate conductor leads are brought out for connection to the electrical circuits in the components below. In turn, these are an electronics housing 140 containing most of the electrical circuit components at atmospheric pressure or thereabouts, and a testing sub 40 sealing the bottom of housing 140 against hydrostatic pressure present therebelow and containing fluid-testing elements besides the flow outlet 40a. Coupled to sub 40 is a pump-locking section 45, below which is the main pump section within an outer protective sleeve 50a slidable with the upper portion of the tool over the pump barrel which is fixed to a pump inlet sub 68. Sub 68 contains not only the pump inlet, but also electrical connection and switching means for establishing an electrical circuit to the parts of the tool therebelow, and a screen for preventing solids in the sample from entering the pump inlet.

Between inlet sub 68 and a hydraulic shoe-setting power sub 82, the tool is generally open to hydrostatic pressure, only one of two parallel support bars 69a being shown in FIG. 1, it being assumed that the other 69b has been removed to show the arrangement of the sampling head and anchoring shoes. In general, the shoe and sample head-setting mechanism somewhat resembles a scissors jack, an upper jack head 72 being held fixed with respect to the support bar 69a and its companion which has been removed, by shear-pin means, not shown. A lower movable jack head 81 attached to a power piston rod 83 rising up from the power sub 82 is movable upwardly relative to the fixed head 72 to actuate two pairs of pivoted scissors arms 80. Pivoted to the outer ends of two of arms 80 is a wall-contacting backup shoe 71, while the other two of arms 80, through a pair of pivoted levers 79a and 79b, move anchor shoes 73a, 73b, and sampling head 78 together radially to or from a well wall in the opposite direction to shoe 71, as head 81 moves up or down relative to fixed head 72. When the shoes are set against a well formation, resilient pad 75 on sampling head 78 facing the well wall provides a seal around the sample inlet. Tension springs 80a and 80b assist in retracting the shoes and sampling head when a sampling operation is completed. A flexible pressure hose 78a is connected between sample head 78 and sub 68 to carry produced formation fluids to the pump inlet in sub 68.

Setting force for the shoes and sampling head is provided by a piston on the bottom of rod 83 and working in power cylinder 84 supplied with hydraulic fluid power at hydrostatic pressure from a supply cylinder 96 through a setting control sub 95. Sub 95 includes both force-controlling means exposed to well-bore pressure at an inlet 94 and an explosively actuated dump plug 89 for releasing shoe-setting hydraulic pressure into a low-pressure space within cylinder 84. The bottom nose 99 of the tool not only closes the hydraulic fluid cylinder 96, but also includes explosive valve means subsequently described for admitting hydrostatic well pressure into cylinder 96. Hydraulic lines 82a and 95a respectively connect power head 82 and setting-control sub 95 to sealed spaces within sub 68, which may be connected by mechanical tool operations to release shoe-setting hydraulic pressure in the event of an electrical malfunction preventing firing of dump plug 89. Shown separated here for clarity, hydraulic lines 82a and 95a normally are run close to and fastened to support bar 69a (or 69b, not shown).

FIGS. 2 through 6, inclusive, show in cross-section and in greater detail the parts and arrangement of a prototype model of the tool representing the presently preferred embodiment of the invention and shown generally in FIG. 1. Electronics housing 140 encloses a reversible direct-current electric motor 24 fixed on a mounting 25 and coupled by a flexible coupling 25a to a ball screw 28. The thrust of screw 28 is carried by a bearing 27a in a mount 27 mechanically connected to mount 25. Extending through most of the length of housing 140 are support tubes 31a, 31b, which are attached by threads to the sub 40. An insulated electrical conductor extends through each of tubes 31a, 31b, and through extension passages (not shown) drilled through sub 40 into the space therebelow, there being bulkhead seals, not shown, surrounding the conductors to withstand the hydrostatic pressure present below sub 40. Tubes 31a, 31b pass through mounts 25 and 27, and the latter are secured against movement relative thereto by means such as set screws, not shown.

Engaged by ball screw 28 is a recirculating ball nut 28a held against rotation by and connected to a sub 30 slidable along rods 31a, 31b and connected in turn to a chassis 141 extending to a lower cross-member 141a. A lower tip member 28b of screw 28 carries a projecting ring 28c of a size to make contact with actuating levers of three microswitches 28d, 28e, and 28f mounted on and movable with chassis 141, these switches therefore serving to indicate three vertical positions of the chassis relative to ring 28c which stays at a fixed level. Cross-member 141a at the bottom of chassis 141 is coupled to a central rod 33 extending through and along the tool axis to a point below the pump barrel 50. Rod 33 is hollow and encloses an insulated electrical conductor 34, an insulating pressure seal 141b preventing leakage around conductor 34 through member 141a.

It is the primary function of the ball screw mechanism and motor 24, the output shaft of which is geared to run at low speed and provide high torque, to move rod 33 lengthwise to Any of the three positions corresponding to the three microswitches 28d, 28e and 28f. A pressure transducer 29 is mounted in the bottom of housing 140 on the upper face of sub 40 and is in fluid communication with the hydrostatic pressure existing within pump barrel 50 in a manner to be described below. Encircling rod 33 is an annular piston 41 within a concentric cylinder 41a formed in sub 40. A seal nut 35 carrying O-rings surrounds and seals both rod 33 and cylinder 41a below piston 41, a passage 41b extending from the space in cylinder 41a between piston 41 and seal 35 back into housing 140. In a second cylindrical space 40b formed in sub 40 parallel to and offset from axial rod 33 is an electrical resistivity cell comprising a first ring electrode 36 between tubular insulators 38 and 39 mounted in the space 40b, a second ring electrode 37 being mounted on the lower end of insulated spacer 39. An insulated lead, not shown, from each of electrodes 36 and 37 extends through one of the tubular supports 31a, 31b to the circuitry in housing 140. Space 40b opens through outlet 40a to the outside of the tool. As will be apparent, liquid passing through the central openings of electrodes 36 and 37 and the tubular insulators 38 and 39 will produce in a constant flow of electric current between the electrodes a voltage drop depending on the liquid resistivity.

The pump lock body 45 is attached by sealed threads to the bottom of sub 40 leaving a substantial open space 45a into which the resistivity cell projects, the bottom of space 45a being sealed by a conical valve member 45b urged downwardly by a spring 45c. Being slidable on rod 33 and sealed by an O-ring thereto, member 45b forms the upper or traveling valve of the pump. Below valve 45b, the central passage through body 45 narrows, and rod 33 is connected to a locking cam 42 carrying at its largest diameter an O-ring seal 42a which cooperates with a construction 42b of body 45 to seal the annular passage around rod 33 and cam 42. Conductor 34 extends from rod 33 through a similar passage along the axis of cam 42 and thence into a further continuation 33a of rod 33 downwardly through the pump plunger. Within a

recess in body 45 is a pivoted locking member 43 urged outwardly by a compression spring 43a, a lock pin or cam follower 44 extending between cam 42 and the other end of locking pawl 43 from spring 43a. While only one lock member 43 is shown, there will preferably be two or more equally spaced around the circumference of lock body 45.

The bottom end of body 45 is attached and sealed to the top end of hollow pump plunger 49, slidable through seals 47 in a sealing sub 48 attached to the outer barrel 50 of the pump. Extending upwardly from sub 48 is a lock-down sub 46 having an inside annular notch to be engaged by lock pawl 43. An outer protective sleeve 50a is threadedly attached to body 45 and extends downwardly around sub 46 to a point near the bottom of barrel 50. A perforated nose piece 50b on the bottom end of sleeve 50a acts as a guide against the outside of barrel 50. A similar guide 49a on the lower end of plunger 49 centralizes it and rod extension 33b in barrel 50.

Attached by sealed threads to the lower end of barrel 50 is a sealing sleeve 63 which extends through the central cylindrical bore of upper end member 68a of pump inlet housing 68, there being only an O-ring seal 68b to prevent fluid leakage along the mating surfaces. Immediately above seal 68b is an annular space 63c made by enlarging the bore through member 68a. A passage 64 in sleeve 63 extending from inside barrel 50 and closed by a screw plug 64a permits removal of a fluid sample after recovery. Into a construction 63a of sleeve 63 extends an elongation 33b of the central rod 33a carrying O-rings 33c to seal with construction 63a. Within the lower end of member 33b is an insulator 56 enclosing a metal female contact member 57 which forms the bottom terminal of conductor 34. Threaded into the bottom of sleeve 63 is a connector tube 62 having pump inlet openings 62a and surrounded by a cylindrical screen 62b. At its lower end, connector 62 is coupled to a selector housing slidably sealed within the central cylindrical opening of lower end member 68d of sub 68. Lengthwise through tube 62 and the center of selector housing 67 extends a selector rod 61 having sliding seals with the housing and a central passage containing a continuation 34a of conductor 34. Sealed at and projecting upwardly from the upper end of selector rod 61 is an insulated, metal male connector 61a for electrically connecting conductor 34a to conductor 34 through connector 57. Encircling rod 61 with an O-ring seal near its upper end above inlet opening 62a, is a conical valve member 62c urged downwardly against a seat by a compression spring 62d. This acts as the foot or standing valve of the pump.

Within selector housing 67 is a body 66 from which projects an insulating sleeve 65 carrying two inwardly facing contact rings 65a and 65b best shown by FIG. 7. Conductor 34a extends through an insulator sleeve 60 surrounding selector rod 61 to a wiper ring 60a having projecting spring fingers which make contact to ring 65a or 65b depending on the lengthwise position of rod 61 in selector housing 67. A compression spring 61b urges selector 61 upwardly and maintains contact between members 61a and 57, as determined by the lengthwise position of rod 33b, until a stop nut 61c abuts the end of body 66.

From ring 65a, two oppositely-poled diodes 65c and 65d, and from ring 65b, two other oppositely-poled diodes 65e and 65f, respectively, connect through four bulkhead sealing connectors to electrical igniters in the bottom portion of the tool, only two of the four diodes and connectors being shown in FIG. 7. Two annular spaces 68e and 68f made by enlarging the central cylindrical bore of end member 68d are isolated by O-ring seals, including the seal 67a between them, and are respectively connected to hydraulic lines 95a and 82a (FIG. 1) through passages diagrammatically indicated by dashed lines 95b and 82b. Between the limits of a shoulder on sleeve 63 and a removable stop ring 66a, the sleeve 63, connecting tube 62, and housing 67 are slidable as a unit through sub 68 end members 68a and 68d except as restrained by a shear screw 63b.

By removing shear screw 63b and stop ring 66a, sleeve 63 may be withdrawn from housing end member 68a so as to give access to screw plug 64a and permit removal of a collected sample through passage 64. The substantial annular space surrounding screen 62b inside housing 68 allows a considerable solids accumulation to occur without the screen becoming blocked.

The shoe and sampling head assembly has the dual function both of isolating the desired sample point and of anchoring the tool against pullup during pumping. Scissors jack links 80 preferably are attached to heads 72 and 81 at pivot points remote from the side of the well toward which the links point, thus extending across the tool axis in the shape of an X. As compared with the short links of U.S. Pat. No. 3,217,804, this greater length of links 80 permits accommodation to relatively greater variations in hole diameter without excessive changes in lateral shoe-setting force. To avoid the possibility of pullup force affecting the seal of packer pad 75, its flanking shoes 73a, 73b receive somewhat more than half of the lateral setting force due to the pivotal connection points from the links 80 to the levers 79a and 79b being closer to the shoe pivots than to the sampling head pivots at 77.

The sampling head 78, besides having wall-contacting inlet tube 78c connected by passages 78d to flexible hose 78a, contains a jet-perforating charge 74 aligned with tube 78c and detonatable by an electric cap 74a connected to one of the electrical conductors emerging from selector body 66.

To move head 81 upwardly toward head 72 and, through links 80, force shoe 71 and head 78 with shoes 73a, 73b outwardly against opposite sides of a well bore, force is transmitted through piston rod 83 from power piston 85 in cylinder 84. Rod 83 is hollow, the space inside it and surrounding it within cylinder 84 below sealing head 82 being at a low pressure such as atmospheric. An aperture 83a equalizes the low pressure throughout the space in cylinder 84 above piston 85.

Setting control sub 95 closes the bottom of cylinder 84. Extending upwardly from sub 95 along the axis of cylinder 84 through a sliding seal with piston 85 and into the center of hollow rod 83 is a dump tube 86 connecting the interior of sub 95 through a passage 86a with the low-pressure space above piston 85. Within sub 95 is a dump valve 87 in a body 88 sealed from hydrostatic pressure by a dump plug 89 containing an electrical detonator also connected to one of the conductors emerging from housing 66. Also within sub 95 is a force-regulating valve 90a controlling flow of hydraulic fluid at hydrostatic pressure from an inlet passage 90b to an outlet passage 90c going into cylinder 84. Valve 90a is actuated by co-axial coupled pistons 90 and 91 having sliding seals in a valve body 92, hydraulic fluid pressure on piston 90 acting to move it and valve 90a to the right to close the valve. Hydrostatic pressure through perforated retainer 94, plus the force of a compression spring 93, acts on small piston 91 to move the valve assembly toward the left to open the valve, the space between valve pistons 90 and 91 being at atmospheric pressure through passage 86a and a continuation thereof. A small-orifice choke 90d limits the flow of high-pressure hydraulic fluid into passage 90b.

Below sub 95 is an elongated hydraulic cylinder 96 containing a wiper piston 97 separating hydraulic oil above from well fluids below. Bottom nose 99 closing the bottom end of cylinder 96 has a passage sealed by a mud plug 98 containing an electrically explosive squib, also wired to one of the conductors emerging from housing 66, which squib can be fired to open the passage and admit fluid under well hydrostatic pressure into cylinder 96 to act upon piston 97.

FIG. 8 is a typical schematic electrical wiring diagram of the preferred prototype tool and the surface equipment used with it during a sampling operation, with the upper and lower portions of the figure respectively showing the surface and the downhole components. Cable 23 contains seven insulated conductors here numbered 1 through 7 surrounded by a grounded metallic wire sheath. Emerging from well bore 22 at the ground surface 21, cable 23 passes over a sheave 20,

through a depth and cable-tension measuring unit 19 to a powered hoisting reel 18 where the various conductors are brought out to conventional slip rings, not shown. A tension indicator 19a and depth indicator 19b show and preferably also record the data provided by unit 19. Cable conductors 1 and 2 from the subsurface pressure unit 29 go to a pressure indicator and recorder 29b, while conductors 3 and 4 transmit fluid resistivity indications from electrodes 36 and 37 to a resistivity indicator and recorder 36a. Cable conductor 5 from ignition lead 34, 34a is connected through a push-button switch 34b and a polarity-reversing switch 34c to a firing box 34d producing a direct-current voltage appropriate to fire the igniters in the lower portion of the downhole tool.

Cable conductor 6 connects through a two-pole switch 17 either to a spontaneous potential recorder 16 separately grounded at point 16a, or through a polarity-reversing switch 24a and ammeter 24b to a source 24c of direct current appropriate to operating tool-control motor 24. Cable conductor 7 connects through a reversing switch 15a to a direct-current power supply unit 15 appropriate to the downhole electronic units.

In the downhole tool, conductor 7 is connected through oppositely poled diodes 15c and 15d respectively to measurement power supplies 29c and 36d, and to a relay 15e acting as a two-pole switch for conductor 6. Unit 29c supplies a constant direct-current voltage to the pressure-sensing unit 29 which acts like a voltage divider 29a to transmit over conductors 1 and 2 a voltage varying with the ambient well-fluid pressure inside pump barrel 50 acting on unit 29. Unit 36b converts the DC power to a constant alternating or pulsating current (i.e., converted by a vibrator or chopper) flowing through the liquid medium between electrodes 36 and 37, the resulting voltage drop, varying directly with liquid resistivity, being amplified by an AC amplifier 36c and demodulated or rectified by unit 36d for transmission via conductors 3 and 4 to recorder 36a. As should be apparent, the output polarity of switch 15a determines which of diodes 15c and 15d is conducting, the other then being cut off or blocked.

With diode 15c conducting, relay 15e is open, and cable conductor 6 is connected to spontaneous potential electrode 14 through a series resistor 14a. Typically, as shown by U.S. Pat. Nos. 2,674,313 and 2,982,130, electrode 14 is mounted on an insulated external area of the tool or of the cable 23 thereabove, and exposed to the surrounding well fluids. Simultaneously, conductor 6 is connected through a Zener diode 14b to a calibration solenoid 14c actuating calibration switches 14d and 14e. With surface switch 17 thrown to the "Down" position, recorder 16 is connected to electrode 14 and, because of its typically low voltage relative to point 16a, diode 14b is essentially an open switch. Upon changing switch 17 to its illustrated upper position, however, the voltage of source 24c is sufficient to make 14b conduct and energize solenoid 14c, the resistor 14a preventing a short circuit to ground through electrode 14. The calibration switches then apply the full output voltage of supply 29c to conductors 1, 2, and substitute standard resistor 36e for the fluid resistivity cell, for the purpose of calibrating recorders 29b and 36a.

With diode 15d conducting and 15c blocked, relay 15e is energized, and voltage can be applied via conductor 6 from source 24c to operate the motor 24. Switch 24a determines the voltage polarity of source 24c and thus the rotational direction of motor 24 and the resulting direction of movement of control rod 33. The three normally-closed rod-position microswitches 28d, 28e and 28f are in series with motor 24 and ground. In parallel with end switches 28d and 28f, are oppositely-poled diodes 28g and 28i, respectively, while middle switch 28e has in parallel a resistance 28h. End switches 28d and 28f act as rod-motion limit switches when energized by projection 28c associated with rod 33, diode 28i being non-conducting when switch 28f opens with rod movement to the right but becoming conducting when voltage is reversed to reverse the direction of motor rotation. Opening of middle switch 28e puts resistor 28h in series so as to cause a substan-

tial drop in motor current as noted on ammeter 24b, which also shows the current cutoff by end switches 28d and 28f at the respective ends of the motion of rod 33.

As is indicated by the dotted mechanical-connection lines from rod 33 in FIG. 8, positioning of the rod establishes or breaks the electrical connection between contacts 57 and 61a, and shifts contactor 60a between points 65a and 65b. Accordingly, by choice of firing-current polarity using switch 34c, combined with positioning of contactor 60a by rod 33, any one of the diodes 65c, 65d, 65e, or 65f will pass firing current to its associated igniter.

In a typical operation, the sampling tool is initially filled with water, with rod 33 in its center position, resulting in the condition illustrated in FIG. 9. Locking pin 44 is at the foot of cam 42, lock 43 is in the engaged position, and seals 42a and 33c respectively are out of engagement with constrictions 42b and 63a. The tool interior is thus open to well pressure through the sample inlet path from inlet 78c through passages 78d and hose 78a into sub 68 during lowering. Accordingly, the prior-art problem of water-cushioning the sample chamber is avoided for the reason that the entire interior of the tool remains full of liquid at hydrostatic pressure. Electrically, contacts 57 and 61a are together, and contactor 60a is in engagement with ring 65a.

Setting of the shoes and sampling head is then done simply by closing reversing switch 34c on the proper polarity to pass electric current through diode 65c, and by pressing firing button 34b momentarily. This detonates mud plug 98, admitting well fluids into the bottom of cylinder 96 beneath piston 97. The hydraulic oil thereabove is placed under hydrostatic pressure and flows through choke 90d, passage 90b, past valve 90a, and through passage 90c into cylinder 84, where it acts on piston 85 causing it to move head 81 upwardly. This movement continues until shoes 71, 73a, 73b, and packer pad 75 are all firmly set against the wall of well 22.

Before the shoes and sampling head contact the well wall, the hydraulic pressure in cylinder 84 and passages 90b and 90c is only that required to overcome friction and the hydrostatic pressure acting on rod 83 at the seals of head 82, the main drop from hydrostatic pressure in cylinder 96 occurring across choke 90d. Both the hydrostatic pressure on piston 91 and the force of spring 93 urge valve 90a to the left so that it stays open. As the shoes and sampling head contact the well wall, upward motion of piston 85 stops, and continued flow through choke 90d rapidly raises the pressure on it and increases the setting force of the shoes and head against the well wall. At a predetermined force level, the pressure at valve 90a acting on large regulator piston 90 is sufficient to overcome the combined opposing forces of both spring 93 and the hydrostatic pressure acting on small piston 91, so the coupled valve and pistons move to the right closing valve 90a and cutting off further flow of hydraulic oil into cylinder 84.

The manner in which this mechanism regulates the shoe-setting force is as follows: the ratio of the face area of piston 85 exposed to hydraulic fluid pressure, to the cross-sectional area of rod 83 exposed to hydrostatic pressure, is a number a greater than unity, for example, 3.5. Coupled regulator pistons 90 and 91, exposed to the same two respective pressures, have the same ratio of areas a . The power piston 85 face area is larger than the face area of regulator piston 90 by a factor n substantially greater than unity, for example, $n = 83$. The low-pressure space above piston 85 is in communication with that between pistons 90 and 91 through opening 83a, dump tube 86, and passage 86a, so that the manner in which the various pressures act on the power piston and on the regulating piston assemblies is the same — only the magnitudes of resulting forces differ because of the area ratio n . That is, a given hydrostatic pressure acting on pistons 85 and 90 creates a force on 85 n times greater than on 90. When this pressure level becomes sufficient for the force on piston 90 to overcome both the force of hydrostatic pressure on piston 91 and the force F of spring 93, then the force of piston 85 acting to overcome the hydrostatic pressure on rod 83 and to set the shoes

produces an upward force nF at heat 81. Thus, if spring 93 exerts a force of 48 pounds, the shoe-setting force at head 81 for $n = 83$ is 83×48 , or about 4,000 pounds.

Assuming, for example, that piston 85 is 5 square inches larger than rod 83 in cross-sectional area, then any hydrostatic pressure that is 800 pounds per square inch or greater provides this shoe-setting force. This means that a submergence depth of at least about 1,600 feet in typical well-bore liquids is usually sufficient to provide the necessary setting force, and any greater submergence is prevented from creating more than this desired setting force, which could damage the linkage mechanism or overstress the well wall and cause it to crumble and possibly leak around the packer pad 75.

With the shoes and sampling head set against the formation, and with control rod 33 still positioned as in FIG. 9, switch 34c is reversed, and 34b momentarily closed to send ignition current through diode 65d to fire perforator charge 74. This is only to assure that any mud cake on the well wall or other obstructing material will not interfere with the entry of formation fluids into the sample inlet, and accordingly may be dispensed with if the formation produces freely without stimulation. It is not necessary to open the sampler, as it has remained open throughout the lowering and setting operations.

Next, switch 17 is thrown from recorder 16 to the upper position as shown in FIG. 8, switch 15a is thrown to the polarity to pass current through diode 15d and energize relay 15e, and finally switch 24a is thrown to the polarity to cause motor 24 to move rod 33 upwardly to the position shown for it in FIG. 10. This is signaled by the opening of microswitch 28d and cut-off motor current seen on ammeter 24b. In this movement, cam 42, through pin 44 depresses lock 43 against spring 43a, unlocking sub 46 from body 45 so that pump plunger 49 is free to move upwardly through seals 47 relative to sub 48 and to barrel 50. FIG. 10 shows these relative positions of the pump parts shortly after the starting of an upstroke by pulling upwardly on cable 23.

It is preferred that the effective cross-section area of plunger 49 be about unity (i.e., about 1 square inch), as this gives approximately a 1:1 ratio between (1) the incremental lifting force, shown by tension indicator 19a, and applied through cable 23 to raise plunger 49 and stroke the pump, and (2) the resulting suction pressure at inlet 78c, within inlet sub 68, and in the interior of the pump traveling valve 45b. For example, neglecting seal sliding friction, an increased upward pull of 500 pounds on cable 23 produces a sample suction pressure of about 500 pounds per square inch in sub 68. The ambient pressure within the pump barrel is transmitted to transducer 29 and indicated by recorder 29b as follows: rod extension 33a has a wall aperture 33d giving communication from the pump interior into the central passage of the rod through which extends conductor 34. Another aperture 33e communicates from the rod central passage to the upper side of piston 41 in cylinder 41a, and a third aperture 40c communicates from cylinder 41a to the recess 29c into which transducer 29 is sealed.

As should be apparent, depending on whether pad 75 is or is not sealed against the well wall and on the rate of sample flow or pump suction conditions, the indicated fluid pressure will be well-bore hydrostatic, pump-suction, formation-producing, or formation-pore static pressure. Thus, the record of pressure recorder 29b, coordinated with suction pressure from tension indicator 19a, contains much information about the effectiveness of seal of packer 75, as well as about the producing characteristics of the formation under a variety of testing and flowing conditions.

The sample-pumping operation and rejection of sample through outlet 40a into the well bore can be continued more or less indefinitely, until a satisfactory sample is assured from the resistivity indications on recorder 36a. When the sample is finally considered satisfactory, pumping is stopped, and motor 24 is energized to move rod 33 to its lowermost position as detected by microswitch 28f. This puts cam 42 in the position shown in FIG. 11, so that lock 43 not only re-engages the

notch of lock sub 46, but also seal 42a engages constriction 42b, sealing the upper end of the pump chamber. Simultaneously, the lower end of the pump is sealed by seals 33c in constriction 63a, connectors 57 and 61a re-establish contact, and selector rod 61 is pushed down to make contact between selector 60a and ring 65b. Then, switch 34c is set and button 34b depressed to send ignition current through diode 65e to dump valve 87. Explosion of squib 89 opens the central passage to hydrostatic pressure, which drives valve member 87 to the left, connecting passages 90c and 86a. The hydraulic fluid exerting pressure on piston 85 then flows rapidly through passage 86a, dump tube 86, and opening 83a into the low-pressure space in cylinder 84 above piston 85. The presence of choke 90d assures that the hydraulic fluid below piston 85 can empty before all of the remaining hydraulic fluid in cylinder 96 flows to the dump chamber.

Ordinarily, the release of pressure by dump valve 87 lets springs 80a and 80b retract the shoes and sampling head, along with the assistance of hydrostatic pressure acting on piston rod 83 to move piston 85 downwardly when the pressure acting on it has thus been relieved, and the tool can then be raised to the ground surface.

If it is likely that there is a pressure differential across pad 75, switch 34c is reversed and button 34b momentarily pressed to detonate the equalizer charge, not shown but corresponding to mud plug 98 except for being in a wall of inlet sub 68. Upon thus admitting well pressure into sub 68, it travels through tube 78a to the formation face at packer 75, equalizing any pressure differential existing there. If pad 75 still adheres to the formation, it can easily be sheared free of its backing plate to which it is lightly held by small screws, to be left behind when the tool is hoisted to the ground surface.

In the event of anY electrical malfunction such that dump valve actuator plug 89 and the equalizer plug cannot be fired, an alternate release procedure is available. A typical cable 23 might have a breaking strength of 11,000 pounds and would pull free of cable head 32 at about half this or at 5,500 pounds. A maximum pump suction pressure of 3,000 pounds, corresponding to 3,000 pounds additional pull on cable 23, might be allowable. Shear screw 63b holding sleeve 63, tube 62, and housing 67 fixed relative to sub 68 is arranged to shear upon an upward pull by cable 23 of 2,000 pounds with the pump locked. When screw 63b shears, the assembly, consisting of sleeve 63, tube 62, and housing 67 moves upwardly in sub 68 until stopped by ring 66a abutting lower end 68d of the inlet sub 68. This moves seal ring 67a into annulus 68e, whereupon the hydraulic fluid in passage 90c flows through tubing 95a to annulus 68e, thence between the mating surfaces to annulus 68f, and returns through tubing 82a to the low-pressure space below power head 82. At the same time, seal 68b moves into annulus 63c admitting hydrostatic well pressure into sub 68 and via tube 78a to sample inlet 78c, thus equalizing any pressure differential that might be there to interfere with freeing the tool.

The reason why a 3,000-pound pull on cable 23 during pumping does not shear 2,000-pound shear screw 63b can best be understood from FIG. 12, which is a simplified drawing of the involved structure of the lower portion of the tool. Pump barrel 50 may be considered to extend completely through inlet sub 68, with seal 68b at upper end 68a being larger than seal 67a at lower end 68d by just the area of plunger 49. That is, the barrel cross-section area A is the same at both ends, and the lower end 68d area is therefore larger than upper end 68a area by the area of plunger 49. Assume, now, that a 3,000-pound pull on cable 23 and plunger 49 creates a (negative) suction pressure of 3,000 pounds per square inch inside chamber 68 relative to the hydrostatic pressure outside. This unbalances the force of the external hydrostatic pressure on ends 68a and 68d, the upward force on 68d being 3,000 pounds greater than the downward force on end 68a, because 68d is 1 square inch (the plunger area) larger than 68a. Hence, the 3,000-pound upward pull on cable 23 is hydraulically transmitted to housing 68 and thence through support

bars 69a and 69b ultimately to the well wall via shoes 71, packer 75, and shoes 73a, 73b. Shear screw 63b during pumping therefore remains unloaded except for the frictional drag of seal 47 against plunger 49.

If efforts to free the tool by firing the dump plug and equalizer charges are unsuccessful, and if the other manipulations to relieve shoe-setting pressure and equalize packer differential pressure are still unsuccessful, and the shoes remain set, cable 23 can be broken free at head 32 and withdrawn, and conventional fishing tools may then be run on a tubing or drill pipe string. After engaging the upper end of the tool housing with the fishing tool, a sufficient downward force or jar on the tool shears the connection between fixed head 72 and the support bars 69a, 69b. Since the slots in bars 69a, 69b adjacent head 72 are longer than the corresponding slots at head 81, the latter is stopped sooner than head 72, so that there is no longer any backup for the head 81 to work against. Accordingly, no lateral force remains in the arms 80 to prevent the shoes and sample head from retracting away from the well wall.

A further feature contributing to the reliable operation of this tool arises in the function of annular piston 41 in sub 40 of FIG. 3. Rod 33 passes from atmospheric pressure within housing 140 through a sliding seal into a hydrostatic-pressure environment. Ordinarily, a force equal to the hydrostatic pressure times the rod cross-section area would have to be overcome by motor 24 to move rod 33 downwardly against this hydrostatic pressure. The face area of annular piston 41, however, is made equal to the rod cross-section area, so that the hydrostatic pressure acting on the upper face of annular piston 41, its lower face being at atmospheric pressure through passage 41b, creates just the downward force necessary to balance the upward force of hydrostatic pressure on rod 33. Hence, motor 24 is required only to overcome the sliding friction of the various seals associated with rod 33 and its extensions in moving the rod to its various positions. Because of this pressure balance provided by annular piston 41, the tool of this invention is virtually unlimited as to the hydrostatic pressure or well depth from which a formation fluid sample can be satisfactorily recovered.

I claim:

1. In a side-wall well-formation fluid sampler of the type run on and controllable over a well-logging cable, said sampler comprising

an elongated tool body having a sample-receiving inlet, means on said body for pressing said inlet against a well wall at a desired sampling point, a fluid flow path extending from said inlet through a sample-holding space within said body to an outlet opening into the well bore, remote-indicating fluid pressure and fluid character-testing means in communication with said flow path, means for transmitting to and exhibiting at the ground surface the indications of said pressure and said character-testing means, and a pump in said flow path operable by reciprocating said cable to draw formation fluids through said inlet, flow them along said flow path, and eject them through said outlet into the well bore, the improvement in which

said inlet-pressing means comprises wall-engaging shoes movable radially from said body into well-wall contact on two opposite sides of a well bore,

a sampling head including said inlet and radially movable with the shoe or shoes contacting one side of said bore, means for applying radial forces from said body to said shoes and said head to press them into well-wall contact on opposite sides of a well with said inlet at said desired sampling point, and

lever means for dividing the radial force directed toward said one side of said bore between said head and said shoe or shoes.

2. A sampler as in claim 1 in which said radial force-applying means comprises

a power piston attached to a power-piston rod and surrounded by a power cylinder with which said piston and rod have sliding seals, the ratio of piston-face area to effective rod cross-section area being a greater than unity, a supply of hydraulic fluid at hydrostatic well-fluid pressure, a bulkhead between said fluid supply and said cylinder having a passage to conduct said fluid into said cylinder to act on said piston face, the other face of said piston and the portion of said rod within said cylinder being in communication with a space at low pressure such as atmospheric, the other end of said rod from said piston being exposed to said hydrostatic pressure,

valve means in said passage to control the flow of said hydraulic fluid therethrough,

a first cylinder enclosing a first regulating piston exposed to the pressure in said passage between said valve means and said fluid supply, the ratio of face areas of said power and said regulating piston being n , a number substantially greater than unity,

a second cylinder enclosing a second regulating piston exposed to hydrostatic pressure and connected to said first regulating piston, the space between said pistons being in communication with said low pressure space, and the ratio of first to second regulating piston face areas being also substantially equal to a ,

spring means exerting a force F on said coupled regulator pistons opposite to that of said hydraulic fluid pressure acting on said first regulator piston,

said regulator piston being coupled to said passage valve means in a sense to close said passage when sufficient hydraulic fluid has flowed to said power cylinder to cause said piston rod to exert a force nF on shoe-setting means coupled thereto.

3. A sampler as in claim 1 in which said pump comprises an outer barrel and an inner plunger, and

said elongated body is formed in two longitudinal sections, that body section carrying said shoes and sampling head including one of said barrel and plunger, and the other body section being operatively connected to said cable and including the other of said barrel and plunger, whereby said pump operates by reciprocating one of said sections relative to the other by reciprocating said cable.

4. A sampler as in claim 3 including also

releasable lock means holding said barrel and plunger fixed relative to each other, and

means controllable from the ground surface for releasing said lock means to permit operation of said pump.

5. A sampler as in claim 4 in which said controllable releasing means comprises

a reversible electric motor,

a rod extending axially through said tool body and having a cam surface,

cam follower means actuatable by said surface and coupled to said locking means, and

coupling means between said motor and said rod to produce movement of said rod and cam surface by said motor to actuate said follower means and thereby cause said lock means to engage or to release said barrel and plunger.

6. In a sampler as in claim 5 in which said rod has a longitudinal passage extending therethrough,

at least one insulated electrical conductor extending through said passage,

electrical switch means actuatable by said rod movement, and

electrical connector means engaged by said rod movement to extend said insulated electrical conductor to said switch means.

7. In a sampler as in claim 5 in which

said rod is movable axially by said motor through seals from a space at low pressure such as atmospheric and is exposed to said hydrostatic pressure, and including also

an annular piston encircling said rod with a face area substantially equal to the sealed cross-sectional area of said rod,

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a cylinder sealingly surrounding said annular piston, and conduit means for applying hydrostatic pressure to one face of said annular piston, the opposite face being exposed to said low pressure, the force of said annular piston on said rod being substantially equal and opposite to that of the hydrostatic pressure urging said rod toward said low-pressure space.

8. In a sampler as in claim 5 in which said rod extends through at least the major part of the length of said pump and through two constrictions in said flow path respectively near the two ends of said pump barrel, and means substantially simultaneously forming seals between said rod and said constrictions at one lengthwise position of said rod, whereby the portion of said pump in said flow path between said seals may become a sealed sample-holding chamber.

9. In a sampler as in claim 3 in which said tool body section carrying said shoes includes an inlet chamber surrounding the inlet to said pump, and through which said pump extends, resilient seals encircling said pump where it passes through

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the upper and lower ends of said chamber, shear-pin means extending between said chamber and said pump to prevent relative longitudinal movement of said pump and chamber, the lower-end area of said chamber surrounding said pump being larger than the corresponding upper-end area of said chamber by substantially the cross-sectional area of said pump plunger, whereby the suction pressure of said pump within said chamber creates an upward hydraulic force on said chamber to be transmitted to said anchor shoes, said force being substantially equal to the lifting force applied to said cable to reciprocate said pump, and whereby said shear-pin means is substantially unstressed during pumping.

10. In a sampler as in claim 9 in which said pump inlet chamber surrounds a cylindrical screen coaxial with and surrounding said pump and the inlet aperture thereto, there being an annular space of substantial volume for solids accumulation outside said screen between it and the wall of said chamber.

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