

[72] Inventors **Robert F. Bauer Whittier;**
Robert C. McNeill, Long Beach; Jerry T. Ledbetter, Whittier, Calif.

[21] Appl. No. **675,714**

[22] Filed **Aug. 1, 1957**

[45] Patented **Jan. 12, 1971**

[73] Assignee **Shell Oil Company**
Los Angeles, Calif.
a corporation of Delaware. by direct and mesne assignment
Continuation-in-part of application Ser. No. 468,214, Nov. 12, 1954, now Patent No. 2,808,229, dated Oct. 1, 1957.

2,534,480	12/1950	Shannon.....	175/8
2,607,422	8/1952	Parks et al.....	166/5
2,653,009	9/1953	Ragland.....	166/187X
2,669,431	2/1954	Crowell.....	175/8
2,684,575	7/1954	Pryor et al.....	175/8X
2,690,344	9/1954	Allen.....	166/75X
2,691,272	10/1954	Townsend et al.....	175/8
2,765,850	10/1956	Allen.....	166/267
2,781,854	2/1957	Boer et al.....	166/187
2,783,027	2/1957	Gilbert.....	175/5
2,786,535	3/1957	Boer et al.....	166/142
2,808,230	10/1957	McNeill et al.....	175/7
2,829,716	4/1958	Stewart.....	166/98

FOREIGN PATENTS

160,865	4/1921	Great Britain.....	175/8
---------	--------	--------------------	-------

Primary Examiner—Marvin A. Champion
Assistant Examiner—Richard E. Favreau
Attorney—Christie, Parker & Hale

[54] **UNDERWATER WELLS**
14 Claims, 12 Drawing Figs.

[52] U.S. Cl..... **166/6,**
175/7

[51] Int. Cl..... **E21b 7/12,**
E21b 33/035

[50] Field of Search..... **255/2.5,**
51S; 166/75, 98, 47, 48, 49, 80, 75, 187; 175/5—8;
166/66.5

[56] **References Cited**

UNITED STATES PATENTS

962,019	6/1910	Flood.....	175/6X
1,691,715	11/1928	Hansen.....	175/10
1,766,628	6/1930	Grant.....	175/10
2,171,672	9/1939	Plummer.....	175/9X
2,187,871	1/1940	Voorhees.....	175/8
2,410,589	11/1946	Segelhorst.....	166/75X

CLAIM: Apparatus for completing a well drilled into a formation under a body of water comprising a casing in the well, means sealing the casing exterior to the formation, a buoyantly supported floating vessel, a tubular conduit, elongated guide means extending from the bottom of the water body to the surface, means maintaining lower extremity of the guide means in fixed relation to the casing, means for maintaining the upper extremity of the guide means in the region of the vessel, means for lowering the tubular conduit from the vessel in engagement with the guide means whereby the tubular conduit is constrained by the guide means to enter the casing as it is lowered, means for sealing the conduit and casing in fixed communicating relation below the water surface, and remote control means for actuating the said sealing means from the water surface.

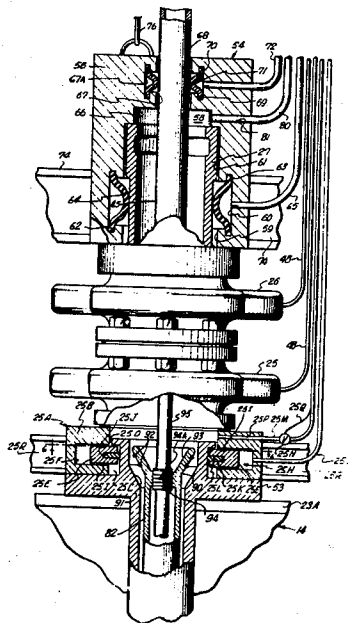
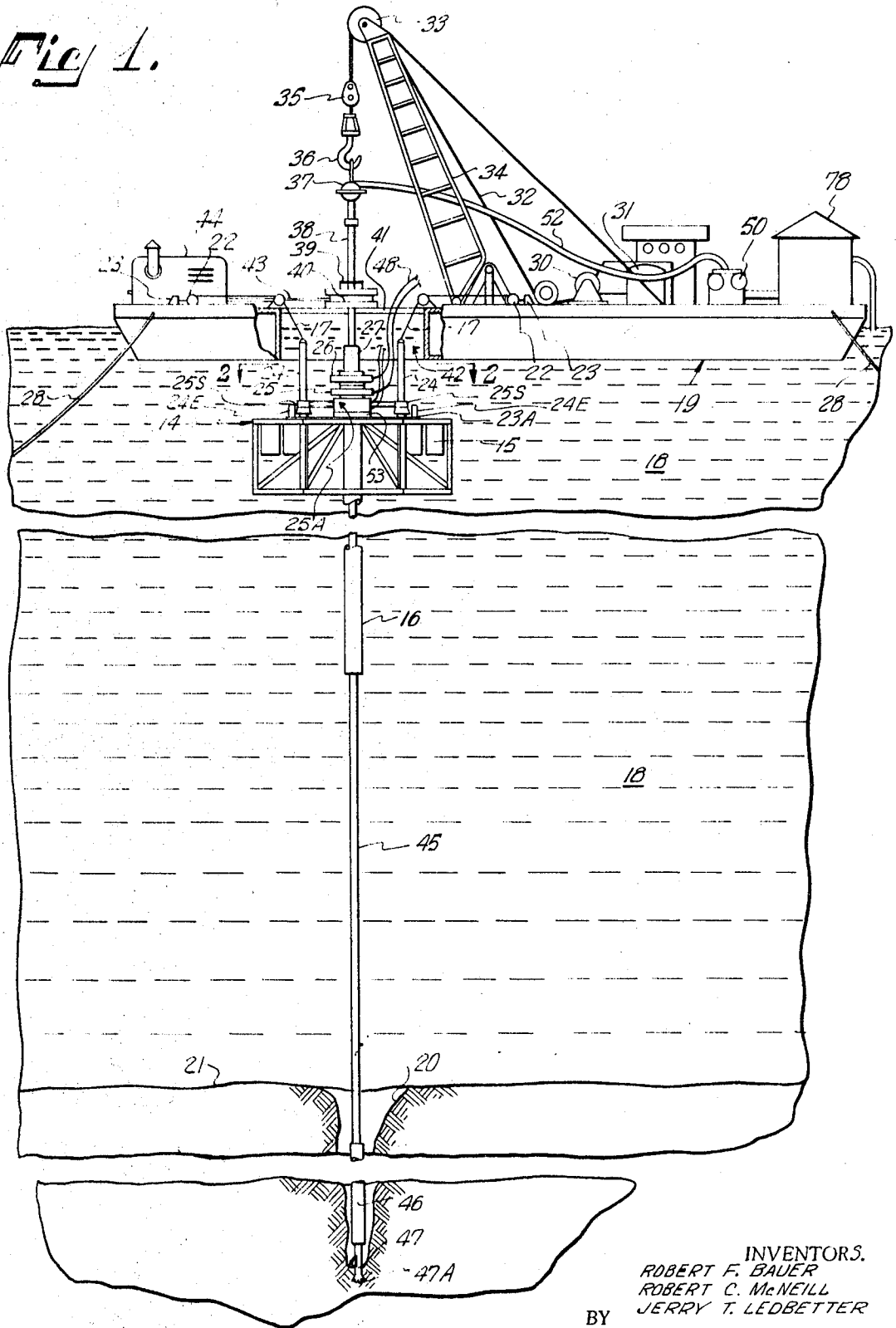


Fig. 1.



INVENTORS.
ROBERT F. BAUER
ROBERT C. McNEILL
JERRY T. LEDBETTER

BY
Christie, Park & Hale
ATTORNEYS.

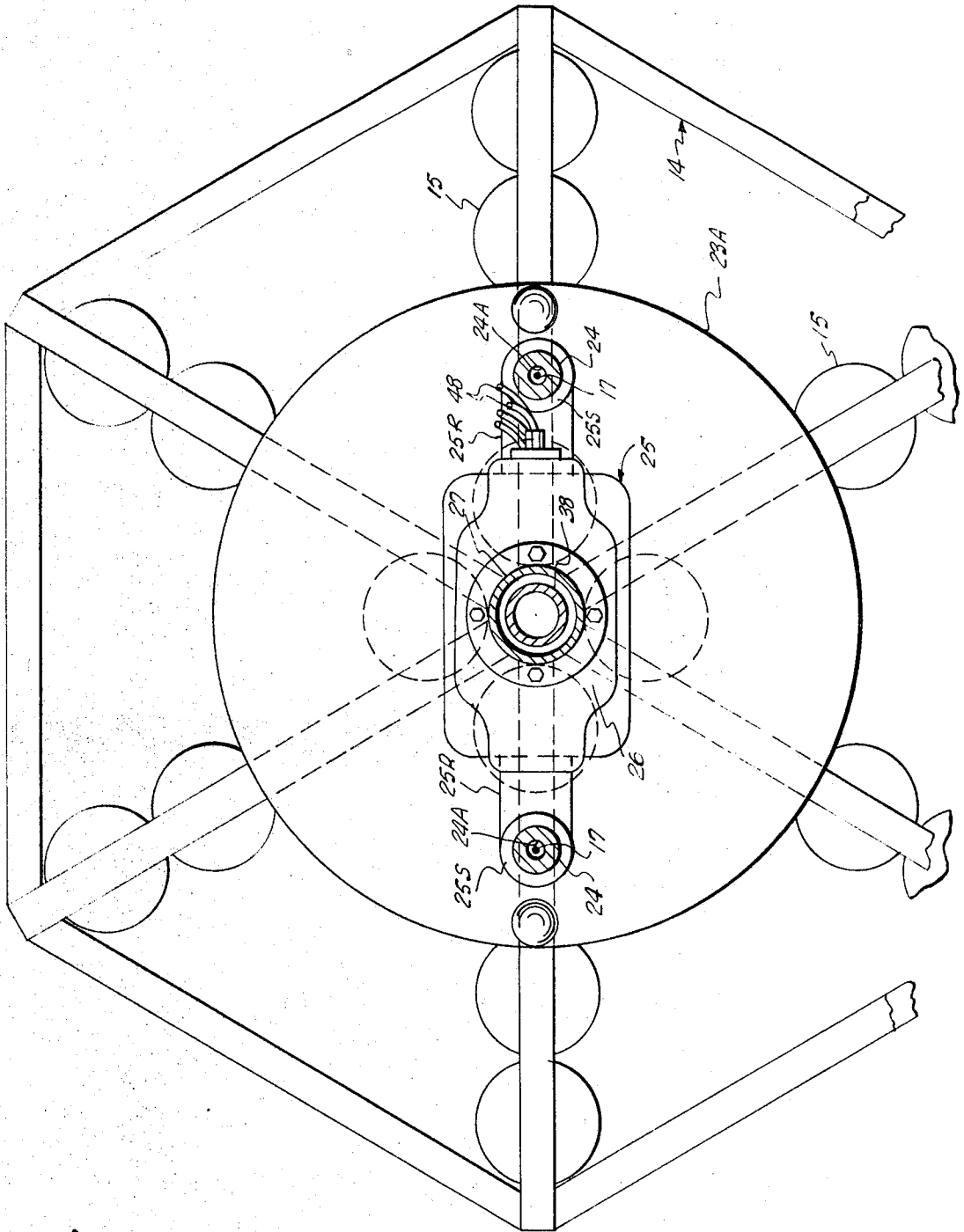
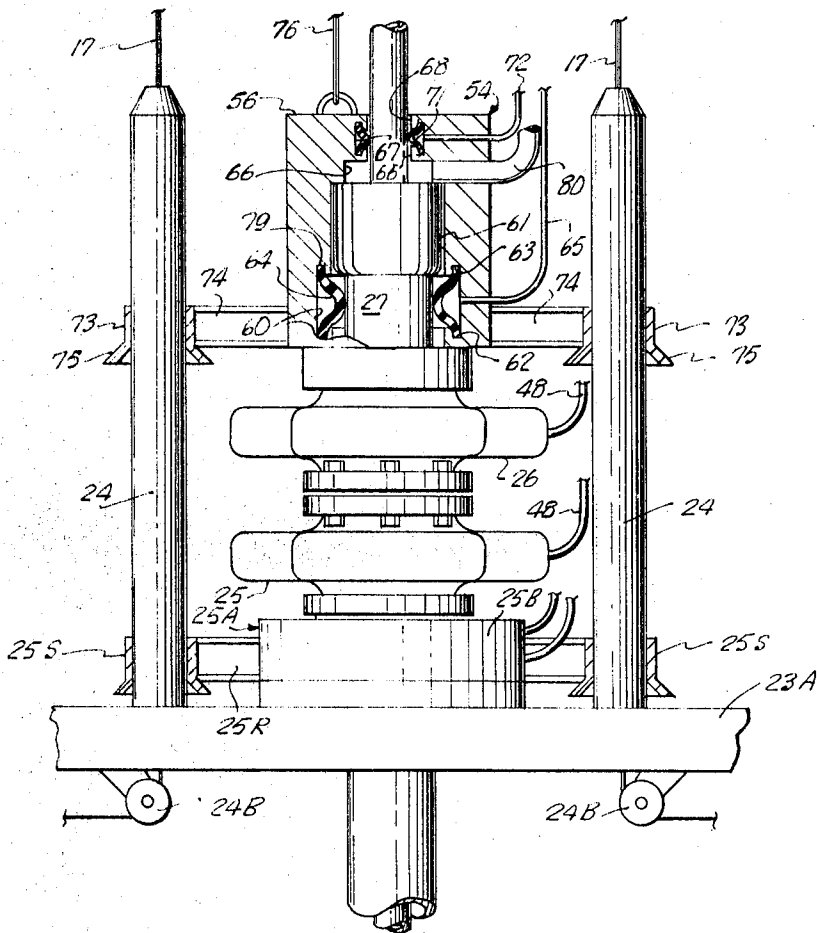


Fig. 2.

INVENTORS.
ROBERT F. BAUER
ROBERT C. McNEILL
BY JERRY T. LEDBETTER

Christie, Parker & Hale
ATTORNEYS.

Fig. 3.



INVENTORS.
ROBERT F. BAUER
ROBERT C. McNEILL
BY JERRY T. LEDBETTER

Christie, Pahn & Hale
ATTORNEYS.

Fig. 6.

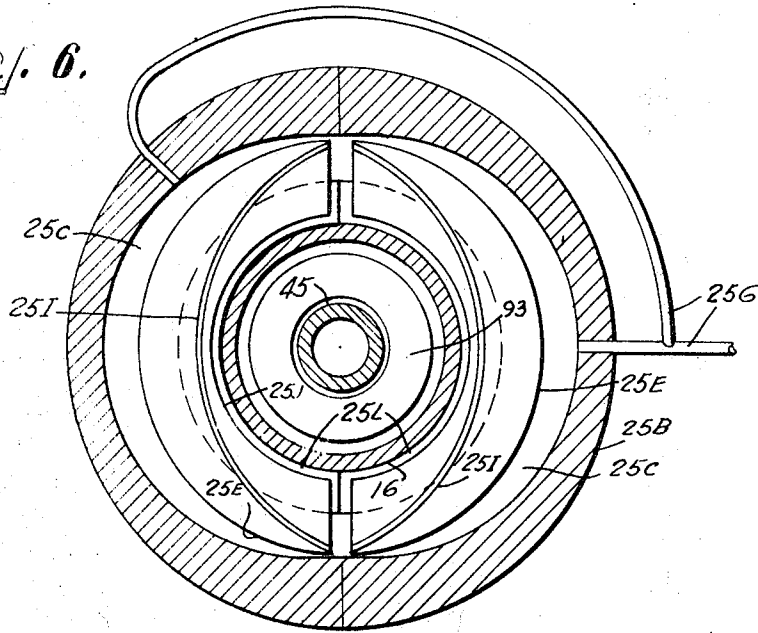
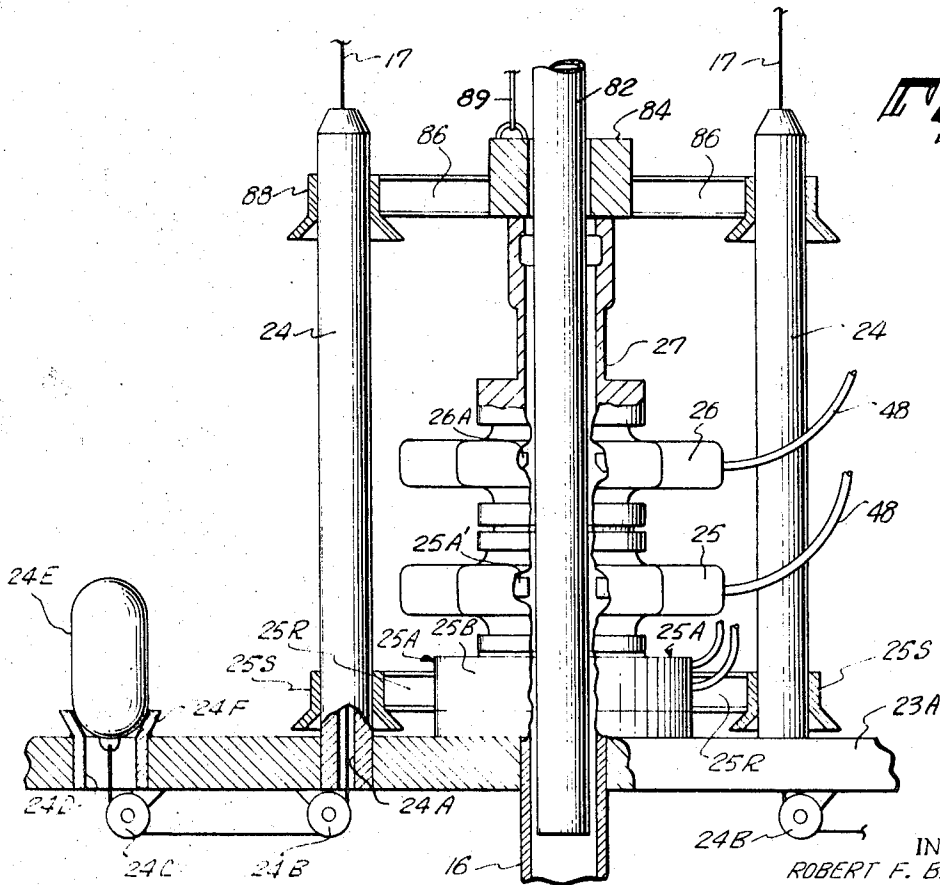


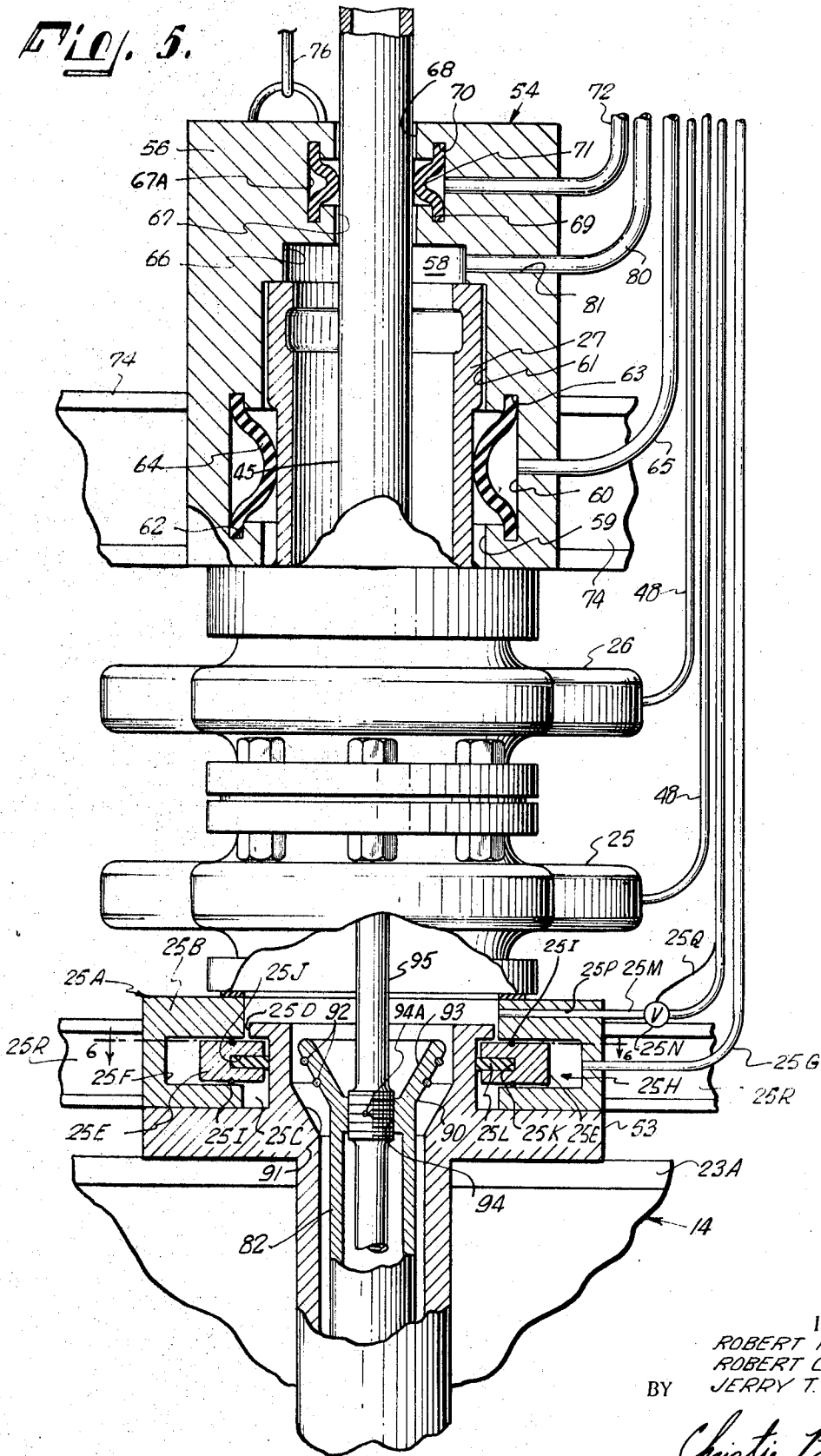
Fig. 4.



INVENTORS.
ROBERT F. BAUER
ROBERT C. McNEILL
BY JERRY T. LEDBETTER

Christie, Pucka & Hale
ATTORNEYS.

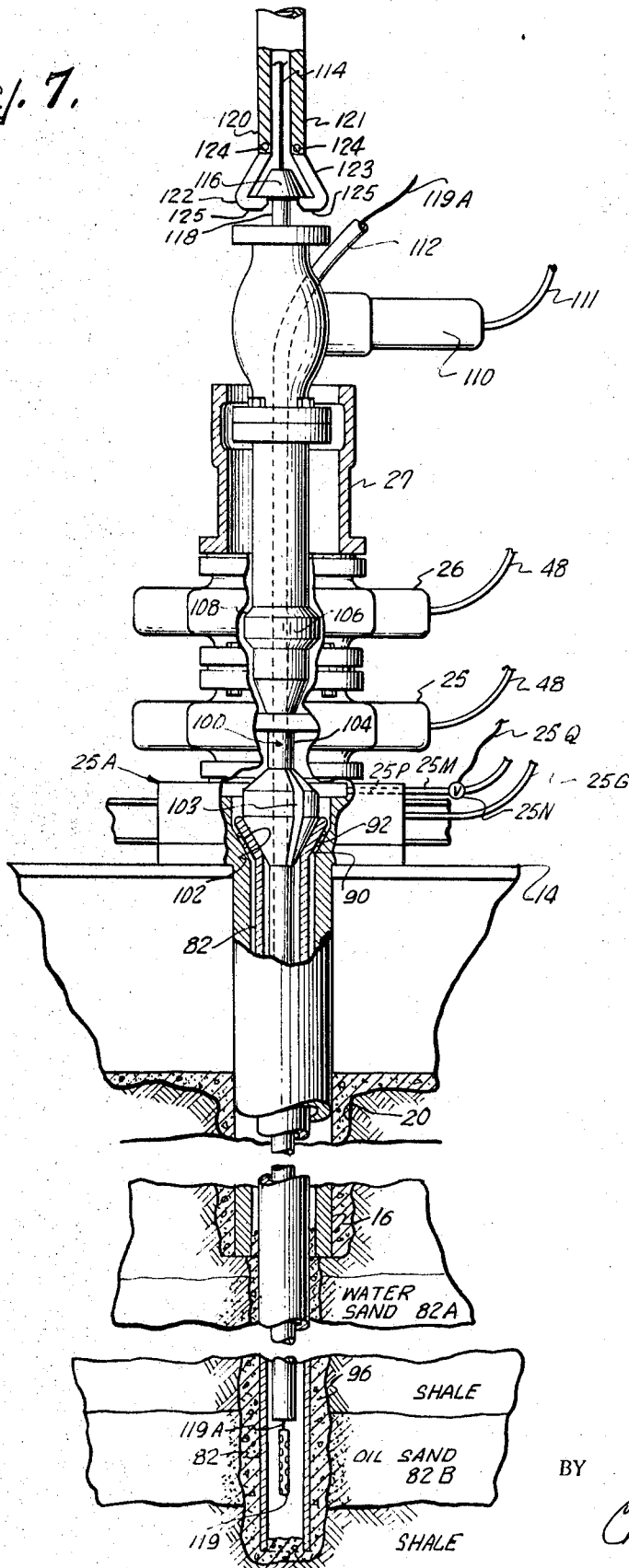
FIG. 5.



INVENTORS.
ROBERT F. BAUER
ROBERT C. McNEILL
BY JERRY T. LEDBETTER

Christie, Parker & Hale
ATTORNEYS.

Fig. 7.



INVENTORS.
ROBERT F. BAUER
ROBERT C. McNEILL
BY JERRY T. LEDBETTER

Christie, Parker & Hale
ATTORNEYS.

Fig. 8.

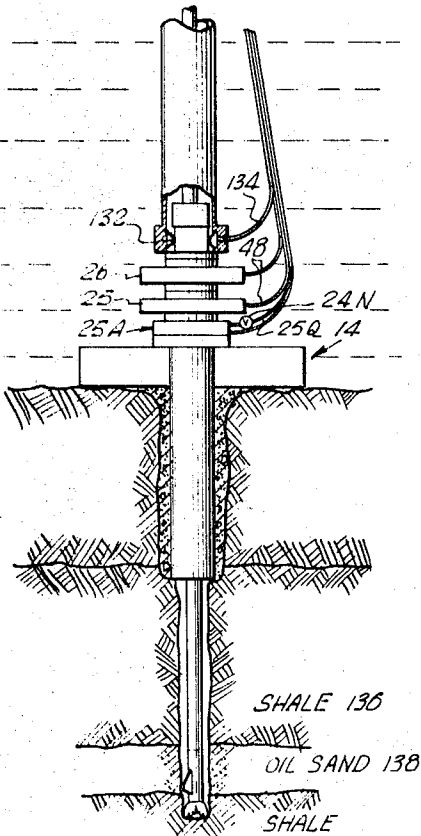
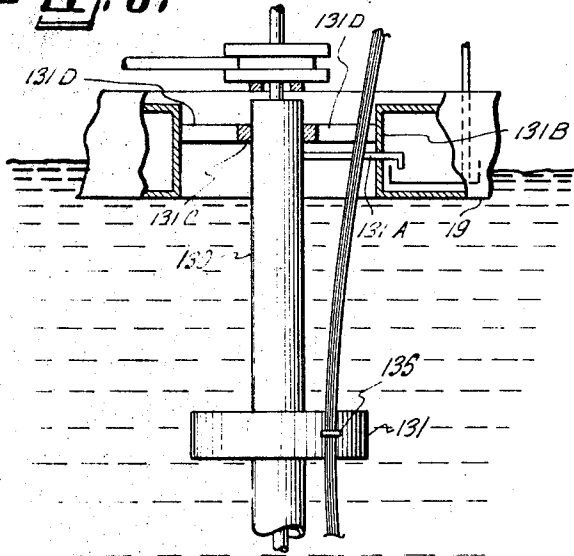
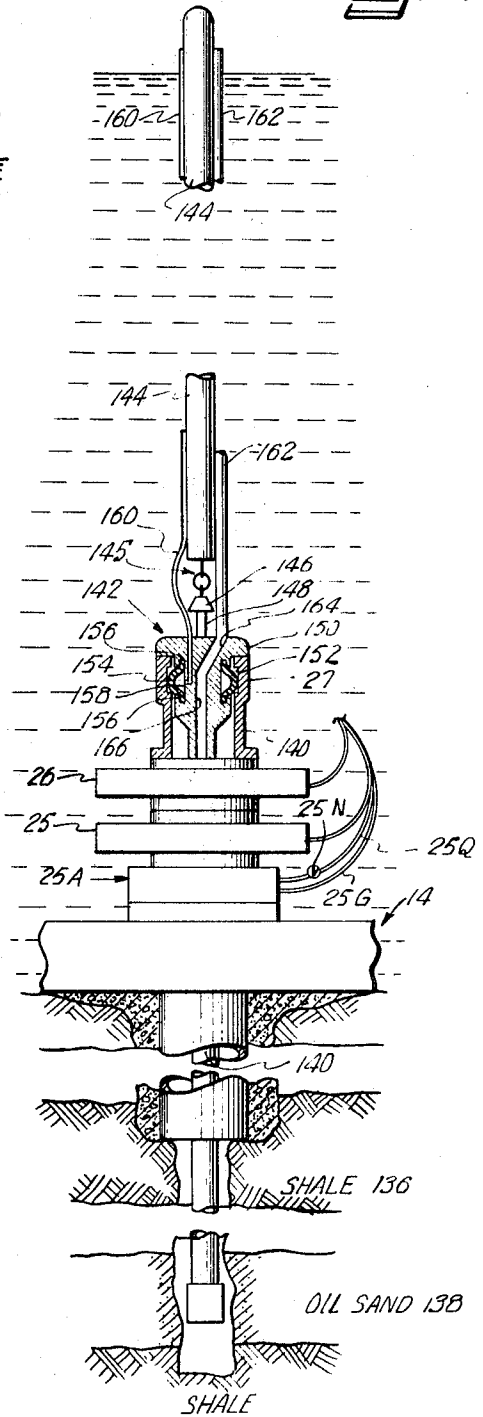


Fig. 9.



INVENTORS,
ROBERT F. BAUER
ROBERT C. McNEILL
BY JERRY T. LEDBETTER

Christie, Parker & Hale
ATTORNEYS.

FIG. 11.

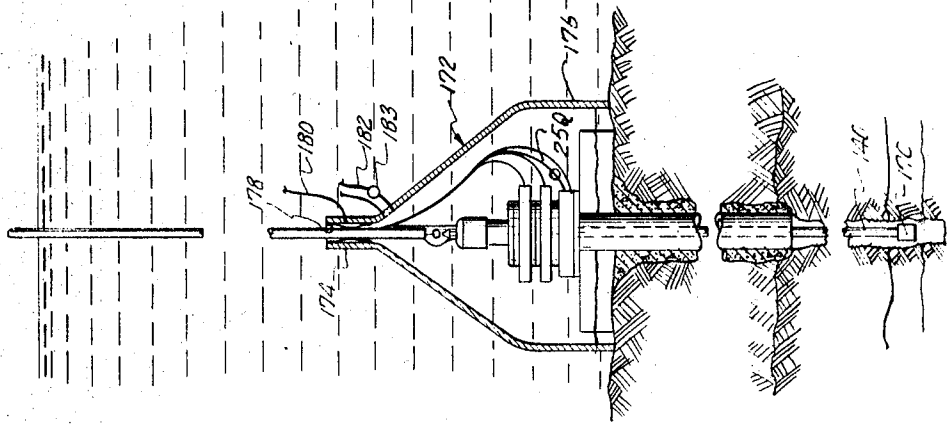
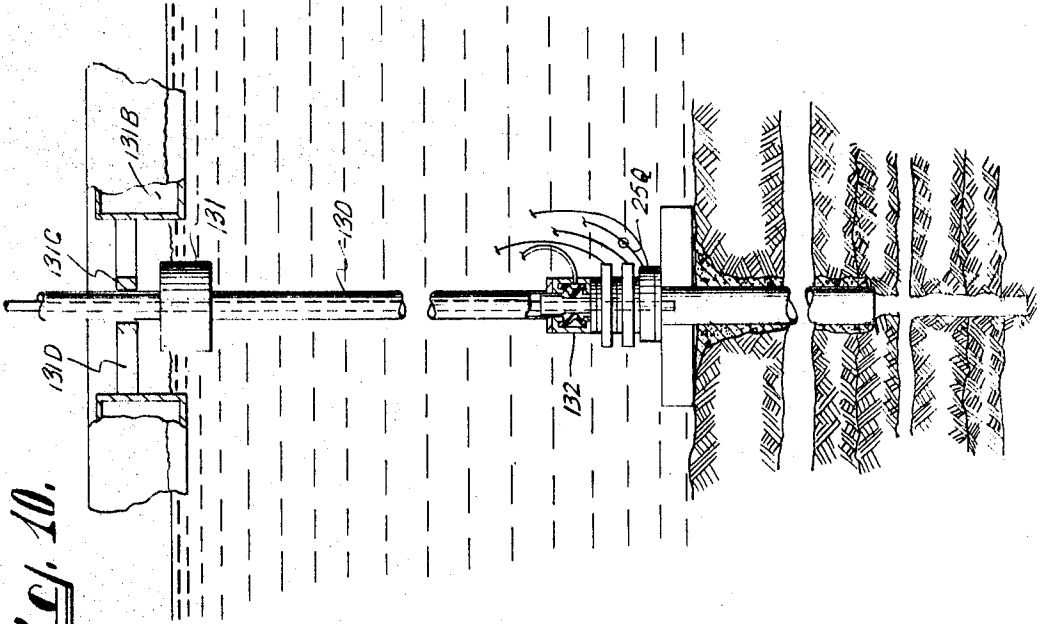


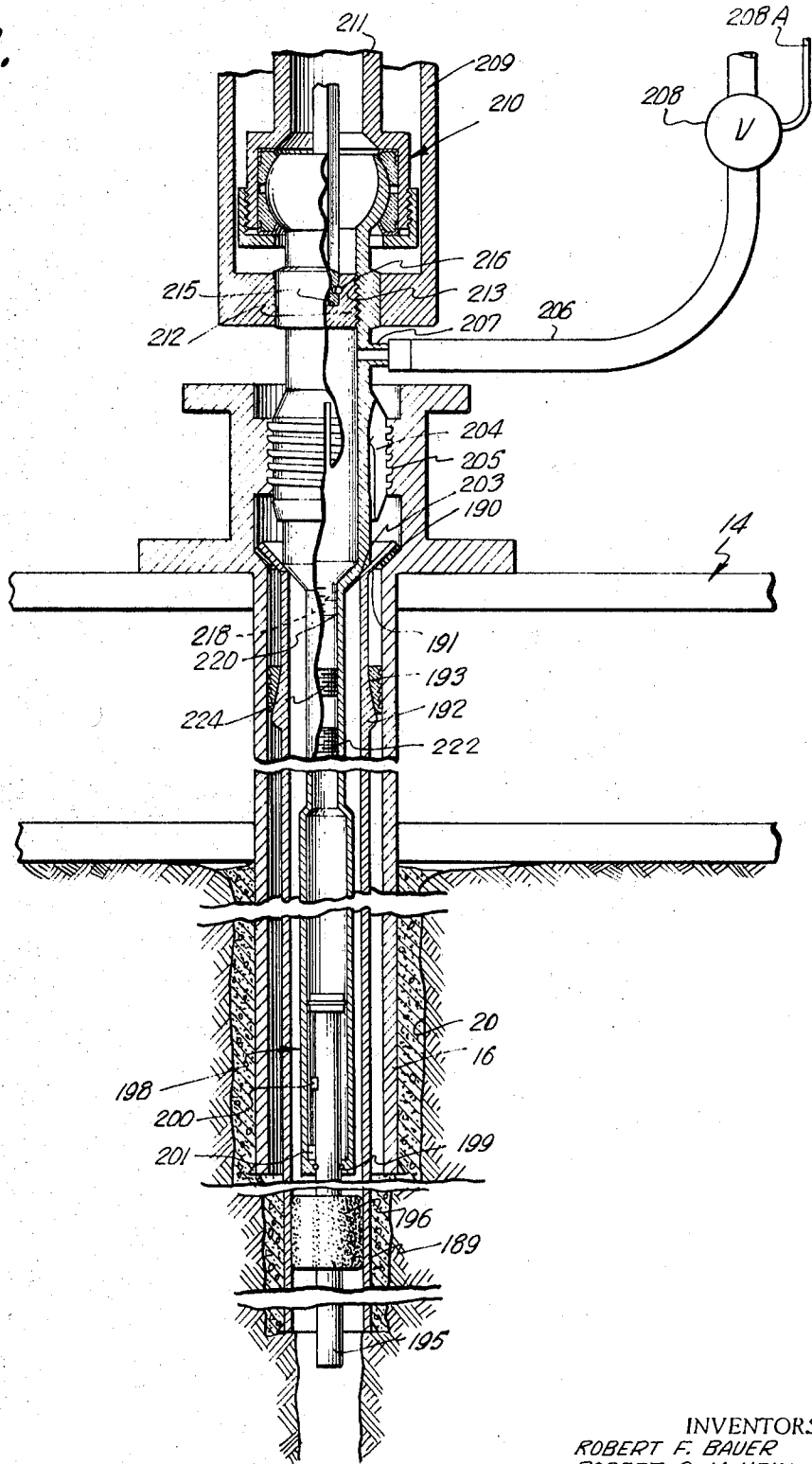
FIG. 10.



INVENTORS.
ROBERT F. BAUER
ROBERT C. McNEILL
BY JERRY T. LEDBETTER

Christie, Parker & Hale
ATTORNEYS

Fig. 10.



INVENTORS.
ROBERT F. BAUER
ROBERT C. McNEILL
BY JERRY T. LEDBETTER

Christie, Parker & Hale
ATTORNEYS.

UNDERWATER WELLS

This is a continuation-in-part of our copending application Ser. No. 468,214, filed Nov. 12, 1954 now U.S. Pat. No. 2,808,229, issued Oct. 1, 1957, and relates to underwater wells.

For the purpose of explaining the invention, the following description deals primarily with producing oil wells located under a body of water, although the invention is also applicable to other types of underwater wells, such as water and gas injection wells.

As the search for oil and gas in offshore locations moves to waters of increasing depth, the problem of drilling and completing underwater wells in relatively deep water becomes increasingly complex. At the present time, the underwater producing wells are drilled either from submersible barges in relatively shallow water, or from stationary platforms in the deeper water. In either case, the wells are completed by conventional methods so that the wellhead, Christmas tree, and other conventional equipment are located at or near the water surface. Such installations are not only sometimes impractical in relatively deep water, say depths of more than about 50 feet, but also present operational and navigational hazards.

This invention provides apparatus for drilling and completing wells below the water surface so that the wellhead equipment is located at the bottom of the water, or at least well below the water surface so as not to present a navigational hazard.

In terms of apparatus for drilling and completing a well in a formation under a body of water, the invention includes guide means extending between the underwater formation and the water surface for guiding equipment to a well drilled in the formation to a depth sufficient to penetrate a permeable stratum. A casing is sealed in the well. Using the guide means, a fluid conduit is guided to the casing, and means are provided for sealing the casing and the conduit below the water surface in fixed communicating relation.

In one form of the invention, the guide means are a pair of elongated and flexible guide lines anchored at their lower ends adjacent the upper end of the well and supported at their upper end at the water surface. Preferably, the lower portion of the guide lines are disposed over respective pulleys at the wellhead so that both ends of each guide line extend back toward the surface of the water to permit the ready replacement of the guide lines as required.

In another form, the guide means is an elongated conduit or conductor pipe which opens at its lower end into the well, and which terminates at its upper end at the water surface so equipment can be transferred between the rig and well through the conductor pipe.

In the preferred embodiment, the invention includes a production tubing extending down into the casing, and at least one blowout preventer attached to the casing and adapted to seal around the tubing and lock it in sealed relationship with the casing.

These and other aspects of the invention will be more fully understood from the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. 1 is a schematic elevation of a floating drilling rig drilling a well in an underwater formation;

FIG. 2 is a view taken on line 2-2 of FIG. 1;

FIG. 3 is a fragmentary schematic sectional elevation of wellhead circulation equipment used for return circulation of drilling fluid as the well is drilled;

FIG. 4 is a fragmentary schematic sectional elevation of apparatus for guiding a second string of casing into the well;

FIG. 5 is a schematic fragmentary sectional elevation of apparatus for cementing and landing the second string of casing in the well;

FIG. 6 is a view taken on line 6-6 of FIG. 5;

FIG. 7 is a fragmentary schematic sectional elevation of an underwater well completed with the production tubing in place;

FIGS. 8 and 9 are fragmentary schematic sectional elevations of an alternate arrangement for drilling and completing an underwater well without using guide lines;

FIG. 10 is a fragmentary schematic sectional elevation of apparatus used to work over an underwater well;

FIG. 11 is a fragmentary schematic sectional elevation of the well of FIG. 9 after the workover has been completed and a pump installed in the bottom of the well; and

FIG. 12 is a schematic sectional elevation of an alternate embodiment of apparatus for underwater well completion.

Referring to the drawings, FIG. 1 shows a wellhead base or anchor 14, including a plurality of buoyant compartments 15 and a downwardly extending surface casing 16 welded at its upper end to the top of the base, being lowered by a pair of guide lines 17 in a body of water 18 from a floating drilling barge or support 19 toward a well 20 being drilled from the barge in an underwater formation 21.

The upper end of each of the guide lines is wound on a respective winch 22 powered through a torque converter transmission 23 to keep the lines under a constant tension. The lower end of each line passes through a respective vertical guide post 24, welded at its lower end to a circular plate 23A (see FIG. 2) welded to the top of the wellhead base. The two guide posts are located in diametrically opposed positions on each side of the casing of the wellhead base. As shown more clearly in FIG. 4, each guide line extends down into a longitudinal bore 24A in its respective guide post, and passes out the bottom of the post outwardly over a first pulley 24B mounted on the underside of the plate 23A. Each line passes over a respective second pulley 24C and up through a sleeve 24D in the plate where it is connected to a counter buoy or releasable anchor 24E held down in an inverted frustoconical receptacle 24F at the upper end of sleeve 24D.

A first or lower blowout preventer 25 is connected to the upper end of a locking head or releasable barrel unit 25A, which is secured to the upper end of the wellhead base casing, which serves as a safety release joint mandrel. The lower blowout preventer has rams 25A' (see FIG. 4) adapted to close around 4½ inch pipe, such as drill pipe or tubing. A second or upper blowout preventer 26 is mounted on top of the first and has blind rams 26A (see FIG. 4) so that it can be closed when no pipe is in the casing. A tubular mandrel or receiver 27 is welded to the top of the second blowout preventer and is collinear with the casing.

The locking head includes an annular body 25B having a vertical bore 25C through it, which is of a diameter slightly larger than an outwardly extending lip 25D on the upper end of the casing. A pair of semicircular locking plates 25E are disposed in an internal annular groove 25F in the locking head body, and are adapted to be moved inwardly and outwardly through fluid pressure, say air, applied through a line 25G to the annular space 25H between the plates and the body interior. Arcuate gaskets 25I in the upper and lower surfaces of the plates make a sliding seal against the top and bottom of groove 25F, and the outer sides of the plates make a sliding seal against a pair of diametrically opposed straight sections 25F' in the groove 25F. The central portion of the inner edge of each plate has a semicircular cutaway portion 25J to match the outside diameter of the casing (see FIG. 6), and also has an internal groove 25K in which is disposed a semicircular sealing gasket 25L that makes a fluidtight seal around the casing when fluid pressure is applied through line 25G. The plates make a close sliding fit within the groove in the locking head body and make a similar fit under the casing lip so that the plates form a positive lock for the blowout preventers to the casing. A "kill" line 25M is connected through valve 25N to the interior of the locking head body through a horizontal bore 25P above the locking plates for a purpose which is explained below. The valve 25N is actuated through a line 25Q, which extends to the barge. A pair of brackets 25R extend outwardly from opposite sides of the locking head body and a separate guide sleeve 25S on the outer end of each bracket makes a slip fit around the lower portion of a respective guide

post. The locking head 25A and the lower blowout prevention 25 form a housing which can be operated to seal around the casing and around a tubular conduit, such as drill pipe or tubing.

As shown in FIG. 1, the barge is anchored over the well by a plurality of suitable anchor lines 28 extending in opposite directions from the barge and connected to anchors (not shown). A draw works 30 and a power unit 31, which may be of conventional type, are mounted on the barge deck to operate a hoisting cable 32 carried over a crown block 33 on the upper end of a derrick 34 mounted on the barge. The travelling end of the hoisting cable carries a travelling block 35 and a hook 36 which supports a swivel joint 37. A kelly joint 38 extends downwardly from the swivel through a kelly bushing 39 in the center of a rotary table 40 mounted on gimbals in a manner similar to that described in U.S. Pat. No. RE 24,083. The rotary table is supported on a platform 41 directly over a cellar 42, which is located on the centerline of the barge and opens out the bottom of the barge. Power is supplied to the rotary table through a shaft 43 turned by a rotary table power unit 44.

A string of drill pipe 45 is connected to the lower end of the kelly joint and extends down through the cellar, the receiver, the open blowout preventers, the locking head, the casing, the water and into the well. Drill collars 46 and a blade-type underreamer 47 with a drill bit 47A on its lower end are attached to the lower end of the drill pipe for boring the well to a diameter slightly larger than the outside diameter of the wellhead base casing. The blowout preventers are actuated through control lines 48 which extend from the preventers to the barge.

Drilling as illustrated in FIG. 1 is carried out as follows:

The wellhead base is either towed or carried on the barge to the desired location, and the barge is firmly anchored over the well site. The supporting lines are connected through the guide posts to the counter buoys, and the wellhead base is launched into the water, if carried on the barge.

The upper ends of the guide lines being controlled from the barge, the wellhead base compartments are flooded, say by puncturing the walls of some of the buoyant compartments, until the base has a slight negative buoyancy. The base is then maneuvered into the position shown in FIG. 1, i.e., directly under the cellar of the barge, where it is held by the lines at a shallow depth. The upper ends of the lines are connected to the winches as shown in FIG. 1. The drill bit, underreamer, drill collars, and drill pipe are made up on the barge and lowered through the receiver, the blowout preventers, the locking head, and the casing. Drilling is begun, sea water being circulated by a pump 50 through a mud hose 52 connected to the swivel, and out the drill bit to wash cuttings up out of the hole, no attempt being made to obtain return circulation of drilling fluid at this time. Drilling continues in this fashion until a sufficient depth is reached to permit the casing to be stripped down over the drill pipe into the well and allow the bottom of the wellhead base to rest on the ocean floor.

For operation in areas where the water depth is less than the overall length of the desired amount of casing and the wellhead base, a slightly different procedure is used. The base is maneuvered into the position shown in FIG. 1 without the casing, locking head, blowout preventers, and receiver. A joint of casing is inserted in the opening of the base and supported by suitable means from the barge so that the lower end of the casing is flush with the bottom of the base. The casing and base are lowered simultaneously, successive joints of casing being added as required, until the base is resting on the bottom, and the upper end of the casing extends up into the barge above the water level. Using a salt water without return circulation, sufficient hole is drilled with the bit and underreamer to receive the desired amount of casing. Salt water is then displaced with drilling mud to keep the hole open, and the bottom of the casing is lowered a few feet into the upper end of the hole. The drill pipe is withdrawn from the hole and casing, and the remainder of the casing is then run down into the hole,

additional joints of casing being added as required. The locking head, blowout preventers and receiver are secured to the upper end of the casing, and the lower end of the drill pipe is disposed within the upper end of the casing so that it extends down below the blowout preventers. The blowout preventers are then closed around the drill pipe, and the upper end of the casing is lowered by means of the drill pipe so that the locking head guide sleeves slide down the guide lines onto the posts until an outwardly extending flange 53 formed integrally near the upper end of the casing rests on the plate 23A on top of the wellhead base.

The casing is cemented in place by pumping cement down through the drill pipe and forcing the cement into the annular space between the casing and the hole. The cement is followed by drilling mud which displaces the cement from the upper portion of the casing to a point below the drill bit. The cement is then allowed to set. The drill bit may either be removed immediately or drilling may proceed to such a depth that it is necessary to replace the bit or provide for return circulation of drilling mud to support the walls of the well bore. At this point it is necessary to have apparatus which permits equipment to be guided accurately to and from the well bore. Such apparatus is shown in FIG. 3.

Referring to FIGS. 3 and 5, a circulating head 54 includes a cylindrical body 56 having a central vertical opening 58 extending through it. Beginning at the bottom of the circulating head, the lower portion of the central opening includes a first relatively short bore 59, followed by a second bore 60 of increased diameter, which is in turn followed by a third bore 61 of the same diameter as the first bore. An upwardly opening annular groove 62 is formed in the shoulder between bores 59 and 60, and a downwardly opening groove 63 is formed in the shoulder between bores 60 and 61. A flexible receiver sealing sleeve 64 is molded at opposite ends into grooves 62 and 63. The sleeve is adapted to be expanded into sealing contact against the receiver when the circulating head is in the position shown in FIG. 3 by fluid pressure applied through a line 65 connected to the annular space between sleeve and bore 60 and to a source of fluid pressure (not shown) on the barge.

Third bore 61 is followed by a fourth bore 66 of smaller diameter, which in turn is followed by a fifth bore 67 of yet smaller diameter, a sixth bore 67A of increased diameter, and then by a final bore 68 of a diameter equal to that of the fifth bore. An upwardly opening annular groove 69 is formed in the shoulder between bores 67 and 68, and a downwardly opening annular groove 70 is formed in the annular shoulder between bores 67A and 68. A flexible drill pipe seal sleeve 71 has its ends molded in grooves 69 and 70. The drill pipe sealing sleeve is forced against the drill pipe to make a seal against the pipe by means of fluid pressure applied through a line 72 connected to the annular space between the sleeve and bore 67A and to a source of fluid pressure (not shown) on the barge.

The circulating head is adapted to be guided up and down the guide lines by a pair of guide sleeves 73 attached by I-beam brackets 74 on opposite sides of the circulating head. As can be seen most clearly in FIG. 3, the guide sleeves are adapted to make a sliding fit over the guide posts and have frustoconical skirts 75 on their lower ends to facilitate mating with the upper ends of the guide posts, which are chamfered. The guide posts each extend a substantial distance above the upper end of the receiver so that as the circulating head is lowered, the guide sleeves slip on the posts and align the opening of the circulating head with the receiver before the bottom of the circulating head reaches the upper end of the receiver.

To obtain return circulation with the circulating head of FIG. 3, it is lowered by a line 76 down the drill pipe toward the position shown in FIG. 3, the guide sleeves first being slipped over the guide lines on the barge. When the bottom of the circulating head rests on the top of the upper blowout preventer, pressure is applied through line 65 to seal the circulating head to the receiver. Pressure is also applied to the drill pipe seal through line 72 sufficient to prevent leakage of drilling fluid and yet permit rotational and longitudinal movement of the

drill pipe in the seal. Drilling mud is circulated from a mud tank 78 (see FIG. 1) on the barge through the mud hose, kelly joint, drill pipe, out the lower end of the drill bit, up the annular space between the drill pipe and the well, back to the circulating head, out a lateral mud return conduit 79 in the circulating head, and back to the mud pit through a mud return line 80 connected at its lower end to a horizontal bore 81 which opens into the circulating head above the receiver seal.

Drilling is continued until such time that a string of protective or secondary casing 82 must be set, say to shut off a water sand 82A from an oil sand 82B penetrated by the well.

The apparatus of FIG. 4 shows how a string of secondary casing 82 is started into the well. The circulating head is released from the well by removing the fluid pressure from lines 65 and 72, and is raised to the surface by line 76, or else is raised to the surface by lifting the drill pipe so that the drill bit moves up into the circulating head and engages the shoulder between bores 66 and 67 to lift the circulating head to the surface.

With the drill pipe out of the well, and drilling mud still in it, the lower end of the secondary casing 82 is disposed in a tubular casing guide 84 which has a pair of outwardly extending bracket arms 86, each of which has a respective guide sleeve 88 on its outer end adapted to slide down the guide lines and on to the guide posts as shown in FIG. 4. Thus, the casing and casing guide are lowered together so that the lower end of the casing is within the guide and brought into collinear alignment with the receiver as the guide seats on the receiver. The casing is then slipped down through the casing guide and receiver into the well, the upper end of the casing being supported from the barge. Once the casing is started into the well, the casing guide is raised by a line 89 attached to it. Lowering of the casing into the well is continued, additional sections of casing being added as required.

As shown in FIG. 5, the uppermost section of the protective casing string includes an outwardly and upwardly extending external landing seat 90 on its upper end, which is adapted to rest on a matching landing seat 91 in the conductor pipe just below the first blowout preventer. The external seat of the secondary casing includes a series of O-rings 92 to effect a fluidtight seal against the first casing. The upper end of the secondary casing string includes an outwardly and upwardly extending internal seat 93 to support a string of tubing as described in detail below. The upper end of the protective casing string also includes an internally threaded section 94 of left-hand threads, which receive matching external threads 94A of an adapter 95 made up in the string of drill pipe. Thus, when the uppermost section of casing is added to the protective casing string at the barge, a short section of drill pipe is lowered into the upper end of the casing, hollow adapter 95 is connected in the drill string, and additional sections of drill pipe are coupled above the adapter. The adapter is screwed into the casing, and the casing is lowered to the position shown in FIG. 5 by adding on additional sections of drill pipe and lowering the entire assembly on the drill pipe. The circulating head is then made up over the drill pipe and lowered to the position shown in FIG. 5 and sealed to the mandrel and around the drill pipe. If necessary, mud is circulated through the well to clean out the well and place the mud in proper condition for cementing the secondary casing in place. Cement is then pumped down the drill pipe to force drilling fluid out of the annular space between the second string of casing and the well bore. Preferably, the casing is moved up and down with the drill pipe to insure uniform distribution of the cement. After the required amount of cement is pumped into the well and properly placed by displacement with mud, the casing is lowered to the position shown in FIG. 7 so that its external seat rests on the internal seat of the conductor. The drill pipe is then rotated to unscrew the adapter from the casing, and the drill pipe is withdrawn. Although only one protective string has been shown as necessary to reach the oil producing sand to simplify the explanation of the invention, as many protective strings as required may be set by following the foregoing procedure.

After the cement has set in the position shown in FIG. 7, the lower end of a tubing 100 is lowered into the upper end of the casing 82 in the well 20 by using a guide device similar to that shown for the casing in FIG. 4. The upper end of the tubing has an external seat 102 adapted to rest on the internal seat of the protective secondary string of casing. A vertical groove 103 in the tubing seat provides communication between the locking head interior above the tubing seat and the annular space between the tubing and casing. The tubing includes a short section of pipe 104 just above its seat around which the rams of the lower blowout preventer are adapted to close and seat. Just above the section 104, the tubing includes a section 106 of enlarged diameter having upwardly and inwardly sloping shoulders 108 against which the blind rams of the upper blowout preventer bear when the upper preventer is closed. The under surface of the inside edges of the blind rams are tapered to match the slope of tubing shoulder 108.

A control valve 110 actuated by a control line 111 extending to the barge is on the upper end of the tubing, and a flow line 112 extends from the valve to the water surface, either to the shore line or to a floating island (not shown) on which the oil produced from the well is collected, separated, and then pumped to bulk storage.

The tubing is lowered to the position shown in FIG. 7 by a line 114 connected to the upper end of a frustoconical boss 116 mounted on a lifting post 118 welded to the top of the tubing valve 110. Once the drilling barge leaves the well site, line 114 is buoyed at its upper end so that the well may be easily relocated for further service as required. The blowout preventer rams are closed by their respective control lines, which are also buoyed along with the valve control line at the water surface after the barge leaves the well site. Preferably, the guide lines are carried away from the well a suitable distance and held there by anchors (not shown) to prevent fouling with the other lines.

After the tubing is placed as shown in FIG. 7, the drilling mud is displaced from the well by pumping a lighter fluid such as oil or gas down line 25M and into the annular space between the tubing and secondary casing. A gun perforator 119 suspended from the tubing by a line 119A is used to perforate the casing and cement to the producing formation. After the perforating operation, the gun is withdrawn to the barge by line 119A. Line 25M is closed by valve 25N and oil flows from the sand up the tubing and line 112. Thus, the tubing 100, valve 110, and flow line 112 form well completion equipment releasably engaged with the casing 82 in the well 20.

Any time the tubing needs to be removed, for example to permit working over the well, the barge is anchored over the well site again, and the various buoys and lines are picked up and mounted on the barge as described previously. If necessary, the well is killed by pumping a heavy fluid into it. The blowout preventers are opened, and a tubing pulling tool 120 comprising an elongated tubular body 121 and a latch 122 on the lower end of the body is lowered down over tubing line 114 so that the latch engages the projection on boss 116 as shown in FIG. 7. The latch includes a pair of diametrically opposed and downwardly extending fingers 123 secured by separate respective horizontal pivot pins 124 at their upper ends to the lower end of the body 121 to pivot about pins 124. The lower end of each finger includes an inwardly extending catch 125 which is forced outwardly as the latch slides down over the boss 116 until the catches are below the bottom of the boss and drop to the position shown in FIG. 7. The tubing is then lifted out of the well by raising the tubing puller. After the necessary remedial work is completed, the well is recompleted as described above.

In some cases, it is preferable to drill and complete an underwater well without using guide lines as described above, and FIGS. 8 through 11 show method and apparatus for such an operation. In this case, the wellhead base, casing, blowout preventers and locking head are landed and cemented in place as previously described. However, instead of using a circulating head, a conduit or marine conductor 130 is located on the

mandrel by stripping the conduit down over the drill pipe, which extends from the drilling barge into the mandrel. A buoyant chamber 131 is attached to the upper portion of the conduit below the water surface and provides support for the conduit. A lateral mud conduit 131A carries mud to a mud pit 131B. The upper end of the conduit is centered in the cellar of the barge by a stabilizing ring 131C supported by a spider 131D secured to the sides of the cellar in the barge. The lower end of the conduit includes an internal seal 132 (FIG. 8), similar to the locking head seal, and it is adapted to be actuated by fluid pressure through line 134 so that the lower end of the conduit can be locked and sealed to the mandrel as shown in FIG. 8. The various control lines coming from the wellhead are secured by a clamp 135 to the buoyant chamber. To simplify the explanation of the invention, it is assumed that the wellhead base casing is of sufficient length to give the desired support to the well, and that the formation below the wellhead conductor is competent to permit an open hole completion. Of course, additional string of casing can be set through the conductor, if required.

The well is drilled through a layer of shale 136 into an oil sand 138. With drilling mud in the well to prevent oil flow, the drill pipe is removed from the well, and a tubing 140 (see FIG. 9) is started down into the well through the surface conduit and supported from the drilling barge. Additional lengths of tubing are made up and lowered in the well until the upper end of the tubing is reached. A tubing head 142 is made on to the upper end of the tubing and lowered on to the position shown in FIG. 9 by a buoyant tubing post 144 connected at its lower end through a swivel joint 145 to a frustoconical projection 146 mounted on the upper end of a post 148 welded to the top of the tubing head.

An outwardly extending flange 150 on the upper end of the tubing head is adapted to rest on the upper end of the receiver which has an internal annular groove 152 to receive a sealing sleeve 154 molded at each end into downwardly and upwardly opening respective annular grooves 156 at each end of an annular groove 158 around the tubing head. Fluid pressure is applied to the interior of the tubing seal through a line 160 which opens into the annular space between the tubing seal and the tubing head. A flow line 162 is connected to a diagonal bore 164 in the top of the tubing head which opens at its lower end into a vertical bore 166 which in turn opens its lower end into the tubing. The maximum outside diameter of the tubing head is the same as the maximum outside diameter of the receiver so that the tubing and its head can be lowered inside the conduit 130.

With the tubing in the position shown in FIG. 9, the tubing seal is actuated through line 160 to seal the tubing head to the interior of the receiver. Preferably, the tubing has an enlarged projection (not shown) similar to that of the tubing shown in FIG. 7 so that the blind rams of the upper blowout preventer can be closed against it to serve as a positive hold down, and the portion of the tubing adjacent the rams of the lower blowout preventer is of such a diameter that the rams of the lower blowout preventer make a fluidtight seal against it when closed. Mud is displaced from the well through flow line 162 by pumping a light fluid such as oil and gas down line 25M, through valve 25N, and into the locking head. When the hydrostatic head of the fluid in the well is sufficiently reduced, the pressure of the oil in the oil sand causes oil to flow up the tubing and out flow line 162, where the oil is collected and stored by any suitable means (not shown). Valve 25N is then closed to shut in line 25M.

Once the well is completed as shown in FIG. 9, conduit 130 is removed and the control lines are disconnected from the barge and buoyant chamber, sealed, buoyed and cast off with the exception of the control line 134 for the conduit seal, which is removed with the conduit from the well. Thus, the location of the underwater well is marked by the buoyant tubing post which has a smooth exterior surface that is not readily fouled by fishing nets. Flotsam jetsam, kelp, etc.

If it should be necessary to work over the well, say to install a pump, the barge is returned to the position shown in FIG. 10, and the tubing is raised either by the tubing post or else by a tubing puller as previously described with respect to FIG. 7. If necessary, the well is killed by the injection of a heavy "kill" fluid. The conduit 130 is either stripped down over the tubing post, before the tubing is lifted from the well, or else is stripped down over the tubing after the tubing has been partially removed from the well. Once the conduit seal is around the receiver, it is sealed in the position shown in FIG. 10. All of the tubing is then withdrawn to the surface, and a pump 170 (see FIG. 11) which may be of conventional type, is assembled on the lower end of the tubing, which is then lowered back into the well through the conduit. Additional sections of tubing are added at the barge and the tubing is again seated as shown in FIG. 9. Once the tubing is sealed in the well, the surface conduit is removed and the pump is placed in operation so that the well is now a pumping well instead of a flowing well. If the well was killed by heavy fluid prior to the setting of the pump, the "kill" fluid is removed by the application of a lighter fluid through line 25Q as previously described.

FIG. 11 also shows apparatus for protecting the wellhead equipment from deterioration such as rust and barnacle attachment while under water. A frustoconical envelope 172 having a neck 174 opening out of its upper end and a cylindrical skirt 176 projecting down from its lower end is slipped down over the buoyant tubing post and various control lines which extend up through the neck of the envelope. The skirt of the envelope rests on the ocean bottom around the wellhead base. An elastic sleeve 178 is secured at each end to the interior of the envelope neck and a line 180 supplies fluid pressure to the annular space between the neck and sleeve 178. Thus, the sleeve 178 can be forced to effect a fluid tight seal around the buoyant posts and control lines. A suitable protective fluid such as gas, oil, or even water with a suitable inhibitor dissolved in it, is pumped down through the envelope through a line 182 and check valve 183 to displace the sea water at least down to a level below the top of the wellhead base. Thus, the wellhead equipment is protected from barnacles, corrosion, and other adverse effects of the underwater environment.

If one of the wells shown in the drawings is to be permanently abandoned, the well is filled with cement (not shown) or otherwise suitably shut in, and the drill pipe withdrawn. Pressure is released from the blowout preventer locking head through line 25G so that the conductor, blowout preventers, and locking head can be lifted from the casing. As shown most clearly in FIG. 5, when the pressure in line 25G is reduced, the hydrostatic head of water pressure forces the locking plates outwardly so that the locking head can be lifted from the casing. If the hydrostatic head of water is not sufficient to retract the locking plates, additional pressure may be applied through the kill line 25M and valve 25N to the interior of the locking plates, the blowout preventers being set to shutoff communication with the circulating head, or conduit 130. The kill line has the additional function of permitting a heavy fluid to be pumped down into the well in the event of a threatened blowout and when the well is shut in by the blowout preventers.

If the well is not to be permanently abandoned, but the blowout preventers require replacement or repair, a drill pipe or other suitable guide is left in the well, and the locking head is released from the casing so that the circulating head or conduit 130, blowout preventers, and locking head can be lifted, say, with the draw-works, to the barge over the drill pipe. After the necessary repairs or replacements have been made, the locking head, blowout preventers, and circulating head or conduit 130 are stripped back down over guide means such as the drill pipe, or guide lines, if used, and into the sealing position shown in FIGS. 5 or 11.

An alternate embodiment of apparatus for underwater well completion is shown in FIG. 12 in which the well base and surface casing are landed in the well by any suitable technique,

say as shown in FIG. 8. An oil string casing 189 is landed on a heavy elastic gasket 190 on an internal seat 191 in the receiver as described previously with respect to FIGS. 4 and 5. The oil string casing of FIG. 12 includes an outwardly and downwardly extending external protuberance 192 a short distance below its upper end. A set of slips 193 are disposed on the protuberance and adapted to engage the interior of the surface casing and prevent upward displacement of the oil string. As the oil string of FIG. 12 is seated in a manner similar to that described with respect to FIG. 5, the upper end of the oil string is subjected to a reciprocating motion to drive and pound the slips as far down inside the surface casing as possible. The gasket 190 absorbs some of the shock and effects a tight seal between the internal landing seat in the receiver.

After the casing is cemented in place, as previously described, a production tubing 195 is lowered into the well through the conduit (not shown in FIG. 12) sealed to the receiver (not shown in FIG. 12) and extends to the drilling barge (not shown in FIG. 12). The lower end of the tubing includes a production packer 196 which may be of the conventional type and which is adapted to be set by rotation of the tubing and the application of tubing weight. The tubing includes a slip joint 198 above the packer, and the lower portion of the tubing is adapted to rotate and slide longitudinally through a seal 199 in the lower end of the slip joint. An external dog 200 on the portion of the tubing in the slip joint is adapted to engage an internal dog 201 at the lower end of the slip joint. Thus, as the tubing is lowered into the well, the external dog rests on the bottom of the slip joint so the two dogs are engaged. The packer makes a loose sliding friction fit against the casing, and when lowered to the desired location, is set by rotation of the tubing. The packer is then set hard by lowering the upper end to the tubing to place the weight of the lower portion of the tubing on the packer. This also disengages the dogs.

The upper portion of the tubing includes an external landing seat 203 adapted to land on the upper end of the oil string casing. A plurality of outwardly and downwardly extending fingers 204 with left-hand threads are attached to the tubing exterior above its landing seat and engage an internally threaded sleeve 205 in the receiver interior. Thus, as the upper end of the tubing is lowered after the packer is set, the fingers are deflected inwardly and slip down through the internally left-hand threaded sleeve until the tubing lands on its seat. The fingers then spring outwardly to engage the threaded sleeve and hold the tubing down in the well. Preferably, the tubing is landed with the well full of a heavy drilling fluid so the annular space between the tubing and oil string above the packer is filled with the fluid, thereby adding to the force tending to hold the tubing and oil string down in the well against formation pressure.

When desired, the tubing then is released by rotating it in a right-hand direction to disengage the left-handed thread, thereby avoiding having to turn the tubing in a left-hand direction, which might accidentally uncouple the tubing. The packer is unseated as the upper end of the tubing is raised to cause the slip joint to take the weight of the lower portion of the tubing off the packer.

A production flow line 206 is connected at its lower end to a lateral conduit 207 in the tubing just above the locking fingers. The flow line extends to the water surface and includes a valve 208 actuated through a fluid line 208A to permit the flow line to be closed when desired. A secondary receiver 209 is welded at its lower end to the tubing exterior just above the lateral conduit for a purpose described in detail below.

A sealed socket joint 210 connects the lower end of a buoyant guide tubing guide post 211, such as shown in FIG. 9, to the upper end of the tubing inside the secondary receiver. The socket joint permits the buoyant post to be deflected laterally in all directions.

A first or upper externally threaded tubing plug 212 is threaded into an internally threaded section 213 in the tubing between the socket joint and the lateral conduit outlet 207.

The threads of the tubing plug are left-handed, and it is inserted or removed by an elongated plug rod of square cross section at its lower end, which is adapted to fit into a matching opening 215 in the upper end of the plug. A detent 216 holds the plug on the lower end of the rod while the plug is being raised and lowered. Once the plug is installed as shown in FIG. 12, the rod may be removed, if desired, by overcoming the holding force of the detent. To shut the well in, say for repair to the wellhead equipment, a second or lower tubing plug 218 (shown only in phantom line) may be installed in a second threaded portion 220 in the tubing below the tubing landing seat.

The tubing also includes the usual safety devices such as a storm choke 222, which is adapted to close when fluid flow through the tubing exceeds a predetermined value. The tubing also includes a choke or bean 224, such as an Otis choke or other suitable subsurface flow control equipment.

Any time it is desired to work over the well shown in FIG. 12, a conduit of the type shown in FIG. 8 is stripped down over the buoyant guide post and sealed at its lower end to the secondary mandrel. If desired, the conduit includes a conventional lubricating means for sealing the upper end of the conduit at the barge so that the conduit interior can be pressurized and tools or equipment moved to and from the well through the conduit at well pressure.

It will be noted that the apparatus of FIG. 12 accomplishes holddown of the tubing and casing without blowout preventers by using the casing slips 193 and the tubing fingers 204.

It will be obvious to those skilled in the art that additional equipment such as storm chokes, adjustable flow beans, etc., can be installed for any degree of safety and control required by various situations without departing from the scope of this invention.

We claim:

1. Apparatus for completing a well drilled into a formation under a body of water comprising a casing in the well, means sealing the casing exterior to the formation, a buoyantly supported floating vessel, elongated and laterally flexible anchoring means holding the vessel in tension over the well, a tubular conduit, elongated guide means extending from the bottom of the water body to the surface, means maintaining the lower extremity of the guide means in fixed relation to the casing, means for maintaining the upper extremity of the guide means in the region of the vessel, means for lowering the tubular conduit from the vessel in engagement with the guide means whereby the tubular conduit is constrained by the guide means to enter the casing as it is lowered, means for sealing the conduit and casing in fixed communicating relation below the water surface, and remote control means for actuating the said sealing means from the water surface.

2. Apparatus for completing a well drilled into a formation under a body of water comprising a casing in the well, means sealing the casing exterior to the formation, a floating vessel, a tubular conduit, elongated guide means extending from the bottom of the water body to the surface, means maintaining the lower extremity of the guide means in fixed relation to the casing, means maintaining the upper extremity of the guide means in the region of the vessel, means for lowering the tubular conduit from the vessel in engagement with the guide means whereby the tubular conduit is constrained by the guide means to enter the casing as it is lowered, a housing disposed around the tubular conduit, first sealing means for releasably sealing the housing to the casing, second sealing means for releasably sealing the tubular conduit to the housing, and remote control means for actuating the two said sealing means from the water surface to seal the tubular conduit to the casing below the water surface.

3. Apparatus for completing a well drilled into a formation under a body of water comprising a casing in the well, means sealing the casing exterior to the formation, a floating vessel, a tubular conduit, elongated guide means extending from the bottom of the water body to the surface, means maintaining the lower extremity of the guide means in fixed relation to the

casing, means maintaining the upper extremity of the guide means in the region of the vessel, means for lowering the tubular conduit from the vessel in engagement with the guide means whereby the tubular conduit is constrained by the guide means to enter the casing as it is lowered, a housing disposed around the tubular conduit, first sealing means for releasably sealing the housing to the casing, second sealing means for releasably sealing the tubular conduit to the housing, remote control means for actuating the two said sealing means from the water surface, and means for introducing fluid into the well through the housing below the means for sealing the tubular conduit to the housing.

4. Apparatus for completing a well drilled into a formation under a body of water comprising a casing in the well, means sealing the casing exterior to the formation, a buoyantly supported floating vessel, elongated and laterally flexible anchoring means holding the vessel in tension over the well, a tubular conduit, means for lowering the tubular conduit from the vessel, guide lines extending from the bottom of the water body to the surface, means maintaining the lower extremity of the guide lines in fixed relation to the casing means maintaining the upper extremity of the guide lines in the region of the vessel, means for connecting the tubular conduit with the guide lines to constrain and guide the tubular conduit to enter the casing as it is lowered, and means for sealing the conduit and casing in fixed communicating relation below the water surface.

5. Apparatus for completing a well drilled into a formation under a body of water comprising a casing in the well, means for sealing the casing exterior to the formation, a floating vessel, a tubular conduit, means for lowering the tubular conduit from the vessel, a wellhead base at the well site, a set of pulleys mounted on the base, a set of guide lines extending between the base and water surface for guiding equipment to a well drilled in the formation to a depth to penetrate a permeable stratum, each guide line being disposed around a respective pulley, a counter buoy secured to one end of each guide line, means for supporting the other end of each guide line at the water surface, means for connecting the tubular conduit with the guide lines to constrain and guide the tubular conduit to enter the casing as it is lowered, and means for sealing the conduit and casing in fixed communicating relation below the water surface.

6. Well completion apparatus for completing a well drilled into a formation under a body of water comprising a casing in the well, means sealing the casing exterior to the formation, a tubular conduit removably disposed in the casing, elongated and laterally flexible guide means extending from the upper portion of the tubular conduit toward the water surface, means securing the lower extremity of the guide means to the upper portion of the tubular conduit, means maintaining the upper extremity of the guide means in the region of the water surface, releasable means for sealing the conduit and casing in fixed communicating relation below the water surface, and a floating vessel disposed over the well, means for raising and lowering the tubular conduit from the floating vessel, and flow means communicating the tubular conduit with the water surface.

7. Apparatus for completing a well drilled into a formation under a body of water comprising a casing in the well, means sealing the casing exterior to the formation, a tubing disposed in the casing, elongated and laterally flexible guide means extending from the bottom of the water body through open water to the surface, means maintaining the lower extremity of the guide means in fixed relation to the casing, means maintaining the upper extremity of the guide means in the region of the water surface, a floating vessel disposed over the well, means for raising and lowering the tubing from the vessel, a packer for sealing the tubing to the casing in fixed communicating relation below the upper end of the casing, and a heavy drilling fluid disposed in the annular space between the tubing and casing above the packer.

8. Apparatus for a well completed in a formation under water comprising casing means in the well, well completion equipment releasably engaged with the casing means in the well and disposed under the water, first latching means on the said equipment, an elongated equipment pulling tool, second latching means on the tool, elongated and laterally flexible guide means extending from the well completion equipment through open water toward the water surface for constraining and guiding the tool to the well so that the said second latching means engages the said first latching means, a floating vessel disposed over the well, and means for lifting the tool and well completion equipment from the floating vessel after the two latching means are engaged to remove the well completion equipment from the well.

9. Apparatus for drilling and working in a well in earth formations submerged under water comprising in combination a floating drilling vessel anchored at the surface of the water above a submerged well site, a landing base positioned at the bottom of the water at the well site and in close contact with the top of the submerged earth formations, a vertically disposed casing affixed to said landing base and to the submerged earth formations within a well and forming the top portion of said well, a submerged means for controlling the opening of said casing rigidly affixed to said landing base in a unitary manner and in close contact with it, flexible means operable from said vessel for operating said submerged means for controlling said opening of said casing while said floating vessel is moving with the said surface of said water and relative to said submerged means, a flexible guide means extending from said vessel to the submerged landing base and a detachable connector connecting said flexible guide means to said landing base, a drilling mechanism operable from said vessel and adapted to be lowered downwardly from said vessel, a guide member engaging said drilling mechanism and said flexible guide means and operating with said flexible guide means to guide said drilling mechanism through said submerged means and into said well.

10. Apparatus for completing a well drilled into a formation under a body of water, the apparatus comprising a casing in the well, concrete sealing the casing exterior to the formation, a floating vessel disposed over the well, means for keeping the vessel substantially over the well, a tubular conduit, elongated guide means extending from adjacent the casing to the water surface, means maintaining the lower extremity of the guide means in fixed relation to the casing, means maintaining the upper extremity of the guide means in the region of the vessel, means for lowering the tubular conduit from the vessel in engagement with the guide means whereby the tubular conduit is constrained by the guide means to enter the casing as it is lowered, and means for sealing the conduit in communicating relation with the casing below the said sealing means.

11. Apparatus for completing a well drilled into a formation under a body of water comprising a casing in the well, concrete sealing the casing exterior to the formation, a floating vessel, means for positioning the vessel over the well, a tubing, elongated guide means extending from the bottom of the water body to the surface, means maintaining the lower extremity of the guide means in fixed relation to the casing, means maintaining the upper extremity of the guide means in the region of the vessel, means for lowering the tubing from the vessel in engagement with the guide means whereby the tubing is constrained by the guide means to enter the casing as it is lowered, means for sealing the tubing in communicating relation with the casing below the said sealing means, and a flow conduit extending from the water surface to the vicinity of the well and communicating with the tubing.

12. In combination with a well drilling string, apparatus for drilling a well in a formation under water, comprising a support, a casing positioned in said formation and having its upper end substantially at the surface thereof, said casing being sealingly cemented in said formation, a safety release joint mandrel secured to the upper end of said casing, an anchor device secured to said casing, guide means extending

13

between said anchor and said support, a vertical assembly of series-connected drilling devices including a control gate having a gate ram and a safety release joint barrel unit, said unit being matable with said mandrel, said assembly defining a drill pipe passageway and said gate ram being operable into a position closing off said drill pipe passageway, means for sliding the assembly up and down the guide means, an upright marine conductor connected at its lower end to the said assembly of series-connected drilling devices and terminating at its upper end in the vicinity of the water surface, and means including connections and apparatus extending from said support for operating said control gate.

13. In combination with a well drilling string, apparatus for drilling a well in a formation under water, comprising a support, a casing positioned in said formation and having its upper end substantially at the surface thereof, said casing being sealingly cemented in said formation, a safety release joint mandrel secured to the upper end of said casing, an anchor device secured to said casing, flexible guides secured to and extending between said anchor device and said support, a vertical assembly of series-connected drilling devices including a control gate having a gate ram and a safety release joint barrel unit, said unit being matable with said mandrel, said assembly defining a drill pipe passageway, and said gate ram being operable into a position closing off said drill pipe

14

passageway, means on said assembly for slidable engagement with said flexible guides, means including connections and apparatus extending from said support for operating said control gate, and means for lowering and raising said assembly from and to said support.

14. In combination with a well drilling string, apparatus for drilling a well in a formation under water, comprising a support, a casing positioned in said formation and having its upper end substantially at the surface thereof, said casing being sealingly cemented in said formation, a safety release joint mandrel secured to the upper end of said casing, an anchor device secured to said casing, flexible guides secured to and extending between said anchor and said support, a vertical assembly of series-connected drilling devices including a control gate having a gate ram and a safety release joint barrel unit, said unit being matable with said mandrel, said assembly defining a drill pipe passageway, and said gate ram being operable into a position closing off said drill pipe passageway, means on said assembly for slidable engagement with said flexible guides, means including connections and apparatus extending from said support for operating said control gate, and means engageable by a ram of said gate for supporting said assembly from said support.

30

35

40

45

50

55

60

65

70

75