Dec. 24, 1968 W. P. ACHESON ET AL 3,417,829

CONICAL JET BITS

Filed Sept. 16, 1966 2 Sheets-Sheet 1

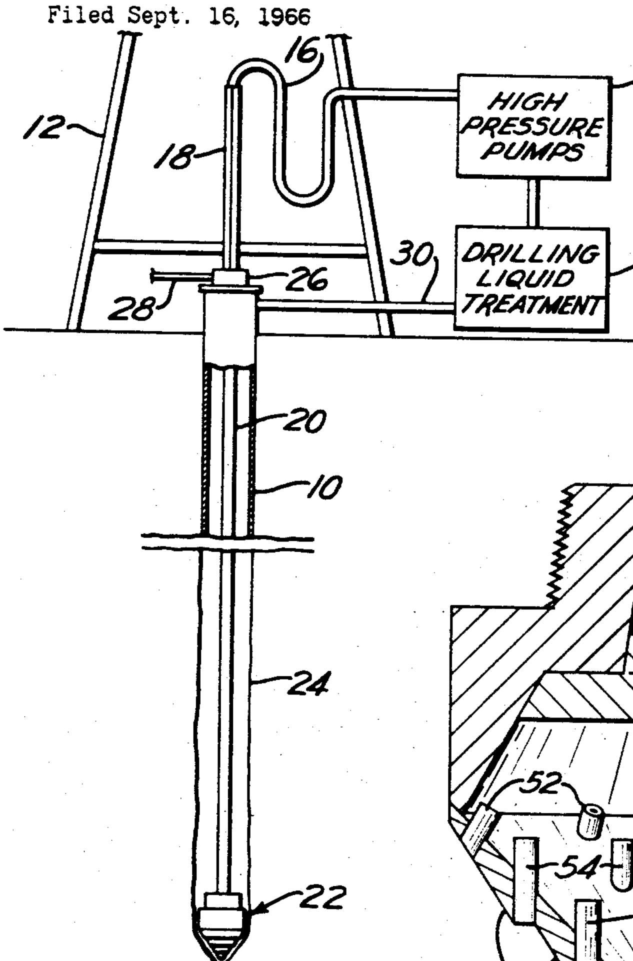

Fig. 1

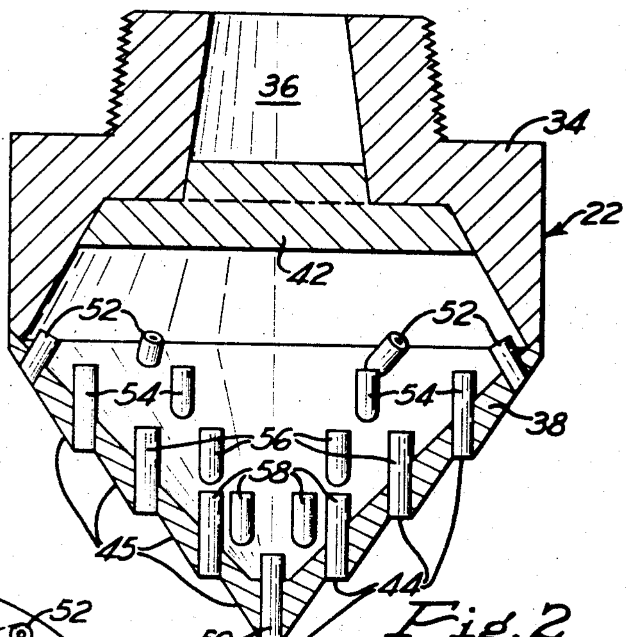

Fig. 2

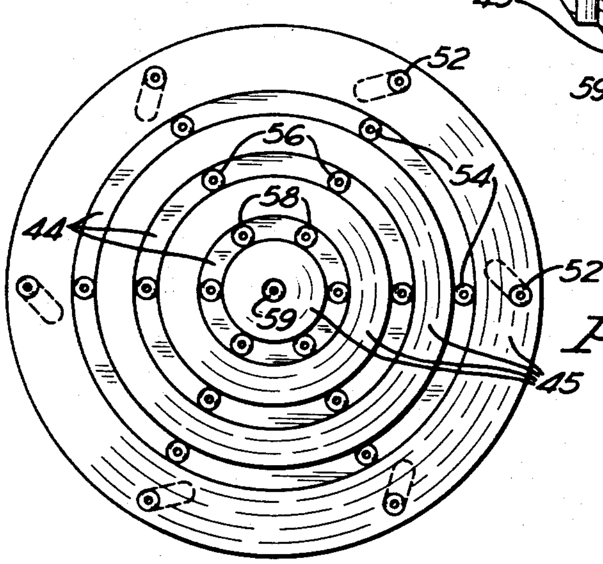

Fig. 3

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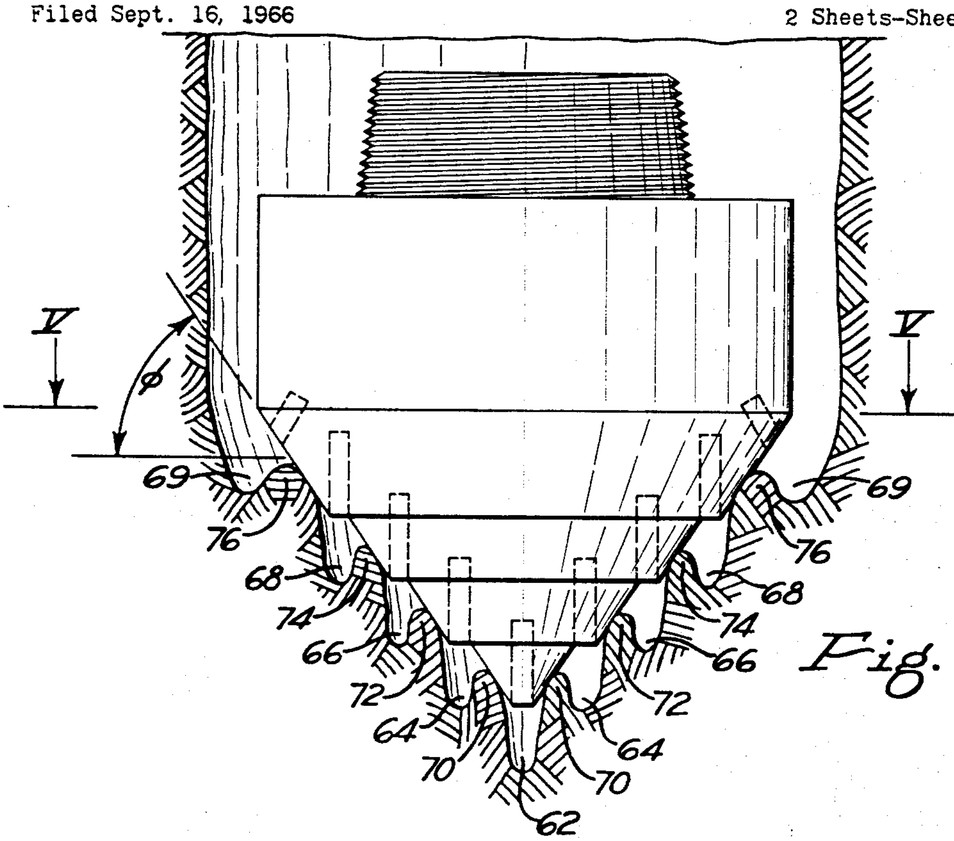

Fig. 4

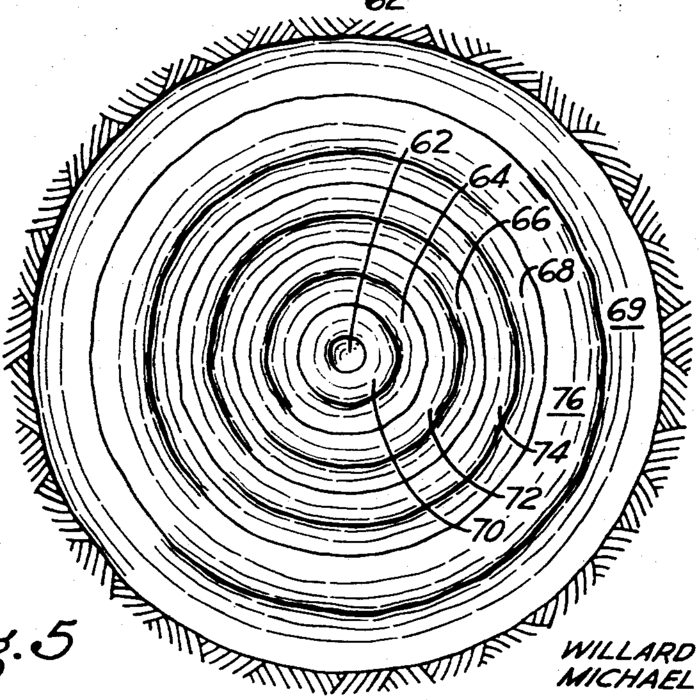

Fig. 5

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United States Patent Office 3,417,829
Patented Dec. 24, 1968

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3,417,829

CONICAL JET BITS

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Filed Sept. 16, 1966, Ser. No. 580,035
7 Claims. (Cl. 175—67)

ABSTRACT OF THE DISCLOSURE

A method and apparatus for the hydraulic jet drilling of the borehole of a well in which high-velocity streams of abrasive-laden liquid are discharged from nozzles extending downwardly at different distances from the center of rotation of a drill bit having a downwardly tapering conical bottom member to cut a plurality of concentric grooves separated by thin ridges. Each groove is lower than any groove of larger diameter. The drill bit is urged downwardly whereby upon rotation the lower surface of the drill bit urges the ridges outwardly to break the rock forming the ridges.

This invention relates to a hydraulic jet method for drilling wells in areas where hard formations may be encountered.

The usual rotary drilling techniques employed where hard rock formations are expected to be encountered consist of applying heavy weights to a double or triconed bit, rotating this bit in contact with the formation and circulating a drilling fluid down the drill pipe and up the annulus surrounding the drill pipe to remove pieces of formation which have been broken from the matrix.

Where extremely hard formations are expected to be encountered button type drill bits having tungsten carbide inserts are utilized to replace the faster wearing, less effective toothed bits. These button coned bits used in hard rock formations frequently experience numerous bearing failures owing to the heavy weight which must be applied on the bit to achieve adequate penetration rates.

A further disadvantage of the use of toothed or button bits is the necessity of utilizing thick walled heavy drill pipe and drill collars in order to withstand the great amount of torque that must be transmitted to the bit and to supply the large bit weights which are needed. These bulky and heavy tubular goods require large amounts of energy to operate, are expensive to maintain and present handling difficulties.

A recent development for drilling hard formations is to utilize abrasive-laden liquid as the drilling fluid and bombard the bottom of the borehole with this liquid by discharging it from nozzles at extremely high velocities of at least 500 feet per second and preferably greater than 650 feet per second. Hard formations are, in general, formations having a compressive strength of 20,000 p.s.i. or higher. In the operation of these heretofore employed jet bits 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 back splash 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 over-lapping grooves or substantially continuous grooves, whereby virtually the entire removal of rock from the bottom of the hole is accomplished by the streams of drilling liquid.

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This invention resides in an improved hydraulic jet drilling process and apparatus by which a hole is cut in the center of the bottom of the borehole by a high-velocity stream of abrasive-laden liquid and a groove is cut around the borehole's outer edge to establish a borehole of desired gauge. High-velocity streams of abrasive-laden liquid are directed downwardly against the matrix at intervals between the center hole and the outer groove to cut a plurality of concentric vertical grooves separated by thin intervening annular ridges less than one-half inch wide. The grooves are vertically separated from each other by every succeeding groove located at a greater radial distance from the center of the borehole occupying a progressively higher position in the borehole. A mechanical force is exerted by the drill bit to urge the ridges outwardly to break off the ridges and lower the bit for further penetration of the high-velocity streams of drilling liquid of the formation being drilled. Smooth concentric stand-off surfaces, located between the circumferentially placed nozzles of this bit, are mounted on the outer face of the bit having an outwardly facing surface at an angle 45 to 80° from the horizontal. As the bit is rotated the angled standoff surfaces will exert a force substantially perpendicular to the intervening ridges toward an adjacent groove thereby subjecting the inner surface of the ridges to principally a tensile force. Penetration of the formation is caused by the high-velocity streams of drilling liquid. The concentric standoff surfaces merely break ridges extending upwardly from the bottom of the borehole and thereby reduce the amount of rock that must be eroded by the jet stream.

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 diagrammatic view partially in vertical section 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 diagrammatic view partially in vertical section diagrammatically showing the bottom of the borehole of a well during drilling by a method of this invention.

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

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 the borehole **24**. Drill string **20** is rotated in the borehole by engagement of the kelly **18** with a rotary drill table **26**, driven through a shaft **28** by a suitable power source, not shown.

Drilling liquid circulated up through the annulus **21** in the well between 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 the fine particles and are removed with the fines. The drilling liquid may also be treated to maintain other properties such as viscosity, density, etc. in the desired range.

In 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 in tension by a moderate weight applied to the drill bit **22**. The grooves are vertically separated from each other with every succeeding groove located at a greater radial distance from the center of the borehole and each groove more remote from the center of the borehole occupying a progressively higher position. In the drilling process of this invention, portions of the borehole coming in contact with the drill bit are subjected on their inner side to a bending moment substantially perpendicular to the ridge. In this manner, tensile stresses are created in the rock and advantage is taken of rock's weakness in tension to facilitate mechanically 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 a hollow tapered 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 FIGURE 2, the drill bit body **34** is reinforced by a web **42** extending across the central opening **36**.

Concentric back splash plates **44** and standoff surfaces **45** made of hard, abrasive-resistant material, such as tungsten carbide, are secured to the lower surface of the bit. The concentric standoff surfaces **45**, existing between the circumferentially placed nozzles, are mounted on the bit at an angle from 45° to 80° upwardly and outwardly from the horizontal.

A plurality of passage extends through the bottom member **38** and back splash 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 nozzle groups, are located at varying radial distances and vertical heights from the center of rotation of the bit and aligned to produce the desired pattern of grooves in the borehole. In the bit illustrated in FIGURE 3 of the drawings, a series of outer nozzles **52** direct the abrasive-laden drilling liquid against the bottom of the borehole at approximately the outer diameter of the drill bit to cut a groove whose diameter is slightly larger than the outer diameter of the drill bit. Other nozzle series **54**, directed downwardly and substantially perpendicular to the radius of the borehole, preferably at an angle from the horizontal of 75° to 90°, strike the bottom of the borehole at a distance from the outer wall of the borehole leaving a minimum ⅛ inch width intervening ridge **76** between the groove **68** and the groove **69**. The groove **68** cut by nozzle series **54** will exist at a lower vertical position than the groove **69** cut by nozzle series **52**. Other circumferentially placed nozzle series **56** are directed downwardly and substantially perpendicular to the radius of the borehole are positioned closer to the center of the drill bit and at a lower vertical height than nozzle series **52** or **54**. This nozzle series **56** cuts a groove **66** of smaller diameter than the grooves **68, 69**. Other circumferentially placed nozzle series **58** directed downwardly and substantially perpendicular to the radius of the borehole are positioned closer to the center of the drill bit and at a lower vertical height than nozzle series **52, 54** or **56**. This nozzle series **58** cuts a groove **64** of smaller diameter than the grooves **66, 68, 69**. In the embodiment illustrated, a single nozzle **59** is located in the center of the borehole, directed in a downwardly direction and positioned as a lowermost nozzle at the bottom of the bit. The radial distance between each nozzle will depend upon the nozzle diameter and the standoff distance maintained. For the nozzle diameters employed in the bit of this invention the radial distance between each nozzle series should be approximately $\frac{5}{32}$ to ¾ inch in order to maintain ridges ⅛ to ½ inch wide.

Because of the severe abrasion to which the nozzles are subjected during the drilling process, nozzle series **52, 54, 56, 58** and **59** 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 concentrically placed back splash plates **44**.

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 particular 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 7 mesh to about 80 mesh can be used. With larger nozzle orifices, larger abrasive particles would be used without plugging the nozzles, but an increase in particle size larger than 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 that is 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 rate 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 casing severe erosion of the nozzles and having a relatively 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 that should be suspended in a drilling liquid, a drilling liquid possessing a relatively high viscosity and gel strength should be employed to prevent excessive settling of the abrasive from the drilling liquid. A suitable drill liquid for suspending abrasives is an invert emulsion of water and diesel oil containing approximately 40 percent diesel oil stabilized with a suitable emulsifier, such as sulfurized potassium soap of tall oil. A six percent suspension of bentonite and water is suitable as a drilling liquid for sand abrasive.

The drilling liquid is delivered through the drill string into the drill bit **22** at a rate resulting in a pressure drop through the nozzles of the drill bit of the order of at least 4000 pounds per square inch to impart the desired high velocity to the drilling liquid discharged from the nozzles. The drill string and the drill bit are rotated during the drilling operation whereby the high-velocity streams of drilling liquid discharged from the downwardly directed nozzles cut a series of concentric grooves separated by thin intervening ridges. The concentric standoff surfaces **45** on the drill bit engage the surface of the intervening ridges and support the drill bit with the nozzle outlet maintained at a proper standoff distance from the formation matrix. A relatively small weight, for example, a weight not exceeding 1000 pounds per inch of diameter of the drill bit, is applied to the drill bit. Engagement of the concentric standoff surfaces **45** with the ridges breaks the ridges to lower the bit during the drilling operation. In drilling with conventional rock bits weights of 4000 pounds per inch of diameter of the bit, or more, are applied during the drilling of hard formations.

Referring to FIGURES 4 and 5 the bottom of the borehole drilled by this invention is diagrammatically illustrated, a central hole **62** is cut by a high-velocity stream discharged from a downwardly directed nozzle in the drill bit. Concentric grooves of larger diameters **64, 66** and **68** are cut by nozzles directed substantially downward. Finally an outer groove **69** is cut by downwardly and outwardly slanting nozzles **42** to establish the desired gauge of the borehole. The ridges **70, 72, 74** and **76** in the borehole are engaged by smooth concentrically placed angled standoff surfaces **45** which break off the upper ends of the ridges as drilling proceeds. The angled surface of the concentric standoff surfaces exert a force on the ridges in a direction in which the ridges are not effectively supported thereby breaking the ridges in tension.

In the drilling method and apparatus of this invention, penetration is accomplished by the high-velocity streams of abrasive-laden liquid. These streams expose unsupported rock up to approximately ½ inch in width which can be easily mechanically broken by exerting a force substantially perpendicular to these ridges. With this method a substantial portion of the rock is removed mechanically from the bottom of the borehole. The effectiveness of ridge removal is increased by applying substantially perpendicular forces to these ridges and nozzle standoff may be more easily maintained by employment of a bit of this design.

Therefore we claim:

1. In a hydraulic jet drilling method for drilling boreholes through subsurface formations in which streams of abrasive-laden fluid are discharged at a velocity of at least 500 feet per second from a rotating drilling tool at the bottom of the borehole against the formation to cut particles from the formation, the improvement comprising discharging a plurality of downwardly directed streams of abrasive-laden fluid from different elevations in, and different distances from the axis of rotation of, the drilling tool to cut a plurality of concentric grooves separated by intervening ridges, each of the streams of drilling liquid discharged from the drilling tool being at a greater distance from the axis of rotation than streams discharged from lower elevations in the drilling tool whereby each groove is lower than the next outer groove, the streams of drilling liquid discharged at the largest distance from the center of rotation traveling downwardly and outwardly to cut a groove having a diameter larger than the diameter of the drilling tool, the streams of drilling liquid discharged at lesser distance from the center of rotation traveling substantially vertically downwardly, and forcing outwardly facing surfaces on the bottom of the drilling tool sloping at an angle of 45° to 80° against the ridges to urge the ridges outwardly to mechanically break said ridges.

2. A method as set forth in claim **1** wherein the ridges are ⅛ to ½ inch wide.

3. A drill bit for the hydraulic jet drilling of wells by discharging suspensions of abrasive particles in liquids from nozzles at a high velocity against the bottom of the bore hole of the well comprising a hollow drill bit body closed on its lower end by a downwardly tapering conical bottom member, a downwardly directed nozzle located near the center of the drill bit passing through the bottom member and adapted to cut a central hole in the bottom of the borehole, at least two series of circumferentially placed nozzles directed substantially vertically downwardly passing through the bottom member with each nozzle series located a larger radial distance from the center of the bit positioned at a higher elevation in the bit than nozzles at a smaller distance from the center of rotation, an outer series of nozzles extending downwardly and outwardly through the bottom member adjacent the periphery thereof and higher than the other nozzles, all of the nozzles having their outlets substantially flush with the bottom surface of the bottom member, and outwardly facing standoff surfaces on the outer surface of the bit between the nozzle series adapted to engage the formation.

4. A drill bit for the hydraulic jet drilling of wells by discharging suspensions of abrasive particles in liquids from nozzles at a velocity of at least 500 feet per second against the bottom of the borehole comprising a hollow drill bit body closed on its lower end by a downwardly tapering conical bottom member, a downwardly directed nozzle extending through the drill bit substantially at the center thereof, a plurality of concentric series of nozzles, each nozzle in the concentric series extending substantially vertically downwardly through the bottom member, each of said concentric series being spaced from adjacent series a distance whereby streams of abrasive-laden liquid discharged from the nozzle cut grooves in the bottom of the borehole separated by intervening ridges, an outer series of nozzles extending downwardly and outwardly through the bottom member adjacent the periphery thereof and higher than the other nozzles, all of the nozzles having their outlets substantially flush with the bottom surface of the bottom member, and abrasive-resistant standoff surfaces on the outer surface of the bit between the series of nozzles, said standoff surfaces extending outwardly and upwardly at an angle of 45° to 80° from the horizontal.

5. A drill bit for the hydraulic jet drilling of wells by discharging suspensions of abrasive particles in liquids from nozzles at a velocity of at least 500 feet per second against the bottom of the borehole of a well comprising a hollow drill bit body closed on its lower end by a downwardly tapering conical bottom member, a downwardly directed central nozzle located near the center of rotation of the drill bit body passing through the bottom member, an outer series of nozzles extending downwardly and outwardly through the bottom member, a plurality of concentric series of nozzles passing through the bottom member directed downwardly and inclined from the vertical no more than 15° with each nozzle series located a larger radial distance from the center of the bit positioned at a higher elevation in the drill bit, the outlets of the nozzles being substantially flush with the bottom surface of the bottom member, and outwardly facing standoff surfaces on the outer surface of the bit between adjacent series of nozzles, said standoff surfaces extending outwardly and upwardly at an angle of 45° to 80° from the horizontal.

6. An apparatus as in claim **5** in which the nozzles are radially located to cut grooves separated by ridges having a width ⅛ to ½ inch in the bottom of the borehole.

7. A hydraulic jet method for drilling the borehole of a well comprising rotating in the borehole drill pipe having secured to its lower end a hollow drill bit having its lower end closed by a downwardly tapering conical bottom member, pumping abrasive-laden liquid down the drill pipe, discharging a first stream of abrasive-laden liquid downwardly and outwardly from the drill bit at a velocity of at least 500 feet per second to cut a first concentric groove having an outer diameter substantially the same as the diameter of the borehole, discharging substantially vertically downward from the bit at a location lower and closer to the center of rotation of the first stream a second stream of abrasive-laden liquid at a velocity of at least 500 feet per second substantially vertically downward from the bit against the bottom of the borehole to cut a second groove smaller in diameter than, lower than, and concentric with the first groove and separated from the first groove by an intervening ridge, discharging substantially vertically downward at a velocity of at least 500 feet per second near the center of rotation of the drill bit and lower than the second stream a third stream of abrasive-laden liquid to cut a groove in the formation at an elevation lower in the borehole than the second groove and separated from said second groove by an intervening ridge, urging the bit downwardly whereby outwardly facing surfaces of the bottom of the bit bear against the inner surface of the ridges to mechanically break 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.

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