April 28, 1964 F. L. JOHNSON 3,130,797

METHODS AND APPARATUS FOR DRILLING BORE HOLES

Filed Jan. 31, 1961 2 Sheets-Sheet 1

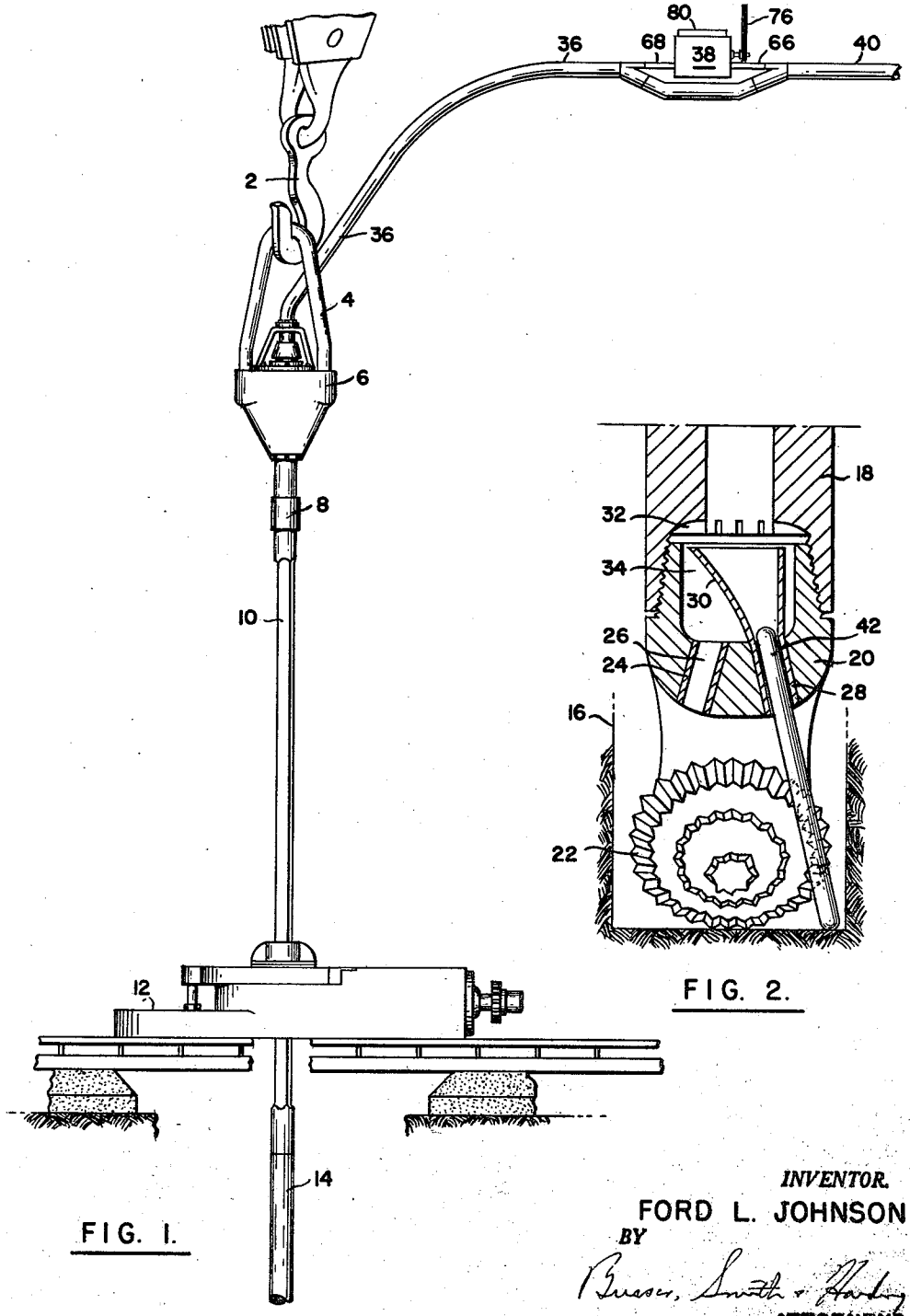


FIG. 1.

FIG. 2.

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METHODS AND APPARATUS FOR DRILLING BORE HOLES

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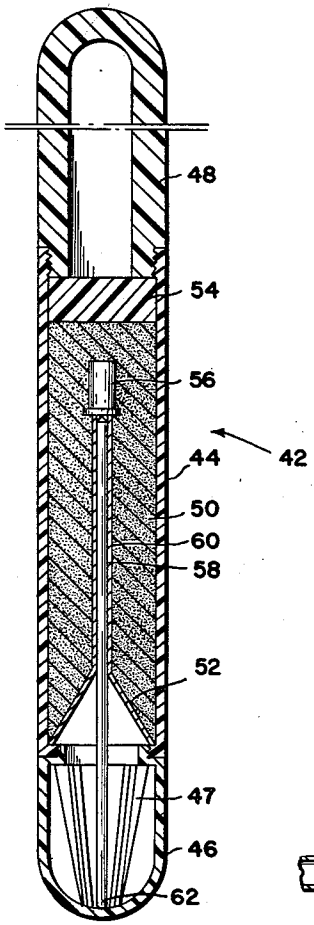


FIG. 3.

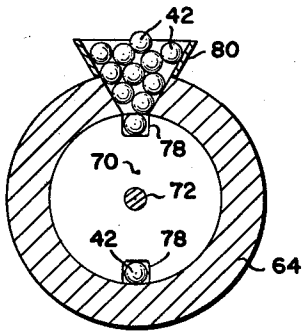


FIG. 5.

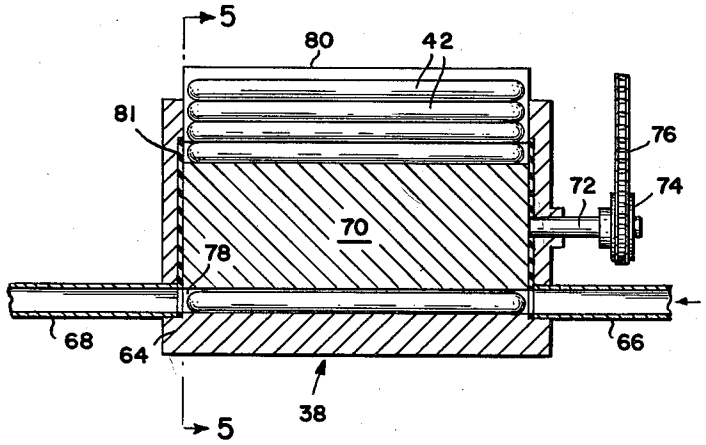


FIG. 4.

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METHODS AND APPARATUS FOR DRILLING BORE HOLES

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This invention relates to methods and apparatus for drilling bore holes, and has particular reference to drilling effected by the auxiliary use of explosives.

The rate of drilling, for example by rotary tools, may vary greatly depending upon the formation which is being drilled. In drilling through extremely hard rock the progress may be slow and consequently costly because the costs of drilling are at least roughly proportional to time expended.

Proposals have been made to effect drilling by the use of explosives, but such procedures have been unsatisfactory due to the fact that not only is there little control over the conditions left in the hole, but the debris requires removal.

In accordance with the present invention explosive is used as an adjunct to what is otherwise essentially conventional drilling procedure. Applied to rotary drilling by means of a bit driven through a hollow drill stem, the invention involves the utilization, as required, of explosive members which may be dropped through the hollow drill stem and guided into or through one or more passages in the bit, these members being exploded to shatter rock at the bottom of the hole and through which drilling is to proceed. Immediately following the explosion the conventional drilling may be carried out with circulation of mud to remove the cuttings. Then, either when the progress of drilling is notably slowed down or alternatively merely after a predetermined lapse of time, another explosion is effected, and so on. Under some conditions there may be produced a series of explosions following each other at short intervals, successive series of the explosions being spaced in time by extended periods of drilling by operation of the bit. As a matter of fact, the drill stem may be rotated continuously, the explosions taking place during the rotation.

The purpose of effecting the explosions will be readily understood. If hard and unfractured rock is being drilled, there is a tendency for the drill to rotate on the surface of the rock with a relatively low rate of rock removal despite heavy pressure exerted on the bit, the action then being largely one of abrasion. However, if the bit encounters rock which has been fractured the cutting edges of the bit will enter openings due to fractures and tend to split the rock along with the production of impacts between loosened portions of the rock with the result that comminution is rapidly effected to produce rock fragments of small size removable by the mud circulation. It will be evident from the last discussion that the use of the explosive in accordance with the invention is not primarily for the purpose of having the explosive actually produce and shape the hole; rather, the objective is to break up the rock so as to cause the bit to function more effectively. Nevertheless, there is advantage in using the so-called shaped charges which have generally as their objectives the production of holes, frequently rather accurately shaped. In the present instance the primary desire is to produce violent shocks which will effect fracturing of the formation, and such shocks are best obtained through the use of the shaped charges.

In the preferred form of the invention, conventional bits are used, and the explosive members are projected into or through one or more openings which, between

explosions, function as usual mud openings and preferably as jet openings, the most effective bits at the present time being of the jet type. Because it is the shattering effect which is desired, it is not required that the explosions should necessarily be directed along the axis of the bore hole, but, rather, the major explosive energy may be directed along the axes of conventional jet openings which are at acute angles relative to the drill stem axis.

While reference has been primarily made to conventional drilling by means of a rotary drill stem driving a bit, it will become evident hereafter that the invention is applicable to hammer drills in which flow of fluid (mud) under pressure is utilized to effect a hammering action on the rock, or to turbo drills in which a rotary bit at the bottom of a drill stem is driven by a mud turbine while the major portion of the drill stem remains stationary and serves merely as a mud conduit and support.

In summary of the advantages of the invention it may be pointed out particularly that throughout the drilling of a complete hole the same drilling apparatus may be used with its action augmented only where that is required by reason of hard rock formations. When these are encountered explosions may be effected as indicated above while the drilling proceeds without interruption. There is no need for removing the drill stem, nor is there generally any need even for raising the drill stem from its active drilling position. No special apparatus is required for taking care of debris since, even if as the result of the explosions large sections of rock are initially produced these are ground up by the operation of the drill bit and thus become fine enough to be removed by the mud flow in completely conventional fashion. As will hereafter appear more clearly, the mud flow is also utilized to effect positioning and firing of the explosive members.

The objects of the invention will be evident from the foregoing and may be broadly stated to involve the accomplishment of the general ends outlined. Detailed objects will become apparent from the following description, read in conjunction with the accompanying drawings, in which:

FIGURE 1 is a diagrammatic illustration showing the upper portion of a conventional drilling rig in association with means for inserting explosive members in the mud flow stream;

FIGURE 2 is an enlarged showing of a conventional jet bit slightly modified to provide for practice of the invention;

FIGURE 3 is a sectional view illustrating the construction of one form of explosive member which may be used;

FIGURE 4 is a longitudinal section illustrating apparatus for inserting explosive members in a high-pressure mud flow line; and

FIGURE 5 is a transverse section taken on the plane indicated at 5—5 in FIGURE 4.

FIGURES 1 and 2 show, merely as an example, a drilling rig which is substantially conventional and which can be used for the practice of the invention. Many other drilling rigs may be used which may also be substantially conventional, involving only minor changes for practice of the invention.

There is indicated at 2 a hook which is connected to the usual traveling block supported by cables and controlled by the drawworks of a derrick (not shown). A bail 4 hung on the hook supports the conventional swivel 6 modified only to the extent that its drilling mud entrance opens upwardly and its interior is provided with means for guiding the explosive members as will be evident hereafter. The swivel is joined at 8 with the usual kelly 10 passing through the rotary table 12 by which

it is driven and supporting the sectional drill stem 14 in conventional fashion. The drill stem terminates in the usual drill collar 18. Various conventional parts of the assembly are not indicated, but it will be understood that they are provided as in usual drilling practices.

The drill collar 18 carries a bit 20 which is illustrated as of the multiple cone type, of which one of the cones is indicated at 22. Jet openings are provided directed between the cones, these being provided at 26 through liners 24 for resisting abrasion by the mud. In the present instance one of these jet openings is modified in that its liner 28 is extended upwardly to provide a guiding funnel 30 which is adapted to guide the explosive members through the opening. The funnel 30 is spaced from the walls of the central upper opening in the bit so that mud may flow not only through the liner 28 but from the annular space 34 about the funnel through the other jet openings 26. To provide for free flow of the mud to the space at 34 there may be provided slots in the lower portion of the drill collar as indicated at 32, the arrangement being such that all of the jet openings receive adequate supplies of mud to provide high velocity jets functioning, during drilling, in conventional fashion. The hole being drilled is indicated at 16.

The mud flows to the swivel 6 through the flexible hose 36, being supplied from the usual high pressure mud pump which is not shown. The main flow takes place through a connection 40, but bypassed flow to carry the explosive members into the hose 36, swivel 6, and the hollow drill stem takes place through the feeding means for the explosive members indicated generally at 38 but described in greater detail hereafter.

A typical explosive member which may be used is designated generally as 42, and is shown in section in FIGURE 3. In the particular form illustrated, this comprises a main housing 44, a lower protective cap 46, and an upper protective cap 48, the latter being primarily for the purpose of giving the member sufficient length for longitudinal guidance and prevention of inversion in position in the connections through which it moves. These parts of the member 42 are preferably formed of either plastic or ceramic, being designed (as through the use of strengthening ribs 47 in the cap 46) to withstand the pressures encountered within the drill stem and the various shocks to which it may be subjected in passing through the system to and into the jet opening in the bit. A frangible metal may also be used for these parts so long as it conforms to the desirable requirements that these parts should be broken up by the explosion, should not weld to, or otherwise become jammed in, the jet opening liner 28, and should be broken up by the operation of the bit. The last requirement is particularly a safety one: in the event of a misfire of the member it will, as will shortly appear, be dragged on the bottom of the hole and broken and destroyed by grinding so that it would not pass in intact fashion upwardly with the mud, with possible hazard to personnel or to the upper portion of the hole, the drill stem, or the casing. After being broken up, even if the detonator should later fire there would be minor explosion thereof with the possibility that the other explosives might also explode but with the explosion confined almost certainly to the region of the bit where it could do no harm. The lower cap 46 should be of such thickness that, while it will withstand the mud pressures it will be crushed if the member is ejected through the jet opening in the bit. The velocity of the jet flow is conventionally very high to the end that the explosive member will be ejected against the bottom of the hole at a velocity comparable with that of a bullet so as to effect crushing of the cap and, as will appear, firing.

The interior of the portion 44 of the member 42 contains a charge 50 of high explosive, desirably in the form of a shaped charge with a conical hollow in its lower end lined by a cone 52 of thin material which may also be

plastic or ceramic. A tube 60 of similar material passes through the center of the charge 50 for the guidance of a metallic firing pin 58 the upper end of which underlies the detonator 56 molded into the charge 50. Above the upper end of the charge is a cap disc 54 which may be of ceramic or plastic.

The particular details of the explosive member 42 are subject to a great variety of choice. The art of shaping charges such as 50 for securing a very great variety of effects is highly developed and well-known, and reference may be made to the many patents and articles thereon for discussions of variations. The shaped charges give rise to what is known as the Munroe effect. Generally, the ends of these charges which are to produce the effect of the explosion are conical or otherwise hollowed to provide more or less directed jets depending upon the results desired. For military uses where piercing of armor is the primary desire, the cavities in the charges are generally truly conical and the explosive at the time of firing is required to be a particular stand-off distance from the surface which is to be penetrated. In such cases the cone liner corresponding to 52 is generally of metal, and the theory of operation is that this metal is formed and projected at extremely high velocity to penetrate the target in the form of a clean hole.

On the other hand, where a shattering effect is desired, as in blasting, the cavities are sometimes more or less dome-shaped or outlined by a plurality of conical surfaces with the effect of spreading the explosive wave for action over a larger area. Since, in the present case, such shattering action is desired, the formation of the cavity for optimum shattering action is desirable.

Various means may be employed for the purpose of inserting the explosive members into the mud for delivery through the hollow drill stem and thence into the jet opening or openings. A suitable mechanism for accomplishing this is illustrated in FIGURE 4 and may, specifically, be provided in a bypass of a portion of the line running from the mud pump to the swivel. A cylindrical housing 64 is provided with inlet and outlet passages 66 and 68, the latter being of a size to pass the explosive members 42. The connections 66 and 68 are joined at their inlet and outlet ends respectively with the mud conduit. Within the housing 64 is mounted a valve member 70 provided with a shaft 72 to which is secured a sprocket 74 arranged to be driven through a chain 76 which, in the simplest form of the apparatus may be driven by a hand crank. The valve member 70 is provided with longitudinal slots 78 arranged to receive the explosive members 42 from a supply hopper 80. Upon each half revolution of the valve member one of the members 42 will be taken from the hopper and advanced to alignment with the connecting passages 66 and 68 so that the explosive member so presented will be driven through the connections 68 by reason of the pressure drop of the mud between the points of connection of the bypass. Thus the time of insertion of the explosive members may be controlled. The bypass arrangement is desirably provided so that the feeding device does not interfere with normal drilling mud flow.

The method of operation of what has been described is as follows:

Ordinarily the drilling will proceed in usual fashion without aid of the explosions. As will be clear from what has been described, the use of the present method of drilling does not involve any deviations from the normal rotary drilling practices carried out by rotation of the drill stem and the bit. The passage defined by the liner 28 operates as one of the jet openings along with the others. Free flow of mud from the mud pump takes place under the desired pressure conditions, and so far as structure is concerned, the only matter of materiality which need be taken into account is that the mud hose running to the swivel should, in all of the positions assumed during drilling, have sufficiently large radii of curvature so as not to

impede the free advance of the explosive members when they are used. Thus, ordinarily the major portions of the drilling will be carried out quite conventionally. (Of course, drilling in relatively soft formations may be augmented by the use of explosions, though this may not be found to be economical if sufficient drilling progress may be secured without the use of explosions.)

The invention comes into play when the progress of drilling is slowed down by the encountering of hard rock. This will be evidenced quite promptly by observation of the downward movement of the drill stem. When this occurs, an explosive member **42** is introduced into the mud line by means of the device **38**. During the period of introduction of the member and the estimated time of its descent to the location of the bit the rotary drilling may be continued or interrupted, as desired, continuation of rotation having no adverse significance with respect to the explosive operation. The only reason for interrupting the drilling might be to prevent such wear on the bit as would be occasioned by the relatively non-productive attempt to drill the hard rock.

The members **42** may be anywhere in the range from substantially heavier to substantially lighter than the mud. Usually it is desirable to have the explosive members somewhat heavier than the displaced mud to help the speeding of their descent, though actually the speed of descent in any case will approximate rather closely the rate of mud flow. The explosive member, accordingly, passes downwardly and will ordinarily repeatedly engage the walls of the drill stem passages, though without firing in view of the presence of the protective nose member, the length of the explosive member, and the contour of the passage which will prevent any direct blows of the member on solid material as it descends. As already indicated, the nose is strong in its resistance to pressure increase and is also sufficiently strong so as not to be broken by glancing impacts. Thus, the firing pin remains protected during the descent.

When the member **42** reaches the position of the bit it will pass into the funnel **30** and will be ejected from the jet liner **28** to pass between the cone cutters (in the case of this type of bit) and engage the bottom of the hole. This engagement will occur at very high velocity. Since the mud circulation is continuing, the velocities involved will be essentially those of jet drilling operation, and the member **42** will be ejected at a velocity of the order of 500 feet per second, more or less. The nose cap is constructed so as to be shattered upon engaging rock at such a velocity, and when shattering occurs the firing pin will be retarded to fire the detonator and ignite the high explosive.

It will be noted that due to the construction of the nose cap the firing, which will occur within an extremely small fraction of a second, will take place while the lower hollow end of the explosive is substantially removed from the bottom of the hole. The usual "stand-off" space is thus provided which has been recognized as desirable in the use of shaped charges. It will be noted that this stand-off space is primarily an air space, filled partially only by relatively light plastic or ceramic material constituting the reinforcing ribs of the nose cap. The violent explosion will cause penetration and disruption of the rock adjacent to the bottom of the hole and in view of the fact that the affected region is bound by solid and liquid (the mud) the shattering effect is widespread rather than involving merely the production of a clean hole irrespective of the shape of the explosive. As pointed out above, the shape may be chosen in accordance with known practice to augment the shattering effect. A secondary effect now also occurs. The explosion will produce hot gas and a displacement effect occurs which will raise the bit and drill stem. This may be felt but little in the surface, since the drill stem has longitudinal elasticity. But as soon as this lifting action ceases the lower portion of the drill stem will be violently driven, with relief of the elastic compression, downwardly against the rock to provide a hammering action which will further produce shattering of the rock. The gas, of course, will also tend to distend the region in the vicinity of the bit with further cracking or shattering action. All of the material of the explosive member will, of course, either practically vaporize or at least be dispersed in the form of small particles so that nothing remains which would impede the further progress of the rotary drilling. Such drilling may then be continued, if not interrupted, or resumed if it had been interrupted.

Various alternatives are here possible:

A single explosion may be produced followed by continuation of rotary drilling of the fractured rock until the progress of the drilling is again noticeably slowed down, whereupon another explosion may be produced in the fashion described. On the other hand, it may be desirable to effect a series of closely spaced explosions with little or substantially no drilling between them. It will be noted that when conventional directions of jets are involved, using a bit such as a multiple cone bit, the explosive member at the time of ignition will occupy a sloping position relative to the bore hole axis as illustrated in FIGURE 2, producing some asymmetry of the shattering effect. But if a series of explosive members are provided to follow each other at short intervals and if the bit is being rotated, the probability will be considerable that the various explosive members of a group will be differently directed azimuthally. Accordingly, the overall result will be in all probability, an approximately uniform shattering effect. The practice of firing a series of explosive members in rapid succession will, therefore, tend to avoid deflection of the hole in the direction of such maximum shattering as might occur if there was a single explosion followed by a relatively extended period of drilling. In drilling there is continuous information from the cuttings returned by the mud to the surface concerning the nature of the rock being drilled, and it will be understood that explosive members of different forms and of different charges may be used to secure the optimum results in the drilling of particular rocks.

The general effect of the shattering will be readily understood. Presented to the bit after shattering of the rock will be irregular pieces which will be more readily crushed than a rock surface which presents merely a smooth surface of revolution to the bit.

The devices and procedures which have been described also provide safety. Assume for example that for some reason the ejection of the explosive member does not result in explosion. The pressure drop across the jet passages is usually very large, and consequently an explosive member reaching the position illustrated in FIGURE 2 will be very forcibly engaged with the bottom of the hole. It will be evident that as rotation occurs either by wear or by catching in irregularities of the rock the explosive member will be broken, and even if the force on the firing pin still does not produce firing, disintegration of the explosive member will take place mechanically with the result that the high explosive will be broken up. Ordinarily, the detonator would be ground under and by the bit and exploded, with or without explosion of the high explosive charge. Even if the detonator did not explode there would be returned to the surface with the mud and cuttings merely the detonator and the broken up pieces of the high explosive. As indicated in FIGURE 2, it is desirable that the explosive member at the time of firing should have its upper end located within the jet opening to insure the disintegration of the member in case of misfiring. While it could be so short as to be completely ejected at the time of explosion, and might remain intact in such case in the event of misfire the risk that it could be carried upwardly with the mud intact is small in view of the crushing action to which it would be subjected during rotation of the drill stem.

While a particular type of bit has been disclosed, it will be evident that the method of the invention may be

carried out utilizing substantially any type of bit suitable for the particular drilling to be accomplished. In the case of core bits, the explosive will be ejected centrally, and if a substantial length of core has been cut and is projecting into the central opening in the form of a pillar, this pillar may be disintegrated by a charge fired against its upper end. Core bits, of course, are usually not used where rapid progress of drilling is desired. If cores are taken, the usual purpose is to recover them intact, and under such circumstances explosive would not generally be desirably used.

Various other types of drills and drilling procedures have been proposed and used to a limited extent, such as hammer drills and turbodrills, in the use of which at least the major portion of a hollow drill stem remains stationary and is used for support and mud circulation. In such cases a through opening does not usually occur, being inconsistent with the production of drilling motions by the circulating mud; but in such cases valves may be provided through which explosive members may pass in the same general fashion as involved in the passage of logging electrodes as described in the applications of John D. Bennett, Serial No. 694,256, filed November 4, 1957, now Patent No. 3,074,493, and John D. Bennett and Fred M. Mayes, Serial No. 694,257, filed November 4, 1957, now Patent No. 3,016,963.

While special guiding passages may be provided in the bit as illustrated in FIGURE 2, even completely conventional jet bits may be used taking advantage of the entraining and guiding action of mud flow to pass the explosive members into the jet openings. Such techniques are known for providing passage of electrode assemblies as disclosed in the application of John D. Bennett, Preston E. Chaney, Jack Weir Jones and Fred M. Mayes, Serial No. 818,162, filed June 4, 1959.

While the use of liquid (mud) has been primarily discussed as the drilling fluid, it will be evident to those skilled in the art that the drilling fluid may be compressed air or foam.

From the foregoing it will be evident that in accordance with the invention there are provided techniques for effecting drilling in which conventional drilling operations are speeded up or augmented by the use of explosions.

It will be obvious that many variations may be made in details of application of the invention without departing from the scope of the invention as defined in the following claims.

What is claimed is:

1. The method of drilling a bore hole through earth strata comprising the steps of;
- effecting rotary drilling with a hollow drill stem driving a drill bit having a solid central portion and a non-axially aligned jet opening to form a bore hole of a first depth,
- introducing an explosive member into said hollow drill stem at the surface of the bore hole,
- effecting axial passage of said member downwardly through said hollow drill stem to the vicinity of said bit,
- orientating said member so as to pass at least partially through said non-axial jet opening to arrive at a position adjacent the earth strata forming the bottom of said bore hole,
- detonating said member in said position to shatter said earth strata, and
- continuing rotary drilling through said shattered strata by said drill bit.

2. The method of drilling a bore hole through earth strata comprising the steps of;
- effecting rotary drilling with a hollow drill stem driving a drill bit having a solid central portion and a non-axially aligned jet opening to form a bore hole of a first depth,
- introducing a plurality of explosive members during spaced time intervals into said hollow drill stem at the surface of the bore hole,
- successively effecting axial passage of each of said members downwardly through said hollow drill stem to the vicinity of said bit,
- successively orientating each of said members so as to pass successively at least partially through said non-axial jet opening to arrive successively at a position adjacent the earth strata forming the bottom of said bore hole,
- successively detonating said members as each arrives at said position to shatter said earth strata, and
- continuing rotary drilling through said shattered strata by said rotary bit.

3. The method of drilling a bore hole through earth strata comprising the steps of;
- effecting rotary drilling with a hollow drill stem driving a drill bit having central cutting surface and at least one non-axially aligned jet opening to form a bore hole of a first depth,
- introducing an explosive member into said hollow drill stem at the surface of the bore hole,
- effecting axial passage of said member downwardly through said hollow drill stem to the vicinity of said bit,
- orientating said member so as to pass at least partially through said non-axial jet opening to arrive at a position adjacent the earth strata forming the bottom of said bore hole,
- detonating said member to shatter said earth strata, and
- continuing rotary drilling through said shattered strata by said drill bit.

4. The method of drilling a bore hole through earth strata comprising the steps of;
- effecting rotary drilling with a hollow drill stem driving a drill bit having a central cutting surface and a non-axially aligned jet opening to form a bore hole of a first depth,
- introducing a plurality of explosive members during spaced time intervals into said hollow drill stem at the surface of the bore hole,
- successively effecting axial passage of each of said members downwardly through said hollow drill stem to the vicinity of said bit,
- successively orientating each of said members so as to pass at least partially through said non-axial jet opening to arrive successively at a position adjacent the earth strata forming the bottom of said bore hole,
- successively detonating said members as each arrives at said position to shatter said earth strata, and
- continuing rotary drilling through said shattered strata by said rotary bit.

5. Apparatus for drilling a bore hole comprising in combination;
- mechanical drilling means,
- said drilling means including a drill stem and a drill bit secured to the lower end of said stem,
- an axially extending passage in said drill stem,
- at least one jet opening extending through said bit in a direction transverse to said drill stem passage and in fluid communication therewith,
- an explosive member of a size sufficiently small to pass through said passage and said jet opening,
- guiding means within said drilling means for effecting the passage of said member from said passage into said transverse jet opening and at least partially through said jet opening to a position adjacent the bottom of the bore hole, and
- means for detonating said member in said position to produce explosive shattering at the bottom of the bore hole for facilitating the rate of progress of said mechanical drilling means.

6. The apparatus as claimed in claim 5 wherein said guiding means includes a funnel shaped member for guiding said explosive member into said jet opening.

7. Apparatus for drilling a bore hole comprising in combination;

mechanical drilling means,

said drilling means including a drill stem and an overlapping cone type drill bit secured to the lower end of said stem,

an axially extending passage in said drill stem,

at least one jet opening extending through said bit in a direction transverse to said drill stem passage and in fluid communication therewith,

an explosive member of a size sufficiently small to pass through said passage and said jet opening,

guiding means within said drilling means for effecting the passage of said member from said passage into said transverse jet opening and at least partially through said jet opening to a position adjacent the bottom of the bore hole, and

means for detonating said member in said position to produce explosive shattering of the bottom of the bore hole for facilitating the rate of progress of said mechanical drilling means.

8. The apparatus as claimed in claim 7 wherein said guiding means includes a funnel shaped member for guiding said explosive member into said jet opening.

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