THE USE OF HORIZONTAL DRAINHOLES IN THE EMPIRE ABO UNIT

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ABSTRACT

ARCO Oil and Gas Company has drilled two horizontal drainhole wells in the Empire Abo Unit. A horizontal drainhole well is one in which the wellbore is turned from vertical to horizontal in a short radius and the horizontal hole is then drilled out some distance into the formation. These wells were drilled to evaluate the mechanical feasibility of the drilling process and to examine the effect producing through the drainholes would have on the well's tendencies to form gas cones. Although several problems were encountered while drilling the drainholes, the drilling technique used does seem to be mechanically sound. The wells have not been on production long enough to fully evaluate their gas coning performance as compared to conventionally completed wells.

This paper will briefly examine the gas coning problem in the Empire Abo Unit, discuss some of the techniques used to limit gas coning in the Unit, and review ARCO's experience with horizontal drainholes.

INTRODUCTION

ARCO Oil and Gas Company operates the Empire Abo Unit, located in the Empire Abo Pool of Eddy County, New Mexico (Fig. 1). The Unit consists of approximately 11,000 acres and represents about 97% of the entire pool.

Production is from the Permian (Lower Leonard) Abo Reef dolomite at a depth of approximately 6200 ft. The productive reef development is approximately 12.5 miles long and 1.5 miles wide (Fig 2). The cross-sectional view in Fig 3 illustrates the massive reef development. The main producing mechanism is gravity drainage which is now supplemented by the injection of the residue gas into the gas cap.

The pool was discovered in 1957. Competitive development of the field on 40-acre spacing was rapid. The pool was operated on a competitive basis until 1972 at which time the Empire Abo Unit was formed. S. H. Christianson's paper[1] gives a detailed description of the reservoir and discusses factors involved in the formation of the Unit.

Prior to unitization, approximately 96 MMBO were produced from the Abo Reef. An additional 91 MMBO have been produced from the date of unitization through April, 1980. The Unit's current production rate is about 25,000 BOPD.

GAS CONING IN THE UNIT

At the time of discovery, the Abo reservoir pressure was above the crude's bubble point. Competitive production of the pool resulted in a drop in pressure to below the bubble point and the formation of a secondary gas cap. By the early 1970's several wells in the up-dip area of the pool began to produce at gas/oil ratios (GOR's) in excess of the solution GOR indicating the production of free gas from the gas cap. Drill stem test information indicated that these high GOR wells were perforated below the level of the regional gas/oil contact. Localized depressions in the gas/oil contact around the wellbores (gas cones) were causing the high GOR production.

Producing Empire Abo wells at high GOR's is undesirable for two reasons. First, free gas production rapidly depletes the reservoir pressure resulting in reduced ultimate recovery. The second problem with high GOR production is illustrated by Fig.4. Due to the relative permeability characteristics of the Abo reservoir, a well's oil production rate drops sharply when it begins to produce at GOR's in excess of the solution GOR (currently about 700 CF/BO).

After unitization, the high GOR wells were shut-in and their allowables were transferred to low GOR producers with excess producing capacity.

There are no longer any Unit wells with excess capacity that can be used to replace the lost oil rate that occurs when wells begin to produce at high GOR's. For this reason, gas coning has become the most serious operating problem facing the Unit owners. Several methods for controlling the problem have been explored.

Many of the older wells in the Unit were originally completed high in the pay. In this instance, the most effective way to reduce a well's GOR when it begins to cone gas is by squeeze cementing the perforations and recompleting lower in the reef. Most of the wells in the Unit are now completed as low in the reef as possible; therefore, very few of these opportunities remain.

The drilling of 158 infill wells in the Unit during the late 1970's was an indirect means of reducing the gas coning problem. Computer modeling indicated that reducing the well spacing from 40 acres to 10 acres in selected areas of the Unit would result in the recovery of additional reserves. With thé additional wells, the oil withdrawals from the reservoir were dispersed while maintaing the overall producing rate. This resulted in a reduction of individual well oil producing rates, thereby reducing gas coning tendencies and increasing ultimate recovery.

As the gas coning problem in the Unit became more severe, ARCO began investigating less conventional means of controlling the problem. Production from horizontal drainholes was one of the alternatives evaluated.

THE DRILLING OF HORIZONTAL DRAINHOLES

The concept of horizontal drainhole drilling is not new. Drainhole drilling technology was actually developed in the 1950's[2,3,4]. With the exception of a few isolated tests, however, the process has not been used in the petroleum industry.

ARCO contacted an outside drainhole drilling consultant who had equipment for drilling drainholes of up to 200 feet in length with a turn radius of less than 30 feet. A short radius turn is critical to the successful use of drainholes to limit coning.

The sharp turn is accomplished by using a whipstock, flexible drill collars, and a specially designed angle building bottom hole assembly.

Fig. 5 illustrates the design of the flexible drill collars. The jig-saw puzzle cut through standard drill collar stock provides for the flexibility. A 1-inch ID high pressure rubber hose runs through the center of each collar to transport mud to the bit. Each drill collar is 10 feet long and is jointed on 11-inch centers.

The angle building bottom hole assembly consists of a 4-3/4 inch cone bit and a 4-inch OD knuckle joint. Below the knuckle joint is a 1/16-inch over gauge stabilizer (Fig.5).

The turn is initiated with the angle building assembly drilling off the whipstock. Once clear of the whipstock, the weight on the knuckle joint continues the turn. When the turn to horizontal is nearly complete, the knuckle joint is removed and additional stabilization is added, resulting in a stablilized bottomhole assembly with no angle building tendencies. The remainder of the drainhole is drilled with this assembly.

SURVEYS

Taking directional surveys in drainholes also requires special equipment. A 120° Eastman Whipstock Type A single shot, survey unit is used. A monel sucker rod is run directly above the survey unit, and several standard sucker rods are run above the monel rod. This assembly is run in the hole on a wire line. The weight of the sucker rods pushes the survey unit to the end of the drainhole.

Surveys are taken frequently during the drilling of the drainhole. The small ID of the hoses in the flexible drill collars necessitates pulling the drillstring to take surveys. Although this makes directional surveying quite time consuming, frequent surveys are necessary to monitor the course of the drainhole.

COST

The estimated total cost to drill and complete a Unit well with a horizontal drainhole completion is about $500,000. This is approximately double the cost of a conventionally completed well in the Unit.

APPLICATION OF DRAINHOLES IN THE EMPIRE ABO UNIT

ARCO's Research and Development Group in Plano, Texas conducted a numeric model study comparing horizontal drainhole completions to conventional completions in the Unit. Their study showed that a drainhole would indeed recover more oil reserves than a conventionally completed well.

Fig. 6 shows how a typical conventional Abo well is completed. The well is drilled through the base of the Abo Reef, and casing is set and cemented. A porosity zone, as near the base of the reef as possible is selected and perforated. The zone is then stimulated with a density controlled acid treatment. This technique consists of pumping pads of lease crude and calcium chloride water ahead of the acid. The acid's density is between the densities of the two pads. The density differences help to keep the treatment confined vertically. Even with this density controlled procedure, significant upward etching often occurs making the acidized well even more susceptible to gas coning than a non-acidized completion. The pressure gradient between the uppermost end of the treated interval and the gas cap is the driving force which causes the gas cone to form.

Fig. 7 illustrates an ideal horizontal drainhole completion in the Abo Reef. The key to the reduced gas coning tendency of the drainhole is the large drainhole surface area open to flow. A simple application of Darcy's law indicates that for the same production rate, the required pressure drop into the wellbore is many times less for the 200 ft drainhole completion than for the 20 ft conventional completion. This reduction in pressure gradient reduces the drainhole's susceptibility to gas coning.

Fig. 8 shows the cumulative oil production versus time results from the model study for a 200 ft horizontal drainhole and for a conventionally completed well. The model study indicated that a drainhole completion would recover approximately 30 MBO more than the conventional completion.

Based on these results, the Unit working interest owners decided to drill a well to test the mechanical feasibility of the drainhole drilling technique and to check performance characteristics of the drainhole. Unit well K-142 was selected to be the first test well (Fig. 2).

DRAINHOLE DRILLING PLAN

The K-142 was spudded in July 1979. The well plan for the K-142 included setting 11 in. surface casing at 1000 ft then drilling an 8-3/4 in. hole to 5900 ft. Hole size was then reduced to 6 in. and drilling continued to 6150 ft. At this point, open hole porosity and resistivity logs were run. A drainhole target depth of 6047 ft was selected based on porosity development.

Straddle packer drill stem tests located the gas/oil contact at approximately 5900 ft. The 6 in. hole was opened to 8-3/4 in. from 5900 ft to 6016 ft. Seven inch casing was run and cemented at 6016 ft. The hole size changes were necessary because the setting depth for the 7 in. casing was dependent on the exact drainhole target depth, and the drainhole tools are designed to kick-off out of a 6 in. hole.

The whipstock was run in the hole and oriented in a S-20°E direction. This direction was selected to ensure that the drainhole intersected the reef's major fracture trend at right angles.

The flexible drill collars and angle building bottom hole assembly were run in the hole, and drainhole drilling began.

After 7 ft of drainhole had been drilled, a drill pipe connection was necessary. Following the connection, the drillstring would not go back to bottom. It stopped at the depth of the whipstock, indicating either a collapse of the drainhole or a rotation of the whipstock. Later evidence indicated that the whipstock had turned.

Drainhole drilling operations resumed. After 19 ft of hole had been drilled in the second drainhole, a directional survey was run. The drift direction indicated that the whipstock had indeed rotated. Another 24 ft was drilled in drainhole No. 2 before the next survey was taken. The survey tool would only go 7 ft below the depth of the whipstock, and the drift direction corresponded to the original orientation of the whipstock. Evidently the whipstock had rotated during the pipe trip; returning to its origianl orientation.

The drilling operations continued in Drainhole No. 1. The turn from vertical to horizontal was accomplished after a total of approximately 35 ft of drainhole had been drilled. This correspondeds to a turn radius of about 28 ft.

Once horizontal, the hole began climbing and corkscrewing to the left. After a total of 106 ft had been drilled in Drainhole No. 1, the drainhole drilling operations were halted due to increased torque on the drillstring in the corkscrewed hole.

Fig. 9 is an isometric drawing of the results of the K-142 drainhole drilling.

COMPLETION OF THE K-142

The completion process began with displacing the drilling fluid from the hole with potassium chloride water. The well was then swabbed for several days resulting in little recovery. Next, coiled tubing was run into drainhole No. 1, and approximately 35 MCF of nitrogen was injected in an attempt to clean out any drilling fluid remaining in the drainhole.

Following the nitrogen treatment, the well began flowing intermittently into the test tank. After a few days, the well was flowing at a rate of about 200 BOPD into the tank; however, the flowing tubing pressure was not sufficient to produce into the Unit's production system.

A hydraulic jet pump was installed on the K-142, and in mid-October, 1979, the well was potentialed at 200 BOPD at a GOR of 670 CF/BO. This rate and GOR are similar to conventionally completed wells in the area. The K-142 has continued to produce at 200 BOPD at GOR's less than 1000 CF/BO. Through April 30, 1980, the well has produced approximately 36 MBO. An important point to note is that the K-142 was never acidized. All of the conventionally completed wells in the area required acid treatments prior to production.

ANALYSIS OF DRILLING PROBLEMS ENCOUNTERED

The two major problems encountered while drilling the K-142 (whipstock rotation and inadequate stabilization) were studied and actions were taken to eliminate these problems prior to the drilling of the second drainhole well in the Unit. The whipstock used in the K-142 relied solely on a spade on the bottom of the tailpipe to maintain its orientation. Any combination of upward force and twisting movement tended to displace the whipstock from its original direction. Residual torque in the drill pipe during a pipe connection and a pipe trip resulted in the two rotations of the whipstock during the drilling of K-142. A whipstock with a positive mechanical hold-down was used in the second drainhole well, and it performed satisfactorily.

The corkscrewing of the hole was attributed to a flaw in the design of the stabilizing bottom hole assembly. The design was modified resulting in much better control while drilling the second well.

DRILLING THE SECOND DRAINHOLE WELL

Based on the results of the drilling of the K-142, the Unit owners spudded the Empire Abo Unit J-213 in March, 1980 as a second drainhole test (Fig. 2).

The first drainhole well was primarily a mechanical test of the drainhole drilling technique. The location of the K-142 was selected in an area of the Unit that contains several low GOR producing wells. This was done so that an economic conventional completion would be possible if the drainhole could not be drilled.

The J-213 location, however, is in an area containing only high GOR wells. Conventional infill wells in this area have produced at low GOR's for only short periods of time before coning gas. This location is a more rigorous test of the use of drainholes in the Unit to reduce gas coning.

The drilling plan for the J-213 was substantially the same as that of the K-142. After the vertical hole had been drilled to 6225 ft, drill stem tests located the gas/oil contact at about 6070 ft.

A drainhole target depth of 6137 ft was selected from the open hole logs.

The whipstock was set at 6115 ft and oriented in a westerly direction. One major difference between this well and the K-142 was that the drilling rig was used to drill the K-142 drainholes, and a pulling unit with power swivel was selected to drill the J-213 drainhole. This change in procedure was implemented to reduce the cost of the J-213.

Drainhole drilling began and initially progressed quite smoothly. The turn from vertical to horizontal was completed in 46 ft and a radius of about 26 ft. At that point, however, as happened on the first well, the drainhole started to climb. Several attempts were made to drop the angle back to 90°, but none succeeded. After a total of 127 ft of drainhole had been drilled in the J-213, drilling operations were suspended. The drainhole had climbed to 6125 ft, and it was decided to stop the drilling, rather than have the drainhole climb any closer to the gas/oil contact. Fig. 10 shows the path of the J-213 drainhole.

The problem of the hole climbing resulted from drilling with the angle building bottom hole assembly for too long. It is evident that the timing of the changeover to the stabilized bottom hole assembly is critical to the drilling of a truly horizontal hole.

The drilling of the J-213 drainhole was finished in late May, and no completion results are available as yet. The completion procedure used in the J-213 will be similar to the K-142 completion procedure.

FUTURE PLANS FOR DRAINHOLES AT EMPIRE

At the time of this writing, the future of drainhole drilling in the Empire Abo Unit is uncertain. Although problems were encountered resulting in premature termination of the drainhole drilling on the first two wells, the basic process seems to be sound.

The question that remains to be answered is whether drainhole completions are less susceptible to gas coning than conventional completions. The K-142 continues to produce at low GOR's; however, there are also low GOR conventionally completed wells in its vicinity. This fact makes analyzing the effect of K-142 drainhole completion difficult.

The Unit owners will closely observe the GOR performance of the J-213. If the results are encouraging, we will probably continue the drainhole drilling program. If the J-213 produces at high GOR's, we will have to re-examine our analysis and decide whether or not further experimentation is justified.

CONCLUSIONS

1. Numeric modeling indicates that producing through a horizontal drainhole completion will result in increased oil recovery as compared to a conventionally completed Empire Abo well.

2. The drainhole drilling process was found to be mechanically feasible, even though problems were encountered during the drilling of the first two drainhole wells in the Empire Abo Unit.

3. Horizontal drainhole wells can be successfully completed in the Empire Abo Unit.

4. The full effect that producing through horizontal drainholes will have on gas coning tendencies has not yet been evaluated.

NOMENCLATURE

CF	- cubic feet of gas
BO	- barrels of oil
BOPD	- barrels of oil per day
GOR	- gas/oil ratio
ID	- inside diameter
MBO	- thousand barrels of oil
MMBO	- million barrels of oil
MCF	- thousand cubic feet
OD	- outside diameter

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3. Eastman, H. John: "Lateral Drain Hole Drilling", The Petroleum Engineer (November, 1954) B-57, B-58, B-61, B-62, B-67, B-68, B-70, B-73.

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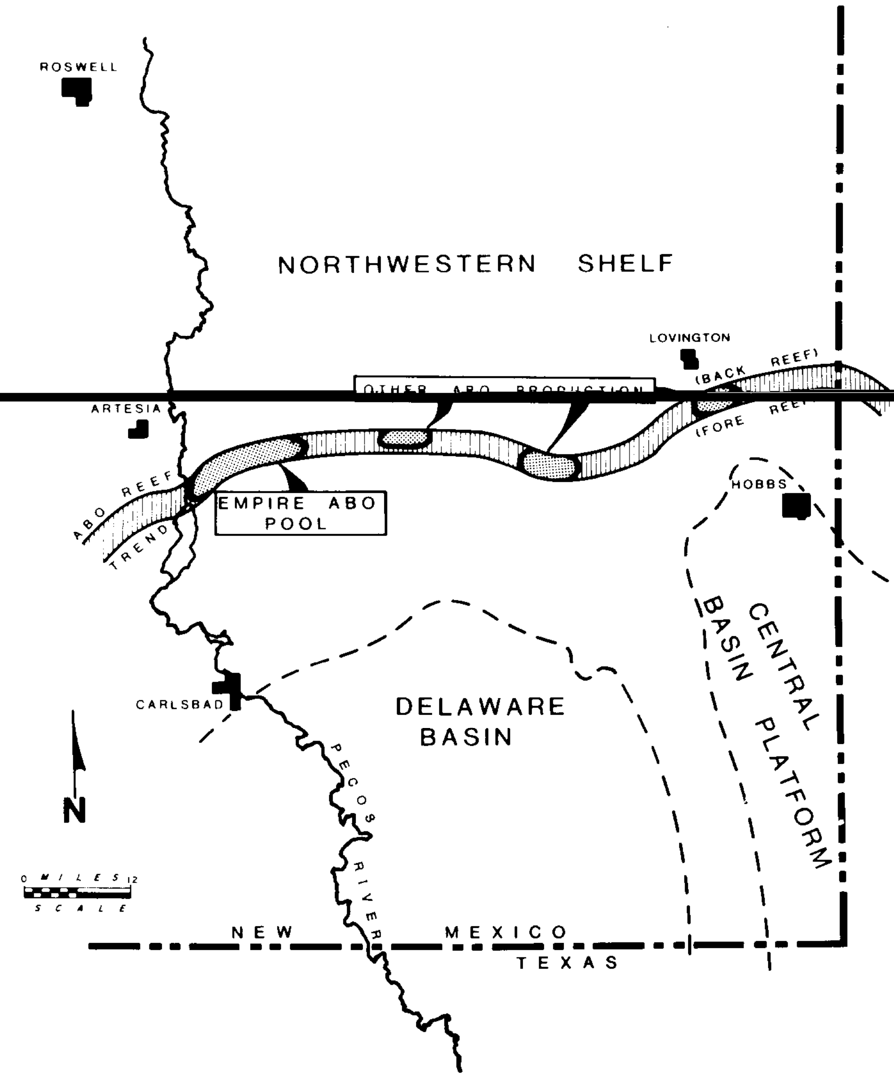
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NORTHWESTERN SHELF
LOVINGTON
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OTHER ABO PRODUCTION
(FORE REEF
ARTESIA
ABO REEF TREND
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DELAWARE BASIN
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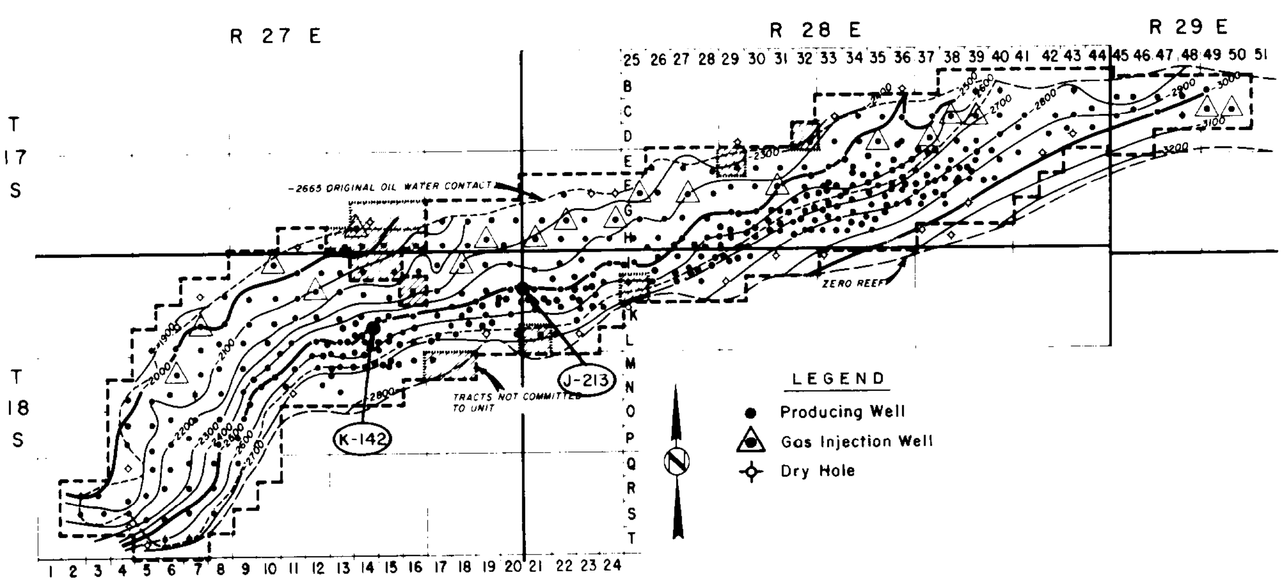
NEW MEXICO
TEXAS


R 27 E
R 28 E
R 29 E
T 17 S
T 18 S
-2665 ORIGINAL OIL WATER CONTACT
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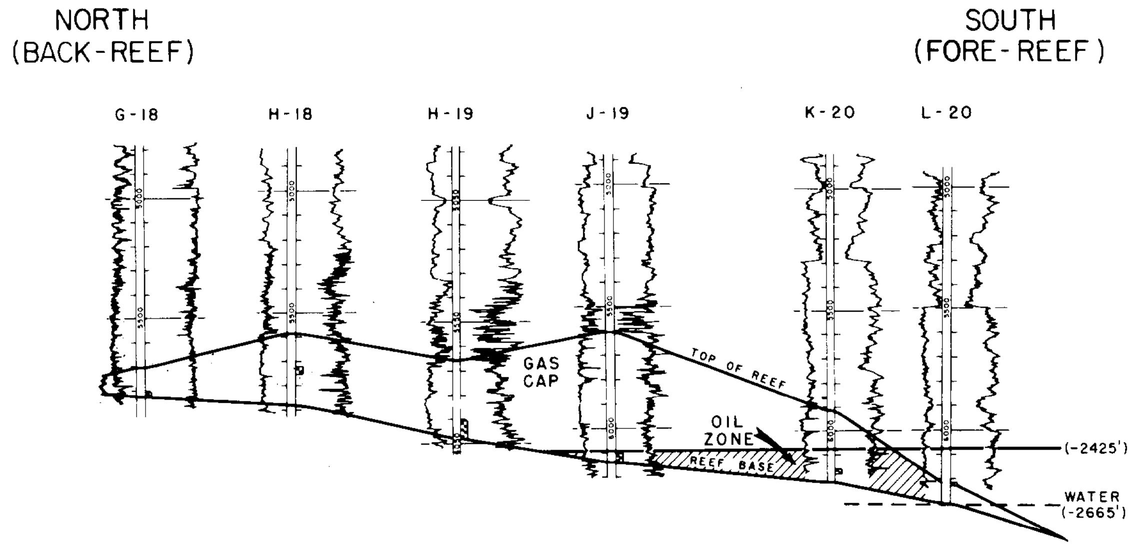
TRACTS NOT COMMITTED TO UNIT
J-213
K-142
LEGEND
Producing Well
Gas Injection Well
Dry Hole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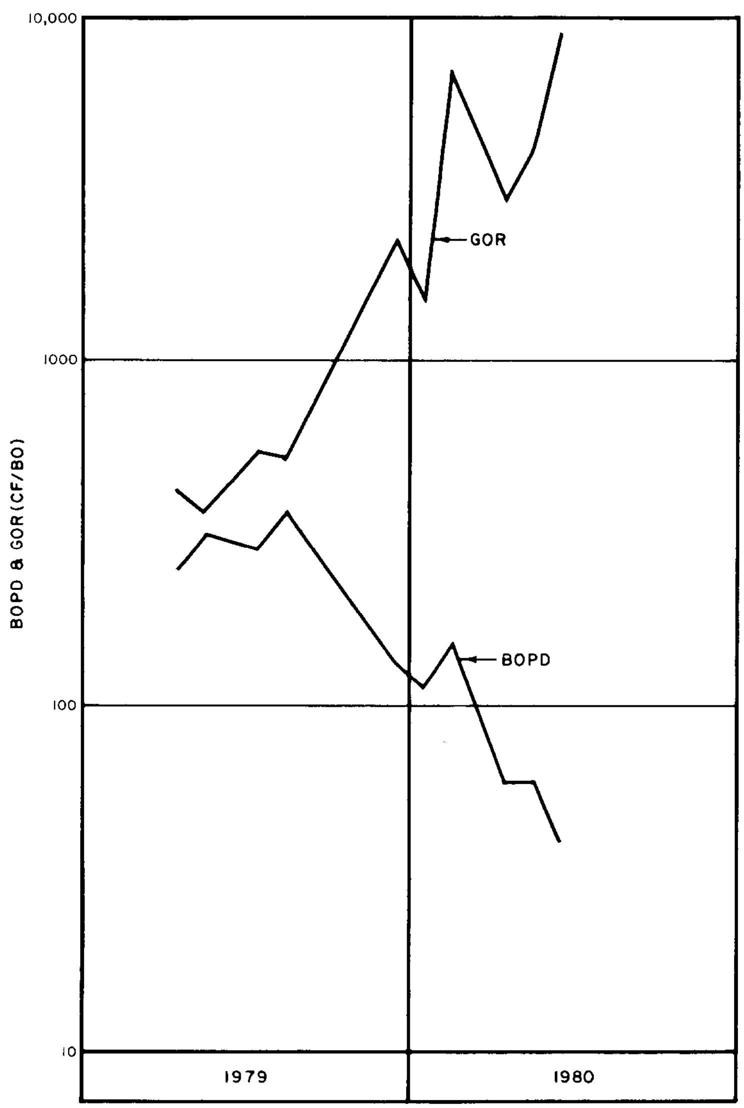
SOUTH
(FORE-REEF)
G-18
H-18
H-19
J-19
K-20
L-20
GAS
CAP
TOP OF REEF
OIL
ZONE
REEF BASE
(-2425')
WATER
(-2665')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100
10
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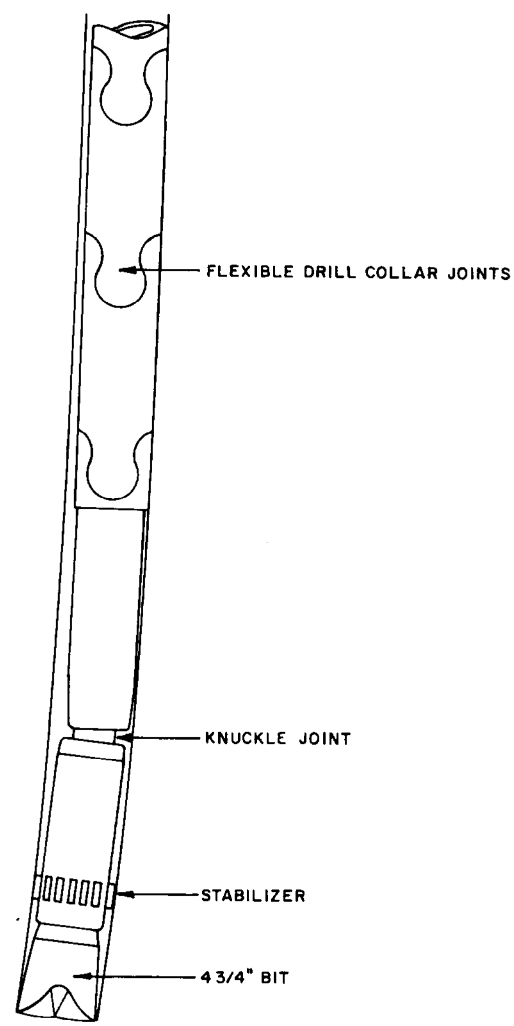
GOR
BOPD
1979
1980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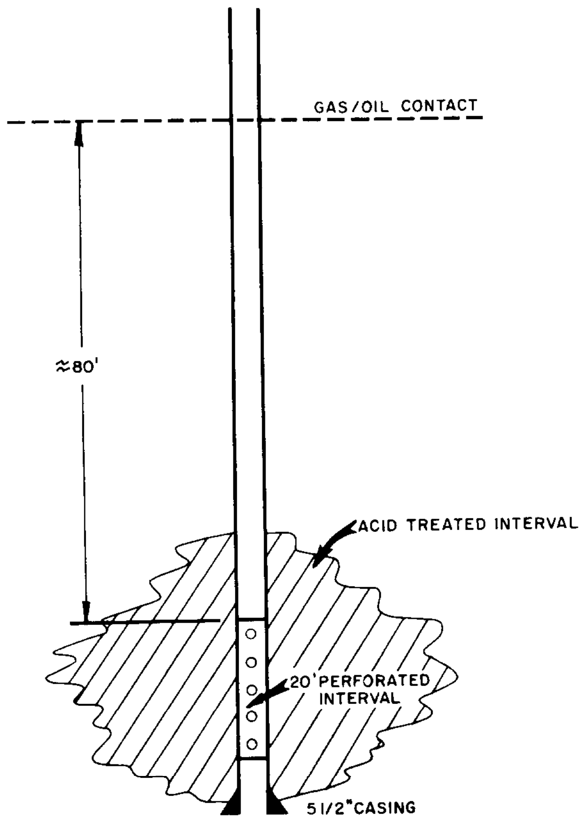
KNUCKLE JOINT
STABILIZER
4 3/4" BIT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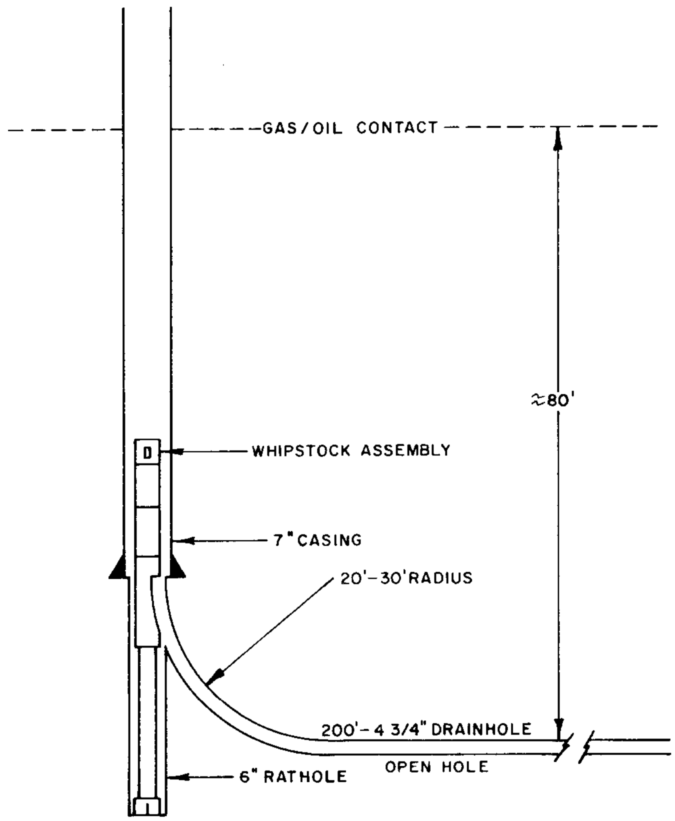
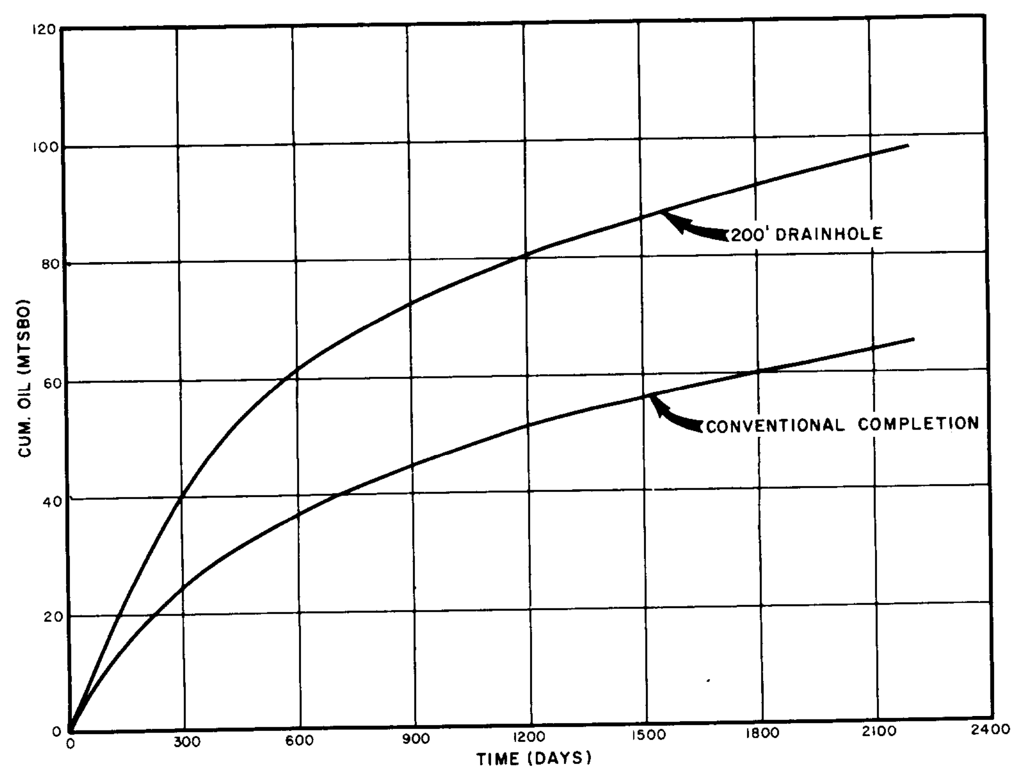
ACID TREATED INTERVAL
20' PERFORATED INTERVAL
5 1/2" CASING


GAS/OIL CONTACT
≈80'
WHIPSTOCK ASSEMBLY
7" CASING
20'-30' RADIUS
200'- 4 3/4" DRAINHOLE
OPEN HOLE
6" RATHOLE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20
0
CUM. OIL (MTSBO)
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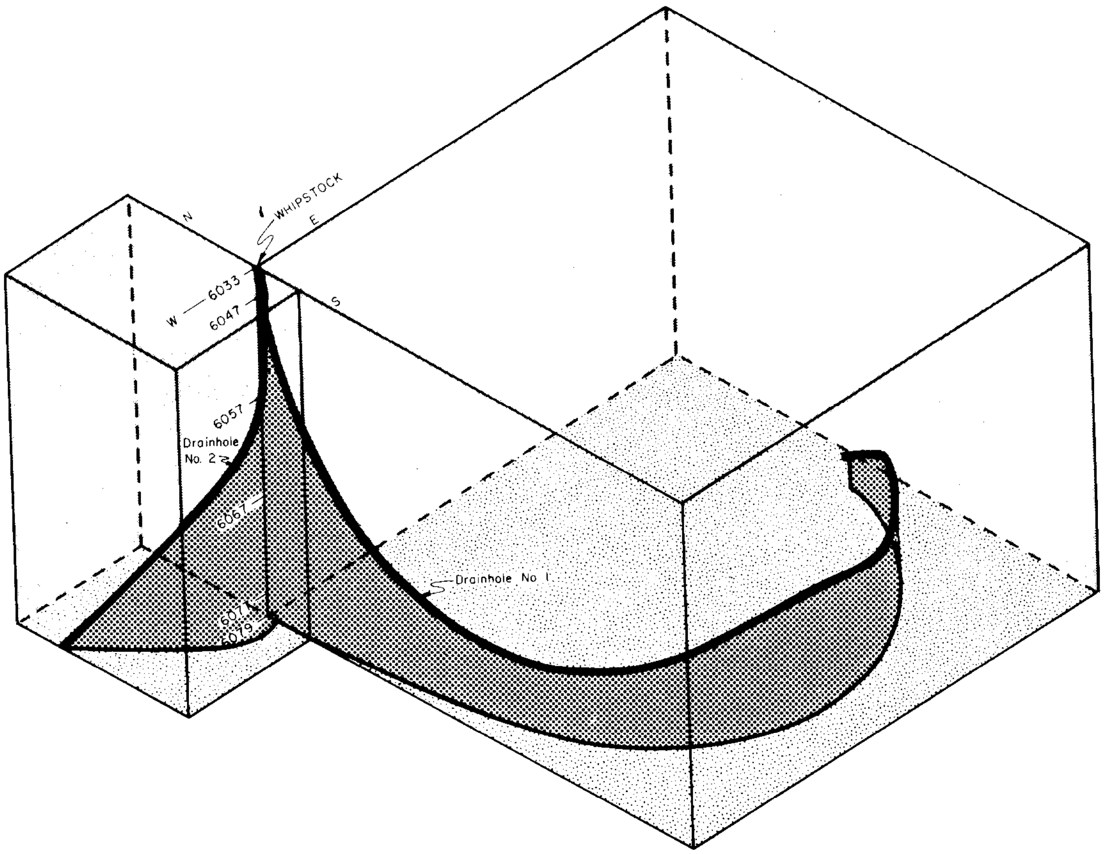
300
600
900
1200
1500
1800
2100
2400
TIME (DAYS)
200' DRAINHOLE
CONVENTIONAL COMPLETION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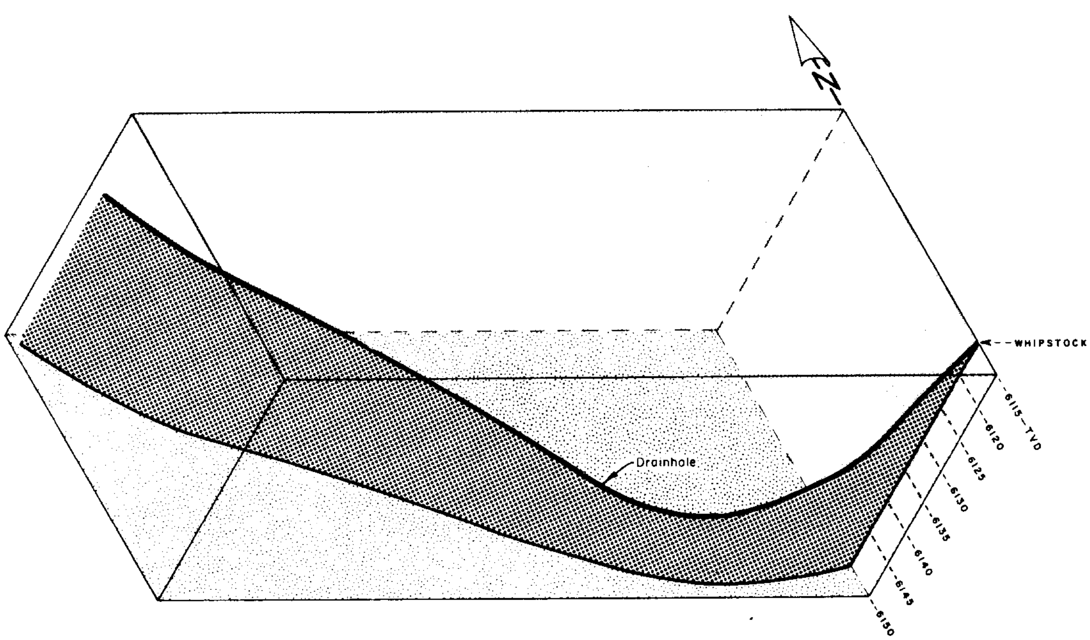
Drainhole No. 1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Drainhole