June 13, 1967 R. J. GOODWIN ET AL 3,324,957
HYDRAULIC JET METHOD OF DRILLING A WELL
THROUGH HARD FORMATIONS
Filed Sept. 24, 1963 8 Sheets-Sheet 1

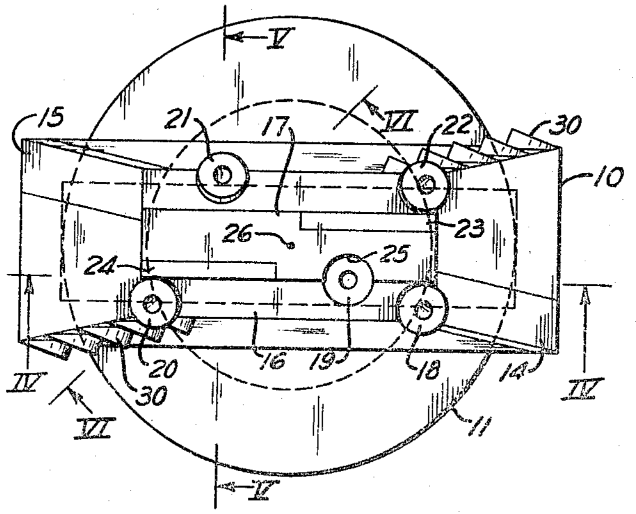

Fig. 1

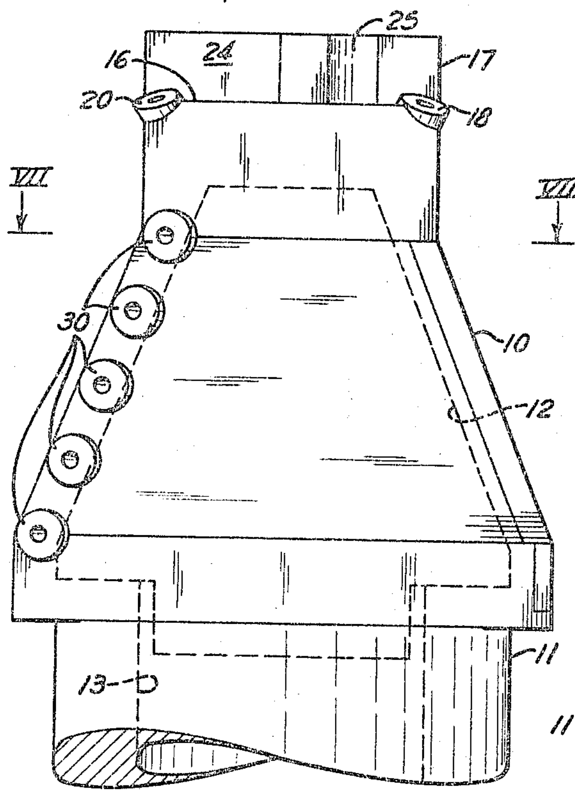

Fig. 2

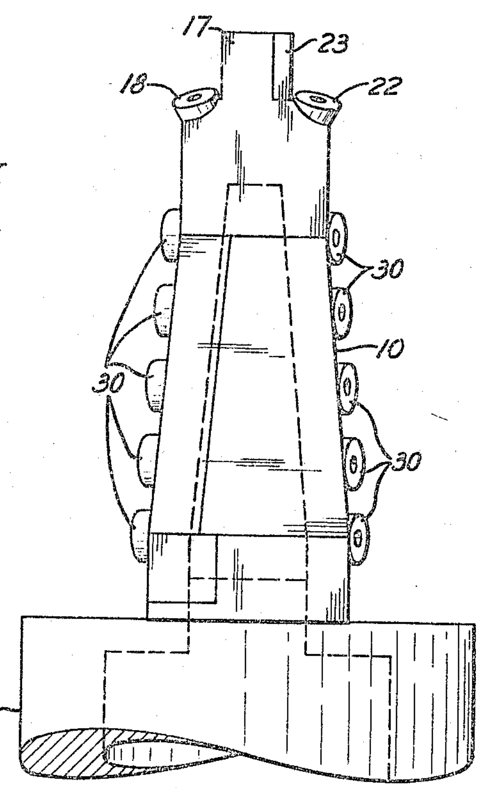

Fig. 3

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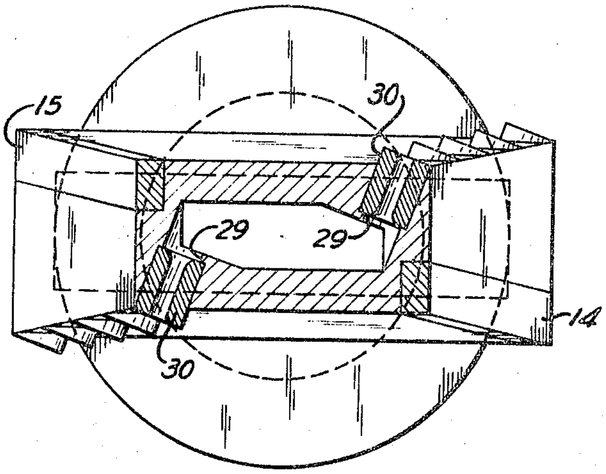

Fig. 7

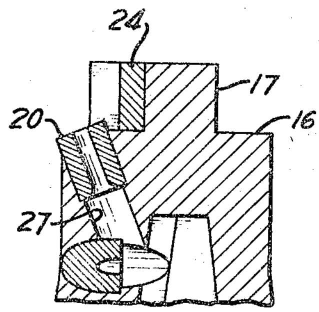

Fig. 6

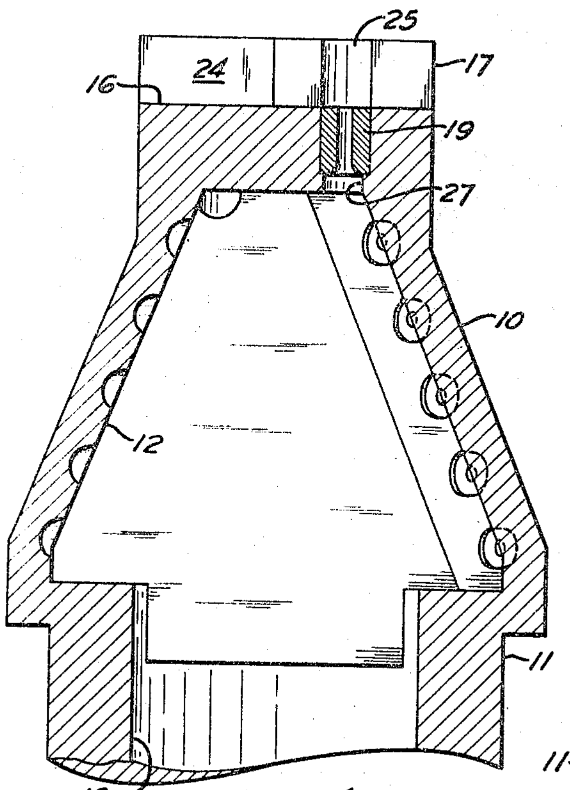

Fig. 4

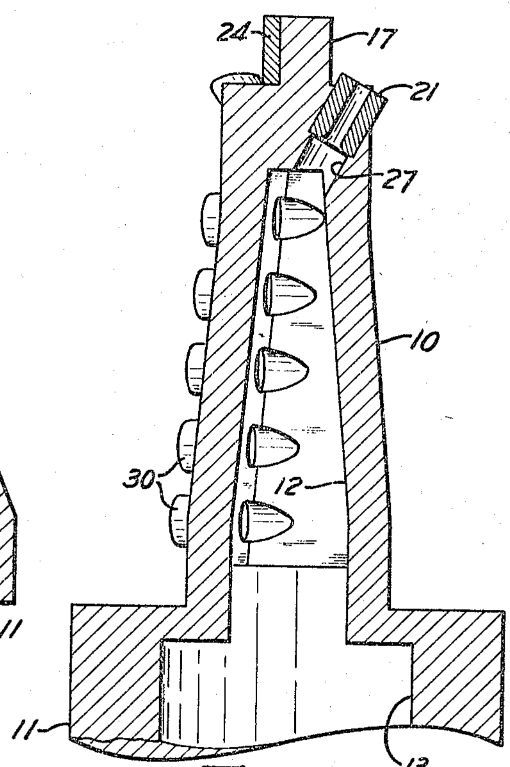

Fig. 5

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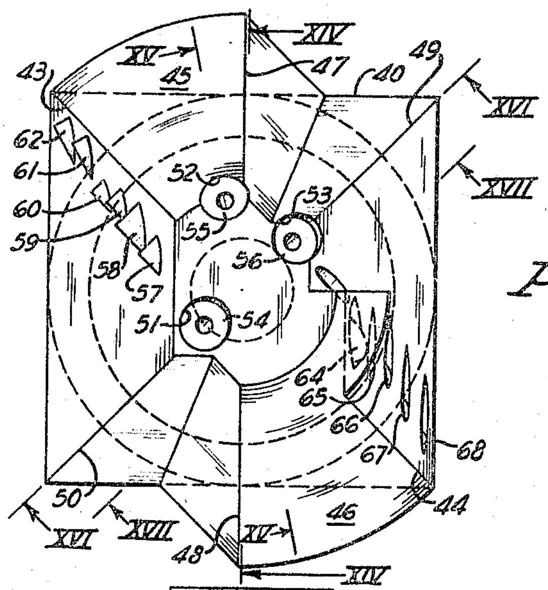


Fig. 8

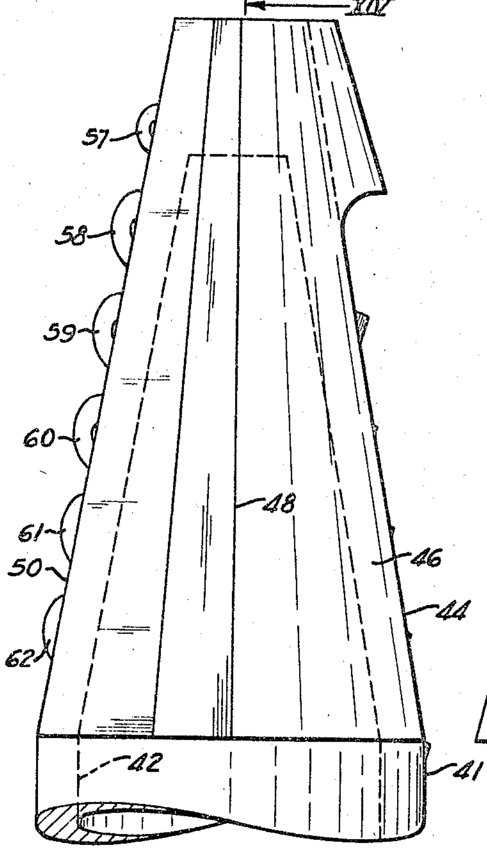
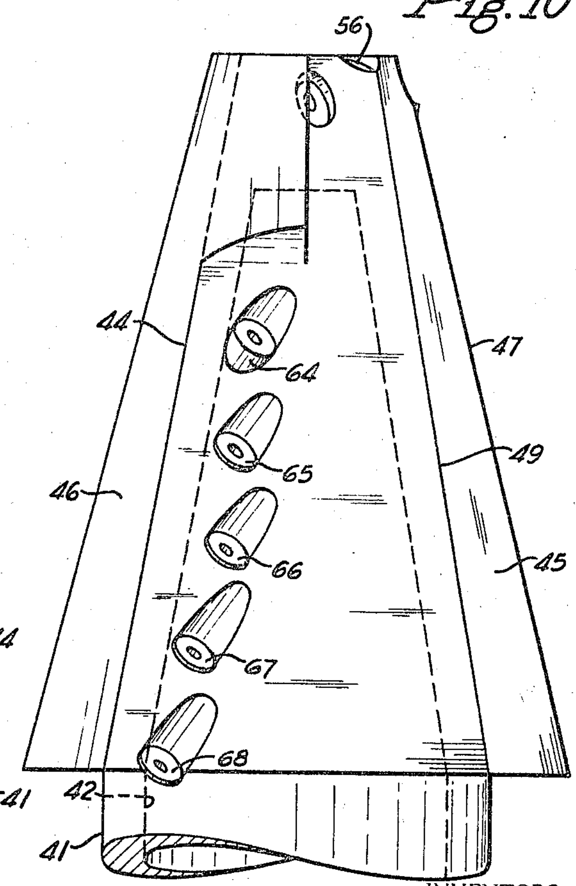


Fig. 9

Fig. 10



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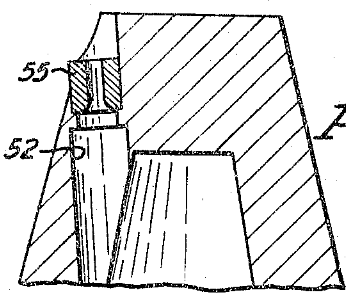

Fig. 15

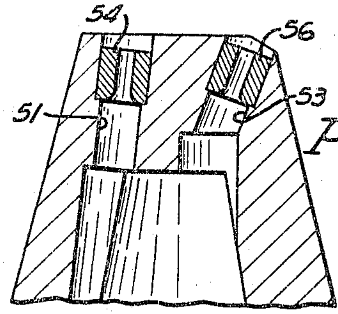

Fig. 16

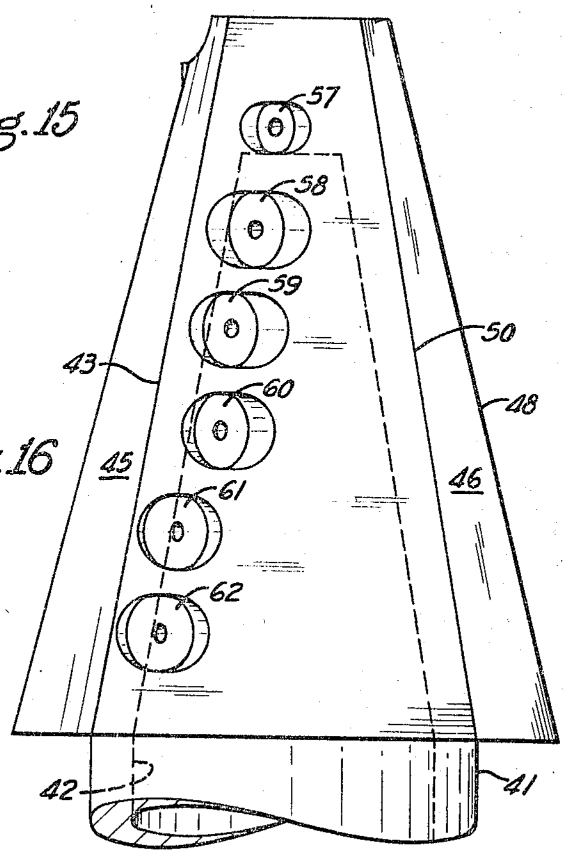

Fig. 11

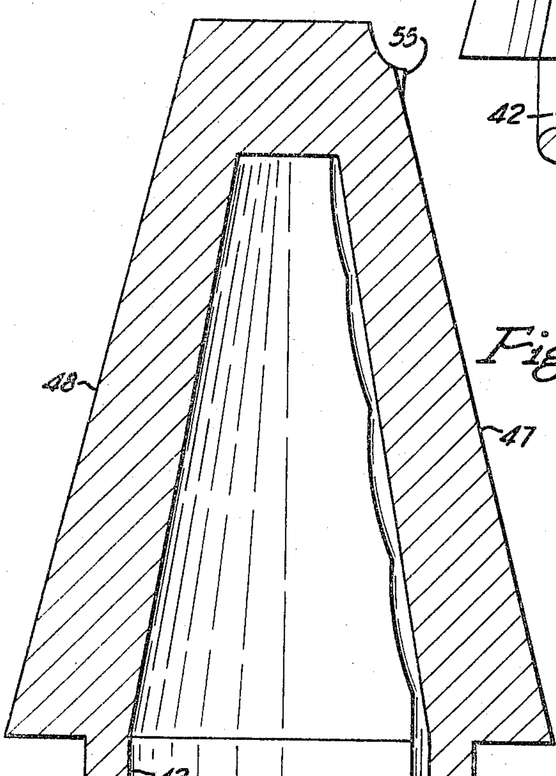

Fig. 14

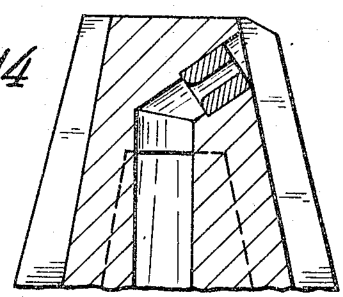

Fig. 17

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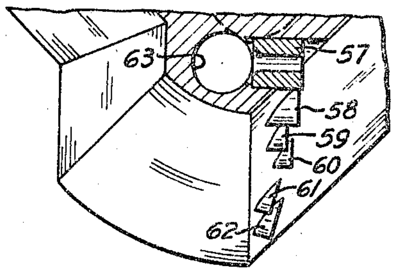


Fig. 19

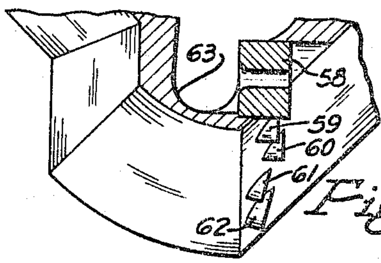


Fig. 20

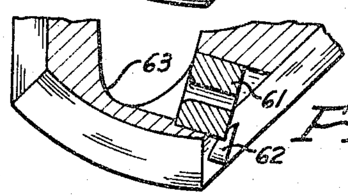
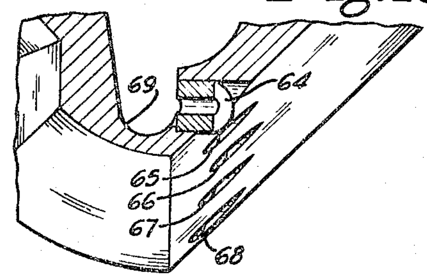


Fig. 21

Fig. 18



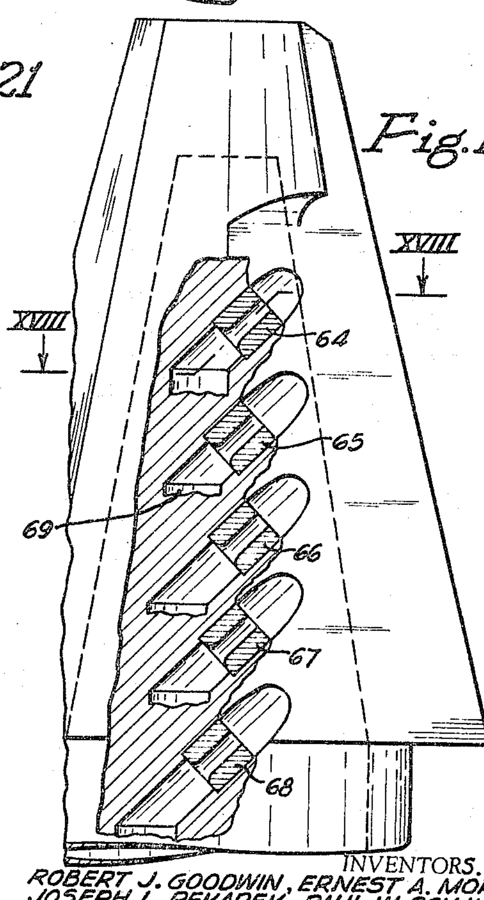


Fig. 12

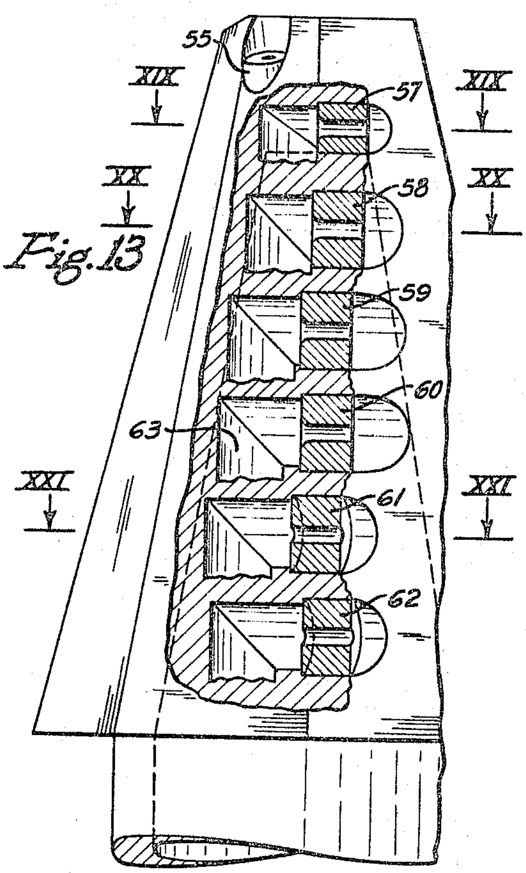


Fig. 13

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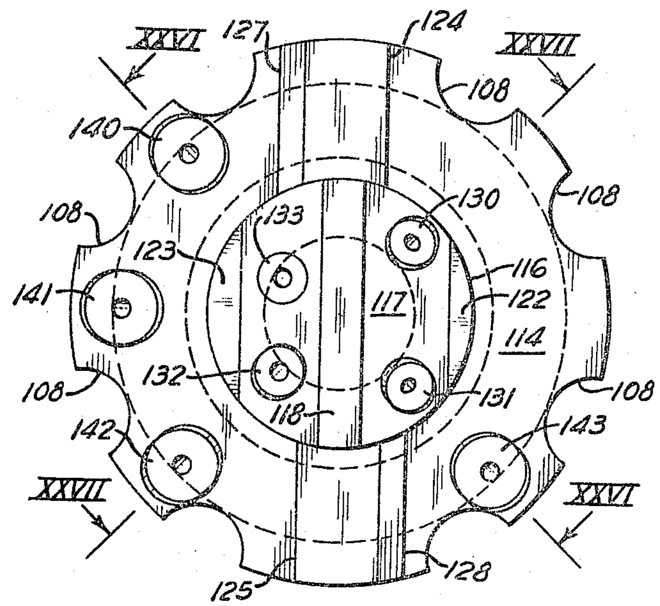

Fig. 22

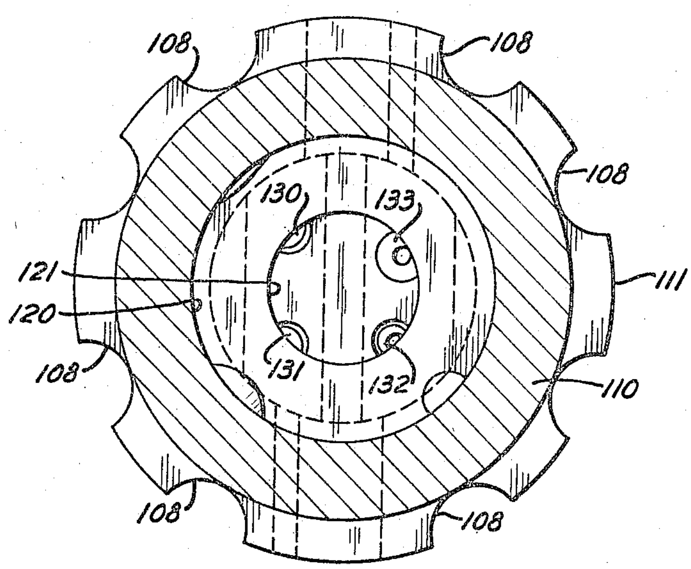

Fig. 23

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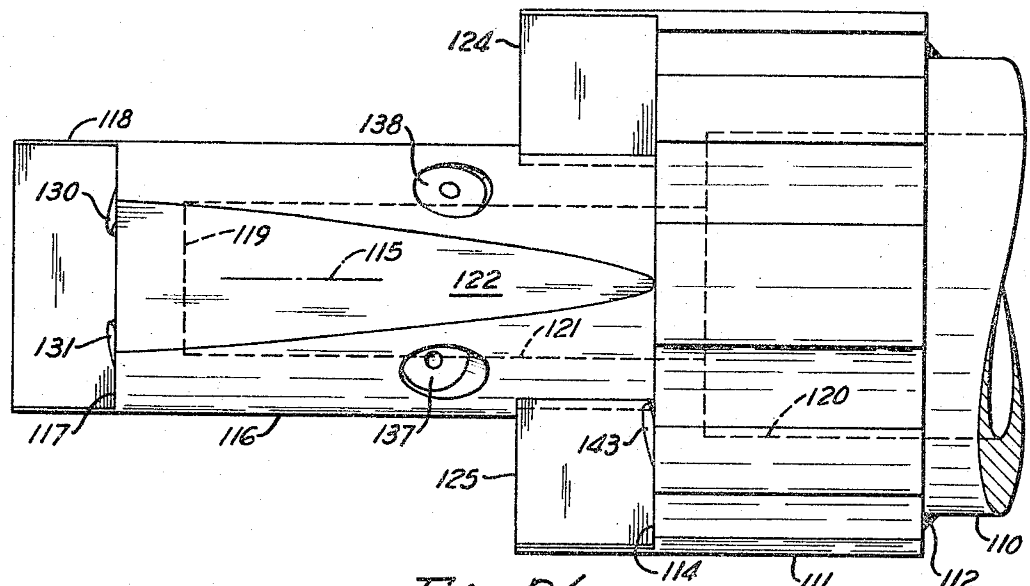

Fig. 24

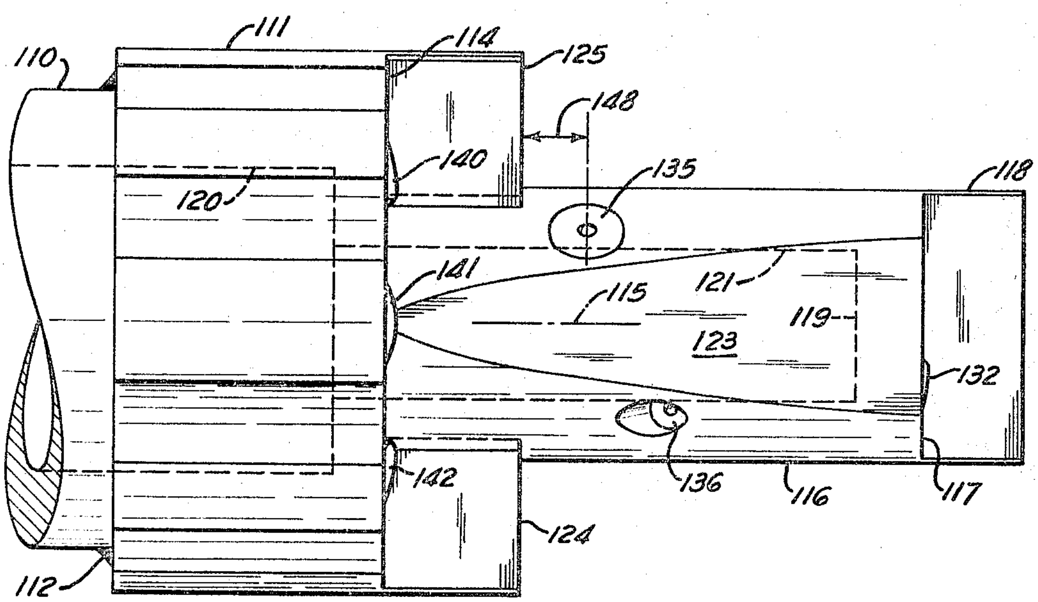

Fig. 25

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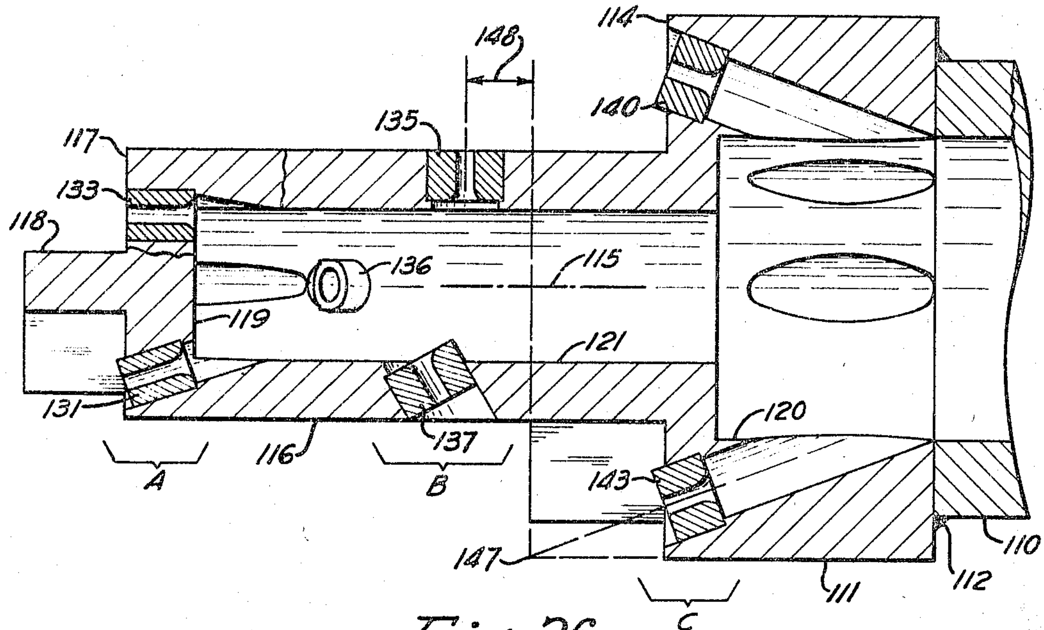

Fig. 26

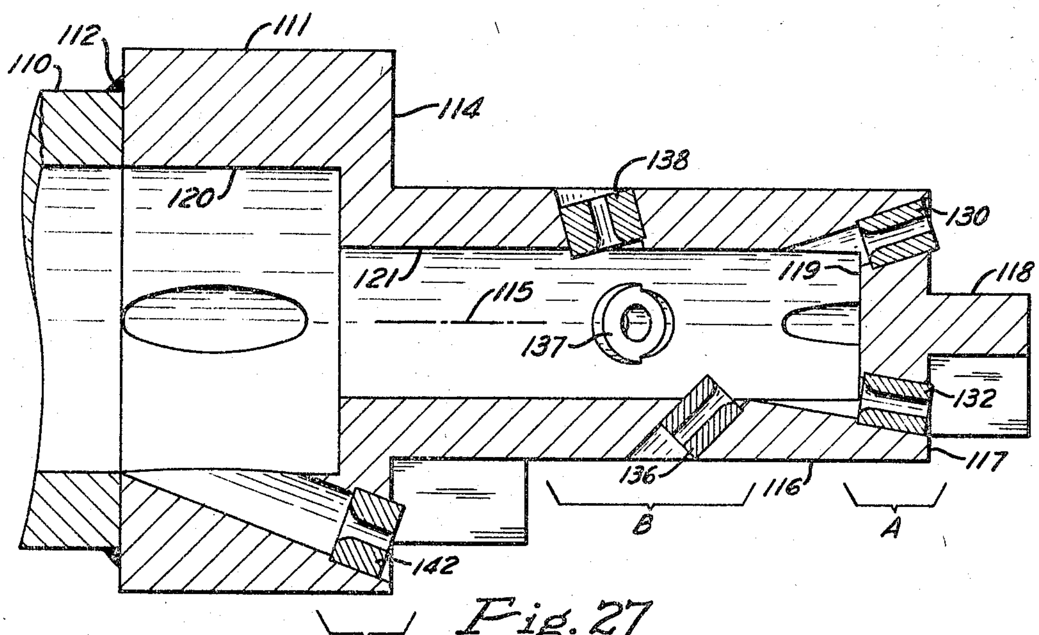

Fig. 27

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HYDRAULIC JET METHOD OF DRILLING A WELL THROUGH HARD FORMATIONS

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Filed Sept. 24, 1963, Ser. No. 311,034
2 Claims. (Cl. 175—67)

This invention relates to the art of drilling deep boreholes in the earth and in particular concerns a drill bit employing hydraulic jets to perform substantially all of the rock-cutting action.

Conventional devices for drilling deep boreholes function by making physical contact of the cutting surfaces of a metal drill bit with the rock formation at the bottom of the hole to mechanically cut the rock away. Such drill bits as the well known fish-tail bit, drag bit, core bit, roller bit, cone bit, disk bit, etc., all operate to make hole by mechanically breaking up the rock at the bottom of the hole whence the cuttings are removed to the surface of the earth by means of a circulating fluid medium such as air, foam, or drilling mud. In mechanically breaking up the rock it is inevitable that a substantial amount of wear and breakage also occurs to the cutting elements of such a drill bit, so that eventually the bit wears out and can no longer make hole. The drill stem must then be withdrawn from the hole, the bit replaced, and the bit stem with the new bit reinserted in the borehole. In drilling hard formations in a deep hole the time spent replacing conventional drill bits may exceed the actual drilling time on bottom, and this results in a loss of efficiency and very substantially increases the expense of the drilling operation.

Hydraulic jets have heretofore been included with conventional drill bits, but these jets have been for the purpose of keeping the cutting edges of the drill bit, or the rock surface being cut, free from mud and chips produced by the bit thereby to increase the efficiency of the mechanical cutters on the bit. However, such ancillary jets as have been employed with conventional rock bits have no effective cutting action when operated under the pressures normally employed for fluid circulation in conventional mechanical drilling operations.

We have found that when hydraulic jets are operated at very high pressures so that extremely high velocities are attained by the emerging jet stream, the fluid jet is very effective in making hole even in hard rock. By omitting substantially all mechanical cutters from the drill bit there is obtained a bit that is substantially free of mechanical wear or breakdown. Accordingly when such a bit is used in the hole, it will remain effective to make hole for a much longer period of time than a bit that includes mechanical cutting elements. Also due to the fact that the jets tear up the rock into very small fragments, the cuttings are more easily removed by the circulating fluid than are the larger cuttings made by conventional mechanical drill bits. Furthermore, because of the mechanical simplicity of such an all-jet bit, such bits are very sturdy and are also relatively inexpensive, thus resulting in a further saving of drilling expense. In addition when such bits are operated in accordance with this invention, they are found to make hole at a much faster rate than conventional bits.

A further disadvantage of conventional mechanical bits which is overcome by this invention is that a mechanical bit requires substantial weight to be applied to the bit in order to make it cut the rock being drilled. It is well known that high bit weight results in faster drilling with

a mechanical drill bit, but it is also known that high bit weights result in greater deviation from a straight hole, as well as greatly increasing wear on mechanical parts of a mechanical bit and thereby decreasing its life. By the use of the present invention the weight on the bit is reduced very substantially over that used in mechanical drilling with resulting improvement in hole straightness.

When using conventional mechanical drill bits, the drill stem is required to perform three functions, namely (1) serve as a conduit for the drilling fluid, (2) serve to apply weight to the drill bit, and (3) serve to apply torque to rotate the drill bit. The latter two of these functions are stringent requirements that dictate the use of heavy pipe made of expensive high-strength steel. By the use of the present invention the requirements of applying weight and torque to the drill bit are substantially eliminated, whereby it becomes possible to use lighter weight, inexpensive drill pipe. In the present invention the only important function of the drill pipe is to serve as a conduit for the high-pressure drilling fluid which in the substantial absence of other mechanical stresses is easily met.

We have found that when a plurality of hydraulic jet streams of extremely high velocity are rotated in a borehole, very effective cutting action is obtained even in hard rock. In contrast to prior-art drilling devices, the drill bit of this invention makes substantially no physical contact of the tool employed to produce the high-velocity hydraulic jets with the surfaces of the earth formation being drilled or bored. Thus the drill bit of this invention is substantially free of the wear or breakdown occasioned by the physical contact of prior-art bit surfaces with the rock formation being drilled.

Although we have for convenience herein used the term "bit" to describe the drilling tool of the present invention, from the foregoing and the detailed description which follows it will be apparent to those skilled in the art that the process and apparatus of the present invention are entirely different from prior-art drill bits. A distinction is made between prior-art drill bits which are of the mechanical type wherein the rock-cutting action results from physical contact of the metal bit surfaces with the rock formation at the bottom of the hole, and the jet bits of this invention wherein the rock-cutting action results from the erosive action of a high-velocity jet stream issuing from a nozzle that does not contact the rock formation, and as will become evident, functions most advantageously when the nozzle is spaced a specified distance (called the "standoff") from the rock being drilled or bored. Physical contact of the jet bits of this invention with the bottom of the hole is used only as a means to maintain standoff of the nozzles during rotation of the bit.

Accordingly, it is an object of this invention to provide a method of drilling capable of rapidly making hole and which employs high-velocity hydraulic jets to disintegrate the rock to be penetrated.

Another object of this invention is to provide a method of drilling that is highly effective in cutting hard rock without the use of mechanical cutters.

Another object of this invention is to provide a method of drilling employing high-velocity hydraulic jets and which drills a pilot hole that is subsequently enlarged to gauge.

These and other useful objects are attained by the invention described in this specification with reference to the accompanying drawings forming a part thereof, and in which:

FIGURE 1 is a bottom view of one embodiment of the drill bit useful in this invention;

FIGURE 2 is a front elevation of one embodiment of the drill bit useful in this invention as viewed from the bottom of FIGURE 1;

FIGURE 3 is a side elevation of one embodiment of the drill bit useful in this invention as viewed from the right side of FIGURE 1;

FIGURE 4 is a cross section of the drill bit of FIGURES 1 to 3 taken on the plane IV—IV of FIGURE 1;

FIGURE 5 is a cross section of the drill bit of FIGURES 1 to 3 taken on the plane V—V of FIGURE 1;

FIGURE 6 is a partial cross section of the drill bit of FIGURE 1 showing details of the end structure of the bit;

FIGURE 7 is a bottom view partly in section of the drill bit of FIGURE 1;

FIGURE 8 is a bottom view of a second embodiment of a drill bit useful in this invention;

FIGURE 9 is a front elevation of the second embodiment of this invention as viewed from the bottom of FIGURE 8;

FIGURE 10 is a side elevation of the second embodiment of a drill bit useful in this invention as viewed from the right side of FIGURE 8;

FIGURE 11 is a side elevation of the second embodiment of a drill bit useful in this invention as viewed from the left side of FIGURE 8;

FIGURE 12 is an oblique elevation partly in section of the second embodiment of a drill bit useful in this invention as viewed from the lower right-hand corner of FIGURE 8;

FIGURE 13 is an oblique elevation partly in section of the second embodiment of a drill bit useful in this invention as viewed from the upper left-hand corner of FIGURE 8;

FIGURE 14 is a longitudinal cross section taken at the plane XIV—XIV of FIGURE 8;

FIGURE 15 is a partial longitudinal section taken at the plane XV—XV of FIGURE 8;

FIGURE 16 is a partial longitudinal section taken at the plane XVI—XVI of FIGURE 8;

FIGURE 17 is a partial longitudinal section taken at the plane XVII—XVII of FIGURE 8;

FIGURE 18 is a partial transverse cross section taken at the plane XVIII—XVIII of FIGURE 12;

FIGURE 19 is a partial transverse section taken at the plane XIX—XIX of FIGURE 13;

FIGURE 20 is a partial transverse section taken at the plane XX—XX of FIGURE 13;

FIGURE 21 is a partial transverse section taken at the plane XXI—XXI of FIGURE 13;

FIGURE 22 is a bottom view of a third embodiment of a drill bit useful in this invention;

FIGURE 23 is a top view of the third embodiment of a drill bit useful in this invention;

FIGURE 24 is a side elevation of the third embodiment of a drill bit useful in this invention as viewed from the right side of FIGURE 22;

FIGURE 25 is a side elevation of the third embodiment of a drill bit useful in this invention as viewed from the left side of FIGURE 22;

FIGURE 26 is a section taken generally at the plane XXVI—XXVI of FIGURE 22; and

FIGURE 27 is a section taken at the plane XXVII—XXVII of FIGURE 22.

We have found that a hydraulic jet is substantially ineffective in cutting or drilling rock at low jet velocities, but at velocities exceeding a critical minimum cutting velocity the cutting rate increases rapidly with increasing jet velocity. In this invention the jet velocity exceeds the critical minimum cutting velocity and by the term high-velocity jet as used herein is meant a jet whose velocity exceeds the critical minimum cutting velocity. Inasmuch as the jet velocity for fluid of constant density is uniquely dependent on the pressure of the fluid applied to the nozzle, it is further to be understood that the pressure inside the bit exceeds the external ambient pressure by an amount sufficient to effect at the exit of the nozzle or nozzles a jet stream whose velocity exceeds the critical minimum cutting velocity for the rock or target being drilled and for the particular drilling fluid employed. The critical minimum cutting pressure is defined as the pressure required to produce a jet whose nozzle exit velocity is the critical minimum cutting velocity. Some typical values of critical velocities and pressures are:

Rock Type	Jet Fluid	Critical Minimum Cutting Velocity and Pressure at 1-inch Standoff [1]	
		Velocity, f.p.s.	Pressure, p.s.i.g.
Indiana limestone	Water	400	1,200
Do	Aqueous mud with 6% sand [2] and 6% bentonite.[2]	300	800
Gray granite	Aqueous mud with 6% sand [2] and 6% bentonite.[2]	400	1,400
Dense limestone	Aqueous mud with 6% sand [2] and 6% bentonite.[2]	450	1,700

[1] Standoff is defined as the distance between the exit end of the nozzle and the target.
[2] Sand measured by bulk volume; bentonite by weight.

In any particular instance the critical minimum cutting pressure for a particular fluid and target material may easily be determined by experiment, since at pressures below the critical value the jets do not appreciably cut the target rock whereas only at pressures above the critical value does any substantial cutting or penetration of the drill occur. It is advantageous to substantially exceed the critical minimum cutting pressure and we prefer to use a pressure across the jet bits of this invention that exceeds about 4000 p.s.i. and have found it advantageous to operate with a pressure at or above about 5000 p.s.i.

In this invention use is made of the fact that when a high velocity jet stream strikes a target at a low elevation angle (i.e high angle of incidence as this term is used in optics) the jet is deviated to follow the target surface with little loss of momentum as a result of its change in direction. This means that a penciliform jet stream incident at a high angle of incidence on a target surface will stream substantially tangent to the surface of impingement with little reduction in velocity, the loss being only that due to the frictional effect of the target surface, which frictional effect at the high velocities employed results in cutting the target. This is in contrast to the behavior of a jet stream that strikes a target at near normal incidence in which case the large change in direction of the splash results in substantial loss of energy of the stream through impact so that the splash velocity is very much lower than the incident velocity. The jet drill bits of this invention utilize jets that strike the borehole wall at a high angle of incidence whereby the jet velocity is not diminished by excessively sudden change in direction of the jet stream. The jet bits of this invention thereby utilize the jets in a manner that substantially increases the cutting effect. At the same time the backsplash of the jet is controlled and directed to expend its energy against the target being cut before it again strikes the tool so that erosion of the bit itself is very materially reduced.

These effects are employed in this invention to provide high rates of target penetration. In the jet bits of this invention the nozzles are so located and directed to produce jets that impinge on the borehole wall at a small angle with the tangent to the borehole wall at the point of impact, whereby the jet upon deflection at the borehole wall retains a substantial amount of its velocity and further erodes the borehole wall beyond the point of impact. Ancillary to the fact that the deflected jet parallels the borehole wall beyond the point of impact is the fact that the jets do not strike the tool itself until the jet energy is materially dissipated, thus substantially avoiding erosion of the tool by backsplash.

In the jet bits used in this invention there are provided nozzles whose jets are directed generally downward to drill a pilot hole ahead of the main hole to be drilled. The bit is also provided with additional nozzles whose jets are directed in such manner as to enlarge the pilot hole to main gauge. By means of such an arrangement of nozzles the jet bits of this invention utilize the enlarging jets to maximum advantage thus achieving high penetration rates for the drill.

Referring first to FIGURES 1 to 3 which respectively show bottom, front, and side views of one embodiment of a jet drill bit useful in this invention, the body **10** of the bit proper has the general shape of a truncated and flattened cone that is fastened to a shank **11** either by welding or forged integral therewith. The shank **11** is provided with conventional drill pipe threads (not shown) for removably attaching the bit to a conventional rotary drill pipe. The inside **12** of the body **10** is hollow and is in communication with the axial opening **13** of the shank and drill pipe in order that drilling fluid under high pressure may be supplied to the jets of the bit.

The body **10** of the bit is generally rectangular in cross section as best seen in FIGURE 7. The two trailing edges of the body are provided with hard wear-resistant inserts **14** and **15** made, for example, of blocks of the material commercially available under the trade name Kennametal. The blocks **14** and **15** are welded or brazed onto the body **10**. The body **10** is also provided with a plurality of nozzles to be described. The nozzles are made of hard wear-resisting material such as Kennametal. Each nozzle comprises a right circular cylinder about ½ inch long and about ⅜ inch in outside diameter. Each nozzle of FIGURES 1 to 7 has an axial opening which in the jet bits of this invention is ⅛ inch in diameter and has a conventional elliptical entrance portion as best seen in FIGURES 4 to 7.

The bottom end **16** of the body of the bit is substantially flat and is provided with a tongue **17** that extends a distance beyond the end of the bit to provide standoff for a number of nozzles **18, 19, 20, 21,** and **22**. The leading edges of the tongue **17** are provided with hard wear-resistant (e.g. Kennametal) inserts **23** and **24** welded or brazed thereon. It has been determined that the optimum standoff is between ½ inch and 1¼ inches and it is preferred that the length of the tongue as measured from the bottom end **16** of the bit body be about 1 inch as disclosed and claimed in our copending coassigned application Ser. No. 311, 088. The nozzles **18** to **22** are inserted and brazed into holes **27** drilled in the bottom of the bit at appropriate locations and directions so that the nozzles are in communication with the interior **12** of the bit. The tongue **17** is recessed at **25** to provide clearance for insertion of nozzle **19** and for the jet issuing therefrom.

The nozzle **19** has its axis sugstantially parallel to the longitudinal axis **26** of the bit, and is located at the smallest radius from the axis. Nozzle **21** is located at a slightly larger radius from the axis **26** of the bit and is also directed outward at an angle, for example about 28.5°, as best seen in FIGURE 5. The nozzle **21** is located and directed so that its jet impinges on the bottom of the hole being drilled at a radius that is one jet-produced groove width farther from the axis of the borehole than the point of impingement of the jet from nozzle **19**. The nozzles **18, 20,** and **22** are each located at a corner of the bottom of the bit and are directed so as to cut a groove at the bottom of the borehole that is one jet-produced groove width farther from the axis of the borehole than the point of impingement of the jet from nozzle **21**. Inasmuch as the radius of the point of impingement of the jets from nozzles **18, 20,** and **22** is considerably larger than that of the nozzles **19** and **21**, it is preferred to employ three such nozzles **18, 20,** and **22**, which are directed as best seen in FIGURE 6 to make an angle of, for example 22° with the axis of the bit. The arrangement of the impingement of the jets **18** to **22** on the bottom of the borehole is such as to achieve substantially uniform areal distribution of penetration rate on the bottom of the borehole as disclosed and claimed in copending, coassigned application Ser. No. 311,088. The standoff bar **17** thus needs only to smooth out minor ridges or irregularities that may remain on the bottom of the pilot hole drilled by the jets **18** to **22**, but the standoff bar does no substantial mechanical cutting.

On the longer side of the rectangular section of the body **10** and close to the leading edges of the body there are provided a plurality of nozzles **30**, as for example five nozzles **30** on each side, as best seen in FIGURE 2. Each of the five side nozzles are of the same type as the bottom nozzles **18–22** and each has an ⅛ inch exit opening. The side nozzles **30** are brazed or welded into holes **29** drilled in the body **10** and which provide communication from the nozzle to the interior of the bit. Each of the holes **29** into which the side nozzles **30** are mounted is drilled on a plane perpendicular to the axis **26** of the bit. Each hole **29** makes a high angle, as for example 70° with the adjacent flat face of the drill body as best seen in FIGURE 7. The location and direction of the respective side nozzles **30** is thus such that the emerging jets strike the borehole wall on the plane through the nozzle perpendicular to the axis of the borehole and make an angle with the tangent to the borehole wall at the point of impingement that varies somewhat with each nozzle, but is in the neighborhood of about 40° to 50°. The angle of incidence (measured to the perpendicular to the target) is thus in the range of 40° to 50°. As a consequence of the high angle of incidence, the jet emerging from the nozzle substantially maintains its velocity after the first impact whereby the jet stream parallels the borehole wall for a substantial distance and effects a further cutting action. In this manner a maximum of hydraulic power is extracted from each of the side jets to obtain high cutting rates. It is further apparent that as the jet stream follows the borehole wall it is constrained to hug the wall because of the curved configuration of the wall whereby the jet effectively scours the borehole wall meanwhile eroding the rock formation being drilled so as to enlarge the local hole diameter thus permitting the generally tapered form of the bit to progress into the drilled hole. It is also apparent that the jet stream does not again strike the body of the bit until the stream has traversed nearly a semi-circumference of the hole by which time the jet has been materially reduced in velocity so that upon again reaching the bit body the jet no longer has sufficient energy to appreciably cut the bit body. It is also seen that if the jets, after traversing the borehole wall strike the bit body they strike on the wear-resistant inserts **14** and **15** and these thus protect the bit body from erosion as well as removing any protrusions accidentally left by the jets.

FIGURES 8 to 21 show a second embodiment of the jet bit useful in this invention. This embodiment comprises a body portion **40** having the shape of a truncated right square pyramid best seen in FIGURES 8, 9, and 10. The base of the body **40** has a shank **41** that is circular in section and has a central opening **42** (best seen in FIGURE 14) which communicates with the inside of the rotary drill pipe to which the tool is fastened. The shank **41** is provided with conventional drill pipe threads (not shown) by means of which the tool is fastened to the drill pipe and rotated in conventional manner.

Each of two diametrically opposing leading corners **43** and **44** of the body **40** is provided with a bulge **45** and **46**, respectively whose outer surface conforms to that of a portion of cone of substantially the same apex angle as the corners **43** and **44**. Clearance is provided in the space between the trailing edge **47** and **48** of each bulge and the next following corner, the latter being respectively **49** and **50**. The clearance between the trailing edges **47** and **48** and the next following corners **49** and **50** provide space for flow of spent drilling fluid upward from the region of the nozzles to the annular space between the drill pipe and the borehole wall.

The apex (bottom) end of the drill bit is provided with openings **51**, **52**, and **53** that communicate with the inner opening **42** of the bit. Into each of the openings there is fastened as by brazing or welding a nozzle **54**, **55**, and **56** respectively, best seen in FIGURES 15 and 16. The openings **51**, **52**, and **53** may be provided with a shoulder as shown against which the respective nozzles abut in order to firmly hold the nozzle in place during the welding or brazing operation. Each nozzle, comprises a right circular cylinder about ½ inch long and about ⅜ inch in outside diameter and is made of wear-resistant material, such as Kennametal. Each nozzle of FIGURES 8 to 21 has an axial opening of ⅛ inch diameter with a conventional elliptical entrance portion as best seen in FIGURES 15 and 16. The openings **51**, **52**, and **53**, and therefore also the respective nozzles **54**, **55**, and **56** are directed so as to impart the rock formation immediately below the bit at substantially zero standoff and at radii such as to deliver substantially uniform areal distribution of penetration rate to the rather limited (apex or pilot) area of the bottom of the borehole, as disclosed and claimed in coassigned, copending application Ser. No. 311,088. To this effect nozzle **54** points slightly toward the axis of the bit, nozzle **55** points slightly outward from the axis of the bit, and nozzle **56** points further outward from the axis substantially as indicated in FIGURES 15 and 16. Thus the jets from nozzles **51** to **54** drill a pilot hole ahead of the main bit.

Returning again to FIGURE 8, each of the flat faces of the body **40**, i.e. the flat face bounded by edges **43** and **50** and that bounded by edges **44** and **49**, are provided wih a plurality of nozzles whose location can be best seen in FIGURES 10 and 11, respectively. In FIGURE 11 the nozzles **57**, **58**, **59**, **60**, **61**, and **62** are brazed or welded into openings drilled in the bit body **40** on a plane perpendicular to the axis of the bit as best seen in FIGURE 13. The nozzles **57** to **62** are brazed in their respective openings, each of which has a slight shoulder against which the nozzle rests. The nozzles **57** to **60** of FIGURE 13 are all directed at substantially the same angle with respect to the radius to the axis of the bit as best seen in FIGURES 19, 20 and 21 and nozzles **61** and **62** at a somewhat less angle as indicated. Nozzle **57** is slightly smaller in outside diameter than the others because of the lack of space at the point of the bit. The inner end of each opening into which the nozzles **57** and **62** are mounted meets with a relief groove **63** to permit drilling fluid access from inside the bit to the nozzles.

Referring again to FIGURE 8, the flat face of the bit body bounded by edges **44** and **49** is provided with nozzles **64**, **65**, **66**, **67**, and **68** mounted by brazing into openings that are drilled at an angle to a transverse plane perpendicular to the axis of the bit. The nozzles are directed downward at an angle of substantially 45° as best seen in FIGURES 10 and 12. These nozzles are also directed at an angle of about 90° with respect to the radius to the axis of the bit as best seen in FIGURE 18. The inner end of the respective openings into which the nozzles **64** to **67** are mounted communicate with a groove **69** that permits drilling fluid access from inside the bit to the nozzles.

It is apparent from the location and directional orientation of the nozzles in the bit of FIGURES 8 to 21 that the angle of incidence of the jets issuing from nozzles **57** to **62** and **64** to **68** as measured with respect to the normal to a tangent plane at the point of impact will be large being in the range of 40° to 50°. The jet upon deflection by the target surface thus is able to retain a substantial portion of its kinetic energy. The jet subsequently follows and, because of the curved configuration of the borehole wall, the jet hugs the borehole wall to scour the wall and effectively erode it to deepen and enlarge the hole. The downwardly directed jets **64** to **68** set up a violent swirling action of the fluid against the borehole wall that effectively erodes the conical end of the borehole to enlarge and deepen it. Furthermore, the jets expend most of their energy in contact with the borehole wall before again encountering the body of the bit thus materially reducing erosion of the bit body.

FIGURES 22 to 27 illustrate a third embodiment of a drill bit useful in this invention in which the jet bit has an elongated pilot drill that extends downward beyond the end of the main body of the drill. The pilot drill is provided with downwardly directed nozzles whose high-velocity jets drill the pilot hole ahead of the main hole to be drilled. In addition, the pilot drill is provided with nozzles in the side thereof whose jets cut away the shoulder at the top of the pilot hole and serve to enlarge the hole to main gauge. The latter jets are directed horizontally or at a generally upwardly directed angle and thereby attack the rock being drilled in a direction of weakness, i.e. along the bedding planes, which results in a high rate of penetration of the drill.

Referring to FIGURES 22 to 27, this embodiment of drill bit comprises a tubular shank **110**, best seen in FIGURES 24 and 25, that is provided at its upper end with standard drill-pipe threads (not shown) by means of which the bit is attached to the conventional rotary drill stem. The bit is enlarged in diameter at **111** and if desired, the enlarged body portion **111** may be manufactured separately and shrunk and welded to the shank **110** as shown at **112**. The outer surface of the body **111** is provided with a plurality of flutes **108**, best seen in FIGURES 22 and 23. The bit has a shoulder at **114** to form a surface that is substantially perpendicular to the axis **115** of the body **111**. The axis **115** of the body of the bit coincides with the axis of the drill pipe to which it is fastened. Extending from the surface **114** is a hollow cylindrical protuberance or nose **116** of reduced diameter that forms a pilot drill whose axis also coincides with the axis **115** of the body of the bit. The cylindrical portion of the nose **116** terminates with a surface **117** that is substantially perpendicular to the axis **115**. The nose **116** has two diametrically opposed angled surfaces **122** and **123** whose intersection with the cylindrical surface of nose **116** forms the semi-elliptical outlines shown in FIGURES 24 and 25. The angled surfaces **122** and **123** need not be symmetrical with respect to the axis **115** of the bit, and in the bit illustrated surface **123** is somewhat closer to the axis than is the surface **122**. The surfaces **122** and **123** are angled to run out just below the transverse shoulder **114**. The outside diameter of the nose **116** is approximately one-half that of the body portion **111**. The lower end of the nose is provided with a transverse extension **118** in the form of a tongue as best seen in FIGURE 22. The tongue **118** extends transversely entirely across the surface **117** at the lower end of the pilot drill **116**. The body of the bit has a central opening **120** which is reduced in diameter to **121** in the nose **116**. The bore terminates at a substantially flat inner surface **119** above the surface **117**.

At the shoulder **114** two diametrically opposed lugs **124** and **125** are provided as best seen in FIGURES 24 and 25. The purpose of lugs **124** and **125** is to insure that the drilled borehole is to gauge and for this purpose the leading edges of lugs **124** and **125** are provided with hard metal surfacings **127** and **128** made, for example, of the material commercially available under the name of Kennametal, fastened thereon as by brazing or welding and best seen in FIGURE 22. The hard surfacings **127** and **128** do no substantial cutting but serve merely to hold the hole to gauge and to break away any remaining protrusions that may accidentally be left by the hydraulic jets to be described.

The bit is provided with three groups of nozzles indicated in FIGURES 26 and 27 generally by A, B, and C, respectively. The nozzles are in the form of right circular cylinders that are mounted in openings drilled in the bit as shown. Each of the nozzles of FIGURES 22 to 27 has a central axial opening of ⅛ inch diameter and whose inside end has a conventional elliptical contour in order that fluid from inside of the bit will flow into each nozzle in streamline fashion. The nozzles may be made of abrasion-resistant material, as for example the material commercially available under the trade name Kennametal. The holes in which the nozzles are mounted in the drill bit have locations and orientations to be described. The direction of the nozzle is defined as the direction of the emerging jet stream.

The group A of nozzles is located at the bottom end of the nose **116** forming the pilot drill. Group A comprises four nozzles, two of which are located on each side of the tongue **118**. The four nozzles, indicated as **130**, **131**, **132**, and **133** are best seen in FIGURE 22. The nozzles are generally inclined with respect to the axis **115** of the bit, and are located to intersect the end surface **117** at various distances from the axis **115** as shown in FIGURE 22. One of the nozzles **133** is parallel to the axis **115**, two of the nozzles **130** and **131** are inclined at an angle of 18° 27′ with respect to the axis of the bit, and nozzle **132** is directed at an angle of 8° with respect to the axis **115**. All of the nozzles are directed so that their respective axes intersect the axis **115** of the bit except nozzle **133** whose axis is parallel to the axis **115**. The nozzles **130**, **131**, and **132** are inclined so as to direct a jet with a radially outward component of velocity. The holes into which the respective nozzles are fastened are drilled at the desired angles through the lower end of the nose **116** to communicate with the inner bore **121** of the bit. The group A nozzles are located and oriented so that the jets issuing therefrom deliver to the bottom of the hole a substantially uniform areal distribution of penetration rate as previously explained in order that the drill will effect uniform penetration over the pilot hole area, thereby leaving little or no material to be removed by the tongue **18**.

Group B of the nozzles comprises four nozzles fastened in openings drilled in the nose **116** substantially halfway between the bottom surface **117** and the shoulder **14**. These nozzles are best seen in FIGURES 26 and 27 and are indicated by **135**, **136**, **137**, and **138**. Three of the nozzles **135**, **137**, and **138** are mounted in openings that are substantially the same axial distance from the surface **117**, and nozzle **136** is placed in a hole started somewhat closer to the surface **117**. Nozzle **135** is directed radially outward at right angles to the axis **115**. Nozzle **137** is directed upward at an angle of 60° to the axis **115**. Nozzle **138** is directed upward at an angle of 75° to the axis **115**. Nozzle **136** is directed upward at an angle of 45° to the axis **115**. The axis of each of the nozzles intersects the axis **115** of the drill bit. It is apparent that whereas the nozzles **130**, **131**, **132**, and **133** are directed downward, the nozzles **136**, **137**, and **138** are directed generally upward and nozzle **135** is directed radially outward. We have found that best results are obtained when nozzle **135** is located in the range between 0 and ½ inch below the lower edge of the lugs **124** and **125**, i.e., when the dimension **148** in FIGURE 26 is in the range 0 to ½ inch.

Group C of the nozzles is best seen in FIGURES 22, 26, and 27 and comprises four nozzles **140**, **141**, **142**, and **143**. Nozzles **140**, **141**, and **142** are located on one side of the lugs **124** and **125**, whereas nozzle **143** is located on the other side of the lugs as best seen in FIGURE 22. The holes for nozzles **140**, **141**, **142**, and **143** are drilled at an angle of 20° with respect to the axis **115** and their respective axes intersect the axis **115**. The nozzles **140**, **141**, and **142** are spaced 45° apart in azimuth about the axis **115**, and nozzles **140** and **142** are spaced 45° from the transverse axis of lugs **124** and **125**. Nozzle **143** is spaced 45° from the transverse axis of the lug **125**. The nozzles of group C are directed outward to strike the shoulder formed in the rock at the top of the pilot hole at a radius equal to the outside radius of the main body of the drill. This is indicated as point **147** in FIGURE 26. Thus the group C jets cut the hole to size, assisted by the group B jets that cut out the shoulder between the pilot hole and the main-gauge hole.

It is apparent that all of the nozzles are in communication with the central opening in the bit and they are supplied with pressurized drilling fluid pumped into the top of the bit stem in conventional manner at a pressure that is sufficient to produce jets whose velocity exceeds the critical minimum cutting velocity. The high velocity jets issuing from nozzles **130**, **131**, **132**, and **133** impinge on the rock directly below the bottom of the pilot bit and the standoff of these nozzles is controlled by the axial height of the tongue **118**. It is preferred that the standoff be in the range ½ inch to 1¼ inches as previously mentioned. As the bit is rotated, these jets affect disintegration of the rock below the nose **116**.

The nozzles **135**, **136**, **137**, and **138** produce jets that serve to enlarge the hole in the region proximately below the shoulder where the pilot hole enlarges to the main hole so as to make room for the enlarged body portion **111** of the bit. The nozzles **140**, **141**, **142**, and **143** serve to further enlarge the hole to the main gauge and remove material below the lugs **124** and **125**. The lugs **124** and **125** serve to maintain proper standoff for jets **140**, **141**, **142**, and **143**. It is preferred that this standoff also be in the range ½ inch to 1¼ inches. The outer edges of the lugs **124** and **125** hold the gauge of the hole and remove any remaining rock protrusions.

It is apparent that when the drill is operating at the bottom of a deep hole there will be a transition in the hole where it enlarges from substantially the diameter of nose **116** to that of body **111**, i.e. from pilot hole to main gauge hole. The group B jets **135**, **136**, **137**, and **138** serve to effectively cut away this shoulder and thereby permit faster drilling. The group B jets are directed generally upward and this makes them particularly effective in removing material from this shoulder. The group B jets are directed at successively increasing angles to the axis **115**, starting with nozzle **136** directed at 45° to the axis, nozzle **137** at 60°, nozzle **138** at 75°, and nozzle **135** at 90°. Therefore, as these jets rotate in the conventional clockwise manner, they successively cut the rock to an increasing angle to effectively cut down the shoulder of rock formed at the top of the pilot hole. Inasmuch as the rock layers in which drilling takes place are generally approximately horizontal and the rock layers are very weak in tension across the bedding planes, it is seen that the upwardly directed jets serve to pry loose flakes or layers of rock and are very effective in enlarging the pilot hole to main gauge size.

The jet bits used in this invention are supplied with drilling fluid under a pressure at the surface exceeding about 4000 p.s.i., substantially all of which will exist as pressure differential across the nozzles effecting an exit velocity exceeding about 650 f.p.s. which exceeds the critical minimum cutting velocity for most rocks. This has been found to be effective in rapidly making hole in hard rock. It is preferred to employ drilling fluid containing between about 5 percent and about 15 percent sand of size predominantly between about 20 mesh and 40 mesh in order to further increase the penetration rate of the bit as disclosed and claimed in copending, coassigned application Ser. No. 311,088.

Certain aspects of the invention herein disclosed are disclosed and claimed in our copending applications Ser. No. 311,035 and Ser. No. 311,088, each filed of even date herewith and assigned to the same assignee as this application.

What we claim as our invention is:

1. A hydraulic jet method for drilling the borehole of a well through hard subsurface formations comprising delivering a drilling liquid having abrasive suspended there-

in downwardly through rotating drill pipe to a drilling tool secured to the lower end thereof, discharging downwardly from the drilling tool at a distance in the range of ½ inch to 1¼ inches above the bottom thereof a plurality of hydraulic jet streams of the drilling liquid located to cut a central pilot hole having a diameter less than the diameter of the borehole, discharging laterally from the drilling tool in a non-radial direction having a horizontal component a plurality of hydraulic jet streams of the drilling liquid to impinge against the wall of the pilot hole at a high angle of incidence and enlarge the pilot hole to the desired borehole diameter, and lowering the drilling tool to maintain the lower end of the drilling tool against the bottom of the pilot hole and the distance between the bottom of the pilot hole and the level of discharge of the drilling liquid in the range of ½ inch to 1¼ inches, each of said jet streams having a velocity exceeding 650 feet per second.

2. A method as set forth in claim **1** which at least some of the laterally directed jet streams are discharged from the drilling tool at different elevations, and each of the

laterally directed hydraulic jet streams is discharged from the drilling tool at a greater distance from the center of rotation of the drilling tool than any lower hydraulic jet stream.

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