Jet Drilling in the Fairbanks Area Alaska

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1539-B

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By D. J. CEDERSTROM *and* G. C. TIBBITTS, Jr.

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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A new approach to water-well drilling in a subarctic agricultural area

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JET DRILLING IN THE FAIRBANKS AREA, ALASKA

By D. J. Cederstrom and G. C. Tibbitts, Jr.

ABSTRACT

The report describes the construction and operation of an experimental jet-drilling machine in the submontane area north of Fairbanks, Alaska. The drilling conducted during a 2-month period in the summer of 1954, penetrated the Birch Creek schist and the sand-, silt-, and gravel-filled old subordinate valleys. Some of the silt has a high organic content and is called muck. Some of the muck was permanently frozen. Silt and muck were drilled rapidly, and required as little as 1½ minutes per foot including time for changing rods, whereas drilling time in hard-packed sand and in schist averaged about 15 to 20 minutes per foot. Frozen muck required about 3 minutes drilling time per foot. It is concluded that the method is a practical and economical one for use in the area in which it was tried, and it could be used with reasonable success in other alluvial areas where boulders are uncommon.

The equipment consisted of a double-acting piston pump capable of furnishing fluid at a pressure of 100 psi, a 7- to 8-horsepower type Z single-cylinder engine, and a derrick. A reciprocating motion was provided by a crank that operated a centrally pivoted beam. The drill rods were 1-inch extra heavy pipe. Z-bits and chisel bits were used. Operation of the rig, difficulties encountered, and suggestions for avoiding time-consuming trouble are discussed.

The usefulness of the method for general earth testing is mentioned, and suggestions are made for jet drilling on a production basis.

SCOPE AND PURPOSE OF THE REPORT

In July and August 1954 a modest drilling program utilizing the water-jet method was carried out by the U.S. Geological Survey in the submontane area just north of Fairbanks, Alaska, to determine the suitability of this method for use in this region. The method was successful, and much interest was shown by well drillers and others who believed the method generally adaptable to much of the Tanana Valley and, perhaps, elsewhere in Alaska. This report discusses in detail the construction and operation of the jet-drilling machine so that the equipment, procedures, and results may be evaluated and utilized by interested persons. The adaptability of the method for geologic testing is also considered.

The personnel who worked on the project were not trained well drillers. The fact that untrained personnel were able to achieve fairly good production results indicates the simplicity of this method of drilling. The test drilling done in 1954 was a part of an overall study of the ground-water resources of the Fairbanks area made by the senior author.

The geology and hydrology of the Fairbanks area are discussed here only to the extent necessary to furnish background data for a better understanding of the functioning of the jet-drilling process as used in the area.

SYNOPSIS OF GEOLOGIC HISTORY

An arcuate series of low mountains a few miles north of Fairbanks forms part of a range elongated approximately east and west. Near Fairbanks these mountains rise from a few hundred feet to more than 1,000 feet above the floor of the Tanana Valley on which the city is located. The mountains have a core of hard rocks, largely Birch Creek schist of Precambrian age (Mertie, 1937, p. 46), a deeply weathered slaty to sandy highly micaceous schist in which only a few hard layers are found, either quartzite or, more commonly, quartz veinlets. Exposures are relatively rare owing to a mantle of fine tan silt of Pleistocene age.

The tan silt that covers most of the hills ranges in thickness from a few feet to about 300 feet, and is thickest on the lower slopes. On some of the slopes and in the mountain valleys, particularly in the larger valleys, the silt has a high organic content and is locally referred to as muck. This black muck and the tan silt which have been considered for the most part contemporaneous overlie coarse gravels flooring the large valleys at low altitudes. However, sandy deposits in the submountane area north of Fairbanks are not confined to the large creeks. Sand and gravel deposits occur also at various depths below silty deposits that almost fill and partly mask old buried channels. These deposits may be found at some places at altitudes of as much as 800 feet above sea level or 350 feet above the Tanana Valley floor. Downslope these coarse deposits merge with highly permeable silt and sand and gravel of the Tanana Valley fill. These are stream-laid deposits, largely derived from the Alaska Range to the south (Mertie, 1937, p. 187).

Much of the alluvium on the Tanana Valley floor is permanently frozen. So far as is known, the frozen masses are wedge-shaped, their thin edges being along the streams. Away from the streams the thickness of frozen ground increases and is known to be as much as

243 feet beneath Fairbanks. The thickness of frozen ground diminishes to a vanishing point on the south-facing mountain slopes north of Fairbanks. In the higher part of the mountains only black muck in some small valleys leading back into the hills is permanently frozen.

GROUND-WATER CONDITIONS

On the lower slopes north of Fairbanks, ground water occurs under artesian conditions. Generally, the confinement is due to an impermeable cover of frozen silt, and wells drilled here may flow or, if the well does not flow, the static water level may be only a few feet below the land surface. Upslope, at the upper limit of permanently frozen ground, artesian conditions may change abruptly to water-table conditions, and at the higher altitudes the water levels in wells may not rise much higher than the level of the upper limit of permanently frozen ground. In one well along the ridge, off Steele Creek Road, depth to water is greater than 250 feet below the surface.

On the wide Tanana Valley floor on which Fairbanks is situated, ground water occurs under water-table conditions; the water table ordinarily is 12 to 14 feet below the surface. Where the ground is frozen above the water table, wells must be drilled through the frozen ground to unfrozen ground below. In such wells water encountered below the permafrost generally rises to the same static level as water in wells drilled in unfrozen ground.

WATER-BEARING FORMATIONS

BIRCH CREEK SCHIST

On the submontane slopes and ridges, ground water ordinarily is obtained from schist bedrock. The depth to bedrock there ranges from a few feet to more than 300 feet, and is greatest at the lower altitudes where bedrock is covered by thick alluvium.

The Birch Creek schist is deeply fissured and weathered, and, in some places, the weathered zone is as much as 300 feet thick. The weathered bedrock is not completely tight and impermeable, but is made up of streaks of fractured more-or-less brittle rock intercalated with clayey and sandy layers and a few very hard thin streaks of silicified (quartzose) material.

Water is obtained from relatively clean (clay-free) fractured rock. Commonly, only a little water is obtained from wells completed in broken shistose material. Fractured silicified material ("quartz streaks") is ordinarily a better source of water; yields of as much as 10 gpm (gallons per minute) from wells of 2-inch diameter have been obtained from tapping highly fractured brittle rock, and more than 50 gpm has been obtained from wells of larger diameter.

OLDER SAND AND GRAVEL DEPOSITS

Above the level of the Tanana Valley floor, thick sand and gravel deposits overlie bedrock in many places, particularly in the large valleys transecting the hills. As determined in part by Geological Survey test drilling, the small and commonly inconspicuous valleys on the higher slopes are floored by sandy material, which, in places, is coarse enough and thick enough to be a source of small to moderately large supplies of water. (See discussion of test hole 15, p. B–24.) The subordinate valleys may be underlain by water-bearing alluvium as high as 800 feet above sea level, or 350 feet above the Tanana Valley flats. However, to the writers' knowledge, there is not a single well in the area that taps these coarse deposits, though at least two wells were cased through permeable water-bearing gravelly deposits and yielded water from schist at greater depth.

It is the writers' opinion that yields greater than 100 gpm might be obtained from properly finished wells drilled in some of these old buried channels at fairly high altitudes in the agricultural area north of Fairbanks.

TAN SILT

The tan silt is generally impermeable, but seemingly furnishes a little water to a few dug wells. A few wells obtain a copious supply of highly mineralized water from thin sandy streaks in black muck.

GRAVEL DEPOSITS OF THE TANANA VALLEY

On the Tanana Valley flats ground water is available practically everywhere in large quantities (Cederstrom, 1952, p. 23, 27) from coarse gravelly deposits requiring only a minimum of development. Wells of 2-inch diameter yield as much as 40 gpm to suction pumps, and larger diameter wells are reported to yield as much as 2,800 gpm. Ordinarily, wells ending in these formations are not screened and are given only a minimum of development.

JET DRILLING

EQUIPMENT

Following Geological Survey test drilling in Fairbanks in 1948 and 1949 by the cable-tool method, it was decided that further test work in the area might be more economically carried out by the jetting method, and that a demonstration of the practicability of the jetting method in the area would be of interest to many. Accordingly, in

1950, an experienced jet driller, Mr. Leonard Reynolds, of Walkerton, Va., was brought to Alaska to build and operate a simple rig suitable for the jetting method of drilling. The drilling equipment subsequently built and used is similar to some in commercial use in eastern Virginia. More modern equipment undoubtedly would result in an appreciable saving of drilling time and would facilitate some of the many jetting operations. As built, however, the rig was generally satisfactory, and for some operations it performed admirably.

The equipment was assembled initially in Palmer in 1950. After drilling in Palmer and Anchorage in 1950, it was decided that basic improvements were desirable, and a crank and walking-beam mechanism was added in 1951. The rig was used briefly in Anchorage that season. When the Fairbanks work was scheduled, it was further decided that the original derrick should be increased in height from 20 to 28 feet. The height was subsequently reduced later to 25 feet.

A jet-drilling rig consists primarily of (a) a positive displacement pump (fig. 1); (b) a source of power for the pump and the drilling motion, which is provided by a walking beam and a crank arm; and (c) a tower (fig. 2). The tools consist of a string of hollow rods at the lower end of which is a drill bit. Water is pumped under moderate to high pressure through the rods and issues from the drill bit. The

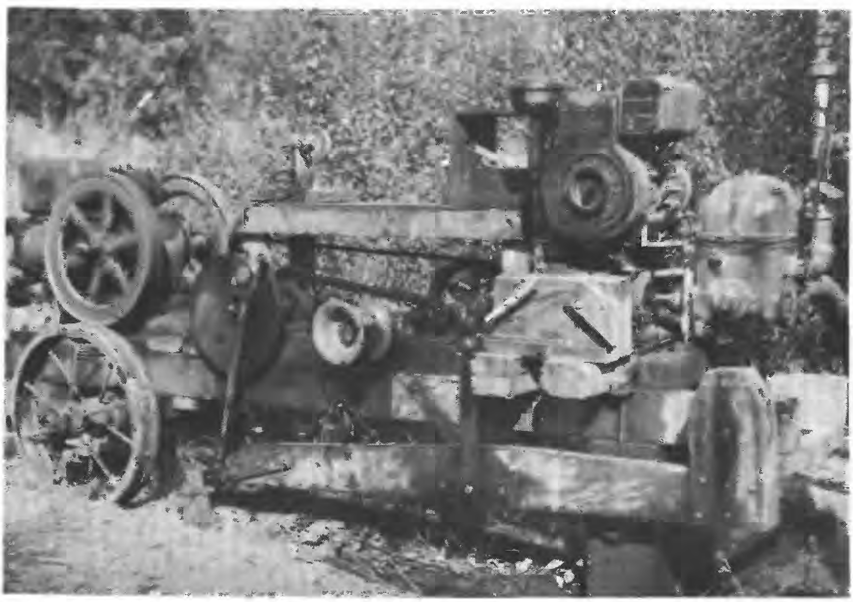

FIGURE 1.—Pump and power unit of jetting rig used in test drilling in Fairbanks in 1954.

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drilling water carries the cuttings to the surface by upward movement in the annular space between the rods and the walls of the hole. It then flows into a series of two or three mud pits (fig. 3) in which the cuttings settle, after which the drilling fluid is picked up again by the pump (fig. 1). As operated in Alaska, one man on the tower rotated the string of rods by hand (in a clockwise direction to keep the joints tight) while the machine provided an up-and-down or spudding motion to the rods. As needed, necessary slack line was released by the operator at the machine (fig. 4).

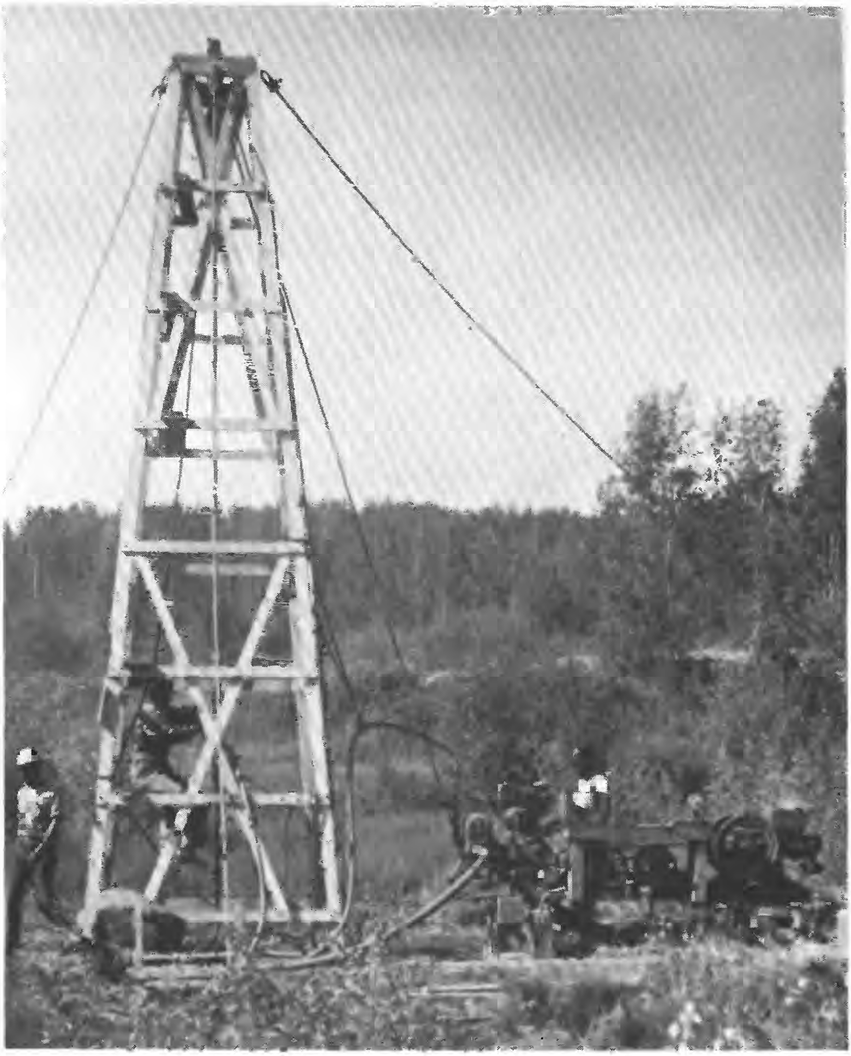

FIGURE 2.—Wood-frame tower used in jet drilling in Fairbanks in 1954.

In the Geological Survey jet drilling of 1954, a 7- to 8-horsepower single-cylinder type-Z engine was used. The speed of the engine shaft was such that gearing down was desirable. Power was transmitted by V-belts to a second shaft and from the second shaft by chain drive to a third shaft (fig. 1), bringing the speed of rotation of the third shaft down to about 30 revolutions per minute. On the end of the third shaft a disk crank was mounted. A connecting rod joined one end of the walking beam with a short crankpin projecting through the faceplate. This pin was located off center on the faceplate, connected by a rod to the walking beam, and converted the rotary motion of the disk to reciprocating motion. Provision was made for changing the length of stroke by changing the pin in the faceplate to a position farther away from the axle. Ordinarily, drilling was done with an 11-inch stroke, at 30 strokes per minute.

The pump for jetting was a double-acting two-piston suction type rated at 100 psi, though somewhat greater pressures were produced. It was belt-driven by a 3-horsepower gasoline engine mounted directly above it.

In addition to the equipment described, several other items deserve special mention. The swivel, which connects to the string of hollow

FIGURE 3.—Water for drilling is drawn by suction hose from third mud pit.

drill rods, consists of an inner perforated rod that can be rotated within a stationary outer shell and receives water from the hose through a suitable union (fig. 4). Thus, the rods may be rotated while the hose and outer shell of the swivel remain in a fixed position.

A jetting bit was generally used on the lower end of the drilling rods; in contrast to cable-tool bits, most jetting bits are relatively light in weight. The weight of the string of 1-inch extra heavy rods used in jetting is ordinarily sufficient to provide good cutting action. During drilling, dual streams of water emerge 2 to 6 inches above the cutting edge of the bit to wash the sides and bottom of the hole. A

FIGURE 4.—Swivel and drill rods alternately raise and fall in jet drilling while operator turns swivel in a clockwise direction, twisting at instant of impact.

variety of bits is available (fig. 5), but, in general, it was found that a bit with a **Z**-shaped cutting edge worked very well in unconsolidated material and a chisel-type bit worked best in schist.. A bit made from a sharpened piece of steel welded across a coupling also cut well, but lost gage rather quickly owing to the lack of body.

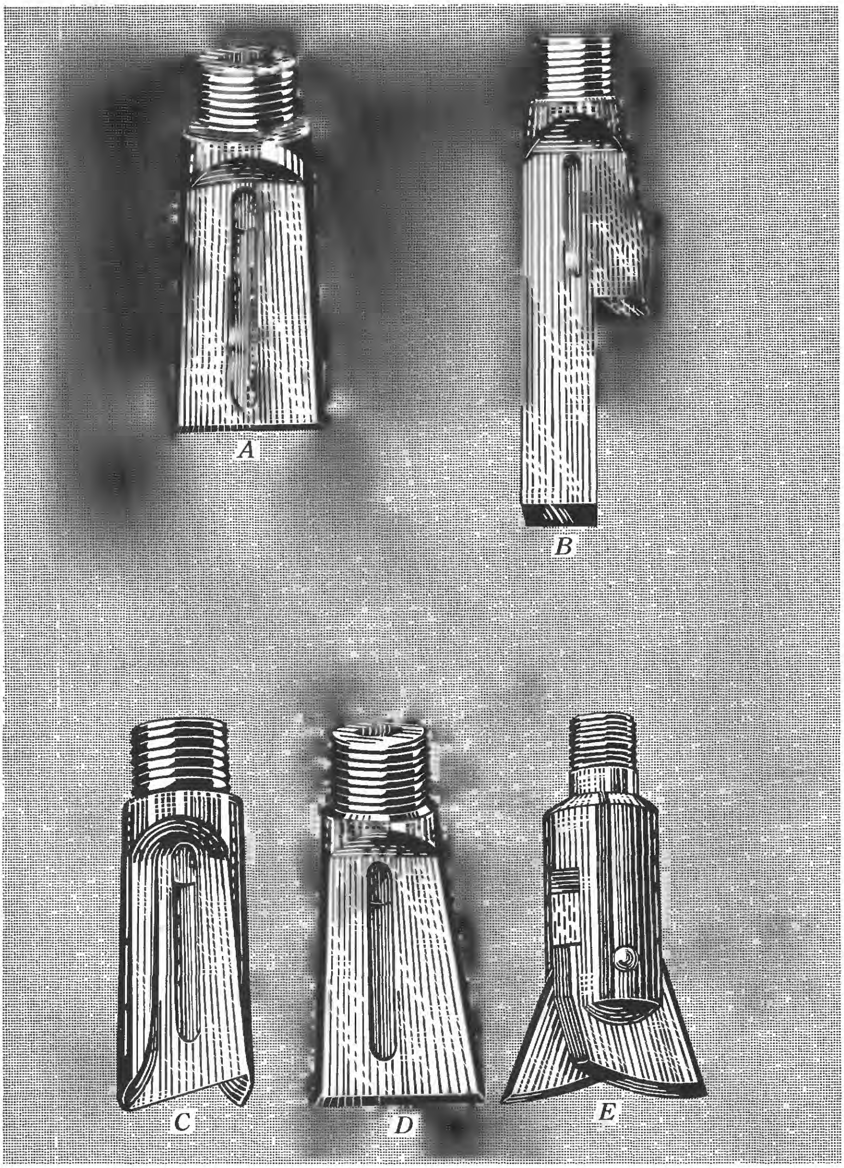

FIGURE 5.—Bits used in jet drilling. *A*, **Straight bit;** *B*, **Chisel bit;** *C*, **Z-bit;** *D*, **Offset bit; and** *E*, **expansion bit. Photograph courtesy of R. R. Howell Co.**

Because of the distribution of the weight of the rig, it could handle only eight 10-foot rods on a straight lift. Greater lift and stability could be gained by placing the machine close to or under the (near) derrick legs and bolting the two units together.

Clamps for holding and lifting drill pipe, heavy suction hose and flexible wire-wound jetting hose pulleys and sheaves, a drive block, wrenches, miscellaneous handtools, and several lengths of new ¾-inch or ⅞-inch rope complete the drilling outfit.

DRILLING OPEN HOLE

When mud pits (fig. 3) have been dug and filled with water, a string of drilling tools, consisting of swivel, rod, and bit, is suspended in place by a rope that passes up through a sheave hung on the crown block of the tower and down and under the sheave on the walking beam. The rope is snubbed on a cleat on the frame or chasis of the pump and power unit (fig. 1). The next step in jetting is to start the pump and establish circulation. The engine that operates the walking beam is then started, the string of rods moves up and down, and, as line is slacked off, the bit strikes the ground and jetting begins (figs. 2, 4). Lacking a walking-beam mechanism, the rods may be given an up-and-down motion by alternately pulling and releasing, by hand, the drilling cable that has been wound several turns around a cathead (fig. 6). The initial length of rod is best guided from the ground rather than at the swivel head so that a plumb hole can be started directly beneath the crown sheave. At this stage, an expansion bit (fig. 5*E*), an oversized bit, or an offset bit (fig. 5*D*) may be used to advantage to produce a hole somewhat larger than the casing to be used.

Hole is made by a combination of cutting and washing action; greater reliance, however, was placed upon washing action. Efforts to speed up progress by more vigorous drilling action were not particularly successful; but in penetrating harder formations, for which the jetting method is not particularly adapted, progress depended almost entirely on the cutting action of the bit.

Drilling fluid used is ordinarily water to which mud or other thickening agent has been added. Such fluid carries out cuttings better than water owing to its higher specific gravity and by forming a mud cake on the walls of the hole, it reduces water loss and prevents caving. As drilling progresses, the level of water in the mud pits must be maintained; losses of water may be minimized by addition of small amounts of bentonite or drilling clay. If necessary, a fairly thin bentonite slurry can be thickened quickly by the addition of a little slaked lime. When the slurry attains the consistency of a very thin cream, it is too thick for use in silt; it might not, however, be too thick for drilling in loose sand where considerable loss of fluid occurs. When too thick, the drilling fluid recirculates mud and fine sand. This accelerates the wear on the pump plungers and pump cylinder linings. The amount of bentonite to be used is determined largely by experience. In the 1954 operations, 6 to 10 heaping handfuls were used at the start of drilling, and a few handfuls were added every hour or two or when water losses became excessive.

Drilling clay can be most easily mixed by sprinkling small amounts on the surface of a mud pit and agitating it with a high-pressure stream of water.

When the length of the initial rod has been drilled, the rods are suspended in the hole resting upon a suitable U-shaped clamp. The hole is then washed for 1 to 5 minutes to eject any wall material that caves, after which the rod is retracted slightly and suspended by a clamp under the lower nipple joint (fig. 4). Operations are facilitated by setting a length of oversized casing as soon as possible. Thus, if a well of 3-inch diameter is being drilled, a short length of casing of 4-inch diameter should be set. This will facilitate changing of the rods and yet permit an oversized 3-inch bit to be used until the uncased part of the hole begins to cave.

FIGURE 6.—Lacking a walking beam or similar mechanism, rods or casing drive weight may be alternately raised and dropped by tightening and loosening the rope wrapped around the cathead.

In drilling sand formations losses of water will be minimized and the walls of the hole less likely to cave if drilling clay is added to the drilling fluid. However, prolonged circulation of heavy drilling fluid may cake the walls and make it difficult to obtain water from sections of the hole that have become plastered with mud, at which time it will be desirable to set casing because caving of the walls will probably occur as the water is lowered by bailing or by test pumping. Casing an open hole in the unconsolidated formations also will be desirable if the drilling is to be discontinued for as short a period as a day, or if appreciable caving occurs frequently during the course of drilling.

After the rods have been clamped, the pump is shut off, the swivel is disconnected, and a new rod is added. The swivel and drill rods are then reconnected and suspended on the drill rope, after which the clamp is removed from the rods. The pump is then started, the string lowered in the hole, and drilling proceeds as before.

When rods are to be changed, they are raised manually and the drill rope is removed from the walking-beam sheave and snubbed on a cleat on a derrick leg. Similarly, after the new rod is connected, the rope must be transferred from the cleat to the walking-beam sheave without allowing the rods to reach the bottom of the hole. The length of rods that can be held while these rope transfers are made is determined by the weight of the men available. As the weight of the rods increases, it may become impractical and even dangerous to make the transfer without using hoisting blocks. When drilling an uncased hole in caving material, the drilling rods should be retracted at least the length of one rod before disconnecting the swivel in order to minimize the danger of caving around the lower end of the string. The tower accordingly must be high enough to accommodate above ground the upper rod, the rod to be added, and the swivel.

Caution should be exercised in choosing drilling speed. The tan silt was cut so rapidly that a minimum gage hole resulted unless an expansion bit was used. A slower stroke of the rods and maximum pump discharge will wash the wall of the hole and effectively create a wider hole, and thereby premit easier setting of casing.

Drilling in black muck without using casing tends to create a large hole. It is probably better to case this material as drilling proceeds, but, if an uncased hole is desired, rapid stroke of the rods and minimum use of the jet stream seem most desirable.

It is possible and practicable to drill an uncased hole in hard-packed sand. It may be desirable in some instances to drill several feet ahead of the casing to wash the hole to a maximum diameter, but the danger of caving and of sandlocking the drill string is ever present. It should not be attempted unless the jet pump is absolutely dependable.

There may be a tendency for a hole to deviate from plumb during drilling, particularly during fast drilling. If the hole is to be cased eventually, it is desirable to case the hole as drilling proceeds. Casing set in a hole will guide the drill rods, and the new hole drilled below casing that is plumb will likely be plumb also. In any event, particular attention should be given to the plumbness of the first two or three lengths of casing.

SETTING CASING

After drilling an uncased hole as far as desired, casing is set. All rods are removed from the hole and set aside. Depending on the height of the derrick, they may be disconnected at every second joint, or even third joint, and stacked.

Casing is lifted for setting in the hole by a separate line and hook. The end of the line by which the pipe is raised may be wrapped around the pipe or the hook may engage a rope, chain, or clamp device. Lifting ordinarily can be done manually if the casing is not more than 3 inches in diameter and 11 feet in length.

The first length of casing should be fitted with a drive shoe, preferably welded to the pipe. If a regular casing shoe is not available, a coupling lined with hard welded material may suffice. A tightly screwed-up coupling alone is better than nothing and may be sufficient for shallow holes in soft material.

The first few lengths of casing may slide down the hole of their own weight; therefore, clamps must be provided to prevent the pipe from falling out of reach (fig. 7). Clamps should be used as a safeguard until the pipe advances with difficulty. If the pipe fails to advance of its own weight, it may be rotated with a wrench; but care must be taken because the pipe may be released suddenly and fall the remainder of the length to the clamp.

DRIVING CASING

In most holes it will be necessary to drive the casing with a heavy weight. The drive weight (fig. 7) is a rectangular block with a center lengthwise hole, through which the drill rods pass. However, the side of the block is slotted to permit the drive weight to be placed in position without disconnecting the rods. Excessive wear on the striking surface may be eliminated by adding a steel faceplate. The separate line and hook used to handle the pipe may be used to pick up the drive weight. As the drive weight should weigh as much

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as 300 pounds, it is lifted by a rope over the cathead (fig. 6). A guide rod or a bar passing through the drive weight and into the casing is used to hold the weight in proper striking position. A short length of 1-inch pipe with a T-fitting or a specially made long pin passing through the weight will serve as a guide, or the weight may be guided by a short string of drill rods suspended from the crown block (fig. 7). Care must be exercised against failure of the guide rod or pin, for dropping the rod or pin into the hole will require a fishing job and may result in loss of the hole.

FIGURE 7.—Drive weight in position to drive casing.

Driving can be done in two ways. If the casing advances easily, it will probably be preferable to lift and release the weight over the cathead, thereby giving a series of light blows and retaining maximum control of casing advance. Manual rotation of the casing may still be helpful at this stage. At some later stage casing may advance more slowly, and it will be desirable to operate the drive weight with the walking beam. It is possible by proper operation of the walking beam to apply sharp continuous blows, thereby setting up a continuous vibration of the casing, and the casing will advance rapidly, at least, at first.

In setting casing, earth material is jarred or sheared off the walls of the hole and the hole begins to fill; this material may even push up into the casing. Thus, it will almost always be more economical of time to discontinue driving and clean out the hole before the full length of the hole is cased.

With casing in place, an oversize bit cannot be used; an oversize hole, therefore, can be made only by using an expansion bit or offset bit (fig. 5), or by slow drilling and rapid washing. Upon resumption of jet drilling, if more casing is required, the long string of rods extending to the bottom of the hole need not be removed. The procedure to be followed under these conditions is outlined on p. B–16.

At some point casing advance may slow down, and the question arises as to the extent that casing may be driven without damage. This depends on many factors, such as the material being penetrated, the condition of the hole, the strength of the casing, the weight of the drive weight, and the length and number of strokes per minute. The answer can be determined only by trial and error. However, it was found that in medium sand at Anchorage, at a depth of about 100 feet, 4-inch (11 pounds per foot) threaded pipe tended to telescope under hard continued driving with a 300 pound weight; telescoping could be minimized by use of heavier pipe or by using welded pipe in preference to screw-joint pipe. It was also concluded that cutting long threads on thin-wall pipe to make butt joints is not desirable; greater strength remains where normal threads with minimum cuts are used. In using pipe that does not make butt joints, extra effort should be made to secure an exceedingly tight joint.

In operations at Fairbanks, no difficulty was experienced in telescoping of 2- or 3-inch pipe with very hard driving. At one locality where hard sand was being cased off, 3-inch pipe was driven for about 20 hours, advancing about 1-inch per 35 to 70 strokes of the drive weight. The pipe was of normal weight with normal-length threads. In 1949, when an observation well was being constructed by jetting and driving, at one stage 2-inch pipe was pounded all day without damage, advancing only a little more than 1 foot in that time. However, although this pipe had standard threads, the couplings were reamed to allow the ends of the pipe to butt together inside the coupling to form butt joints. The drive weight weighed only about 100 pounds and was operated by alternately tightening and releasing, by hand, the hoisting line which was wound several turns around a revolving cathead.

A general rule, to which there are exceptions, however, is that as long as the pipe moves it may be driven without damage. Attempting to drive casing when it has reached a solid obstruction may result in serious damage to the pipe very quickly.

SETTING CASING WITHOUT REMOVING DRILL RODS

Casing may be joined to a string of casing already in the hole and subsequently driven without removing a long string of drill rods from the hole.

Assuming that the hole has been drilled approximately one casing length or more deeper than the string of casing in the hole, and that the casing already in place protrudes to a foot above the surface, the procedure is as follows:

1. The string of rods in the hole is retracted until the bit is inside the casing.
2. The joint is then disconnected at the surface to free the swivel and one length of drill rod.
3. The remaining rods are suspended inside the casing in the hole by a clamp.

To pick up the piece of casing to be added, the swivel with one length of drill rod attached is lowered, the rod is pushed through the length of casing, and the casing is then tied against the swivel by a rope or chain. These are then lifted as a unit (fig. 8) and suspended over the hole.

The rod in the casing suspended over the hole is now coupled to the rod projecting from the hole. If the rod within the suspended casing projects, it may be easily coupled to the rods already in the hole. If, however, the rod does not project, coupling the rod to the drill string may be difficult and even dangerous if the grip on the rod slips while it is being coupled. The operator should not reach up inside the suspended casing to bring the drill rods together, but a small tool or metal bar should be used to pry the sections into line. It should be apparent that, in any event, the drill rod fastened to the swivel must extend nearly to the end of the casing to complete the coupling.

The rods are tightened by holding the lower coupling and turning the swivel handle. The string of rods then is lifted, the clamp is removed, and the string is allowed to hang free. The piece of casing to be added, still fastened to the swivel, then is lowered into place. It is then untied from the swivel, and the coupling is completed. Rods are then raised several feet for clearance and driving is begun.

It is not necessary to remove the drive weight when casing is being driven as the hole is advanced, nor is it necessary to remove the weight to add more rods for drilling additional open hole. However, the weight must be removed when casing is added; therefore an open-side drive weight is more convenient than one that is a solid block, except for the hole through which the drill rods pass.

FIGURE 8.—Lifting casing using swivel and one joint of drill rod.

SPECIAL PROBLEMS

If jet drilling is carried on extensively anywhere in Alaska, resistant earth formations will be penetrated sooner or later. The drilling of these formations will impose considerable strain on the light equipment used. Consequently, care must be used to avoid stressing the equipment beyond its normal capacity; otherwise, loss of time due to equipment breakdown will certainly result.

Short shank bits, such as are commonly available commercially, have a distressing tendency to break off at the joint. When this occurs, a fishing job will be necessary. Fishing jobs, though well planned, do not always recover lost tools. Tool breaking may be largely eliminated by welding the bit on a 3-foot length of double extra-heavy 1¼-inch hollow rod. A high-grade-steel reducer coupling should be used to connect the bit shaft with the drill rods. In the event that the drill rods should break out of the reducer coupling, the bit and shaft will rest upright, and the consequent fishing job should not be difficult.

The greatest point of weakness that appeared during long periods of hard drilling were at the lowest joint and at the 4-inch nipple between the swivel and first drill rod. It is suggested, therefore, that after each well is drilled, the last foot of the lowest rod should be cut off and the rod rethreaded, and the nipple below the swivel should be replaced by a new one.

It also follows that all threads should be cut absolutely true and all joints made up well. Twisting on the swivel in a clockwise direction at the instant of impact during drilling operations will tend to keep the rod connections tight, in addition to increasing the cutting action of the bit.

Fishing for lost rods is accomplished by using a tapered tap made especially for the purpose. The tap is lowered into the hole at the end of a drill pipe or rod. By careful handling it is usually possible to insert the tap in the upper end of the hollow rods. After engagement the tap is turned carefully to cut a thread in the rod. After it is connected together, the tap is raised with the string of rods attached.

Forging bits to maintain gage and sharpness was found to be expensive and generally unsatisfactory. Use of hard-surface weld material on cutting edges and at outer wear points was relatively cheap and satisfactory. Use of a bit not up to gage is poor practice and ordinarily leads to difficulty.

The height of the tower is an important factor in obtaining satisfactory drilling progress. If the tower is not high enough, standard-length drill rods or casing cannot be handled efficiently. The minimum height that is satisfactory is equal to the length of the casing used (ordinarily less than 11 feet in half-lengths), the length of the swivel and nipple (about 3 feet), the distance between the bottom of the sheave and the crown block (about 2 feet), plus a working distance of 4 feet, or a total of 20 feet.

Extra operations may be required where casing follows the hole closely; unless the total length of rods is only slightly longer than the full length of the casing, substitution of rods or casing, cutting off of casing, or other time-consuming operations are involved. Such difficulties can commonly, but not always, be avoided by anticipating the lengths of casing and rods that will be needed.

When subsurface conditions require that casing be advanced as the drilling progresses, a higher tower and use of shorter lengths of casing and rods will eliminate most of the potential difficulties; but the desirability of a high tower must be balanced against its increased weight and the greater difficulty in erecting it. The tower used in Geological Survey drilling was somewhat cumbersome and awkward and even a little dangerous to erect. Unskilled personnel required 2 to 4 hours to set it up. Efficient production work would require that a derrick be erected safely by one man in half that time. Weight could have been reduced somewhat by planing down the rough 4- by 4-inch derrick legs and by using lighter braces, but time was not taken to test the advantage of thus decreasing the weight. Suggestions are made below for other types of towers to suit various needs.

A minor problem in the Fairbanks area is the large amount of organic material in the tan silt. This tends to clog the intakes of the suction line and the pump (fig. 3). Common window screening was used successfully as a filter in the circulating drilling fluid, but in at least one location much of one man's time was required to keep the screen clean.

Drilling in loose water-bearing sand may be very difficult. Marked losses of water that may occur may be minimized by thickening the drilling fluid with clay. However, the clay thus introduced may be difficult to remove in developing the well. Therefore, in drilling loose sand it is advisable to follow the hole very closely with the casing, drilling only a few inches before driving casing. It may even be necessary to reverse the procedure and drive the casing ahead of the hole; but this generally is a slower operation and, because it imposes a greater stress on the casing, is to be avoided if possible.

Large boulders are the nemesis of jet drillers. Boulders as large as 4 to 5 inches in diameter may stop the advance of casing; but with continued alternate drilling, washing and driving, they may be moved aside. Glacial till, locally known as hardpan, which is common in many places in Alaska, generally is a tough coherent material. In this material it is generally very difficult to sidetrack even small boulders. If the casing can be retracted upon reaching a boulder, or if the boulder is discovered ahead of the casing in open drilling, it is advisable to break it up by blasting. The use of light cable tools to break up boulders is not particularly desirable, unless a combination cable tool-jet rig is used. Instead, the cutting power of the drill rods may be increased by adding weights to the uppermost drill rod.

DEVELOPMENT AND TESTING OF WATER-BEARING DEPOSITS

Water-bearing deposits may be recognized (a) by inspection of the cuttings brought up with the drilling fluid, (b) by a high rate of loss of water from the mud pits, or (c) by discharging water from the hole by one method or another.

Sandy formations, particularly coarse gravelly sands, generally yield water readily to wells. Marked losses of water in the mud pits will generally occur when coarse sands are penetrated, unless the drilling fluid is very thick. In some instances, bailing or pumping will quickly establish the water-yielding character of the formation. Other sands may be difficult to develop and will require bailing, pumping, and agitation for long periods before they yield appreciable amounts of water.

Although a deep uncased hole in unconsolidated formations may be drilled successfully by the jet method, lowering of the water in the hole to below the static level will promote caving of the walls; therefore, the hole should be cased to the water-bearing formation before testing is begun.

Some sand deposits will not yield water, or will yield only small amounts unless a well screen is used. Where an open hole can be drilled ahead of the casing, the screen can be simply lowered in place. However, where sand deposits will not stand open, the most practical method to set the well screen is to advance the casing to the bottom of the water-bearing formation, lower the screen, and then retract the casing to expose the screen. Another useful technique is to wash the screen down into the loose deposits below the casing on a 1-inch wash pipe that passes through a one-way valve at the bottom of the screen and is connected by a reverse-thread joint. After the screen is set, the wash pipe can be disengaged and removed.

Where casing is 2-inches in diameter, the screen should be fitted with an extension of blank pipe that extends well up inside the 2-inch casing. Where 3-inch or larger casing is used, screen with a lead collar at its upper end will probably be more satisfactory. When such a screen has been placed, the lead collar may be swedged out against the casing to make a seal. In any event, after placement of the screen, rapid pumping may be sufficient to develop the well. If this is not successful, the well may be developed further by pouring water into it, or by agitating with a surge block or by compressed air. Sand that accumulates during development may be removed by bailing or perhaps, preferably, by running in the drill rods and washing.

For detailed information on the function and use of screens and development of wells, the reader is referred to several excellent publications on the subject (Bowman, 1911, p. 98; Johnston, 1951, p. 25; Stewart, 1934, p. 25, 48; U.S. War Dept. 1943, p. 192; U.S. Bur. Yards and Docks, 1943, chap. 12, p. 16; Bennison and Bollenbach, 1947, p. 219, 233). Some manufacturers of well screens have published this information in pamphlet form.

In jet drilling in bedrock, such as the weathered zone of the Birch Creek schist, marked losses of water may occur, suggesting that a water-bearing formation has been penetrated. Flushing with fresh water or removal of the rods and bailing the hole dry may show that the hole has not yet reached the zone of saturation. Careful measurements of the water level, or by the absence thereof, following a period of rest (that is, overnight) will show whether or not the zone of saturation has been reached. To avoid marked losses of water in weathered schist above the water table and therefore to be better able to observe drilling-water losses below static level, it is desirable to seat casing tightly at some point below the water level, as will be possible in many places. In fact, considering the fragmental nature and included granular and clayey material of much of the schist, it will probably be desirable to case off to as great a depth as possible.

Although water-bearing formations below the water table ordinarily may be recognized by losses of water from the mud pits, it is advisable to stop drilling and bail or pump the well occasionally to ascertain whether water-bearing formations have been penetrated. The most efficient time to make such a check is at the end of each day's work, because some of the drill rods will have to be withdrawn anyway to eliminate the possibility of their being buried by caving overnight. An accurate measurement of the water level and further testing, if necessary, can be performed the following morning.

Where the water level lies within suction lift of the surface (about 20 feet), the well may be tested by discharging water without pulling all the rods by pumping through the rods. The rods should be retracted at least 20 feet to avoid the danger of clogging the bit or sandlocking the string of rods in the event sand is drawn up into the well.

Where the static level is more than 20 feet below the surface, testing can be done by bailing, or, if a longer test and more accurate data are desired, by pumping with a force-type pump.

Bailing can be done manually, by handling the bailer with a rope through the sheave in the crown block. Lifting the bailer with the cathead was found to be impracticable on the rig used, because the light rope used twisted and tended to wrap around the cathead. Where the depth to water is more than 30 or 40 feet, manual bailing is slow, hard work, although not entirely impractical. A reel for taking up and paying off the bailer line, preferably a thin steel cable rather than a light rope line, which could be run by the power engine by means of an idler pulley arrangement, would be most helpful.

TEST HOLES DRILLED IN 1954

The drilling of test holes in 1954 will be briefly summarized. The conditions found in the drilling of these holes may be considered typical of those found in the submontane area north of Fairbanks. USGS test hole 11 was drilled on the north side of the Chena Hot Springs Road, about one-eighth mile east of the Steese Highway. The drilling site was on a saddle, or pass, in a low mountain ridge where data on depth to bedrock and the possible presence of deeply buried sand were sought.

Tan silt was found to extend to a depth of 54 feet, at which point Birch Creek schist was penetrated. While using a 3-inch Z-bit the drilling rate in silt averaged 3 minutes per foot. The hole was continued to a depth of 112 feet in weathered schist in which quartz veins were present at 67, 74, 92, and 112 feet. Because the siliceous material (quartz) was cut slowly, as little as 1 inch in 20 minutes, the overall drilling rate in weathered rock averaged 20 minutes per foot. The hole was stopped in siliceous rock at 112 feet depth. The casing advanced easily to 54 feet and with light driving was extended to 70 feet.

USGS test hole 12 was drilled on the northeast corner of the Chena Hot Springs Road and the Steese Highway, high on the slope below the pass where hole 11 was drilled. Data on depth to bedrock and the possible presence of deeply buried sandy beds were sought.

In this hole tan silt extended to a depth of 84 feet. Below this, 5 feet of very soft schist was penetrated, and then 11 feet of harder schist.

The drilling rate in the silt, using a 3-inch Z-bit, was 2 minutes per foot. The drilling rate in the schist, using a 2-inch chisel bit, was 20 minutes per foot. Open-hole drilling was done in this well, and caving in the lower part of the silt, below the static level of 56 feet, began a few hours after the hole was completed. The hole was then reamed with a 4-inch bit to a depth of 80 feet, and 3-inch casing was set without difficulty.

The well was tested with a cylinder pump for 1½ hours at a rate of 3 gpm at 19 feet of drawdown, but clear water was not obtained because the casing was not seated on bedrock.

Test hole 13 was drilled at the Bushey Farm on the Steese Highway where it crosses the head of a small valley extending back into the mountains (fig. 2). Data on the presence of deeply buried sands or gravels in this valley were considered of particular importance to the investigation.

Black muck extended from the surface to a depth of 96 feet, below which 4 feet of medium-gray sand and 8 feet of Birch Creek schist were penetrated. The ground was frozen from 7 to 42 feet below the surface.

The drilling rate in the unfrozen black muck averaged 1½ minutes per foot, but drilling in frozen muck was slower, averaging about 3 minutes per foot. The progress in drilling permafrost seemed to be almost entirely a function of the thawing action of the drilling fluid. In addition to thawing the bottom of the hole, the circulation caused thawing of the walls above and a large irregular hole was created. Better progress might have been made by casing off the frozen ground at intervals as soon as enough hole had been made to admit a full length of casing.

The drilling rate in the sand and bedrock was much greater, about 15 minutes being required per foot of penetration. When the sand was reached, a string of 2-inch casing was literally dropped in the hole, and the well was tested. The test efforts were unsuccessful; it seems that the fine material present choked off such water as might otherwise have been available. However, when the hole reached a depth of 108 feet, having passed through 8 feet of yellow, fragmented, and sandy weathered rock, the well began to flow at the rate of about 5 gpm, at a discharge level 4 feet above land surface. The well was subsequently pumped at a rate of 20 gpm at a pumping level of 7 feet below land surface (drawdown of 14 feet).

Test hole 14 was located on the north side of the Farmers Loop Road in the SE½NW¼ of sec. 22. The site chosen was on an alluvial slope between two major valleys leading back toward a mountain ridge. The depth to bedrock, believed to be slight, was of particular interest here as was the presence of deeply buried sands.

The hole was drilled without casing through 183 feet of tan to gray silt to bedrock to a depth of 184 feet. No appreciable sand was found at the base of the silt sequence. The drilling-time rate averaged 1½ minutes per foot, and in 1 day 145 feet of hole was drilled. Even so, more than half the time was spent in operations other than drilling. A heavy bentonite slurry was used to hold the hole open during drilling. After bailing in an attempt to determine static level, the hole caved and was abandoned.

Test hole 15 was drilled off the Farmers Loop Road in sec. 23, SW¼NE¼, in a small stream valley extending back into the mountains. Data on the presence of deeply buried sands and depth to bedrock were sought at this locality.

Tan and gray silt, including a coarse sandy zone at 103 to 109 feet, was penetrated to a depth of 137½ feet. Medium sand extended from 137½ to 143 feet and medium-coarse sand from 143 to 164½ feet. Below this, 13½ feet of silt and 1 foot of fine sand were penetrated. The total depth was 179 feet. The drilling rate in the upper silt was 1¼ minutes per foot, but in sand it was 18 minutes per foot.

The hole was cased with 3-inch casing and, except for the first 40 to 50 feet, casing was advanced with difficulty. The last 30 to 40 feet of casing advanced very slowly, requiring as many as 64 blows with the drive weight to advance it an inch. The reasons for this difficulty are believed to be (a) the hole was somewhat crooked owing to fast drilling, (b) the hole had not been enlarged appreciably by washing action because of fast drilling, (c) and sandy material in the 103- to 109-foot depth zone tended to follow the pipe and build up skin friction.

Time was not available for testing, but, judging from losses of water from the mud pits and the appearance of the cuttings, the medium-coarse sand between 143 and 164½ feet should have yielded water if development procedures had been applied.

SUMMARY OF TEST DRILLING

Investigations carried out by the Geological Survey in 1954 showed that the unconsolidated formations on the submontane slopes north of Fairbanks could be penetrated quickly and easily by the jet method of drilling. As experience was gained in operating the rig, the average time required to penetrate silt deposits decreased from 3 minutes per foot at the beginning of the season to 1½ minutes per foot near the end of the season.

Drilling in bedrock appeared practicable and was reasonably rapid; a total of about 82 feet of rock was drilled at an average rate of 15 to 20 minutes per foot. Quartz or quartzose rock was penetrated only with difficulty.

Unfrozen black muck was drilled somewhat more quickly than tan silt; and 35 feet of frozen muck drilled in the 2-month period was penetrated without difficulty, requiring about 3 minutes' drilling time per foot. The drilling rate in hard-packed sand was comparable to that in rock.

USE OF THE JET METHOD OF DRILLING

In considering the applicability of the jet method of drilling in the Fairbanks area, the following aspects of this method seem most important:

1. The speed of drilling progress is great where conditions are favorable.
2. The method may be used effectively in several greatly different geologic environments.
3. Holes of any diameter up to 4 inches may be drilled easily, and
4. Modern well screens may be set and the well developed to optimum yield.
5. Where conditions are especially favorable, simple equipment as described in this paper can be used successfully for the construction of wells.
6. Production drilling, or any kind of difficult or deep drilling, may necessitate the use of a commercially built machine that will provide greater ease and speed of operation and greater safety to the operator.

The writers believe that in the Fairbanks area and other places of similar geologic conditions, jet drilling of small-diameter wells will be practical. Furthermore, the speed of drilling generally will not be slower than that of the cable-tool method, and in many places jet drilling will be considerably faster.

The experimental work of the Geological Survey in the Fairbanks area shows that the jet drill is effective in the construction of wells and test holes in many different types of earth material. Silt and muck formations are penetrated with ease. However, not as much is known about rock drilling as might be desired. Although much of the weathered schist of the Fairbanks area is penetrated easily, relatively thick hard layers of rock might be difficult to penetrate with the jet drill, although not necessarily more difficult with lightweight cable-tool equipment.

Drilling in the sandy sediments of the valley flats in Fairbanks may be entirely practicable. The method may not be notably more efficient than the drive-jet method of drilling wells of 2-inch diameter now carried out extensively in the area (Cederstrom and others, 1952, p. 19). With a jet drill built to deal with the wide range of conditions existing on the slopes and hills, it may be found entirely practicable to drill wells of 2-, 3-, and 4-inch diameter in the valley flat areas also.

Drilling on the valley flats in frozen or unfrozen sandy ground will necessarily be relatively slow—it may be recalled that at test hole 15 an average of 18 minutes was required to drill each foot of a hole of 3-inch diameter in hard-packed sand. Jet drilling at Anchorage in 1951 indicated that a 4-inch hole might be drilled in sandy ground at the rate of from 15 to 30 feet per day when working within 100 feet of the surface, including the setting of 4-inch casings. It is thought that the drilling of frozen sandy ground will not be more difficult than that of thawed sandy ground; in fact, it may be less difficult because caving can be reduced to a minimum if the casing follows the hole rather closely.

The advantage of using the jet drill, described in this report, on the valley flats is its versatility. Holes as large as 4 inches in diameter can be drilled with relative ease, thus permitting the use of large pumps or, if necessary, permitting relining with smaller diameter pipe. The casing installed is open at the bottom, and screens of optimum length and slot size may be placed if desired.

PRODUCTION DRILLING

Generally, professional drilling will demand that the best equipment available be used in order that the time factor be reduced to a minimum. It is pointed out that modern jet-drilling machines are available commercially. These machines are truck- or trailer-mounted, with a folding steel mast that can be quickly raised and lowered. Lever controls are so situated that one man alone can perform most operations called for in sinking a well.

However, in some instances, conversion of a cable-tool rig already on hand may be practicable by the addition of a relatively inexpensive jet pump activated from a power takeoff on the rig.

Drive-jet outfits in use might be converted to reasonably efficient jet drilling with little expense, provided that the engine has adequate horsepower and the pump can deliver turbid water at a pressure of, perhaps, 50 pounds per square inch or more. Lacking sufficient horsepower, excessive gearing down of the engine may be necessary and operations may be slower because more block-and-tackle operations will be necessary.

A drilling outfit of the type used by the Geological Survey might not be quite practical for production work. Certainly, it would be desirable that the entire outfit, including a more easily raised derrick, be trailer- or truck-mounted and that a reel with appropriate controls be provided for running a bailer. It should be pointed out that a separate engine to operate the pump is not necessary, though it is desirable to insure good drilling circulation in times of difficulty. A jet-drill power unit presently in use in eastern Virginia has both pump and walking beam activated by one engine. The pulleys are double, one fixed to the pump shaft and one free. By sliding the belt from one pulley to another, a clutch arrangement is achieved.

In the final analysis, what can be used successfully will be decided by many factors, chief among which is the cost of the equipment, the ingenuity of the driller, and the manner in which he decides to conduct his business.

SIMPLE DRILLING EQUIPMENT

Simple jet-drilling equipment can be used where only one or a few wells are to be drilled, provided the time required to drill is not an important factor and conditions are especially favorable.

One individual in the Steele Creek area was able to wash a ¾-inch pipe down 149 feet in less than 2 days' working time. A simple electrically operated household piston pump was used for circulating the drilling water. No derrick was used and the wash pipe was twisted manually as required, in order to advance the hole. The well, which was cased with 2-inch pipe, flows about 5 gpm. Practically all the drilling was done in blue muck. The ease of drilling in this instance should not be regarded as a criterion of what will commonly be penetrated in the submontane area north of Fairbanks. Holes to a depth of 150 feet generally cannot be drilled with such simple equipment where ground conditions are at all difficult. Such areas normally require the use of proper equipment in the hands of a skilled operator.

GEOLOGIC TEST DRILLING

The results of Geological Survey test drilling in the Fairbanks area indicate that the jet method of drilling, in addition to being a practical method of constructing water wells in many places, is well suited for certain types of geologic investigations. Uncased 2-inch holes can be drilled easily in the unconsolidated silty sediments, and where exploration is concerned primarily with depth to bedrock or frozen ground or the type of alluvial material present, holes can be put down quickly and cheaply.

Samples of drill cuttings collected in jet drilling are not as representative of the formations as cable-tool samples, but are adequate for many types of study. Although the desirability of test holes for ground-water exploration may not be apparent, in many places it might be desirable to drill a number of small-diameter holes to locate and determine the maximum thickness of water-bearing deposits before constructing an expensive production well. Such holes, especially where casing is not needed, can be drilled by jetting at small expense. The information gained would, first, provide assurance that an expensive large-diameter well would be successful and, second, would enable contracts to be prepared on the basis of a detailed summary of formations to be penetrated in the production well. Furthermore, the method by which the well was to be constructed and finished could be specified with greater assurance.

Holes of somewhat larger diameter required for special purposes can also be drilled without casing and will remain open long enough to permit the installation of special devices, as, for example, recording temperature.

Investigation of building foundations could be carried out economically and quickly in many places by putting down jetted holes. The type of material present, the thickness of unfrozen and frozen ground, and the depth to bedrock could be determined with ease; and if special equipment is utilized, cores may be taken where required.

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