OIL WELL DIAMOND DRILLING

By MATTHE BRODIE

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Chairman's Introduction.

Gentlemen, as the chairman of our meeting this afternoon, it is my great pleasure to present Mr. Brodie to you. Mr. Brodie is one of the resident engineers in Tokyo of the Sullivan Co. of New York, and will speak about a new method of oil-well drilling and its practice in the United States.

I have been asked to speak about recent developments in drilling, for determining structural arrangements of oil formations, for prospecting for oil and for producing oil.

Ever since the antichlinal theory of oil accumulation was proven correct, nearly forty years ago, it has been used by oil geologists with great success. This theory is based on the simple fact that oil is lighter than water and is thus forced to the high places in sandrocks and

other porous strata. Oil and gas pass from deep laying formations to the domes, or anticlines, leaving the surrounding areas drained. There is almost always a close relation between the arrangement of the rock strata and the oil and gas deposits.

Structural maps of nearly all the oil fields of the World have been made and many of them published. These maps are made from the study of outcrops of rock strata at the surface, or from records of wells and test borings. In many cases where a new oil deposit is promising or has been opened, there are no surface outcrops, or none that can be relied upon. It is then necessary to get beneath the surface soil and deep enough to discover a stratum of rock which may be mapped for "structure" study. Such a stratum is called a "key bed".

Geologists and oil companies in the past few years, are placing more and more importance on scientific structure study, based on data secured from test hole drillings. This recent development is largely due to the introduction of the diamond core drill into the oil prospecting and oil producing industry.

The churn and the rotary types of oil well drills that are in general use for drilling oil wells, have been improved so that to-day they do their work as well as such methods can be expected to do. Most geologists and practical oil men, however, know how difficult it is to get an accurate log, or record, of the formations drilled by means of these outfits. This is largely due to the cable or line of drill rods, striking the walls of the hole and dislodging particles. The results is that the cuttings brought to the surface by the bailer contain sands, different shales, or different kinds of limestone, which keep falling to the bottom of the hole from several hundred feet above. It is difficult and often impossible to determine just what the formation is at the bottom of the drill hole. Great sums of money have been lost because of unsuccessful wells located on unavoidably inaccurate records of such drilling.

The diamond core drill is not an experiment. It is an old thoroughly established machine. They have been in successful operation for over fifty years in practically all parts of the World, prospecting for coal and minerals, testing for foundations and other hard rock forma-

tions, where the actual drilling difficulties encountered are much greater than in oil formations.

A few years ago progressive oil men began to see the possibilities of the core drill combined with the use of "mud fluid" for their work. In the past three years there has been a rapid increase in the use of these machines in many of the oil fields in different parts of the World. New and larger special machines have been developed to handle the larger casings and tools for deep oil prospecting and oil producing wells.

To give an idea of what is being done with the core drill, a short description of the conditions in which the work is done may be of interest. The generally accepted theory is, that oil had its origin in shallow waters along ancient sea shores. Changes in the earth's surface, due to sedimentary extension, or upheaval or depression, have left many of the old sea shores hundreds of miles inland and thousands of feet below present sea level.

Geologists tell us that small forms of marine life existed in the shallow waters. As they died their bodies were deposited in mud. Under favorable conditions a

thin stratum of mud was formed containing considerable organic matter and perhaps some free oil. This mud was later covered with sand, then more mud and, sometimes lime, until there was a thick mass. Through the ages the mass hardened, or some parts hardened and some remained soft. The organic matter in the mud bellow, which is now a shale, was next converted to oil through heat or chemical changes.

The oil, being below natural water level and being lighter than water, began to move upward. Capillary attraction played an important part in this movement, porous rocks acting like a lamp wick does. If an impervious stratum were encountered, the oil moved laterally for many miles seeking an outlet. When it reached a fault, or fissure or change of rock, it moved upward. If it reached a porous sandstone it moved up through the water and continued until it reached the surface where it was dissipated. Most oil passed off in this way and was lost. Fortunately, nature provided some store houses and the modern geologist looks first for the store house and then investigates to see what is in it.

It should be remembered that oil does not originate

in sandstone; but as sandstone is porous it is capable of storing more oil in its voids than other rocks. The proper condition for storing oil underground is known as "structure". It may take queer shapes, but generally it is the shape of a dome, or anticline. It must be closed at the ends like the roof of a house, because oil will not remain in what is known as "open structure".

A typical structure is a dome with porous sandstone and an impervious capping above it. The oil in its travels comes to the dome, moves up through the water in the sandstone and stops at the impervious capping. As it cannot travel upward and cannot go down through the heavier water, it remains through the ages awaiting the drill to penetrate the capping and permit it to resume its journey to the surface. Gas forms on top of these oil pools and comes to the surface first. The gas, being scattered through the sand under pressure, forces the oil upward through the drill hole. Generally the pressure does not exceed the hydrostatic head to the surface. However, in some cases, as at Tampico, Mexico, the pressure does exceed the hydrostatic head. In such cases the oil and water below it, are sealed off from

surface water and the pressure comes from steam or hot water.

Finding "structure" where the dome can be located from surface outcrops of rock strata, is a simple matter. But, in most oil fields, where heavy overburdens and few rock exposures exist, there is little to guide the geologist. Oil bearing formations may be covered with hundreds of feet of later formation, or the formation may be eroded so that a valley on the surface may be directly above a structural high point or dome of an oil bearing series. This is a field for the core drill.

My object in speaking of this is that you may understand what is meant by "structure drilling". Imagine your geologist studying a formation, he knows it is capable of producing oil. He knows that if oil is there, it is in the natural store house. His object is to find the store house rather than to blindly punch a hole in the ground and trust to luck. To find the structure he must know the elevation of the strata at various points. The oil may be 3000 feet below surface, but if he can get the elevation of some persistent marker, or "key bed" say 300 feet below surface, which he knows conforms to the

oil sand stones, he can locate the high point where the oil will be found. Generally two or three key beds at different depths are cored to act as checks on each other. The diamond core drill, producing an actual core or sample of the formations, is unrivaled in this work.

Fig. 1

The success of the diamond core drill in drilling test holes, and also producing wells in oil formations, depends largely on the proper use of mud fluid. This mud fluid consists of a mixture of clay, or shale cuttings and water. It should be of about 1.3 specific gravity and of the viscosity of cold molasses. In a good mixture the clay

will not settle for long periods and there is little danger of sticking the drilling tools, even when they are left standing in the hole for a long time without circulation.

The principal object of using mud fluid is to seal up pores and crevices in the rock. When this is done the fluid will return to the surface thus giving a full head of fluid to counteract the inward pressure of sand or loose or broken material. If clear water was used it would disappear in the pores of the rock and with less head and less specific gravity the walls of the hole would gradually close or cave in. The mud also plasters the walls of the drill hole and prevents disintegration of solid rocks that ordinarily decompose quickly when exposed to air or water. Some rocks that make perfect cores and are sound, will crumble within a few days, so the usual practice is to use the mud fluid throughout all drilling, even if a driller may be deceived at times into thinking it unnecessary. A special mud pump is used for this work and the whole system of drilling is built around the use of mud fluid and success or failure depends largely on the proper understanding of its use. Aside from sustaining the walls of the hole, the mud

fluid is useful in sealing off gas, water or oil under pressure, that might have to be excluded by means of expensive casing work in order to continue drilling.

There is a strong objection to mud fluid when used with rotary type drills as there is danger of entirely sealing off a gas or oil sandstone that may be of vital importance, without knowing it. The diamond core drill uses all the advantages of mud fluid and eliminates all danger of passing through oil sandstones without detecting them, by producing an actual core of them. The ability of the core drill to handle soft formations and produce an exact record makes it by far the most valuable of all drills, for structure testing and for oil prospecting, and these advantages are rapidly increasing the use of diamond core drills for this work in many of the most important oil fields as well as for remote exploration work.

In drilling test holes and oil wells many variations in stratification, conditions in the hole and unforeseeable accidents, require changes in arrangements of casing, and sometimes call for special tools and equipment. I shall give an outline description of a typical diamond drill oil well.

The first operation is to drill through the surface drift with a 10 inch diameter fish-tail bit, down to bed rock. This is shown at 200 feet depth on Chart No. 2. The 8-5/8 inch casing, called the "Conductor", is then placed and seated several feet into the bed rock. This conductor is left in the hole until the well is completed, and all future drilling is done through it. It excludes surface water and prevents loose drift deposit from caving into the hole. After the well is completed this casing is sometimes withdrawn, unless it has become too tight to pull out.

The next 1200 feet is through blue clay or gumbo beds separated by lime shells (thin bands of limestone). This is drilled with a 7-7/8 inch diameter fish-tail bit through the clays, and with a diamond bit of the same diameter when the limestones are met. Rapid progress is made with both bits—the fish-tail bit going through the clays as much as 290 feet in a double shift, and the diamond bit through the lime shells 4 to 8 feet per hour. During this 1200 feet of drilling the hole is held open by the mud fluid.

At 1400 feet depth a porous sandstone is found which

it seems desirable to test for oil. The 7 inch casing is inserted and then cemented in. It is necessary to cement in this casing, because the walls of the hole are not solid enough to attach a packer, and a tight joint is necessary to prevent material outside the casing from entering the hole. The hole is then continued with a size $5\frac{13}{16}$ inch diameter fish-tail bit in the softer strata and a diamond bit of the same diameter in the harder line shells. These are worked through the line of 7 inch casing. At a depth of 1900 feet a mass of fossils is found which define the formation to the geologist and enable him to predict with considerable accuracy the stratifications below. At this point the fossil bed and the sandstone and limestone formations below it, are too hard for the fish-tail bit, so the diamond bit is used for all the rest of the hole.

At 2000 feet depth a conglomerate is encountered. This at first caves and falls into the hole, forming a cavity. But, the plastering effect of the mud fluid builds up a coating which effectively holds the loose material in place. At 2300 feet depth a hard Red Bed formation is reached and, although the same size $5\frac{13}{16}$ inch bit

can be continued, it is decided to place the line of 5 inch casing at this point for the following reasons:

- (a) We will assume that the weight of the 2300 feet of 5 inch casing is becoming difficult for the machine being used in this case to handle. If a larger size machine was being used it could handle this casing to 4000 feet or more depth.
- (2) Although all the hole above this point is now standing firmly, it is best to insert the casing here because it may be desirable later on to flush out the hole with clear water for a test, and this might wash away the mud filling and cause caves.
- (c) The casing will also prevent whipping of the drill rods and increase the velocity of flow of the returning mud fluid.
- (d) This is a good place to take advantage of the hard solid ledge to support the weight of the casing.

The hole is drilled into the Red Bed about 6 inches and the line of 5 inch casing inserted and the drive shoe on the lower end of it allowed to rest on the rock and thus support the weight of the entire line of casing,

rather than suspend the line of casing by means of clamps at the surface. From here drilling is continued with a $4\frac{1}{4}$ inch diameter bit working through the line of 5 inch casing.

At 2350 feet depth more conglomerate is unexpectedly run into. This is drilled with the $4\frac{1}{4}$ inch diamond bit. The walls of the hole, after caving in to some extent as occurred above at 2000 feet depth, are firmly held by the mudding effect. It is now necessary to ream out the hole and then drop the line of 5 inch casing down past this conglomerate. Before doing this however drilling is continued with the $4\frac{1}{4}$ inch bit until another Red Bed formation is reached, on which to rest the casing. Assume this is found at 2400 feet depth. The line of 5 inch casing is now lifted about six feet off the Red Bed at 2300 feet depth and held with clamps at the surface. I should explain here that this line of casing, and all other casing in the hole is jointed by using hot rosin on the threads to prevent the casing unscrewing when suspended from the surface. The hole is now reamed out to $5\frac{13}{16}$ inch diameter with an expanding reamer set with diamonds. When

this reaming is finished to 2400 feet depth the line of 5 inch casing is lowered and rested on the Red Bed ledge. Drilling is now continued with the $4\frac{1}{4}$ inch bit.

At 2700 feet depth an oil and gas bearing sandrock is encountered. After examination of the core by the geologists, it is decided to continue drilling without testing this sand rock. Limestones and shales are now drilled rapidly for 800 feet. As the geologists are expecting the oil bed, core is drawn every eight or ten feet. At 3500 feet depth the drill runner notes a change in the drilling action. On hoisting the rods, two feet of sand rock showing oil is found in the core barrel. This is examined and tested carefully and found to be the oil and gas bed expected. Had a rotary type of drill been used this oil sand rock would probably have been passed without finding it, as there is not sufficient oil or gas pressure to force indications to the surface and there would have been no core to show that the ledge had been passed. A wooden plug about two feet long and slightly larger than the $4\frac{1}{4}$ inch bit is forced down the hole to the bottom to temporarily seal off the

oil sand rock while a casing is set.

The line of 3-1/2 inch casing, called the "Oil String", is lowered to within a few inches of the oil sand rock ending in the impervious stratum directly above the oil sand rock. This oil string is cemented in to make a permanent tight line between the oil bearing stratum and the surface. Sometimes, when the formations above, up to the deepest line of casing previously set (in this case at 2400 feet depth) are solid and impervious lime-stones, as at Tampico, Mexico, this oil string is not placed at all. After allowing five or six days for the cementing to set, the wooden plugs and cement remaining in the hole are drilled out with a fish-tail or saw-tooth bit, down into the oil sand rock, thus completing the hole.

The size and type of diamond core drill to use for structure testing naturally depends on the expected depth of the drilling. However, it should be remembered that a heavier machine than actually needed may be advisable, as possession of the more powerful machine will enable its owner to drill the larger wells needed for production later on after the property has been mapped.

For structure testing work it is usual to remove a two inch diameter core. This is of ample size to give the geologists all the information they want as to the character, thickness, dip and strike of the strata penetrated. It is very seldom that there is any loss of core even in friable or soft rocks, because in such conditions the double-tube core barrel may be used which protects the friable core from the wash water of mud fluid, and also from vibration during drilling.

The portability of diamond core drill outfits, because of their light weight compared with churn or rotary types of drill outfits, is of great importance. It reduces the time required to complete drilling and also the cost very materially. I recently heard of one drill crew in Oklahoma, U.S.A., drilling 1100 feet of holes in 20 days including moving their outfit six times.

There is a strong tendency for oil geologists to-day to demand that the first wells on promising structure be drilled with a diamond core drill. Core samples are then secured of the structure all the way down, and finally, samples of the oil sand rock itself. Besides the geological information furnished by a core from above

the sand rock, a core of the sand rock itself show :

- (a) Exact nature, thickness and hardness of each bed.
- (b) Thickness, character and porosity of each oil bearing stratum.
- (c) The bed best adapted for seating casing.
- (d) Data as to the position to place shots to be most effective.
- (e) Data for size of shot to give best results.
- (f) In case of "blanket" sands, estimate of barrels per acre of oil content.
- (g) By determining size of pore spaces in the sand rock, it furnishes data for spacing wells to get maximum production with minimum number of wells.
- (h) By comparing the cores, the quantitative and qualitative changes in character and thickness of oil sandrocks in any district can be determined.

I shall quote from a report of one of the oil geologists of the United States Bureau of Mines, on one of the early diamond core drill wells bored in the Tampico, Mexico district.

"Probably no one feature of the drilling attracted as much attention as the core. It was a new and satisfac-

tory experience to both operators and geologists to be able to see and handle the rocks which were actually producing the oil. Sometimes the gas could be seen bubbling out of the core. Many of the cores contained fractures, which, when broken open, were found to contain drops of oil. As the drill reached greater depths the fractures contained more and more oil, until at about 1850 feet they began to give actual production. The well came in rather gradually from that point, until at 2153 feet enough oil was struck to bring the production up to 1200 barrels."

"It was observed that these fractures occurred in zones. The drill would penetrate 20 or 30 feet of fractured ground and then go back into solid rock again. This would continue for 50 or 60 feet and then another fractured zone would be encountered. This information would have been very important had it been desirable to shoot the well. The shooter would have known, almost to the inch, just where to put the shot, and he could have judged much more accurately as to the amount of explosive required. In general, it is hard to over-estimate the practical value of the information to

be obtained from such cores. The ordinary practical oil operator can obtain more information from them than the trained geologist does now from a microscopic study of well cuttings".

Some oil companies now have from two to twelve or more diamond core drills working on structure testing alone.

There is no reason why the diamond core drill cannot drill a large hole, but in structure study and oil prospecting, a 2 inch core from a 3 inch hole will give as much information on geological conditions as a larger core could give. A large hole would require a larger more powerful machine and rods and tools, and would cost much more money. When it is desired to not only prove the existence of oil bearing formation and to prospect for the oil, but also to take care of production as well, then a machine of suitable capacity should be selected.

There is sometimes a mistaken idea that the production of a well depends on the size of the pipe. This is true to some extent sometimes, when it is desired to get the maximum "flush" production, but otherwise, a

smaller casing will give the same results without the danger of drawing sand and salt water. Gas pressures are maintained longer and the net results over a given time will be about the same. There is no advantage in using casing larger than the surface flow line or larger than is necessary to take care of the pump in a pumping well.

Oil men are realizing that it is not the size of the casing, but the porosity of the rock, the size of the rock channels and the quantity of oil that determine the flow. A well drilled by a diamond core drill in one of the leaner parts of the Tampico field is flowing 1200 barrels of oil per day through a 4 inch casing. Near by, another well drilled with a standard type of well drilling outfit, is producing only 500 barrels per day through an 8 inch casing.

When high pressures of oil or gas are run into with rotary type outfits, it is impossible to control the pressure, because outside couplings are used on the rods, which make it impossible to use a packing box. With the diamond core drill, where flush joint drill rods are used, drilling can be continued through a packing box

at the surface and the oil and gas pressure always kept under perfect control and the rods can be removed regardless of the pressure, and there is no loss when the well "comes in".

For structure testing, for oil prospecting and for oil production, there can be no doubt but what the use of the diamond core drill is a big progressive step in the oil business.

Discussion.

Prof. Y. Oshima (Chairman)—I desire to express our thanks to Mr. Brodie. The process and the machine of which the speaker gave us very helpful impression are very interesting and scientific. It seems to me the principle of the process is the combination of a diamond core drill and an improved well drilling. It is not only scientific and help geologists, but also gives very useful information to oil men. In these days, gentlemen, any process and improvement for oil-well drilling which do not based on a scientific foundation may not be taken

up by practical men, because, so far as I have heard, the oil men are somewhat tired away with cut-and-try processes. It is quite radical to see that this process is very widely worked on in the States and we should look after the present conditions of our oil field and its survey.

I know, gentlemen, you all know the business line of the Sullivan Co. and how the rockdrills of this company have ever been favored in this country. As I told you before, Mr. Brodie is an expert of that company and I like to advise you again to ask him any thing about the process he has spoken, for which, I am sure, he will be very glad.

Mr. T. Esaka asked—

(a) How many feet can be drilled per hour through limestone beds with a diamond drill? What is the drilling speed of a diamond drill, compared with that of a fish-tail bit, in relation to a limestone bed?

REPLY.—It is impossible to give a close estimate of drilling speeds for any kind of a drilling outfit. The rate of progress depends so much on such

things as, the size of the drilling machine being used, the depth of the drilling, the hardness and nature of the rock being penetrated, the ability, experience and energy of the operator and his crew. However, a general average rate of progress with a diamond bit in limestone would be about five to eight feet per hour while actually drilling, sometimes more.

The fish-tail bit is seldom used in the limestones as better progress is made with a diamond bit. The fish-tail bit is used only in the softer clays and shales and then when the harder limestones are encountered it is replaced with a diamond bit.

- (b) Can you obtain a table showing the records of drilling speeds taken when the hydraulic feed type diamond drill was used in drilling 2" and 3" holes through various rocks?

REPLY—As just explained in the previous question, the conditions vary so greatly with different holes that it is impossible to give drilling speeds. Not only this but it is generally impossible to get details like this because they are seldom published

as the company paying for the drilling generally considered this data strictly private.

- (c) Is any material used for fixing the joints when the casing tubes are screwed down?

REPLY—When the casing joints are screwed up when lowering all casing it is general to joint them with hot rosin. When the casing is withdrawn these joints are easily broken by heating slightly.

Mr. D. Matsuzawa, told about his recent visit to the United States when he investigated the new type of special diamond drills for deep oil well drilling and told about having visited some of the oil fields and seeing these and smaller outfits drilling for "structure" testing.