HYDRAULIC JET DRILLING METHOD

Filed Dec. 27, 1965 2 Sheets-Sheet 1

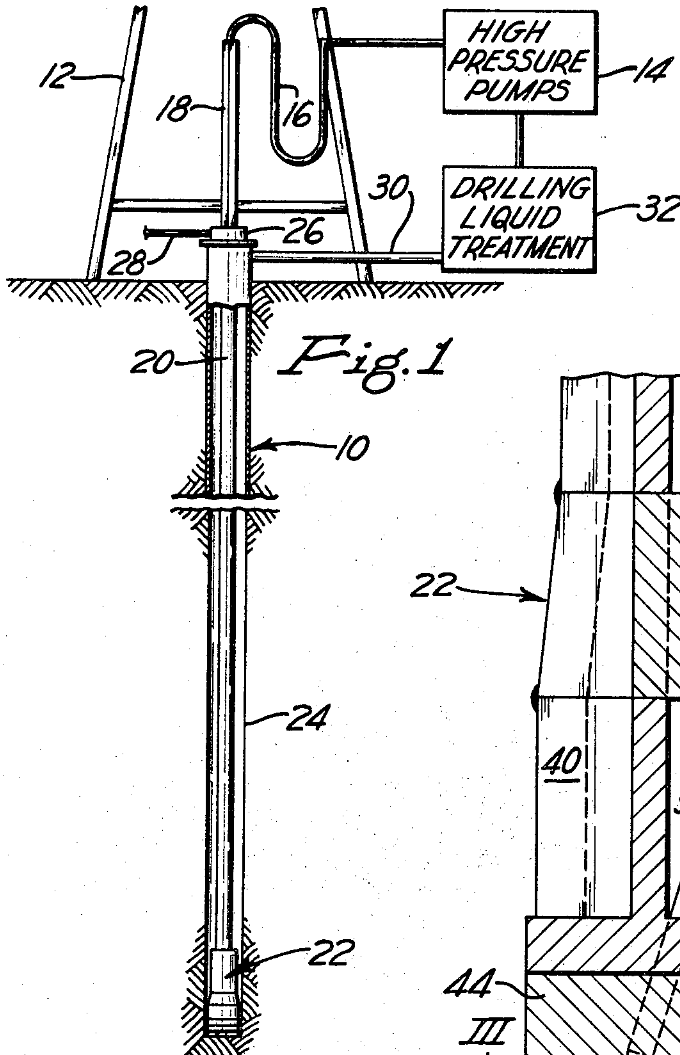

Fig. 1

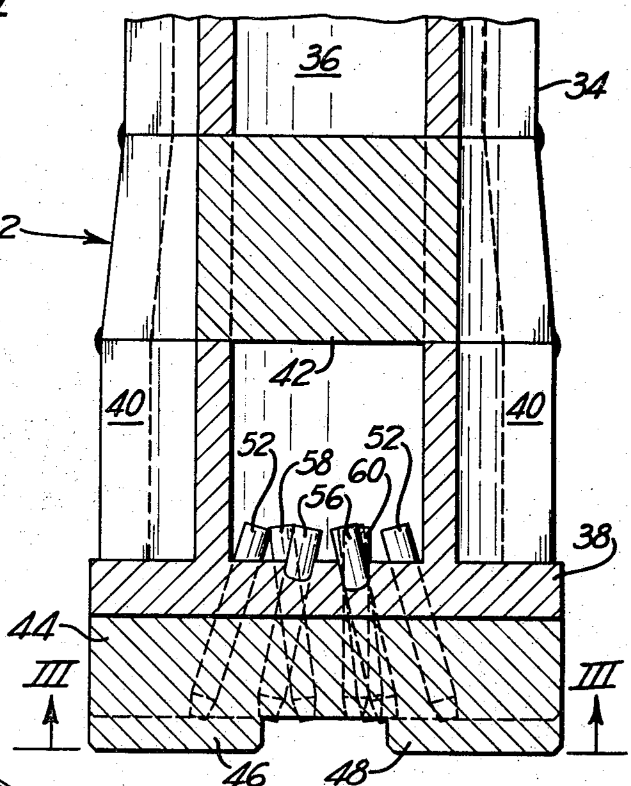

Fig. 2

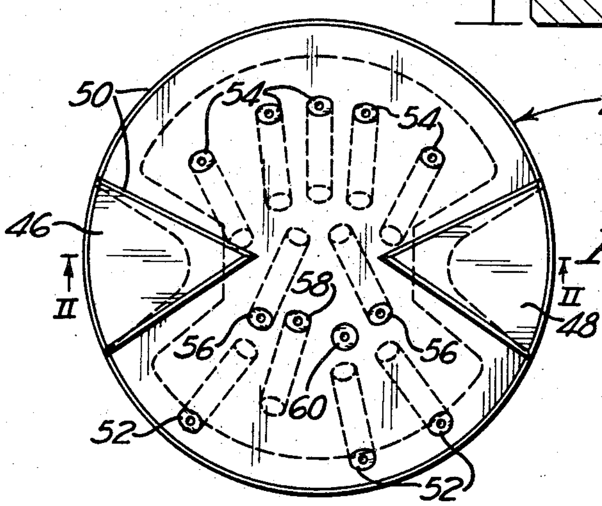

Fig. 3

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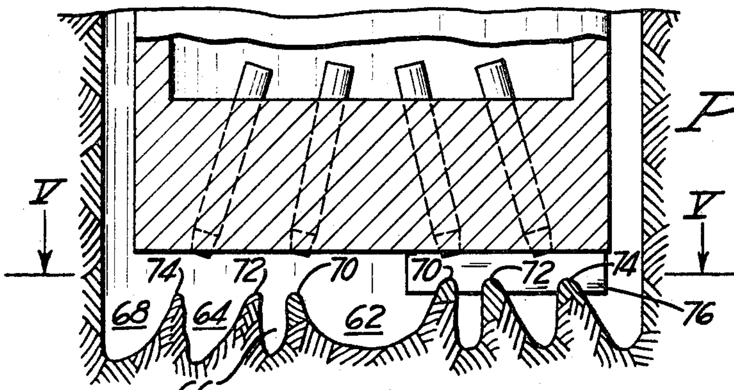

Fig. 4

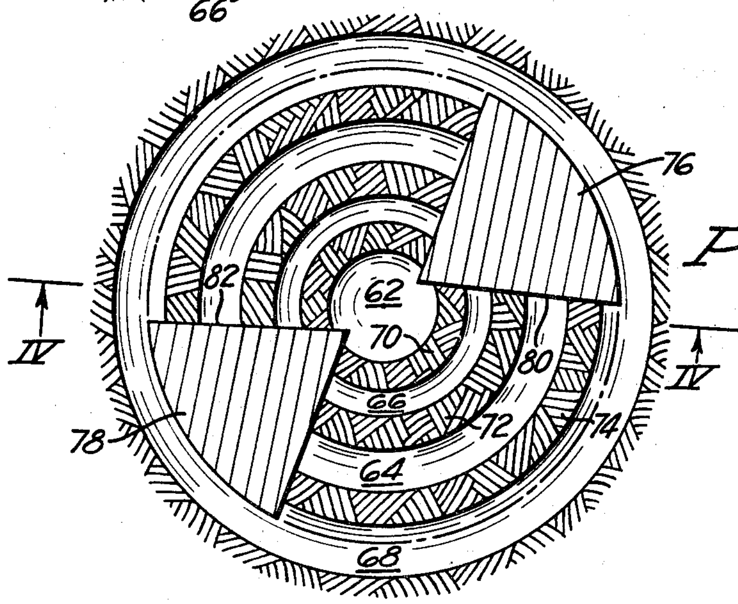

Fig. 5

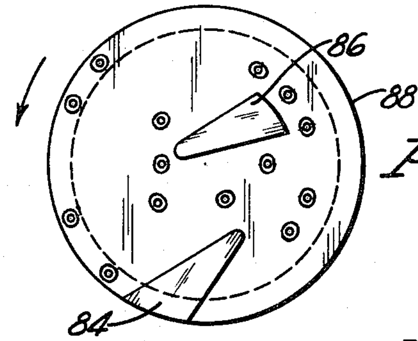

Fig. 6

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3,402,780

HYDRAULIC JET DRILLING METHOD

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6 Claims. (Cl. 175—67)

ABSTRACT OF THE DISCLOSURE

Wells are drilled through hard formations by discharging streams of abrasive-laden liquid from nozzles in a rotating drill bit at velocities in excess of 500 feet per second against the bottom of the borehole of a well. The streams are positioned in the drill bit to cut a central hole, a plurality of concentric grooves around the central hole, and an outer groove having an outer diameter equal to the borehole diameter. Thin intervening ridges between the grooves are readily broken by engagement with the drill bit.

This application is a continuation-in-part of copending application Ser. No. 311,088, entitled Method and Apparatus, filed Sept. 24, 1963 by Robert J. Goodwin, Ernest A. Mori, Joseph L. Pekarek, Paul W. Schaub and Robert E. Zinkham, now abandoned.

This invention relates to the drilling of wells, and more particularly to a hydraulic jet method for drilling wells in hard formations.

In the usual rotary drilling method, a bit connected to the lower end of a drill string is rotated against the bottom of the borehole of the well while a heavy weight is applied to the bit by drill collars forming the lower end of the drill string. A drilling mud is circulated down the drill string through outlets in the drill bit and upwardly around the drill string to carry cuttings from the well. Most of the bits used in rotary drilling operations are rock bits in which a cone-shaped roller having teeth along its outer surface engages the bottom of the borehole to break rock particles therefrom.

One type of bit that has been used with increasing frequency in rotary drilling operations is referred to as the jet bit. Those bits are provided with nozzles which direct a stream of drilling mud downwardly against the bottom of the formation with the primary purpose of sweeping cuttings from the bottom of the hole to prevent regrinding of the cuttings. In soft formations, the stream of drilling mud discharged from jet bits may penetrate the formation being drilled and thereby increase the rate of drilling of soft formations, but the conventional jet bits have not been effective in increasing drilling rates in hard formations. Hard formations are, in general, formations having a compressive strength of 20,000 p.s.i. or higher.

Drill bits having tungsten carbide inserts in the outer surface of the rollers have been used to increase the drilling rate in hard formations. Such bits are able to withstand the severe abrasion caused by hard formations much better than the ordinary roller bit. However, the rate of drilling of hard formations even with bits having tungsten carbide inserts in their outer surface is slow. Moreover, the bearings of such bits frequently fail, at least partly because of the heavy weight placed on the bit, before the tungsten carbide inserts. The heavy weight applied to the drill bit necessitates heavy-walled drill pipe to provide sufficient weight and transmit the torque required to rotate the bit.

In a drilling method that has recently been developed to increase the rate of penetration of hard formations, an abrasive-laden liquid, as distinguished from a drilling mud, is pumped down the drill string and discharged from

nozzles at an extremely high velocity of at least 500 feet per second, and preferably higher than 600 feet per second, against the bottom of the borehole. The outlet of the nozzles is maintained within a close and carefully controlled distance from the bottom of the borehole to prevent dissipation of the energy in the high-velocity stream of abrasive-laden liquid discharged from the nozzles and to avoid excessive erosion of the bit by backsplash of the abrasive-laden liquid against the bottom of the bit. The drill string is rotated to rotate the bit and cause the high-velocity stream to travel over the bottom of the borehole to cut a borehole of the desired diameter. Drilling liquid discharged from the nozzles cuts overlapping grooves, or substantially contiguous grooves, whereby virtually the entire removal of rock from the bottom of the borehole is accomplished by the streams of drilling liquid.

This invention resides in an improved hydraulic jet drilling process in which a hole is cut in the center of the bottom of the borehole by a high-velocity stream of an abrasive-laden liquid and a groove is cut in the bottom of the borehole around its outer edge to establish a borehole of the desired gauge. High-velocity streams of abrasive-laden liquid are directed against the bottom of the hole at intermediate areas between the central hole and the outer groove to cut a plurality of concentric grooves separated by thin, intervening annular ridges less than ½ inch wide. A mechanical force is exerted by the drill bit directly against the ridges to break off the tops of the ridges and lower the bit for further penetration by the high-velocity streams of drilling liquid of the formation being drilled. In the preferred form of this invention, a stand-off bar extending downwardly from the drill bit has a leading surface extending in a non-radial direction to exert a force against the intervening ridges toward an adjacent groove to subject the ridges to tensile as well as compressive forces. Penetration of the formation at the bottom of the borehole is caused by the high-velocity streams of drilling liquid. The stand-off bar merely breaks ridges extending upwardly from the bottom of the borehole.

FIGURE 1 of the drawings is a diagrammatic view of a derrick in place over a well with equipment for treating and circulating the abrasive-laden liquid in the well in a hydraulic jet drilling method.

FIGURE 2 is a longitudinal sectional view along section line 2—2 in FIGURE 3 of a drill bit suitable for use in this invention.

FIGURE 3 is a plan view of the bottom of the drill bit illustrated in FIGURE 2.

FIGURE 4 is a vertical sectional view taken along the section line 4—4 in FIGURE 5 diagrammatically showing the bottom of the borehole of a well during drilling by the method of this invention.

FIGURE 5 is a horizontal sectional view along section line 5—5 in FIGURE 4 showing a plan view of the bottom of the borehole.

FIGURE 6 is a plan view of the bottom of a drill bit for use in this invention in which mechanical elements for breaking the ridges are positioned at an oblique angle with the radius of the drill bit.

Referring to FIGURE 1, a well indicated generally by reference numeral **10** is illustrated with a derrick **12** positioned above it. An abrasive-laden drilling liquid is delivered from high-pressure pumps **14** through a suitable conduit **16** into the upper end of a kelly **18** for delivery into a drill string **20**. Mounted on the lower end of the drill string **20** is a drill bit indicated generally by reference numeral **22**. The abrasive-laden drilling liquid is discharged through nozzles in the drill bit to cut the formation at the bottom of borehole **24**. Drill string **20** is rotated in the borehole by engagement of the kelly **18** with a rotary table **26** driven through a shaft **28** by a suitable power source, not shown.

Drilling liquid circulated up through the annulus in the well between the drill string **20** and the wall of the borehole **24** is discharged at the surface and is delivered through line **30** to apparatus **32** for treatment of the drilling liquid. The treatment generally consists of removal of large cuttings from the drilling liquid, removal of fines which tend to increase the density of the drilling liquid, cooling the drilling liquid to the desired temperature, and incorporating additional abrasive particles to replace those that are broken into fine particles and are removed with the fines. The drilling liquid may also be treated to maintain other properties such as viscosity, water loss, etc., in the desired range.

In the process of this invention, the abrasive-laden drilling liquid is discharged at an extremely high velocity through nozzles in the drill bit **22** to cut a central hole in the bottom of the borehole, an outer groove having an outer diameter equal to the diameter of the borehole, and a plurality of intermediate grooves separated by thin, intervening annular ridges. The ridges should have a width in the range from about ⅛ inch up to a maximum of approximately ½ inch to allow the ridges to be easily broken by a moderate weight applied to the drill bit **22**. In the drilling process of this invention, all portions of the bottom of the borehole coming in contact with the drill bit are exposed on two sides to permit a bending moment to be applied against the ridges. In this manner, tensile stresses are created in the rock and advantage is taken of rock's relative weakness in tension to facilitate breaking particles of rock by engagement with the drill bit.

Referring to FIGURES 2 and 3 in which a drill bit suitable for use in this invention is illustrated, the drill bit **22** has an elongated hollow body **34** with a central opening **36** extending upwardly through it for communicating with the opening in the drill string **20**. The lower end of the opening **36** is closed by a bottom member **38**. In the drill bit in FIGURE 2, hollow drill bit body **34** has a pair of diametrically opposed flutes **40** extending upwardly from the bottom member **38** to the upper end of the drill bit body **34**. Flutes **40** provide space for upward flow of drilling liquid and entrained cuttings during the drilling. The drill bit body **34** illustrated in FIGURE 2 is reinforced by a web **42** extending across the central opening **36**.

A backsplash plate **44** made of a hard, abrasion-resistant material, such as tungsten carbide, is secured to the lower surface of bottom member **38** by suitable means such as silver soldering to protect the bottom member from abrasive particles rebounding from the bottom of the borehole. Backsplash plate **44** has sufficient thickness, of the order of 1½ inches, to locate the bottom member **38** and the silver solder joint above the area where abrasive particles discharged from the nozzles in the drill bit strike the formation being drilled and rebound against the drill bit. Integral with the backsplash plate **44** are a pair of stand-off bars **46** and **48** which extend ¼ to 1¼ inches below the remainder of the lower surface of the backsplash plate **44** to maintain the outlet of the nozzles at the desired stand-off distance from the formation being drilled. In the embodiment shown in FIGURES 2 and 3 of the drawings, stand-off bars **46** and **48** are of triangular shape, with the apex of the triangle terminating at a point spaced from the center of the drill bit. The inner end or apex of at least one of the stand-off bars should be close enough to the center of rotation of the drill bit to extend inwardly beyond the innermost ridge in the bottom of the borehole. To reduce chipping of the stand-off bars and backsplash plate, their edges are beveled or rounded at **50**, as illustrated in FIGURE 3.

A plurality of passages extend through the bottom member **38** and backsplash plate **44** to receive nozzles adapted to discharge the abrasive-laden drilling liquid downwardly at a high velocity against the bottom of the borehole. The passages, and hence the nozzles, are located at several different radial distances from the center of rotation of the bit and aligned to produce the desired pattern of grooves in the bottom of the borehole. In the bit illustrated in FIGURE 3 of the drawings, a plurality of outer nozzles **52** are secured in outwardly slanting passages to direct the abrasive-laden drilling liquid against the bottom of the hole at approximately the outer diameter of the drill bit to cut a groove having an outer diameter slightly larger than the outer diameter of the drill bit. Other outwardly slanting nozzles **54** strike the bottom of the borehole at a distance from the outer wall of the borehole leaving an intervening ridge less than ½ inch wide between the groove cut by the nozzles **54** and the groove cut by the nozzles **52**. Still other outwardly slanting nozzles **56** positioned closer to the center of the drill bit than nozzles **54** cut a groove of smaller diameter than the groove cut by nozzles **54** in the bottom of the bore-hole.

An inwardly slanting nozzle **58** is positioned to cut in the center of the bottom of the borehole a hole extending outwardly beyond the inner ends of stand-off bars **48** and **50** and thereby prevent a central core extending upwardly from the bottom of the borehole to engage the lower surface of the backsplash plate. A vertical nozzle **60** is positioned to cut a groove in the ridge that would otherwise extend between the groove cut by nozzle **56** and the central hole cut by nozzle **58** and avoid excessive ridge thickness that would be caused by the oppositely sloping walls of the two grooves. Because of the severe abrasion to which the nozzles are subjected during the drilling process, nozzles **52, 54, 56, 58,** and **60** are constructed of a hard, abrasion-resistant material such as tungsten carbide. The lower ends of the nozzles terminate substantially at the lower surface of the backsplash plate **44**, as is best illustrated in FIGURE 2 of the drawings. The drill bit illustrated in the drawings is described and claimed in our copending application Ser. No. 516,493, entitled Hydraulic Jet Bit, filed on Dec. 27, 1965.

In the drilling process of this invention, an abrasive-laden drilling liquid is delivered by high-pressure pumps **14** into the upper end of the drill string **20** for delivery to the drill bit **22**. The particle size of the abrasive material suspended in the drilling liquid will depend in part on the size of the orifice in the drill bit. If the nozzle orifices have a diameter of ⅛ inch, abrasive particles ranging in size from about 7 mesh to 80 mesh can be used. With larger nozzle orifices, larger abrasive particles can be used without danger of plugging the nozzles, but an increase in particle size above 7 mesh increases the difficulty of pumping the drilling liquid. Nozzles having an orifice diameter of $\frac{3}{32}$ to ¼ inch can be used in the hydraulic jet drilling process. Larger nozzles require excessive pump capacity to deliver the drilling liquid at the required high velocity. Smaller nozzle orifices reduce the rate of penetration because of the limitation they put on the size of the abrasive particles. One of the abrasive materials that can be used advantageously because of its availability and low cost is sand. Sand particles having a size in the range of 20 to 40 mesh are suitable for use in drilling by the process of this invention with nozzle orifices ⅛ inch in diameter.

Preferred abrasive materials because of the faster cutting rates that they cause are ferrous abrasives which may be either cast iron or steel and may be in the form of either shot or granular grit. Ferrous abrasive particles ranging in size from 10 to 80 mesh can be used effectively through nozzles ⅛ inch in diameter. Aluminum oxide provides a high rate of cutting of rock formations, but has the serious disadvantages of causing severe erosion of the nozzles and having a relative high rate of break-up. Concentrations of ferrous abrasives in the drilling liquid of ½ to 4 percent by volume are preferred, while higher concentrations of sand, for example, 5 to 15 percent, are required to obtain optimum drilling rates for that abrasive.

The drilling liquid used will depend in part upon the abrasive used. Because of the higher density of ferrous abrasive particles, they should be suspended in a drilling liquid of relatively high viscosity and gel strength to prevent excessive settling of the abrasive from the drilling liquid. A suitable drilling liquid for suspending ferrous abrasives is an invert emulsion of water in diesel oil containing approximately 40-percent diesel oil stabilized with a suitable emulsifier, such as a sulfurized potassium soap of tall oil. A 6 percent suspension of bentonite and water is suitable as a drilling liquid with a sand abrasive.

The drilling liquid is delivered through the drill string into the drill bit **22** at a pressure resulting in a pressure drop through the nozzles of the drill bit of the order of at least 4,000 pounds per square inch to impart the desired high velocity to the drilling liquid discharged from the nozzles. The drill string and drill bit are rotated during the drilling operation whereby the high velocity stream of drilling liquid discharged from the inwardly slanting nozzle cuts a central hole in the bottom of the borehole and the streams from the other nozzles cut a series of concentric grooves separated by thin intervening ridges. The stand-off bars on the bottom of the drill bit engage the intervening ridges and support the drill bit, with the nozzle outlet at a distance of ¼ inch to 1¼ inches above the tops of the ridges. A relatively small weight, for example, a weight not exceeding about 1,000 pounds per inch of diameter of the drill bit, is applied to the drill bit. Engagement of the stand-off bars with the ridges breaks the ridges to lower the bit during the drilling operation. In drilling with conventional rock bits or the usual jet bit having cutting elements designed to penetrate the bottom of the borehole, weights of 4,000 pounds per inch of diameter of the bit, or more, are applied during the drilling of hard formations.

Referring to FIGURES 4 and 5 in which the bottom of a borehole drilled by this invention is diagrammatically illustrated, a central hole **62** is cut by a high-velocity stream discharged from an inwardly slanting nozzle in the drill bit. A concentric groove of larger diameter **64** is cut by an outwardly slanting nozzle. To reduce the thickness of the ridge between the central hole **62** and the groove **64**, a vertically directed nozzle was provided to cut a groove **66**. Finally, an outer groove **68** is cut by outwardly slanting nozzles to establish the desired gauge of the borehole. The ridges **70**, **72**, and **74** in the bottom of the borehole are engaged by stand-off bar **76** which breaks off the upper ends of the ridges as drilling proceeds. As illustrated in FIGURE 5, the leading surfaces **80** and **82** of stand-off bars **76** and **78**, respectively, do not lie on the radius of the drill bit, and because of this arrangement exert a force on the ridges in a direction in which the ridges are not effectively supported.

In the drill bit illustrated in FIGURE 6 of the drawings, stand-off bars **84** and **86** are oriented whereby a large component of the force exerted by them is applied to the side of the ridges. The drill bit **88** in FIGURE 6, like the drill bit illustrated in FIGURE 3, is provided with a plurality of nozzles oriented to cut a number of concentric grooves in the bottom of the borehole. The nonsymmetric arrangement of the stand-off bars on the drill bit illustrated in FIGURE 6 causes some of the ridges to be loaded by only one of the stand-off bars while other ridges may be loaded only by the other stand-off bar.

The cutting of a central hole in the bottom of the borehole leaves only ridges unsupported on two sides and positioned whereby tensile stresses can be created in the rock by the rotating drill bit. If a central core is left in the borehole bottom, the only substantial forces exerted against the core are compressive.

In the drilling method of this invention, penetration of the bottom of the hole is accomplished by the high-velocity streams of abrasive-laden liquid. Those streams

expose unsupported ridges of rock of thin cross section which can be easily mechanically broken. With this method, a substantial portion of the rock is removed mechanically from the bottom of the borehole. Important savings in hydraulic horsepower are realized from the mechanical removal of the rock.

We claim:

1. A hydraulic jet method for drilling the borehole of a well through hard formations comprising rotating in the borehole drill pipe having a drill bit secured to its lower end, said drill bit having an abrasion-resistant stand-off bar extending downwardly from its bottom, pumping down the drill pipe and discharging from the drill bit at a velocity of at least 500 feet per second a first stream of abrasive-laden liquid, said first stream being directed downwardly against the center of the bottom of the borehole to cut a central hole in the bottom of the borehole, discharging a second stream of abrasive-laden liquid from the drill bit at a velocity of at least 500 feet per second, said second stream of abrasive-laden liquid being directed outwardly to cut a groove having an outer diameter substantially equal to the diameter of the borehole, directing other high-velocity streams of abrasive-laden liquid at a velocity of at least 500 feet per second from the drill bit against the bottom of the hole to cut intermediate grooves between the central hole and the outer groove separated by intervening ridges having a width not more than ½ inch, forcing the drill bit downwardly against the ridges whereby the stand-off bar engages the ridges and breaks particles from the ridges, and circulating the drilling liquid up the borehole to remove therefrom particles of rock cut and broken from the bottom of the borehole.

2. In a hydraulic jet method for drilling the borehole of a well through hard formations in which a drill pipe having a drill bit mounted on the lower end thereof is rotated in the borehole, said drill bit having abrasion-resistant stand-off bars extending from the lower surface thereof, the improvement comprising delivering an abrasive-laden drilling liquid down the drill pipe to the drill bit, discharging an inner stream of drilling liquid from the drill bit against the central portion of the bottom of the borehole at a velocity of at least 500 feet per second to cut a central hole in the bottom of the borehole, discharging an outer stream of drilling liquid at a velocity of at least 500 feet per second against the outer portion of the bottom of the borehole to cut a groove having an outer diameter substantially equal to the diameter of the borehole, discharging intermediate streams of drilling liquid at a velocity of at least 500 feet per second from the drill bit and against the bottom of the borehole to cut grooves therein, said intermediate streams being located to cut a series of concentric grooves separated by intervening ridges not more than ½ inch wide in the bottom of the borehole, engaging the intervening ridges with the stand-off bars on the lower surface of the drill bit to break particles from the ridges, and circulating the drilling liquid up the borehole through the annulus between the drill pipe and the borehole wall.

3. In a hydraulic jet drilling method for drilling a borehole in hard formations in which a drill bit having a plurality of downwardly opening nozzles mounted therein is secured to the lower end of drill pipe rotating in the borehole and an abrasion-resistant stand-off bar extends downwardly from the bottom of the drill bit, the improvement comprising pumping a drilling liquid having abrasive particles suspended therein down the drill pipe, discharging an inner stream of drilling liquid from an inner nozzle at a velocity of at least 500 feet per second against the central portion of the bottom of the borehole to cut a central hole therein, discharging a stream of drilling liquid from outer nozzles at a velocity of at least 500 feet per second downwardly against the bottom of the borehole to cut an outer groove therein, said outer groove having an outer diameter substantially equal to the diameter of the borehole, discharging streams of drilling liquid at a velocity of at least 500 feet per second from intermediate nozzles downwardly against the bottom of the borehole to cut a plurality of concentric grooves in the bottom of the borehole between the central hole and the outer groove, said nozzles being positioned to leave intervening ridges ⅛ inch to ½ inch wide between the concentric grooves, supporting the drill bit on the ridges with the outlets of the nozzles ¼ inch to 1¼ inches above the ridges in the bottom of the borehole, applying to the bit a weight not exceeding about 1,000 pounds per inch of diameter whereby the stand-off bar engages and breaks the ridges, and circulating the drilling liquid up the borehole between the drill pipe and the borehole wall to carry cuttings from the borehole.

4. A method as set forth in claim **3** in which the drilling liquid contains ½ to 4 percent by volume of ferrous abrasive particles having a size in the range of 7 to 80 mesh, and in which the nozzles have a diameter of $\frac{3}{32}$ to ¼ inch.

5. In a hydraulic jet method for drilling the borehole of a well through hard formations in which a drill pipe having a drill bit mounted on the lower end thereof is rotated in the borehole of the well, the improvement comprising pumping an abrasive-laden drilling liquid down the drill pipe to the drill bit, discharging streams of drilling liquid from the drill bit at a velocity of at least 500 feet per second to cut in the bottom of the borehole a central hole surrounded by a plurality of concentric grooves separated by intervening ridges, the outer groove having an outer diameter substantially the same as the diameter of the borehole, moving a substantially vertical surface on the bottom of the drill bit oriented in a non-radial position against the intervening ridges to exert against said ridges a force having a radial component, applying to the drill bit a weight up to about 1,000 pounds per inch of diameter of the drill bit to break the ridges, and circulating drilling liquid and cuttings upwardly through the annulus between the drill pipe and the borehole wall.

6. In a hydraulic jet method for drilling the borehole of a well through hard formations, the method including rotating a drill pipe having a drill bit mounted on the lower end thereof for rotation therewith, the improvement comprising delivering down the drill pipe to the drill bit a liquid having suspended therein ½ to 4 percent ferrous abrasive particles having a size in the range of 7 to 80 mesh, discharging from the drill bit through nozzles $\frac{3}{32}$ to ¼ inch in diameter opening downwardly ¼ inch to 1¼ inches above the bottom of the bit a plurality of streams of drilling liquid at a velocity of at least 500 feet per second and a pressure drop through the nozzles of at least 4,000 pounds per square inch, said streams of drilling liquid including an inner stream discharged against the central portion of the bottom of the borehole to cut a central hole therein, an outer stream directed against the outer portion of the bottom of the borehole to cut a groove having an outer diameter substantially equal to the diameter of the borehole and intermediate streams directed against the bottom of the borehole to cut a plurality of concentric grooves between the central hole and the outer groove, said grooves being separated by intervening ridges ⅛ to ½ inch wide, forcing the bit downwardly on the ridges with a force not exceeding 1,000 pounds per inch of diameter, and engaging the ridges with substantially vertical surfaces of the bit constructed and arranged to urge the ridges toward the grooves on rotation of the bit.

References Cited

UNITED STATES PATENTS

878,208	2/1908	Kuschniok	175—67
1,661,672	3/1928	Morrison	175—67 X
1,853,379	4/1932	Rotinoff	175—67 X
2,678,203	5/1954	Huff	175—422 X
2,963,102	12/1960	Smith	175—422 X
3,020,965	2/1962	Keller	175—422
3,112,800	12/1963	Bobo	175—67

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U.S. DEPARTMENT OF COMMERCE

PATENT OFFICE

Washington, D.C. 20231

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,402,780 September 24, 1968

Robert J. Goodwin et al.

It is certified that error appears in the above identified patent and that said Letters Patent are hereby corrected as shown below:

Column 8, line 31, "Kuschniok" should read -- Kirschniok -- same column 8, after line 37, insert

FOREIGN PATENT
109,272 4/1925 Switzerland

Signed and sealed this 10th day of February 1970.

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents