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Drilling and Early Testing of a Sidetrack From the Slant Hole Completion Test Well

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DISCLAIMER

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CONTRACT INFORMATION

Contract Number	DE-AC21-90MC26024
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Principal Investigators	F. Richard Myal Paul T. Branagan
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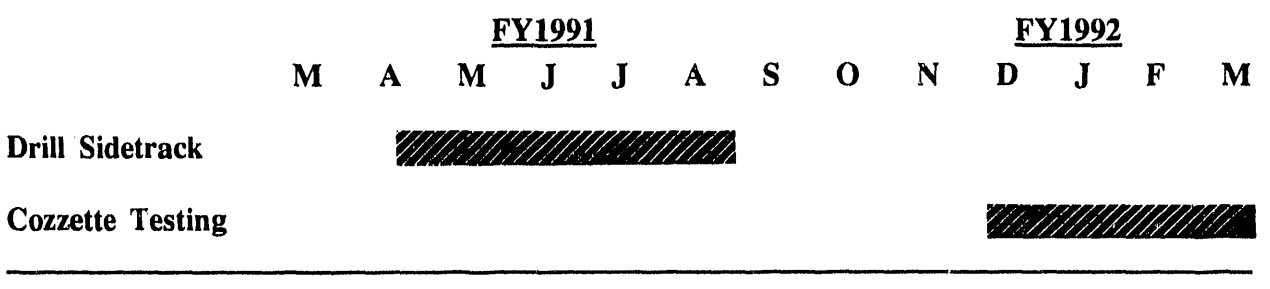
Period of Performance	April 26, 1991 through March 26, 1992

Schedule and Milestones

FY91/92 Program Schedule



OBJECTIVES

During the winter of 1990 to 1991, the Department of Energy evaluated several options to completing the originally-planned slant hole production tests. A decision was made to sidetrack the original hole and to redrill the 60 and 90° sections.

The objectives for drilling the sidetrack to the original slant hole wellbore are as follows:

1. Test high angle and horizontal drilling and completion technologies as an alternative to vertical wells and hydraulic fracture treatments in tight, naturally-fractured reservoirs.

2. Production test the Cozzette open-hole interval into the pipeline to determine long-term gas productivity.

3. Production test selected paludal sandstones in the 60° section of the wellbore to determine long term gas productivity.

A complex well path was designed to parallel the optimum northerly azimuth and the high angle-horizontal inclination program, but to directionally drill the lower wellbore 1,000 ft to the east of the old hole. The hole displacement was planned to avoid formation damage from over 1,500 barrels of drilling mud lost in the first well. Figure 1 presents the Mesaverde geologic column near the wellsite.

BACKGROUND INFORMATION

The directional program called for the well to be kicked off at 5,250 ft, and then drilled away from the old hole at a constant 12° inclination and a S60°E heading to a measured depth of 6,500 ft. MWD equipment was to be used throughout for steering, and mud motors were to be used for all build sections and correction runs. At that point, the hole was to be turned gradually to a N20°E azimuth while building the hole inclination to 60° at a measured depth of 7,100 ft. A constant 60° tangent was to be drilled through the lenticular sands/coal seams completion target and the underlying lost circulation zone in the Rollins sand to the top of the second build at 8,900 ft MD. When the Rollins was reached, a set of wireline correlation logs were to be run across the target reservoirs to correlate the sidetrack with the original slant hole. The second build was to take the well to 87° on a north heading and to the planned casing point in the top of the Cozzette target, which was expected at around 9,250 ft. Seven-inch casing was to be run and cemented in two stages, to seal off the Rollins lost circulation interval and to isolate the sands and coal seam reservoirs in the upper completion interval for the planned stimulation test.

At that point, the rig was to be converted to operate with 3-1/2-in. drillpipe and smaller MWD and motors; this was done to drill through the Cozzette sand pay at a near-horizontal inclination of 87° and a north heading. It was planned to drill underbalanced 500 ft of 6-in. hole, while slowly dropping through the Cozzette pay zone. The projected TD was to be 9,750 ft MD, and the Cozzette was to be completed as open hole. On reaching TD, a production packer with a sealbore and an 'R' nipple assembly were to be set in the 7-in. casing just above the shoe joint. Prior to releasing the drilling rig, the 3-1/2-in. drillpipe was to be stung into the packer to backflow drilling mud from the open hole. A retrievable 'R' plug was then to be set in the 'R' nipple to shut off the Cozzette open hole in preparation for the production testing program which was to start later that year.

PROJECT DESCRIPTION

Introduction

Sidetrack drilling was initiated at 4,162 ft in the original hole. An 8-3/4-in. hole was drilled at 11 to 16° inclination, on a complex azimuth starting at S 71°E at the first KOP at 6,550 ft, and ending at N 13°E at the end of the first build at 7,309 ft. Drilling proceeded satisfactorily with 6-3/4-in. motors, until a bit and stabilizer were lost at 6,708 ft. Fishing operations created a 15°/100 ft dogleg, and subsequent efforts to ream out the hole resulted in sidetracking the sidetrack. The hole was plugged back to 6,450 ft and was then successfully redrilled with motors to the top of a long tangent section at a 57° inclination on an azimuth of N 14.6°E. A 1,230 ft tangent section was rotary drilled at 60° through the paludal Mesaverde, the Rollins sand, and the Mancos Tongue shale at 8,588 ft. The

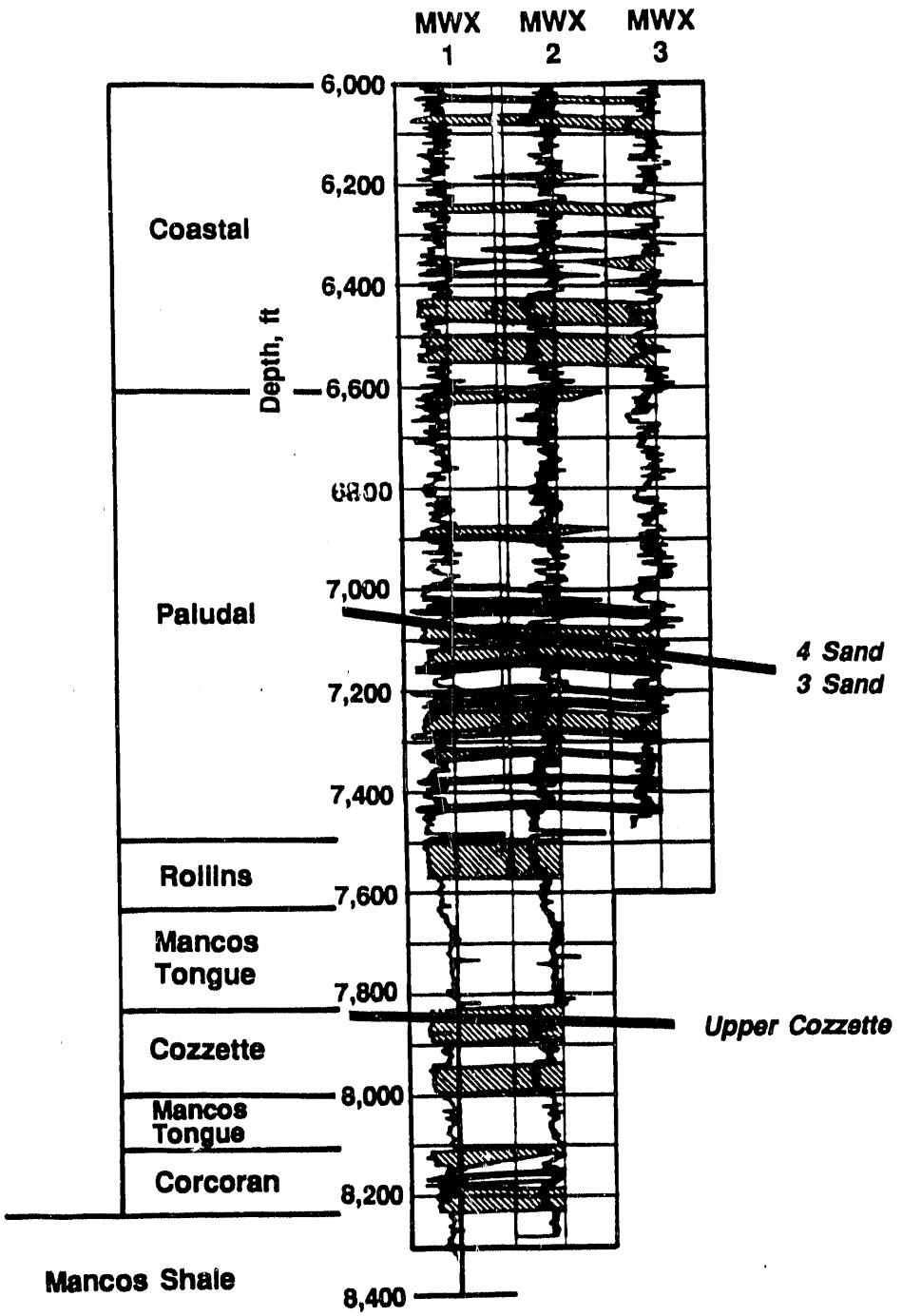


Figure 1. Mesaverde Geologic Column Near the Slant Hole Test Site

tangent was logged using drillpipe conveyed tools; the well was cased to 8,588 ft and cemented to isolate the tight target sands and preserve caving coals. A 3-1/2-in. drillpipe was picked up to drill a 6-in. hole to final depth. The second build to near-horizontal was drilled using 4-1/2-in. motors to 9,051 ft, at an angle of 86.5° and an azimuth of N 10°E. The Cozzette lateral was then rotaried to 9,308 ft, using an underbalanced mud weight of 14 ppg to prevent formation damage to natural fractures. A brief but quickly controlled blowout, resulting from inadvertently swabbing the well in during a trip, then forced the use of 16+ ppg mud over the rest of the hole. Significant mud losses during the last footage in the Cozzette lateral resulted in drilling being terminated at a total depth of 9,407 ft.

Figure 2 presents the sidetrack wellbore profile and plan views. A permanent packer with a landing nipple was set at 8,453 ft, just above the 7-in. casing shoe. The well was flowed through the drillpipe to remove as much mud as possible from the Cozzette fractures. It then was briefly tested at very high gas volumes from the Cozzette open hole before being shut in to await the formal testing program.

After re-entering the well in late 1991, early production testing of the Cozzette showed that the 300 ft of in-pay horizontal hole can produce at rate 5 to 10 times higher than vertical wells in the same area. Well testing and results will be presented in the paper.

Sidetrack Operations

The sidetracking plan called for pulling of about 5,300 ft of the 7-in. casing from the old well, so that the lower hole could be redrilled with 8-3/4-in. bits. Pipe recovery operations were initiated on April 26, 1991, and operations halted 10 days later at 4,100 ft when no more joints came free. Following washover of 140 ft of tightly held 7-in. casing, the hole was plugged back from 4,237 to 4,019 ft with a Class G cement kickoff plug.

The kickoff plug was dressed off to 4,160 ft. A bottomhole assembly, consisting of an 8-3/4-in. natural diamond sidetrack bit, a steerable mud motor with a 2° bent sub, and eleven 6-1/4-in. drill collars were used to kick off the sidetrack. At 4,254 ft, the kickoff BHA was pulled after drilling a distance of 92 ft. The hole inclination had been built to 6°, while the hole azimuth was S88°E. The sidetrack bit was replaced with an 8-3/4-in. insert bit, and a 1.5° bent sub was run with the steerable motor. Drilling continued to 4,504 ft, and the motor and the sidetrack drilling assembly were laid down. At 4,504 ft MD, 4,499 ft TVD, the hole inclination was 12° and the azimuth was S78°E.

The new hole was rotary drilled using conventional surface rotation, single shot surveys for position control, and an 8-3/4-in. insert bit on a packed hole assembly. The well was drilled away from the old hole on a straight tangent, at an inclination of 12 to 15 degrees and a southeasterly azimuth to the first kickoff point at 6,550 ft MD.

Drilling the First Build

The kickoff point was reached at 6,550 ft at a hole inclination of 15.8°, on an azimuth of S67.7°E. Drilling the first build proceeded satisfactorily, completing the compound turn at 7,309 ft and a hole inclination of 56° on an azimuth of N13.3°E. A 10.4 ppg mud weight was carried throughout the first build to 7,309 ft.

At this depth, a packed hole rotary assembly was run to begin drilling the tangent section. The assembly became stuck at 6,708 ft in a portion of the build having a 15°/100 ft dogleg. On jarring loose, the bit and a near-bit stabilizer were left in the hole, but were subsequently recovered. Efforts to ream out a second 15°/100 ft dogleg

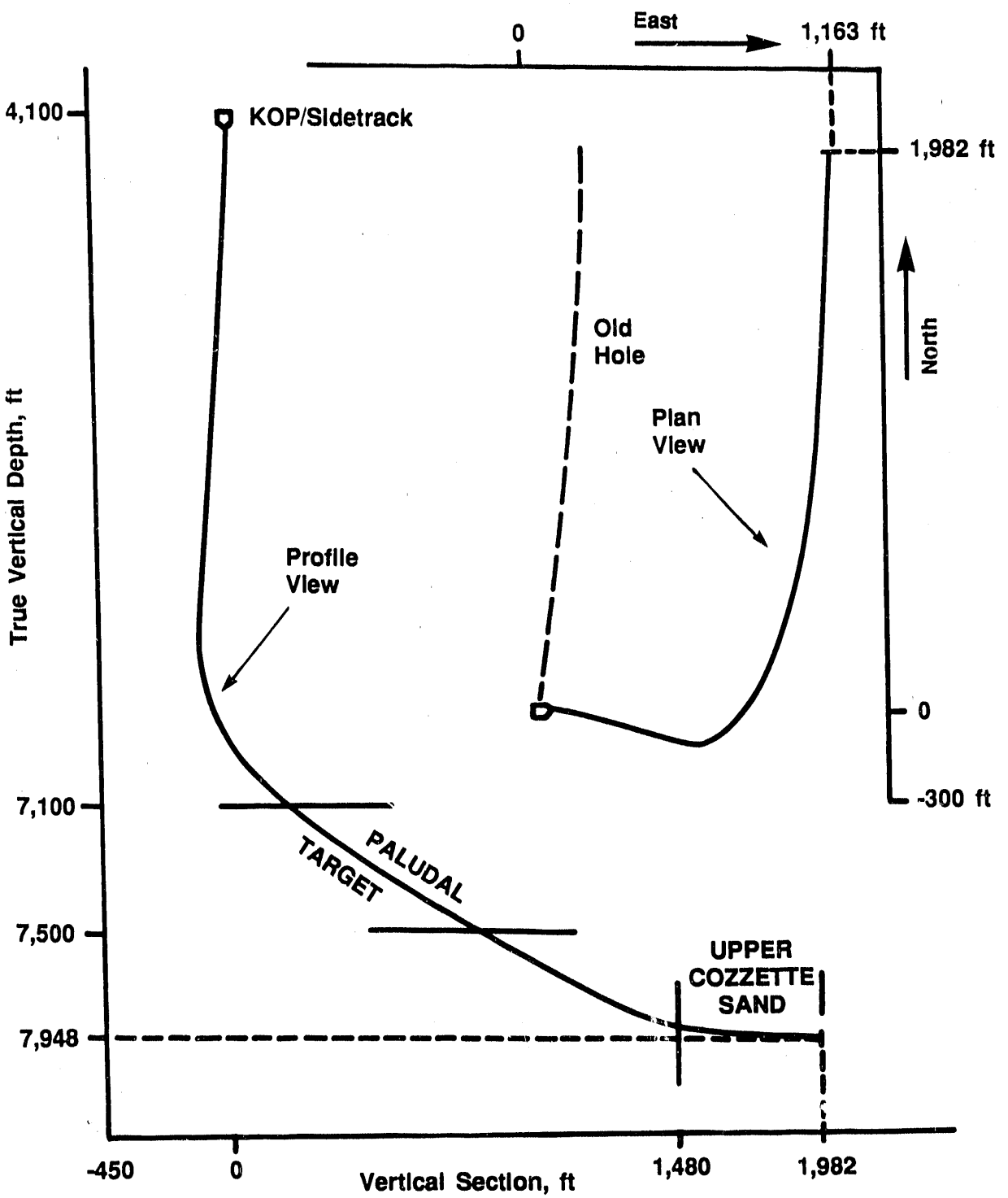


Figure 2. Sidetrack Wellbore Profile and Plan Views

between 6,803 ft and 6,833 ft in a coaly section ultimately resulted in the hole being sidetracked at 6,833 ft. It was then decided to plug back to 6,450 ft and attempt a second kickoff. The first cement plug failed to set and was circulated from the hole. The second plug was satisfactory and a second kickoff was undertaken at 6,475 ft.

Redrilling the first build proceeded slowly to 7,358 ft. The mud weight ultimately was raised to 12.5 ppg to stabilize sloughing shales and coal stringers. Extreme care was taken to hold dogleg severity below 8°/100 ft while drilling the fractured interval where the 15°/100 ft doglegs occurred in the original hole. At the end of the build at 7,358 ft, the wellbore inclination was 57.1°, and the hole azimuth was N14.6°E. The average penetration rate while drilling the 823 ft of the first build was 6.11 ft/hr.

Drilling the Tangent

The first 208 ft of the tangent to 7,566 ft were drilled with both motor and surface rotation. An 8-3/4-in. insert bit was utilized with the steerable and rotatable motor to hold the hole inclination at 57.3° while turning the azimuth to N9.7°E. The remainder of the 1,230 ft tangent section to 8,588 ft was rotary drilled using an insert bit with heel buttons and stabilizer lugs. At 8,588 ft MD, the hole inclination was 60.4° and the hole azimuth was N9.7°E.

While drilling the tangent section, it was necessary to steadily increase the mud weight to 14.3 ppg at 8,588 ft in the Mancos Shale to maintain wellbore stability. The lost circulation zone in the Rollins sand, where over 1,000 bbl of mud had been lost in the original slant hole, was drilled without incident. The mudlogger's background gas peaked at about 1,000 units while drilling through two paludal sand lenses. The coal (pressure-cored in the original slant hole[1]) above the upper sand peaked at 950 units, while the coal (conventionally cored in the slant hole[1]) below the lower sand peaked at about 900 units. Figure 3 presents a plot of mud weight versus true vertical depth for the sidetrack and for the original slant hole.

Due to increased hole instability, particularly caving in the paludal coals, it was decided to run drillpipe-conveyed logs across the paludal Mesaverde completion target, and then to run and cement the 7-in. casing at 8,588 ft to stabilize the wellbore.

Drilling the Second Build

The second kickoff point was determined as the well was being drilled, using detailed structural mapping of the Cozzette sand target in conjunction with well-to-well correlation of geologic markers. A gamma ray log was run through drillpipe to fine tune the geologic correlation points and to accurately select the second kickoff point.

A 6-in. diameter hole was drilled out from under the 7-in. casing shoe at 8,588 ft to the second kickoff point at 8,660 ft, using surface rotation and an angle building BHA with an insert bit.

The first part of the second build interval, from 8,660 to 8,812 ft, was drilled with 5°/100 ft steerable motors and two insert bits. The average penetration rate was poor at 3.61 ft/hr. Three different fixed angle-build assemblies were run over this 152 ft interval attempting to build angle. These BHAs seriously underperformed, and only built 7° of hole angle over the distance. The remainder of the second build, from 8,812 to 9,020 ft, was drilled with an 11.6°/100 ft fixed angle-build motor and three insert bits. The average penetration rate was 4.17 ft/hr, and the build rate improved. The overall build rate through the second build interval averaged 6.9°/100 ft. At this point, the wellbore inclination was 85.9°, and the Cozzette was reached.

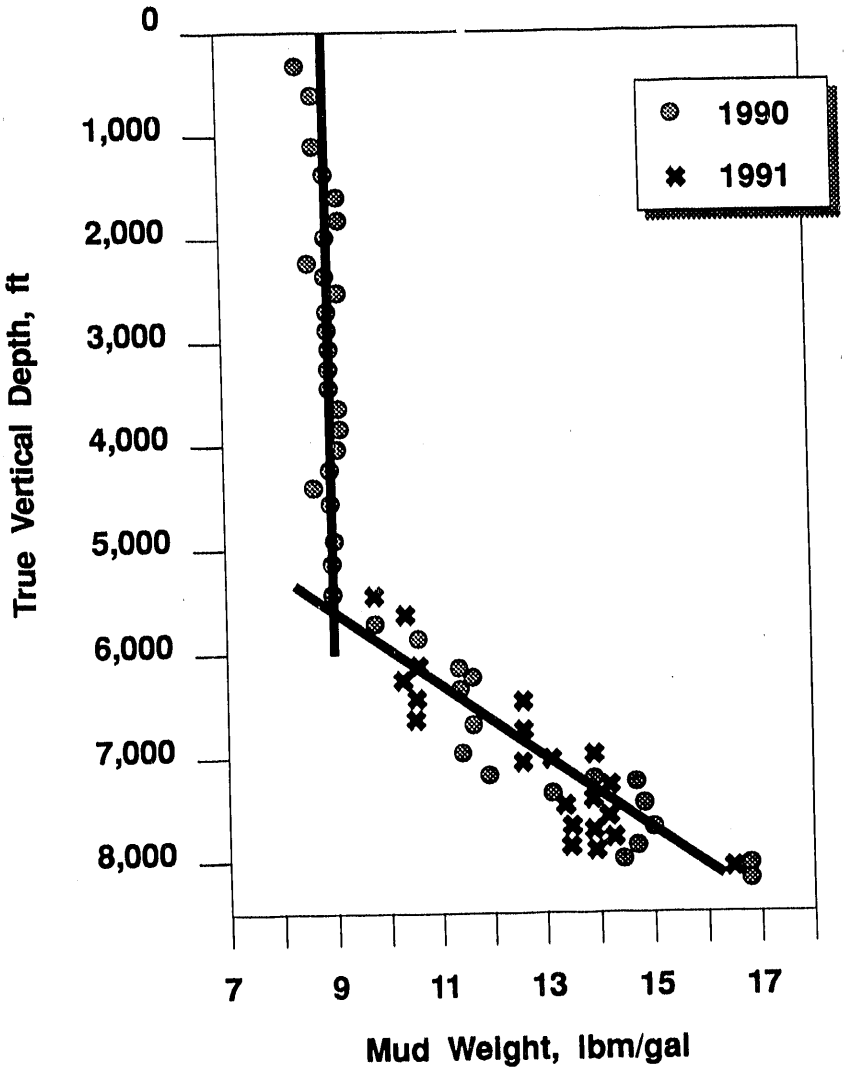


Figure 3. Mud Weight Vs. True Vertical Depth

Cozzette Horizontal Section

The First 300 Ft. The top of the upper Cozzette target interval was encountered at a depth of approximately 9,006 ft MD, 7,928 ft TVD, where the hole azimuth was N10.9°E. Detailed structural mapping indicated that the Cozzette dips to the north at about 1.7°.

The Cozzette lateral from 9,006 to 9,289 ft was drilled using a natural diamond bit on a rotary angle hold assembly. Surveys from 9,050 to 9,112 ft indicated that the hole inclination was locked on 87.7°; unexpectedly, the bit tended to remain parallel to bedding, and the borehole was not cutting across the sand's thickness as planned. This problem did not occur in the original slant hole; in fact there the hole dropped out of the sand a little ahead of schedule. An attempt was made with a steerable motor to increase the drop angle, but with marginal results. The diamond bit run averaged a penetration rate

of 4.04 ft/hr. The lateral to 9,308 ft was rotary drilled ahead with an insert bit at an average penetration rate of 2.5 ft/hr.

The mud weight was held at 14 ppg to drill the naturally fractured Cozzette pay. By design, this weight underbalanced reservoir pressure to minimize the loss of drilling fluid to the fracture system, as experienced in the original slant hole, as well as to minimize suppression of gas shows. The mud log indicated at least ten major gas shows with chromatograph readings ranging from 190 units to 800 units between 9,138 ft and 9,308 ft. The produced gas was successfully handled through the rig's gas buster. Figure 4 illustrates the location of natural fractures as indicated by gas increases on the mud log.

Fire at 9,308 Ft. While tripping out of the hole for a bit change and with the bit at 5,200 ft, a very heavy gas kick threatened to blow out the well. The BOP was closed with 2,100 psi on the kelly, and an attempt was made to check the annular pressure. At that point, the 4-in. return line from the BOP stack ruptured just upstream of the choke manifold house. The released gas pressure pulled loose some electrical wiring and ignited. The resulting flash fire was quickly extinguished by closing the lower pipe rams on the BOP stack. Two rig site employees were injured. Only minor damage was done to the choke manifold house, but the 4-in. line to the choke manifold house had to be replaced.

As a result of the gas kick, the retrievable MWD tool was blown up the inside of the drillpipe approximately 1,000 ft, before it wedged in a tool joint and plugged the drillstring. Since it was not possible to circulate during subsequent well control efforts, a hole volume (250 bbl) of 16 ppg mud was bull headed down the drillpipe-casing annulus to kill the well. After a short quiet period, the well resumed flowing gas. Finally, 250 bbls of 18.7 ppg mud were pumped down the annulus to control the well. The pipe trip out was completed, and the MWD tool was located and recovered. A cleanout trip was made to 9,234 ft to circulate out the 18.7 ppg kill mud and replace it with 16.3 ppg mud prior to drilling the remainder of the Cozzette lateral.

Drilling on to 9,407 Ft TMD. A natural diamond bit was selected to drill the remainder of the hole to TMD, projected at 9,500 ft, using

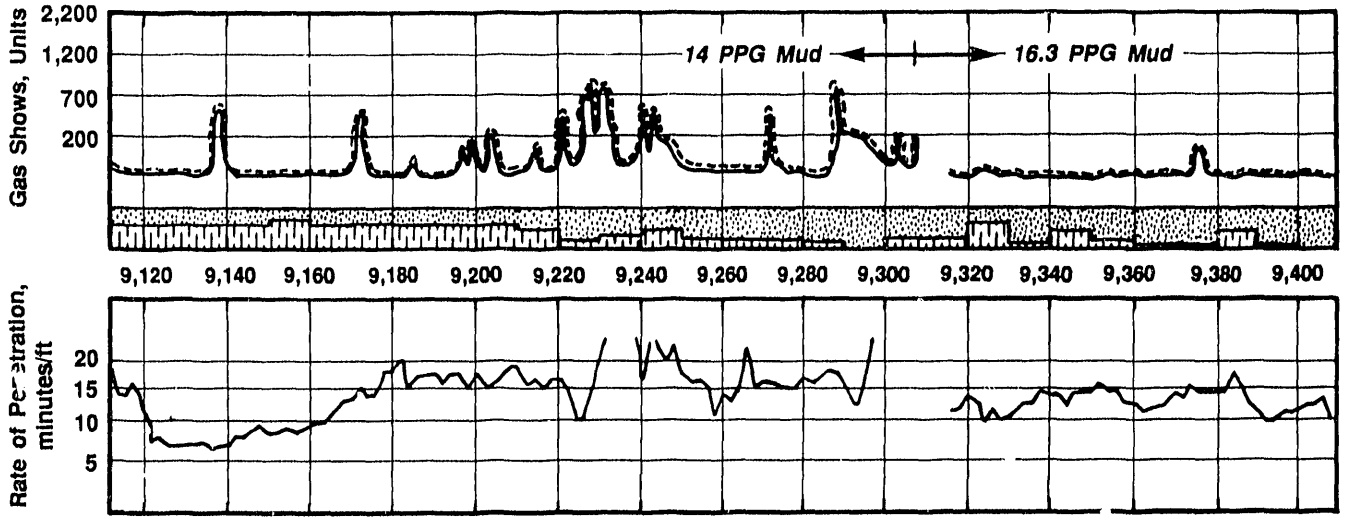


Figure 4. Mud Log Gas Shows in Cozzette Horizontal Hole

an angle drop BHA and surface rotation. Seventy-five barrels of mud were lost while drilling from 9,308 to 9,358 ft. The presence of natural fractures was indicated by calcite and quartz crystals in cuttings samples. The mud weight was sufficiently overbalanced to suppress most of the gas shows. An additional 60 barrels of mud were lost as more fractured intervals were intersected between 9,376 ft and 9,407 ft TMD. Three hundred feet of horizontal, highly-fractured Cozzette pay had been cut. At that point, it was decided to stop drilling operations at 9,407 ft TMD, 7,948 ft TVD, to minimize further mud loss to the fracture system. Approximately 400 bbls of drilling mud were lost into the Cozzette natural fracture system as a result of drilling and the post-fire well control operations. Figure 5 presents a diagram of the slant hole sidetrack wellbore at the end of drilling.

Flow Back Testing at 9,407 Ft. A permanent production packer with one 6-ft joint of 2-7/8-in. tubing and an 'R' nipple was run on drillpipe and set at 8,453 ft. The mud in the drillpipe

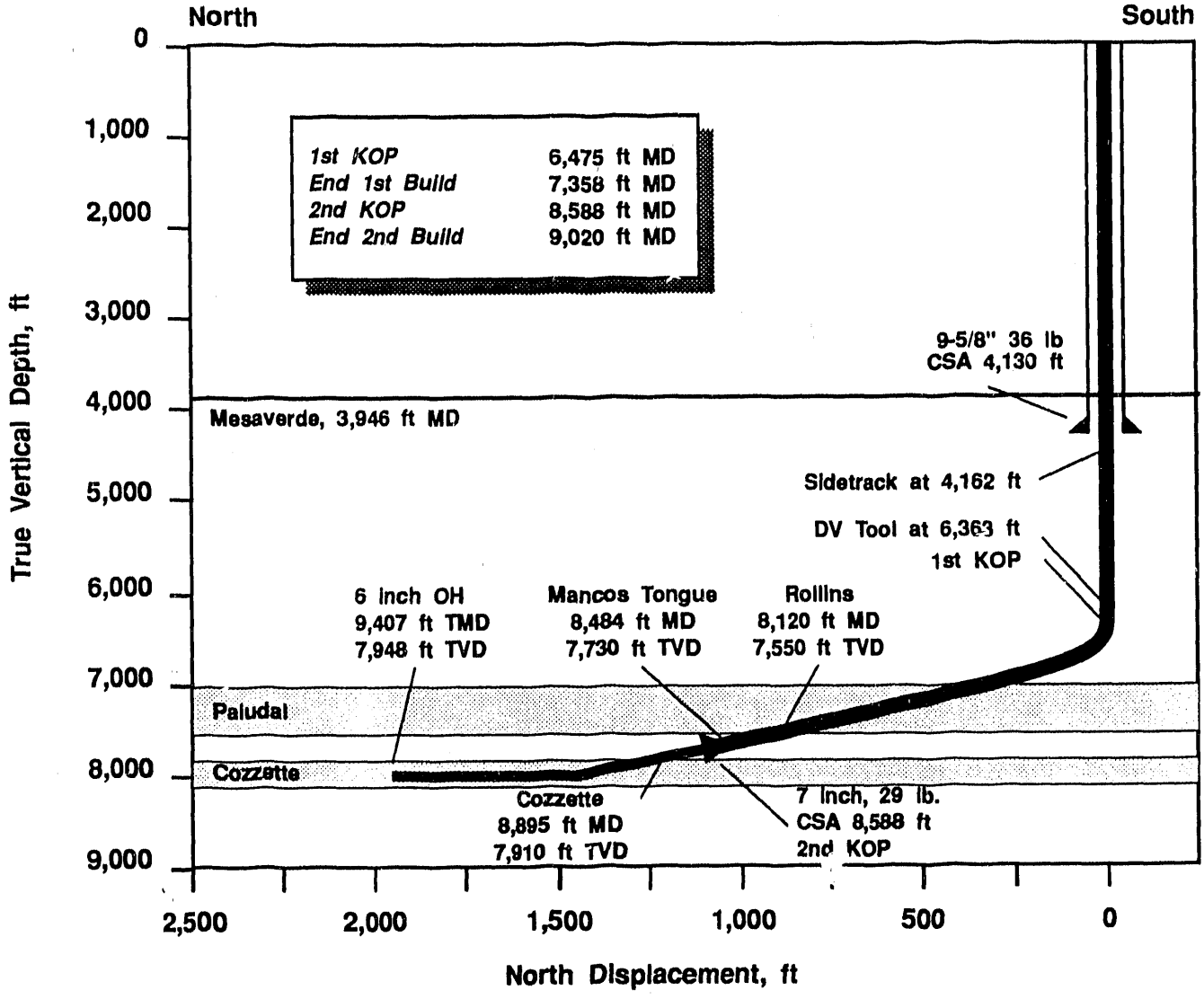


Figure 5. Slant Hole Sidetrack Wellbore Diagram

was displaced with 2 percent KCl water, and the seal assembly was stung into the packer. The Cozzette was allowed to flow back to the burn pit through a choke manifold. Gas began arriving at the flare after 40 minutes. Gas, water, and mud continued to flow until approximately 200 bbls of water and drilling mud were recovered. After recovery of liquids stopped, up to 15.8 MMCFD of gas production were tested over a 3-hour period.

Following the brief flow test, a plug was set in the packer's 'R' nipple to isolate the Cozzette open hole, a retrievable bridge plug was set at 8,372 ft as a safety precaution, and the hole was displaced with 2 percent KCl water. The drilling rig was released on August 24, 1991.

Early Cozzette Testing

Reentry Problems. Operations to prepare the well for testing and production were initiated on December 10, 1991. A cement bond log run with 1,500 psi on the casing indicated 60 to 80 percent cement bond between 7,200 ft and 8,210 ft. It should be remembered that the casing was subjected to very high internal pressures during well control operations after the flash fire, which may have degraded the cement to casing bond. The retrievable bridge plug was successfully recovered, and the hole was cleaned out to the production packer at 8,453 ft. A 2-in. flush joint stinger assembly was picked up and run on 2-7/8-in. tubing to circulate mud from the pup joint and 'R' plug below the packer. Following recovery of several barrels of drilling mud, the tubing was pulled from the well minus the stinger. Following three days fishing, the stinger was recovered.

The seal assembly was run in the well on 2-7/8-in. tubing and stung into the packer, the wellhead was installed, and the well was prepared for flowback to the flare pit. Following an unsuccessful attempt to wireline retrieve the 'R' plug, a coiled tubing unit was used to circulate 160°F water to clean out the remaining mud above the 'R' plug. The plug's equalizing pin was retrieved, using wireline conveyed tools, without incident. This allowed gas to flow through two 3/16-in. ports in the 'R' plug. Further attempts to recover the 'R' plug with wireline tools were unsuccessful.

It was decided to run a modified isochronal flow test to determine the extent of flow restriction caused by the 'R' plug. The results of this testing were inconclusive. A decision was made to cut off the 'R' plug to eliminate any conjecture about downhole restriction and the validity of future well test information.

The attempt to cut off the 'R' nipple using a jet cutter resulted in leaving the jet cutter body and 33 ft of sinker bars in the hole, when the wireline pulled out of the rope socket following cutting off the 'R' plug. On the way out of the hole, the wireline became hung up in the grease injector, jammed and parted. This left 3,000 ft of braided line hanging from the top of the lubricator, through the master valves, and into the well. The wireline BOPs would not hold pressure sufficiently to allow removing the lubricator to replace the grease head so that the line could be pulled from the well. A wellhead freeze (using a bentonite plug and dry ice) was used to isolate the wellbore at the upper master valve. The lubricator and wireline BOP were then removed and repaired, the wireline was restrung, and the lubricator was reinstalled. The wellhead was thawed, and the wireline was recovered without incident.

Initial Flow Testing. The slant hole completion test was turned into the pipeline on January 16, 1992, at a rate of 3,048 MSCFD, 0 BWPD at 4,700 psi FTP. The well is currently being tested into the pipeline at various rates to determine the effect of pressure draw down on gas and liquid production rates. The current projection of absolute open flow potential for the

Cozzette horizontal hole is in excess of 11 MMCFD.

RESULTS

Several findings concerning the production potential of the tight sands and coals were made while drilling and testing in the slant hole sidetrack wellbore.

- Building hole angle smoothly in fractured, interbedded shale and coal intervals is difficult. Care must be taken to avoid dog legs that can lead to other problems.

- Holding mud weight below the point where the Rollins lost circulation interval breaks down results in caving of the coals and general hole instability.

- Underbalanced drilling of the naturally fractured Cozzette sand can be a safe practice that prevents mud damage to the fractures and permits recording of gas shows by the mudlogger.

- While drilling underbalanced, multiple mudlog gas shows indicated the location of open natural fractures as they were intersected by the horizontal Cozzette wellbore.

- Even after sustaining heavy mud loss to the natural fracture system, three hundred feet of horizontal hole in the Cozzette pay has a production potential of at least 5 to 10 times that of vertical wells in the area of the slant hole test.

- Intersection of the natural fracture system, even in microdarcy rocks, can produce excellent production rates from Mesaverde tight gas reservoirs.

FUTURE WORK

Testing of the selected paludal Mesaverde sandstone intervals in the 60° portion of the wellbore between 7,500 and 7,800 ft MD will be undertaken during 1992.

REFERENCES

1. Myal, F. R. and Frohne, K-H.: "Slant-Hole Completion Test in the Piceance Basin, Colorado," SPE 21866, presented at the 1991 Rocky Mountain Regional Meeting and Low-Permeability Reservoirs Symposium, Denver, Colorado, April 15-17, 1991.

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