A Slant Hole Drilling Test at the DOE Multiwell Experiment Site in Colorado's Piceance Basin

- Well Prognosis -

Technical Note

By

K-H. Frohne

U. S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
PO. Box 880
Morgantown, West Virginia 26507-0880

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-A Drilling Prognosis Proposal-

1.0 INTRODUCTION AND GENERAL BACKGROUND

A part of the United States Department of Energy (DOE) mission consists of performing research on unconventional energy resources, including improving the recovery of natural gas that is not yet commercially producible. The western US contains huge amounts of gas in place[1] in sandstone reservoirs with very low permeability and complex geology (Figure 1). It includes an estimated 420 trillion cubic feet (Tcf) of gas[2] in the thick Mesaverde Group of the Piceance Basin in western Colorado. This large energy resource has not been developed on a large scale, due to its high technical risk resulting in poor development economics. To date, hydraulic fracturing of conventional vertical wells represents the state of the art production strategy for tight sands, but fracturing alone has not reliably resulted in commercial production rates. Permeability of tight gas sands is usually made up of two flow components: gas moving through the ultra-low permeability rock pore spaces, and then into more permeable natural natural fractures which act as gathering systems to move the gas to the hydraulically stimulated wellbore. Natural fractures were created by regional geologic stresses, and as such are usually oriented systematically. Hydraulic fracture direction is controlled by that same formation stress, and so runs parallel to most natural fractures instead of intersecting them. A possible alternative to standard vertical wells is directional drilling, where the wellbore can be directed to intersect the primary natual fracture system for maximum gas extraction efficiency.

This report presents a drilling prognosis for a proposed directional test well at the Department of Energy's Multiwell Experiment[3,4,5] (MWX) site in Colorado (Figure 2). Such a test is currently being considered by the Department's Morgantown Energy Technology Center (METC) for a possible initiation in 1988 or 1989. The go-ahead decision will be determined by FY88/89 congressional action. This document provides the basis both for a planned METC engineering study of the slant hole technique applied to tight western reservoirs, and for the statement of work of the potential drilling contract to be let by DOE.

2.0 OBJECTIVE

The objective of the slanted hole test is to evaluate under field conditions the directional drilling concept as a possible alternative development strategy for tight western gas reservoirs. Utilizing the extensive geologic model[6,7] and reservoir engineering database developed at the DOE multiwell experiment site, the field experiment will investigate technical and economic efficiencies of the concept as applied to the complex mixed layer gas reservoirs of the Mesaverde Formation.

3.0 PROJECT PLAN

3.1 Background

The fully characterized Mesaverde Formation[8] (Figure 3) at the MWX test facility in the Piceance Basin will provide the reservoir targets for the slant hole test. The proposed completion horizons for the drilling scenario are situated within the lenticular and blanket tight sands underlying the MWX field site. The dominant natural fracture system under the site is oriented on an azimuth of about N70W, and the slanted hole would be drilled on an orthagonal azimuth of N20E to take maximum advantage of the system (Figure 4). The field test proposal discussed in this report consists of a new well offsetting the site and located about 700 ft.to the south of the existing test pad. The surface drilling location would would be situated on the same parcel of land as the present MWX wells, and the directional wellbore would be contained within the existing Section 34 production unit.

At the MWX site the Mesaverde top is at about 3,900 ft. and intermediate casing strings are set at around 4,100 ft., about 200 ft. into the formation. The precise setting depth for the proposed well would be determined by the specific surface elevation of the aquired site. For the purpose of this prognosis outline the casing is to be set at 4,100 ft. and the surface location is about 700 feet south of the MWX site. True vertical depths in the prognosis are based on the surface elevation datum of the multiwell site (ground elevation of 5,355 ft.), and would be adjusted when the specific location is aquired and the slant hole is drilled. Table 1. lists a personal computer-generated computation of the directional drilling path. The table shows vertical hole angle, true vertical depth, azimuthal bearing, and lateral departure against measured (as drilled) hole length.

The scenario is targeted at a portion of the Paludal Zone made up of lenticular sands and also containing gas bearing coal seams, and at the Upper Cozzette blanket sand (Figure 5). Two specific completion intervals are planned.

1) The upper target involves a 60 degree penetration, and including 350 ft. of core, of the gas-rich lower Paludal interval between 7,000 and 7,500 ft. vertical depth. The slanted wellbore will intersect Paludal Zones 3 and 4 beneath the MWX test pad, to permit well-to-well interference testing between the new directional hole and the offsetting MWX-1, -2, and -3 wells. These two lenses have been previously stimulated and extensively tested[9,10] at the MWX site. Potential gas reservoirs are composed of intermingled tight lenticular sands and coal seams.

2) The lower target completion is made up of a 500 ft. long horizontal hole in the Upper Cozzette Sandstone, a blanket tight reservoir locally about 65 ft. thick with the formation top at approximately 7,030 ft. About 100 ft. of horizontal core will be taken to evaluate the spacing, orientation, and distribution of natural fractures. A important aspect of the Cozzette completion will be to evaluate the production performance of a horizontal well as an alternative completion technique for naturally fractured tight sands. The Cozzette has also been production-tested[11] in MWX-1 and -2. The sand has not been stimulated at the site, but regional post-stimulation performance data are available and can be extrapolated to the MWX location.

Table 1.

MWX OFFSET SLANT HOLE DRILLING PROGRAM

MEAS'D DEPTH	VA	BEARING	NORTH	EAST	TVD	LATERAL DEPARTURE
0	0	0	0	0	0	0
100	0	0	0	0	100	0
200	0	0	0	0	200	0
300	0	0	0	0	300	0
400	0	0	0	0	400	0
500	0	0	0	0	500	0
600	0	0	0	0	600	0
700	0	0	0	0	700	0
800	0	0	0	0	800	0
900	0	0	0	0	900	0
1000	0	0	0	0	1000	0
1100	0	0	0	0	1100	0
1200	0	0	0	0	1200	0
1300	0	0	0	0	1300	0
1400	0	0	0	0	1400	0
1500	0	0	0	0	1500	0
1600	0	0	0	0	1600	0
1700	0	0	0	0	1700	0
1800	0	0	0	0	1800	0
1900	0	0	0	0	1900	0
2000	0	0	0	0	2000	0
2100	0	0	0	0	2100	0
2200	0	0	0	0	2200	0
2300	0	0	0	0	2300	0
2400	0	0	0	0	2400	0
2500	0	0	0	0	2500	0
2600	0	0	0	0	2600	0
2700	0	0	0	0	2700	0
2800	0	0	0	0	2800	0
2900	0	0	0	0	2900	0
3000	0	0	0	0	3000	0
3100	0	0	0	0	3100	0
3200	0	0	0	0	3200	0
3300	0	0	0	0	3300	0
3400	0	0	0	0	3400	0
3500	0	0	0	0	3500	0
3600	0	0	0	0	3600	0
3700	0	0	0	0	3700	0
3800	0	0	0	0	3800	0
3900	0	0	0	0	3900	0
4000	0	0	0	0	4000	0
4100	0	0	0	0	4100	0
4200	0	0	0	0	4200	0
4300	0	0	0	0	4300	0

Table 1. Cont'd.

MWX OFFSET SLANT HOLE DRILLING PROGRAM

MEAS'D DEPTH	VA	BEARING	NORTH	EAST	TVD	LATERAL DEPARTURE
------	------	------	------	------	------	------
4400	0	0	0	0	4400	0
4500	0	0	0	0	4500	0
4600	0	0	0	0	4600	0
4700	0	0	0	0	4700	0
4800	0	0	0	0	4800	0
4900	0	0	0	0	4900	0
5000	0	0	0	0	5000	0
5100	0	0	0	0	5100	0
5200	0	0	0	0	5200	0
5300	0	0	0	0	5300	0
5400	0	0	0	0	5400	0
5500	0	0	0	0	5500	0
5600	0	0	0	0	5600	0
5700	0	0	0	0	5700	0
5800	0	0	0	0	5800	0
5900	0	0	0	0	5900	0
6000	0	0	0	0	6000	0
6100	0	0	0	0	6100.00	0
6250	3	0	3.926093	0	6249.93	3.926093
6300	6	0	7.848600	0	6299.77	7.848600
6400	12	0	23.48489	0	6398.50	23.48489
6500	18	0	49.35498	0	6495.04	49.35498
6600	24	0	85.17540	0	6588.36	85.17540
6700	30	0	130.5537	0	6677.42	130.5537
6800	36	0	184.9927	0	6761.25	184.9927
6900	42	0	247.8960	0	6838.93	247.8960
7000	48	0	318.5743	0	6909.61	318.5743
7100	54	0	396.2534	0	6972.51	396.2534
7200	60	0	480.0822	0	7026.95	480.0822
7300	60	0	566.6847	0	7076.95	566.6847
7400	60	0	653.2873	0	7126.95	653.2873
7500	60	0	739.8898	0	7176.95	739.8898
7600	60	0	826.4923	0	7226.95	826.4923
7700	60	0	913.0949	0	7276.95	913.0949
7800	60	0	999.6974	0	7326.95	999.6974
7900	60	0	1086.300	0	7376.95	1086.300
8000	60	0	1172.902	0	7426.95	1172.902
8100	60	0	1259.505	0	7476.95	1259.505
8200	60	0	1346.107	0	7526.95	1346.107
8300	60	0	1432.710	0	7576.95	1432.710
8400	60	0	1519.312	0	7626.95	1519.312
8500	64	0	1607.589	0	7673.89	1607.589
8600	68	0	1698.925	0	7714.55	1698.925

Table 1. Cont'd.

MWX OFFSET SLANT HOLE DRILLING PROGRAM

MEAS'D DEPTH	VA	BEARING	NORTH	EAST	TVD	LATERAL DEPARTURE
8700	72	0	1792.875	0	7748.75	1792.875
8900	76	0	1985.089	0	7803.86	1985.089
9000	80	0	2082.883	0	7824.65	2082.883
9100	84	0	2181.890	0	7838.56	2181.890
9200	88	0	2281.626	0	7845.54	2281.626
9300	90	0	2381.606	0	7847.28	2381.606
9400	90	0	2481.606	0	7847.28	2481.606
9500	90	0	2581.606	0	7847.28	2581.606
9600	90	0	2681.606	0	7847.28	2681.606
9700	90	0	2781.606	0	7847.28	2781.606
9800	90	0	2881.606	0	7847.28	2881.606

The entire well operation, including surface site and the directional wellbore, will be contained within Section 34, R94W, T6S. Section 34 constitutes an established gas production unit, of which the existing MWX site is a part. The directional hole portion will be drilled with 8 3/4 in. bits and water-based mud, and will utilize a combination of conventional surface rotary drive and downhole drilling motors to power the bit.

Standard bent subs and (possibly) bent housing motors will be employed to drill curved hole sections, and mud telemetry measurement-while-drilling (MWD) technology will be used to monitor and control hole angle and azimuth. If dictated by potential hole control problems, so-called navigation drilling techniques could be brought to bear to regain hole directional control. It should be noted that navigation drilling is an alternative but more costly approach, which provides the capability to make downhole directional adjustments to hole inclination and azimuth from the rig floor without having to trip pipe. Final hole configuration will be determined as a function of operational requirements. The well would be cased to total depth (TD) with 7 in. casing to permit extensive post-completion well testing and possible stimulation experiments. After the directional drilling activities have been completed and the slant hole has been cased, the production potential of selected completion intervals will be thoroughly characterized by a reservoir testing program, possibly including stimulation. The evaluation program details will be the subject of another report.

3.2 Site Preparation

The option requires the construction of a new drilling location, a short lease road, power and telephone connections, and a multi-cable instrumentation line to connect the directional well and its diagnostics system to the instrumentation network on the MWX pad. The area about 700 ft. to the south of the MWX pad is essentially level and will require little excavation to develop the new pad. The site is also adjacent to the existing lease and county roads and requires only a few feet of access road. Instrumentation and communication lines can be readily strung on poles between the two pads.

The site preparation prognosis is outlined below:

- o Negotiate access and royalty agreements and aquire site and mineral leases for the drilling location with access road and the directional well
- o Establish rights of way for instrumentation and electric power and telephone lines.
- o Construct lease road and drilling location, establish electric power and telephone connections, and set instrumentation poles along line right of way, setting up a road crossing as necessary
- o Move in rig and support infrastructure, dig mud and reserve pits, and set up an instrumentation and communication transfer system to the MWX pad

3.3 Drilling Plan

Once the site has been constructed and the rig and associated drilling equipment have been set up, drilling of the slanted hole can coomence. The drilling prognosis is listed below:

- o Drill rat and mouse holes, build mud system, spud the directional hole
- o Drill 17 1/2 in. surface hole to about 120 ft., set 13 3/8 in., 54.5 lb./ft., K55 casing, and cement to surface with Class G cement
- o Drill 12 1/4 in. intermediate hole through the Ohio Creek into the top of the Mesaverde Formation, run correlation log, and set 4,100 ft. of 9 5/8 in., 36 lb./ft., K55, LT&C casing, cement to surface
- o Drill out cement shoe, and drill straight vertical hole to 6,250 ft. with 8 3/4 in. bit
- o Set whipstock at 6,250 ft. and orient on N20E heading
- o Design downhole assemblies for straight drilling while maintaining a constant hole angle and for drilling 8 3/4 in. hole directionally at 4 and 6 degrees/100 ft. of angular rate of turn, using bent subs, mud motors, and mud telemetry to monitor hole angle and azimuth
- o Go in hole (GIH) with 6 degree angle building assembly and kick off on N20E heading
- o Build angle at a constant 6 degrees/100 ft. and on a N20E heading to 60 degrees inclination at 7,200 ft. measured depth (MD), 7,027 ft. true vertical depth (TVD)
- o Pull out of hole (POH) directional assembly
- o GIH with straight hole assembly and drill 150 ft. at 60 degrees on N20E heading
- o POH straight assembly
- o GIH/POH with 6 3/4 x 4 in. core barrel and cut 350 ft. of core at 60 degrees and a N20E heading
- o GIH with straight hole assembly and drill at 60 degrees and N20E heading to 8,400 ft. MD, 7,627 ft. TVD
- o Clean and condition hole, POH for logging
- o Using conventional gravity-conveyed tools, log the Mesaverde Formation to current total depth (TD)

- GIH with directional assembly and build angle at 4 degrees/100 ft. on N20E azimuth to 90 degrees at 9,200 ft. MD, 7,843 ft. TVD, ascertaining that hole is located in Upper Cozzette Sandstone

- POH directional assembly

- GIH with straight hole assembly, drill horizontally 100 ft. on N20E heading to 9,300 ft MD

- Clean and condition hole, POH for coring

- Using a 6 1/4 x 4 in. barrel, core 100 ft. horizontally on N20E heading

- GIH with straight hole assembly, drill horizontally to total depth at 9,700 ft. MD, 7,843 ft. TVD

- Clean and condition hole, POH for logging

- Using pipe-conveyed tools, run logs from 8,400 ft. MD to TD

- GIH with bit and clean and condition hole for casing

- Run 7 in. combination production casing (5,900 ft. of 29 lb./ft., buttress thread N80, and 3,800 ft. of 29 lb./ft., Extreme Line (integral couplings) N80) to TD and cement from bottom to 4,300 ft.

- Nipple up casing seat and tree, and release drilling rig

- Move out rig and drilling accessory equipment and prepare site for well testing and reservoir characterization

4.0 PROGNOSIS COST ESTIMATE

4.1 Introduction

The costs for the proposed directional well project can be partitioned into two broad categories: well drilling operations and reservoir testing. A detailed cost estimate has been prepared for the first category, drilling of the slanted hole. The estimate includes rig location preparation, drilling, logging, coring, and casing operations, up to the installation of the well head and demobilization of the drilling rig. The estimate was prepared on the basis of industry experienced costs in western Colorado, and are representative of service company qotations during the fall of 1987.

4.2 Estimate

The cost estimate is broken down into five main categories: site preparation, drilling operations, materials and equipment, services, and engineering and supervision. The overall cost for the drilling project, ie. the installation of the test well, is estimated at $ 3,278,300. Slant hole project costs are summarized in Table 2.

Table 2.

SUMMARY OF ESTIMATED SLANT HOLE COSTS

Description	Total $	Subtotal $	Grand Total $
1. Site Preparation	60,000		
2. Drilling Operations	821,800		
3. Materials and Equipment	737,900		
4. Services	835,600		
5. Total Third Party Costs	2,455,300		
6. Colorado state sales tax at 3 percent	73,700		
7. Well Costs Subtotal		2,529,000	
8. Contingency at 20 %		505,800	
9. Slant Hole Drilling Costs Subtotal		3,034,800	
10. Engineering and Supervision Costs	243,500		
11. Project Installation Grand Total			$ 3,278,300

4.2.1 Site Preparations

Table 3. shows a detailed cost estimate for the new drilling location for the slant hole rig. The main cost factors are soil grading and gravel surfacing. Since the new location is adjacent to the existing MWX site, costs are relatively low for this category.

Table 3.

DETAILED COST ESTIMATE FOR SITE PREPARATION

Site Preparation

Description	Subtotal $	Grand Total $
1. Prepare 150 x 150 ft. Location, 50 x 50 ft. Reserve Pit, 100 ft. Access Road	50,000	
2. 1,000 ft. Power and Communication Line	10,000	
Site Preparation Total:		60,000

4.2.2 Drilling Operations

Drilling operations costs consist entirely of rig time. At the present time, rig charges for a unit rated for the proposed drilling project are estimated at a day rate of $ 5,820 per 24 hour day. This includes rig and accessory rental, operating crew and immediate supervision, and ancillary equipment such as a welding unit. Since the slant hole drilling is experimental, rig standby charges, when due to operational problems other than driller negligence, accrue at the same day rate. Table 4 lists the components of the estimate.

Table 4.

DETAILED COST ESTIMATE FOR DRILLING OPERATIONS

Drilling Operations
(At $5,820 per day, all depths in feet as drilled and measured, all hole and bit sizes in inches)

Description	Days	Subtotal	Grand Total
1. Mobilization (lump sum)	10.0	$ 120,000	$
2. Drill 17-1/2 in. Surface Hole to 120 ft.	1.0	5,820	
3. Run 120 ft. of 13-3/8 Casing and Cement to Surface	.5	2,910	
4. Drill 12-1/4 Hole to 4,100	23.0	133,860	
5. Run Logs	1.5	8,730	
6. Run 4,100 of 9-5/8 Casing, Cement to Surface, WOC, Nipple Up/Test BOP	2.5	14,550	
7. Drill 8-3/4 Vertical Hole to 6,250	12.0	69,840	
8. Run and Set Whipstock	2.5	14,550	
9. Drill 8-3/4 Directional Hole with Mud Motors, Build Angle at 6 deg. /100 ft. to 7,200	12.0	69,840	

Table 4. Cont'd

DETAILED COST ESTIMATE FOR DRILLING OPERATIONS

Description	Days	Subtotal $	Grand Total $
10. Drill 8-3/4 Hole, Maintaining 60 deg. Angle, to 7,350	1.5	8,730	
11. Cut 350 ft. of Oriented Core with 6-3/4 x 4 Core Barrel and 8-3/4 Bit to 7,700	9.0	52,380	
12. Drill 8-3/4 hole at 60 deg. to 8,400	5.5	32,010	
13. Condition Hole to Run Logs, Log from 4,100 to 8,400	2.0	11,640	
14. Drill 8-3/4 Directional Hole with Mud Motors, Building Angle at 4 deg./100 ft. to 90 deg. at 9,300	12.0	69,840	
15. Drill Horizontal 8-3/4 Hole to 9,400	1.5	8,730	
16. Cut Oriented Horizontal Core Using 6-1/4 x 4 BBL and 8-3/4 Bit to 9,500	2.5	14,550	
17. Drill Horizontal 8-3/4 Hole to 9,800 Total Depth	4.0	23,280	
18. Condition Hole to Run Logs, Log from 8,400-9,800	3.5	20,370	
19. Condition Hole and Run 7 in. Casing to 9,800, Cement from 9,800 to 4,000, Run Cement Log(s), Nipple Up Tree	3.5	20,370	

Table 4. Cont'd

DETAILED COST ESTIMATE FOR DRILLING OPERATIONS

Description	Days	Subtotal $	Grand Total $
20. Miscellaneous Operations and Delays	12.0	69,840	
21. Demobilization (lump sum)	5.0	50,000	
Drilling Time Total: 127.5 Days			
Drilling Operations Total:			$ 821,840

4.2.3 Materials and Equipment

Materials and equipment consists of purchased hardware and supplies. Big ticket items include three strings of casing ($ 272,617), drill bits ($ 134,955), and drilling mud materials ($ 269,374). These items are either consumed during drilling, or are left in the ground at the end of the field test, ie. "sunk". Table 5. details the cost category.

Table 5.

DETAILED COST ESTIMATE FOR MATERIALS AND EQUIPMENT

Materials and Equipment

Description	Total $	Subtotal $	Grand Total $
1. Casing, FOB Rifle, CO:			
a. 13-3/8 in., 54.5 lb., K55, STC, 100 ft.	3,414		
b. 9-5/8 in., 36 lb., K55, LTC, 4,100 ft.	80,400		
c. 7 in., 29 lb., N80, buttress thread, 6,000 ft.	104,590		
d. 7 in., 29 lb., N80, Extreme Line (integral couplings), 3,800 ft.	84,213		
		272,617	
2. Casing Equipment:			
a. Float Shoe:			
1. 13-3/8 in., 1 ea.	617		
2. 9-5/8 in., 1 ea.	507		
3. 7 in., 1 ea.	287		
	1,411		
b. Float Collars:			
1. 7 in.	586		
2. 9-5/8 in.	376		
	944		

Table 5. cont'd

DETAILED COST ESTIMATE FOR MATERIALS AND EQUIPMENT

Materials and Equipment

Description	Total $	Subtotal $	Grand Total $
c. Centralizers:			
1. 13-3/8 in., 3 ea.	272		
2. 9-5/8 in., 30 ea.	1,920		
3. 7 in., 100 ea.	4,975		
	7,167		
d. Plugs:			
1. 13-3/8 in., 1 ea.	245		
2. 9-5/8 in., 1 ea.	140		
3. 7 in., 1 ea.	70		
	455		
		9,977	
3. Drill Bits:			
a. Surface Hole, 0-120 ft.:			
1. 17-1/2 in. MT, 1 @ $ 4,495 ea.	4,945		
b. Intermediate Hole, 120-4,100 ft.:			
1. 12-1/4 in. Button Journal Bearing, 7 @ $ 8,420 ea.	58,940		
c. Vertical 8-3/4 in. Hole, 4,100-6,200 ft.:			
1. 8-3/4 in. Button Journal Bearing, 3 @ $ 4,345 ea.	13,035		

Table 5. Cont'd

DETAILED COST ESTIMATE FOR MATERIALS AND EQUIPMENT

Materials and Equipment

Description	Total $	Subtotal $	Grand Total $
d. Directional 8-3/4 in. Hole, 6,200-9,800 ft.:			
1. 8-3/4 in. Button Journal Bearing, 3 @ $ 4,345 ea.	13,035		
2. 8-3/4 in. PDC, 3 @ $ 15,000 ea.	45,000		
		134,955	
4. Mud Materials:			
a. 0-120 ft., 17-1/2 in. Hole	2,955		
b. 120-4,100 ft., 12-1/4 in. Hole	20,932		
c. 4,100-6,250 ft., 8-3/4 in. Hole	24,487		
d. 6,250-9,800 ft., 8-3/4 in. Hole	221,000		
		269,374	
5. Wellhead:		51,000	
	Total Materials and Equipment:		$ 737,923

4.2.4 Services

This is the largest single cost category at an estimated $ 835,600, and provides subcontractor services and special equipment and tool rentals to support the drilling effort. Main cost centers include mud logging ($ 96,000), oriented coring ($ 84,353), directional MWD services ($ 107,450), mud motor rental ($ 147,290), and geophysical logging services ($ 181,647). Table 6. provides the estimate details.

Table 6.

DETAILED COST ESTIMATE FOR SERVICES

Services

Description	Total $	Subtotal $	Grand Total $
1. Mud Logging Service:			
a. Mobilization	500		
b. Operation, 85 Days @ $ 1,000 ea.	85,000		
c. Standby Days, 21 @ $ 500 ea.	10,500		
		96,000	
2. Oriented Coring Service:			
a. 7,350-7,700 ft.:			
1. 2 Service Men, 9 Days @ $ 1,050	9,450		
2. Equipment, 350 ft. @ $ 148.55/ft.	51,993		
b. 9,400-9,500 ft.:			
1. 2 Service Men, 5 Days @ $1,050	5,250		
2. Equipment, 100 ft. @ $ 176.60/ft.	17,660		
		84,353	
3. Mud Engineering:			
24 Hour/Day Coverage, 74 Days @ $ 250/Day		18,500	

Table 6. Cont'd

DETAILED COST ESTIMATE FOR SERVICES

Services

Description	Total $	Subtotal $	Grand Total $
4. Directional Drillers:			
From 6,250 to 9,800 ft.			
a. 68 Days of Operation, 1 Man @ $ 400/Man/Day	27,200		
b. 24 Additional Man Days @ $400	9,600	36,800	
5. MWD Services:			
From 6,250 to 9,800 ft.			
a. 31 Days of Operation, @ $ 2,450/Day	75,950		
b. 35 Days of Standby, @ $ 900/Day	31,500	107,450	
6. Mud Motor Rental: (3 Tools on Location)			
a. 31 Days of Operation, 16 Hours/Day @ $ 275/Hour	136,400		
b. 66 Days of Standby, 3 Tools, @ $ 55/Tool/Day	10,890	147,290	
7. Monel DC Rental:			
a. 3 Collars @ $ 40/DC/Day for 66 Days	7,920		
b. Trucking	700	8,620	

Table 6. Cont'd

DETAILED COST ESTIMATE FOR SERVICES

Services

Description	Total $	Subtotal $	Grand Total $
8. Logging Services:			
a. 170 to 4,100 ft.	16,386		
b. 4,100 to 8,400 ft.	73,261		
c. 8,400 to 9,800 ft.	57,610		
d. Tool Insurance	1,890		
e. Transportation	10,000		
f. Location Charge, 10 Days @ $ 2,250/Day	22,500		
		181,647	
9. Cementing Services:			
a. Cement 13-3/8 in. Surface Casing	1,651		
b. Cement 9-5/8 in. Intermediate Csg.	12,646		
c. Cement 7 in. Production Csg.	12,626		
		26,923	
10. Whipstock Service: 1 Set @ 6,250 ft.			
a. Tool, Service, and Equipment	8,913		
b. Inspection/Repair	1,000		
c. Service Man			
1. 3 days @ $500/D.	1,500		
2. Mileage	503		
		11,916	

Table 6. Cont'd

DETAILED COST ESTIMATE FOR SERVICES

Services

Description	Total $	Subtotal $	Grand Total $
11. Water Hauling:			
114 Days @ 8 Hours/Day, @ $ 39.25/Hour		35,796	
12. Road Maintenance: 8 Trips @ $660 ea.		5,280	
13. Miscellaneous Rentals		50,000	
14. Miscellaneous Trucking		25,000	
	Total Services:		$ 835,575

4.2.5 Engineering and Supervision

The slant hole drilling task is designed as a "turn-key" job. The Engineering and Supervision category estimates the cost of planning, execution, and technical and administrative support of the slant hole drilling test by a prime contractor. The contractor will be responsible for the execution of the specified field effort. This includes preparation of a drilling AFE (authority for expenditure) and subcontracting for and monitoring of materials, supplies, and services. The prime contractor will also provide engineering and geological technical support of special activities such as logging and coring, as well as supervise technical service personnel and test activities on site. Table 7. provides the details of the estimate.

Table 7.

DETAILED COST ESTIMATE FOR ENGINEERING AND SUPERVISION

Description	Total $	Subtotal $	Grand Total $
1. Direct Labor:			
a. Project Engineer ($ 30/Hr., 1,040 Hrs.)	31,200		
b. Logging Engineer ($ 29/Hr., 240 Hrs.)	6,960		
c. Geologist ($ 28/Hr., 240 Hrs.)	6,720		
d. Administrative Support ($ 10/Hr., 1,040 Hrs.)	10,400		
		55,280	
2. Labor Overhead: (150 % of Direct Labor)		82,800	
3. Other Costs:			
a. Drilling Consultant ($ 300/Day, 130 Days)	39,000		
b. Travel	17,500		
c. Per Diem ($ 60/Day, 85 Days)	5,100		
c. Computer Support (Lump Sum)	5,000		
d. Lease, Legal, and Permit Costs (Lump Sum)	10,000		
		76,600	
		214,680	
4. G&A: (7 % of Direct and Other Costs)		15,020	
		229,700	
5. Fee: (6% of Total Costs)		13,800	
Grand Total, Engineering and Supervision			$ 243,500

5.0 CONCLUSION

5.1 Summary

A plan is being proposed to drill a directional well to investigate the slant hole approach as applied to tight interbedded gas formations of the western geologic basins. The well is targeted at the interbedded tight sands and coals of the Piceance Basin's Mesaverde Group, a thick formation containing an estimated 420 Tcf of gas in place. The proposed test well is close to the Department of Energy's multiwell experiment field laboratory and its field lab infrastructure. The multiwell site offers a superior geologic model of the Mesaverde, a complete reservoir performance data base, fully characterized offset wells available for interwell reservoir performance analysis testing, and a large test pad set up for instrumentation and support equipment.

The slant hole requires a new but small drilling surface pad to be located adjacent to the existing lease road, about 700 feet south of the MWX well pattern. The well would be drilled with off-the-shelf technology, utilyzing mud motors, bent subs, and MWD techniques to penetrate the Paludal horizon of mixed lenticular sands and gassy coals at a 60 degree angle, and then to emplace a 500 foot horizontal hole in the Cozzette blanket sand.

A detailed slant hole drilling prognosis, including a complete set of cost estimates, has been prepared for the proposed slant hole field test. The well installation is estimated to cost $ 3,278,300. This cost figure includes site preparation, drilling, coring, casing and cementing of the well, and engineering and field supervision of the drilling project. The field phase is expected to take close to four months to execute, with detail planning and subcontracting/purchasing by a prime contractor taking an additional two months for an overall six month slant hole drilling schedule. Casing the well at total depth in the Cozzette Sandstone will ready the new hole for extensive reservoir and production engineering experimentation and analyses. Figure 7 shows an "as built" sketch of the various hole diameters and casing sizes of the finished hole as it should look at completion of the drilling stage.

5.2 Conclusion

The multiwell site and its technical data base and field lab infrastructure offers a unique opportunity to perform a directional drilling evaluation of mixed, naturally fractured, tight gas reservoirs. The project would be a logical follow-on to conventional vertical well measurements at MWX. The new field test would help characterize slant hole performance as an alternative development strategy for these widespread tight gas reservoirs.

6.0 ACRONYMS AND ABBREVIATIONS

1.	AFE	Authority for expenditure
2.	DOE	Department of Energy
3.	ft.	Foot, unit of measurement
4.	FY 88	Fiscal Year 1988
5.	GIH	Go in(to) hole
6.	in.	Inch
7.	lb.	Pound
8.	KOP	Kick-off point (of directional hole)
9.	LT&C	Long threads and collars
10.	MD	Measured depth (drilled hole length)
11.	METC	Morgantown Energy Technology Center
12.	MT	Mill tooth (drill bit)
13.	MWD	Measurement while drilling
14.	MWX	Multiwell Experiment
15.	N20E	North 20 (degrees) East
16.	N70W	North 70 West
17.	PDC	Poly-crystalline diamond (drill bit)
18.	POH	Pull out (of) hole
19.	R94W	Range 94 West (standard location identifier)
20.	T6S	Township 6 South (standard location identifier)
21.	Tcf	Trillion cubic feet (of gas)
22.	TD	Total depth
23.	TVD	True vertical depth
24.	VA	Vertical angle

7.0 REFERENCES

1. National Petroleum Council. December 1980. Unconventional Gas Resources. Vol. V, Tight Gas Reservoirs, Part 1.

2. Johnson, Ronald C., Robert A. Crovelli, Charles W. Spencer, and Richard F. Mast. November 1987. An Assessment of Gas Resources in Low Permeability Sandstones of the Upper Cretaceous Mesaverde Group, Piceance Basin, Colorado. USGS Open File Report No. 87-357.

3. Northrop, D.A., A.R. Sattler, and J.K. Westhusing. March 1983. Multiwell Experiment: A Field Laboratory for Tight Gas Sands. SPE/DOE Paper No. 11646.

4. Sattler, A.R. March 1983. The Multiwell Experiment Core Program. SPE/DOE Paper No. 11763

5. Northrop, D.A., A.R. Sattler, R.L. Mann, and K-H. Frohne. May 1984. Current Status of the Multiwell Experiment. SPE/DOE/GRI Paper No. 12868.

6. Lorenz, John C. June 1983. Reservoir Secimentology in Mesaverde Rocks at the Multi-Well Experiment Site. Sandia Report SAND83-1078.UC92

7. Lorenz, John C. May 1985. Predictions of Size and Orientations of Lenticular Reservoirs in the Mesaverde Group, Northwestern Colorado. SPE/DOE Paper No. 13851.

8. Johnson, R.C. Geologic History and Hydrocarbom Potential of Late Cretaceous-Age, Low Permeability Reservoirs, Piceance Basin, Western Colorado. 97 p. DOE/MC/20422-2337, NTIS/DE87006476.

9. Branagan, P.T., C.L. Cipolla, S.J. Lee, and R.H. Wilmer. May 1985. Comprehensive Well Testing and Modeling of Pre- and Post-Fracture Well Performance of the MWX Lenticular Gas Sands. SPE/DOE Paper No. 13867.

10. Branagan P.T., C.L. Cipolla, S.J. Lee, and L. Yan. May 1987. Case History of Hydraulic Fracture Performance in the Naturally Fractured Paludal Zone: The Transitory Effects of Damage. SPE/DOE Paper No. 16397.

11. Multiwell Experiment Groups, at Sandia National Laboratories and CER Corporation. April 1987. Multiwell Experiment Final Report: The Marine Interval of the Mesaverde Formation. Sandia Report SAND87-0327.UC-92a.

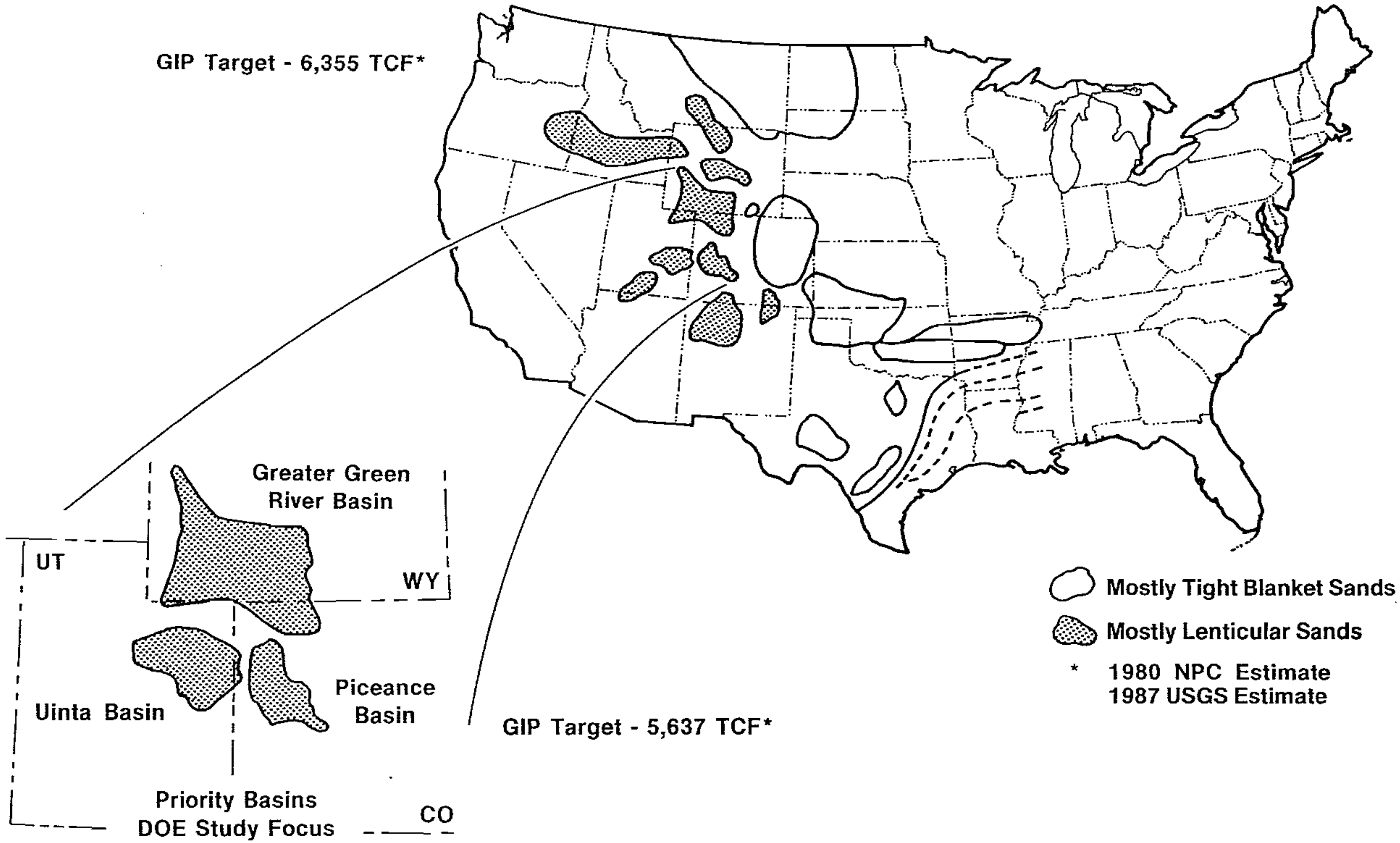

Figure 1. Location of Western Tight Gas Sands Resource

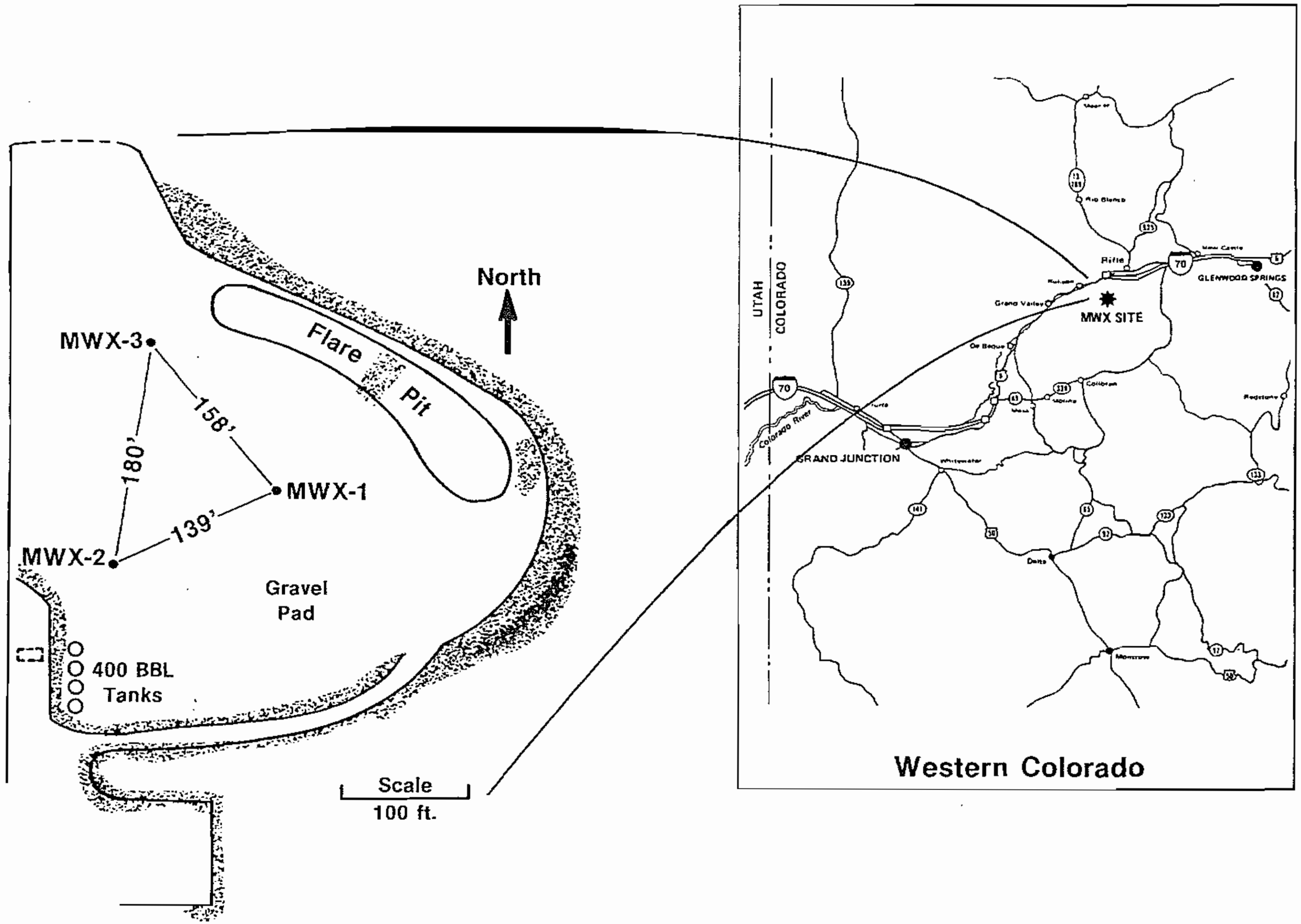

Figure 2. Location and Layout of the Multiwell Experiment Site

188-623-A TE3

WASATCH FM

Group	Formation	Formation Members	Thickness at MWX Site
MESAVERDE GROUP	WILLIAMS FORK FORMATION	Ohio Creek Member	350 ft
		fluvial member	1650 ft
		coastal member	600 ft
		paludal member	850 ft
	ILES FORMATION	Rollins Sandstone	200 ft
		Mancos Tongue	200 ft
		Cozzette Sandstone	175 ft
		Mancos Tongue	125 ft
		Corcoran Sandstone	150 ft

MANCOS SHALE

Figure 3. Site-Specific Geologic Column at the MWX Site

C88-623-D TE3

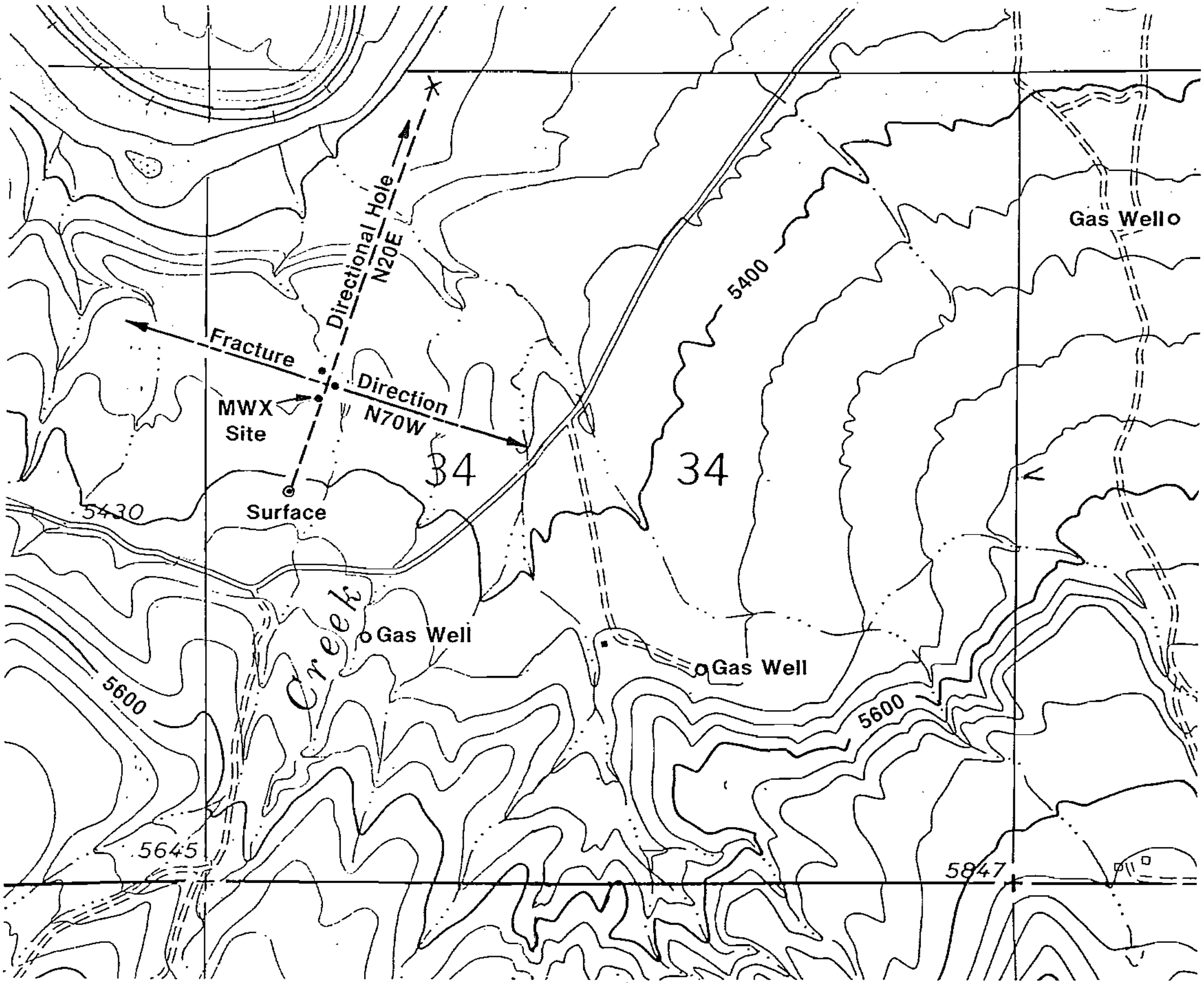

Figure 4. Topograpic Map of MWX Area with MWX Site and Fracture and Slant Hole Azimuths

I88-623-B TE3

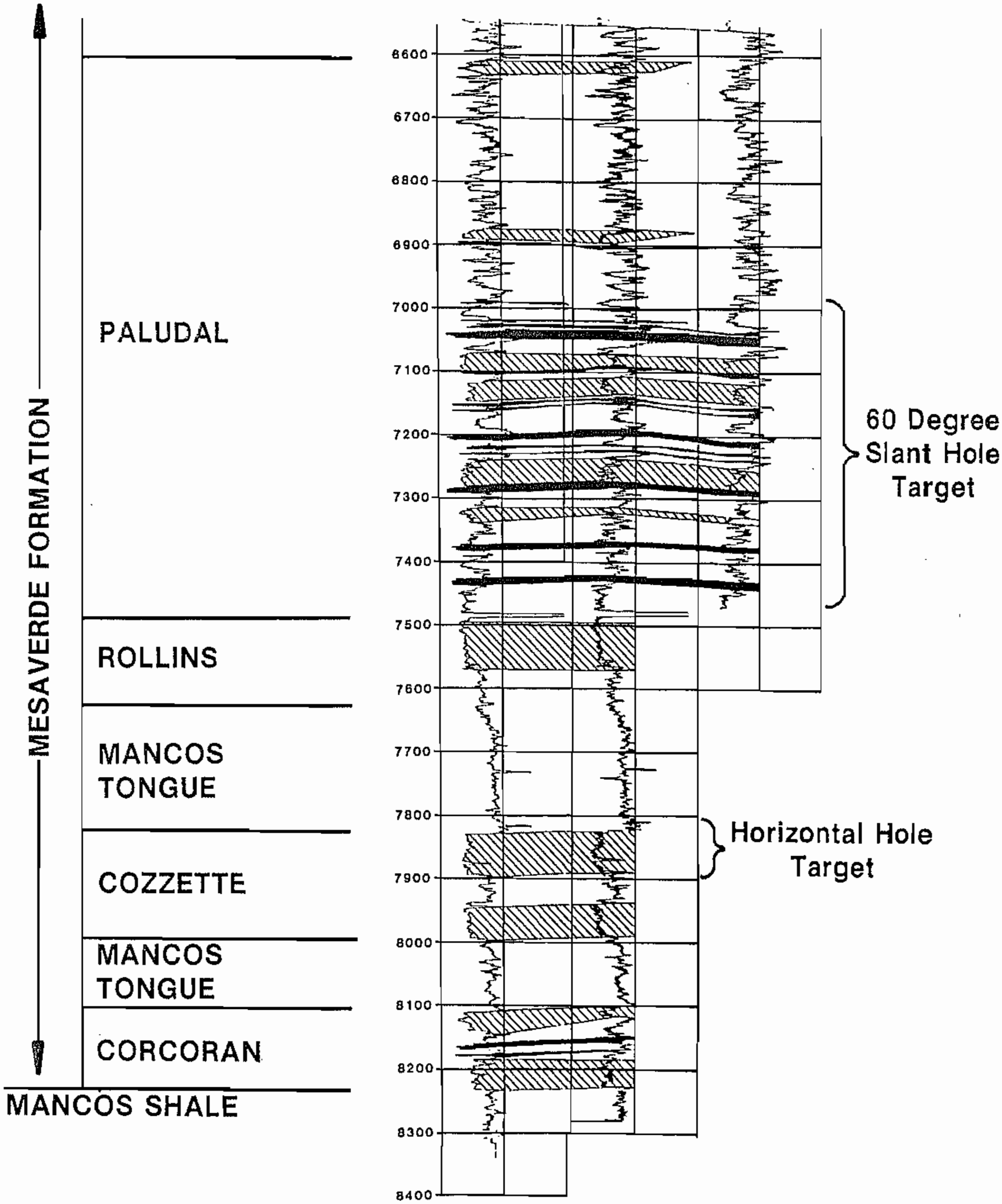

Figure 5. Reservoir Completion Targets

188-623-C TE3

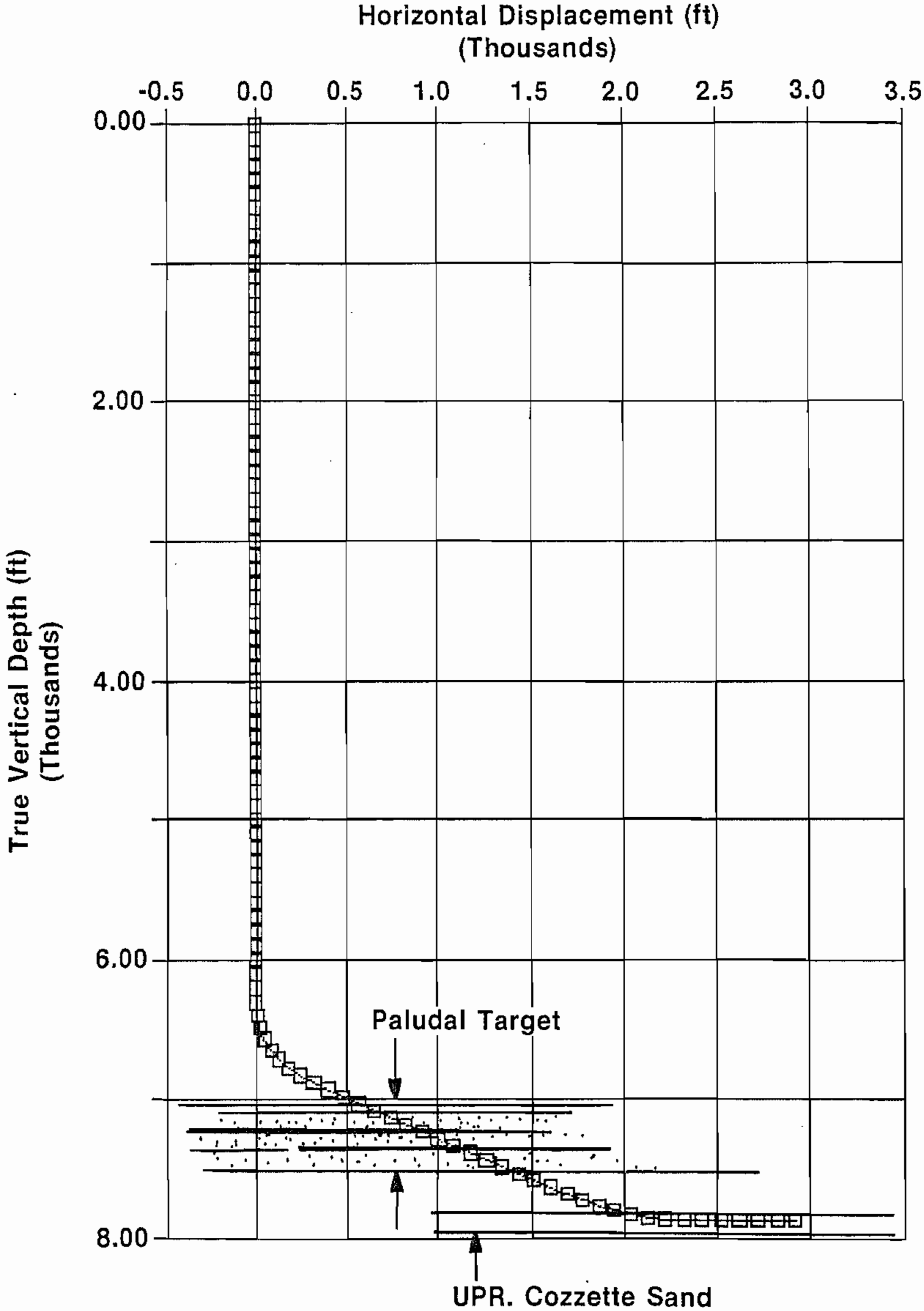

Figure 6. MWX Offset (6 degree plot)
Vertical Depth vs. Departure (ft.)

188-623-E TE3

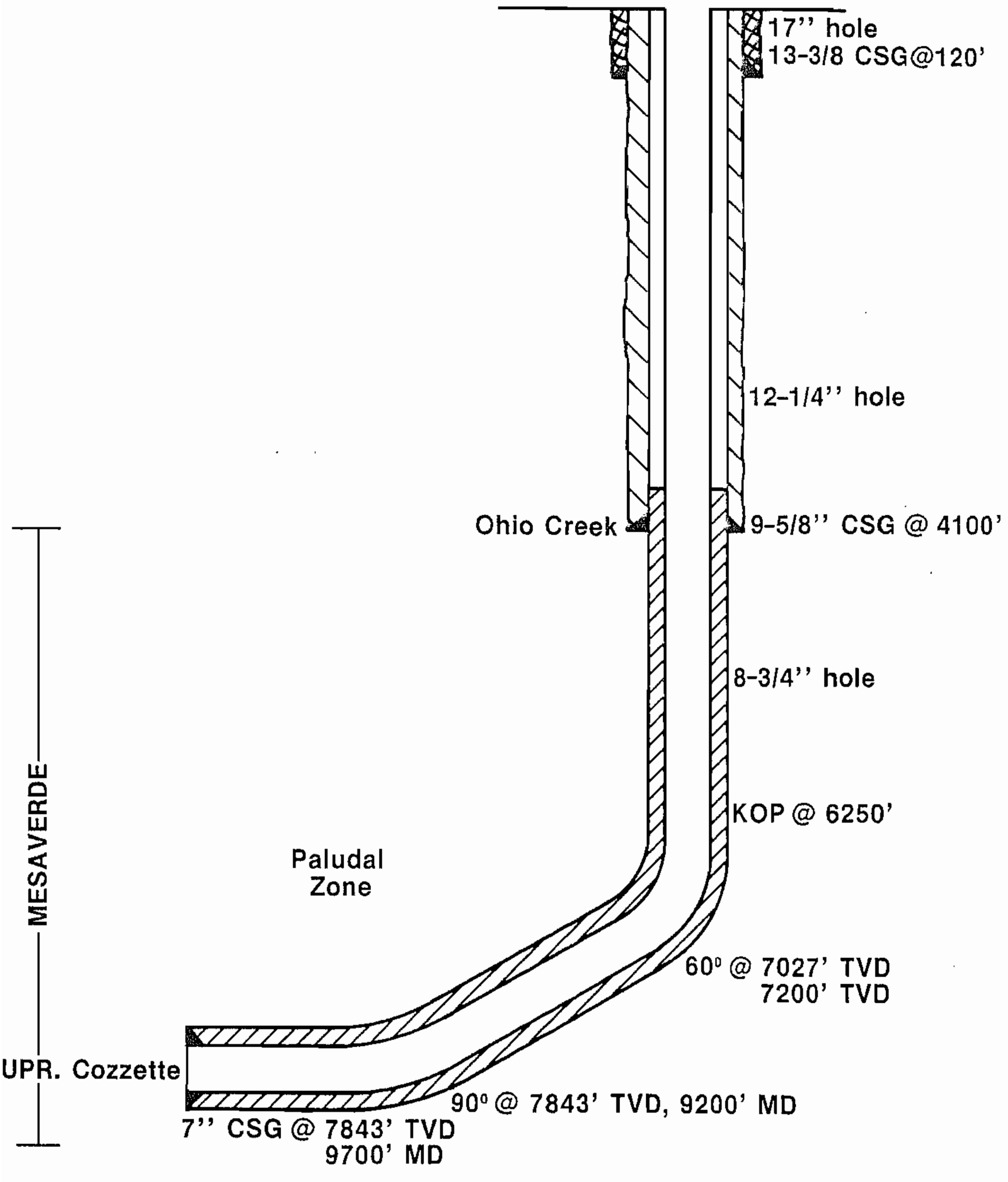

Figure 7. Slant Hole 'As Built' Plot