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Horizontal Drilling in the Lower Glen Rose Formation, Maverick County, Texas

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Authors:
Muncey, G.
Drimal, C.E.

Contractor:
PrimeEnergy Corporation
One Landmark Square
Stamford, Connecticut 06901

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CONTRACT INFORMATION

Contract Number	DE - AC21 - 91MC28239
Contractor	PrimeEnergy Corporation One Landmark Square Stamford, CT 06901
Contractor Project Manager	Gery Muncey
Principle Investigators	Charles E. Drimal Gery Muncey
METC Project Manager	Albert Yost, II
Period of Performance	September 30, 1991 to May 31, 1993

Schedule and Milestones

FY 1992 Program Schedule

	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J
Work Plan	—	—	—	—	—	—										
NEPA Evaluation	—	—	—	—	—	—	—	—	—	—	—					
Seismic Reprocessing										—						
Seismic Acquisition											—					
Seismic Processing											—					
Drilling													—			
Completion														—		
Well Testing															—	—
Final Report																

OBJECTIVES

The primary objective of this project is to test the hypothesis that a horizontally drilled borehole can increase gas production sufficiently from the Lower Glen Rose Formation to provide an economic advantage over conventional vertical drilling. Additional objectives are to conduct detailed investigations of reservoir properties and completion methods.

BACKGROUND INFORMATION

This paper presents preliminary results of a project, co-funded by PrimeEnergy Corporation and the United States Department of Energy (DOE), to assess the economic viability of horizontal drilling in the Lower Glen Rose Formation of Maverick County, Texas. This project is part of an ongoing DOE investigation of directional drilling in the development of gas resources within the United States.

PROJECT DESCRIPTION

PrimeEnergy Corporation has obtained a farmout on approximately 10,218 acres in Maverick County, Texas on which to drill the test well. The PrimeEnergy acreage lies on the crest of the Chittim Anticline, on the northwest flank of the Chittim Field. Since its discovery in 1929, the Chittim Field has produced in excess of 50 billion cubic feet (BCF) of natural gas and 200,000 barrels (BBLS) of retrograde condensate from the Cretaceous-age Lower Glen Rose carbonates. Large well-to-well variances in reserves characterize the Lower Glen Rose production in the Chittim field. Ultimate reserves range from on the order of 100 million cubic feet (MMCF) to 10 BCF per well.

Analysis of extensive well control has shown that Lower Glen Rose gas and condensate production is from diagenetically-altered grainstones deposited in carbonate bank and/or bar-type facies. Subsurface depths of the porosity developments range from about 5,100 to about 5,700 feet within the study area, depending upon structural position. The areas of enhanced porosity tend to be elliptical in plan view; range in size from tens of acres to on the order of a thousand acres and are separated by large areas of marginal quality to non-reservoir-quality rock. Well control also suggests large variances in Lower Glen Rose permeability throughout the study area.

Seismic work on the PrimeEnergy farmout acreage and adjacent leases has shown that economically significant developments of Lower Glen Rose porosity are seismically resolvable and that seismic data can be effectively used in selection of drilling locations. Based on analysis of existing seismic data, a vibroseis-source survey was designed and will be implemented to further detail the distribution of porosity on the PrimeEnergy acreage. Analysis of the full seismic data set will facilitate selection of the best available drilling location. Since it is not possible to derive the exact depth of the target zone from the seismic data, it is necessary to drill through the producing interval to determine the exact target interval. After logging, the hole will be plugged back to the intermediate casing and kicked off building angle at 12.5 degrees per 100 feet. Once the well reaches 90 degrees, the horizontal section will provide up to approximately 2400 feet of wellbore in the target zone.

The total projected well cost is $958,084 with DOE and PrimeEnergy contributing 70% and 30% of drilling and completion costs respectively.

RESULTS

Geologic Setting

The study area, shown in Figure 1, lies in the east-central Maverick Basin in Maverick County, Texas. The Maverick Basin lies in the northwest end of the Rio Grande embayment where Lower Cretaceous sedimentary rocks, primarily carbonates, accumulated in a rapidly subsiding basinal area.

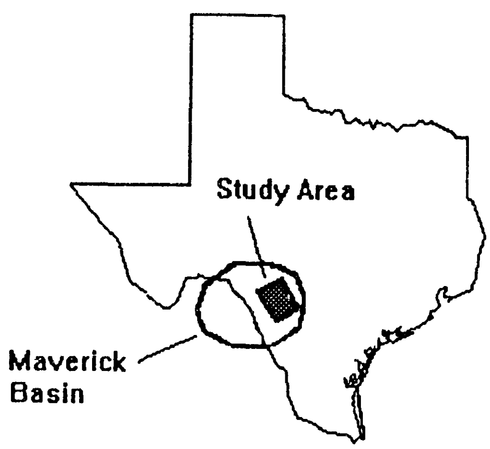

Figure 1. Study Area

In the survey area, stratigraphy of the Lower Glen Rose Formation is characterized by a shoal-water complex. The target of the project well is a porous zone within the Lower Glen Rose formation. The porosity occurrs in isolated "pods" throughout the project area at sub-surface depths ranging from 5,100 feet to 5,700 feet depending on structural position on the Chittim anticline. Much of the porosity of the Lower Glen Rose section was lost during burial diagenisis. Lower Glen Rose porosity developed in skeletal grainstones which were deposited in high-energy bank and bar environments. Two types of grainstones are thought to have been deposited in the study area; (1) "storm" or "washover" deposits with thicknesses in the range of 5 to 10 feet and very limited areal extent, and (2) grainstone banks and/or bars with thicknesses ranging from 20 to over 100 feet and relatively larger areal extent.

Log signatures suggest that the grainstones exhibited an upward-coarsening character. They are reported to have been composed primarily of pelecypod shell hash. The grainstones have been so altered during diagenisis, however, that little remains of the original skeletal grains. The matrix is typically sparry calcite, which is suggestive of subareal exposure and remaining porosity is primarily moldic. Porous zones are overlain and underlain by dense, non-porous carbonates with thin shale stringers (Gary Servos, Servos Exploration Associates, personal communication).

Structural geology of the Maverick basin is characterized by Laramide-age, long, open, asymmetric anticlines with southeast plunge. Antithetic and, to a lesser extent, synthetic faults with primarily northeast trends; and extensive fracturing with northeast and northwest trends are present in the study area. However, faulting is most apparent at depths shallower than the Lower Glen Rose and there is some question as to whether fracturing plays any significant role in Lower Glen Rose porosity enhancement.

Figure 2 illustrates the structure on the Lower Glen Rose in the study area. Many of the 58 some-odd wells which have been drilled in the Chittim Field to date are shown on this map. The characteristic broad, open style of folding is clearly evident on the Chittim Anticline, and three northeast-striking antithetic faults are mapped from the well control. Also shown is the eastern edge of PrimeEnergy's acreage block and two possible drilling locations "A" and "B" as are two of the Chittim Field discovery wells, the Rycade Oil Company No. 4 and No. 5.

Reservoir Engineering

Production data were available for study for 49 wells which tested the Lower Glen Rose Formation in the study area. The results of that analysis are shown in the histogram of projected ultimate reserves presented in Figure 3. Almost 50% of the wells drilled to date will cum less than 250 MMCF of gas. This group also includes 17 wells which were "dry" and abandoned. A few of the early dry holes probably would have been capable of sustained commercial gas production by today's standards but were abandoned due to a lack of a gas market in the late 1920s and early 1930s.

Economic modeling suggests that at a cost of approximately $325,000, a vertical well would have to cum on the order of 0.75 BCF to be considered economic. . However, Figure 3 shows that almost 70% of the 49-well population will cum less than the 0.75 BCF minimum. Economic modeling also shows that, with average yield rates of about 0.004 BBLS/MCF, condensate production is relatively unimportant to the drilling economics. Assumptions underlying the minimum economic reserves figure are outlined in Table 1

Clearly these factors suggest marginal economics for vertical drilling in the Lower Glen Rose of the study area. However, about 15% of the 49-well population will cum over 2 BCF, and among those wells projected cums range from a minimum of approximately 3 BCF to a maximum of approximately 10 BCF. This potential for large reserves, combined with the directionally anisotropic porosity and permeability distribution of the Lower Glen Rose, suggest that this area may be an excellent one in which to apply directional drilling techniques.

Figure 4 shows the projected gas cums in map form. The axis of the Chittim anticline and the three faults are carried over from Figure 2 for spatial reference and to show the apparent correlation of production trends with the structural fabric. The contoured projected cums presented in Figure 4 and production from the Aztec Barclay 71-1 and the Zinke & Philpe 72-1, located further up dip on the axis of the Chittim anticline (see Figure 8 for location of these two wells), suggest that the trend of Lower Glen Rose

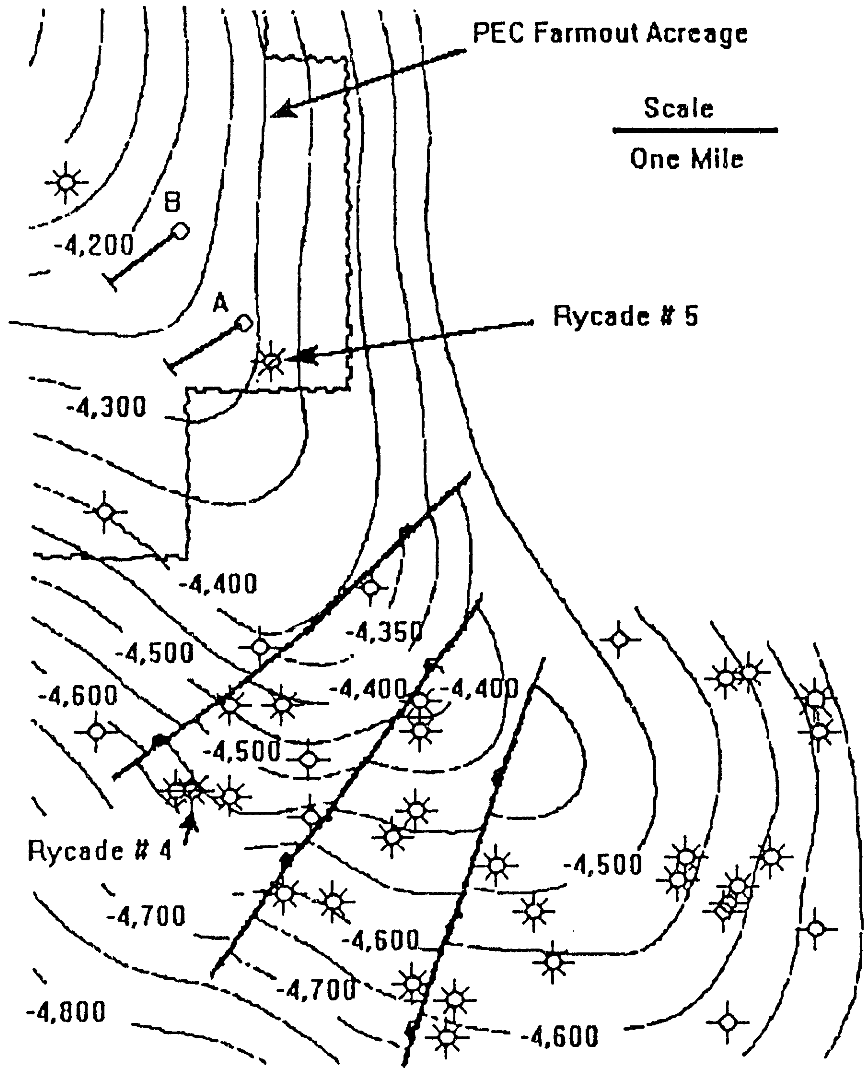

Figure 2. Structure on the Lower Glen Rose Formation, Chittim Field, Maverick County, Texas

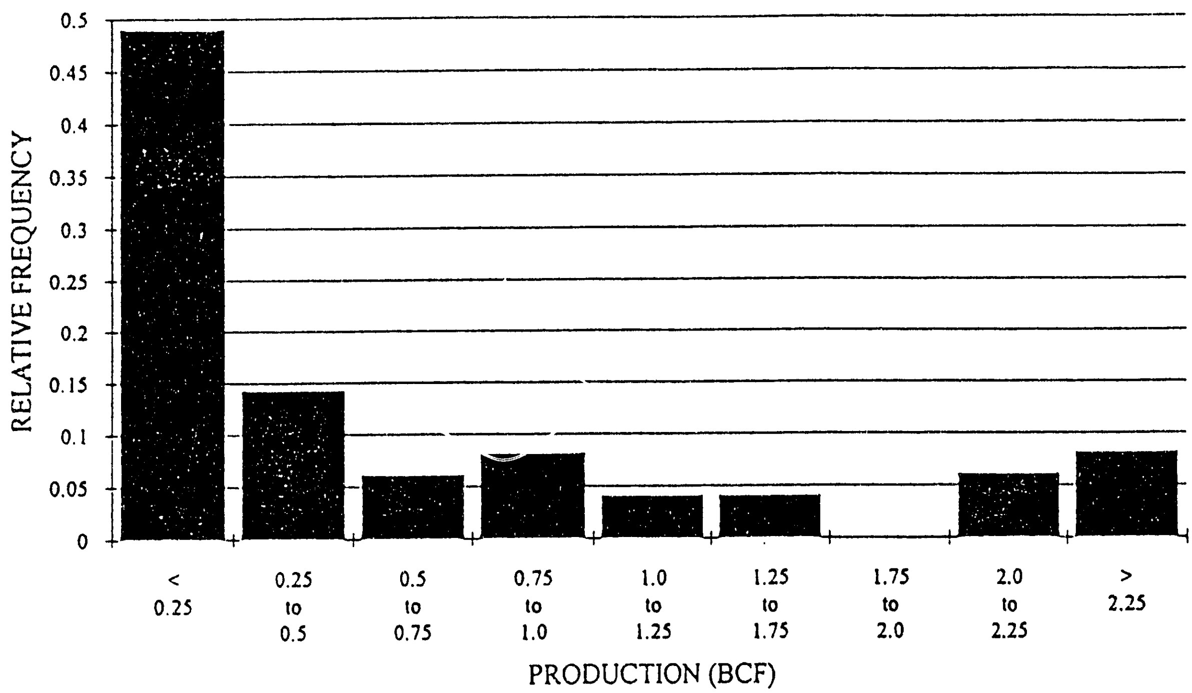

Figure 3. Histogram of Ultimate Reserves, Chittim Field, Maverick County, Texas

Table 1. Selected Economic Assumptions

Net Revenue Interest: 80% Lease Operating Cost: \$800/Month costs escalated at 5% per year for 5 years, 3% thereafter Minimum Internal Rate of Return: 15%	Initial Gas Price: \$1.35/MCF Initial Oil Price: \$ 18.50/BBL prices escalated at 5% per year for 5 years, 3% thereafter

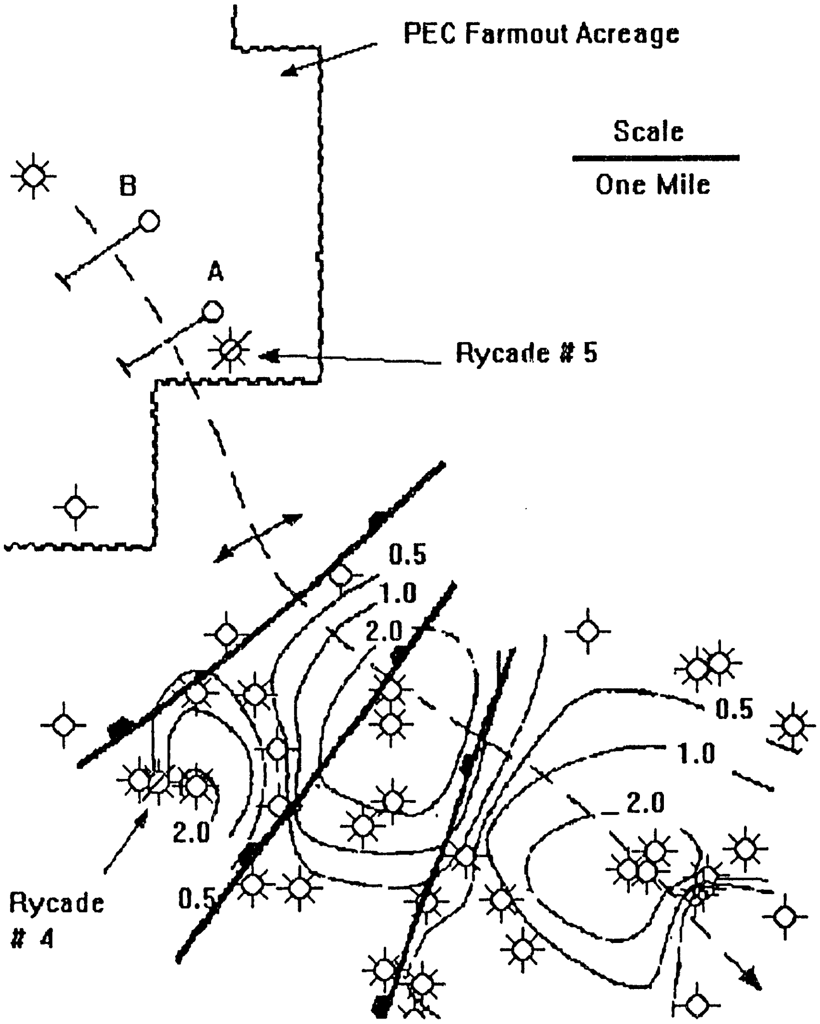

Figure 4. Isocum Map, Chittim Field, Maverick County, Texas and a Portion of the PrimeEnergy Acreage Block. Contoured values = BCFs

production may correlate closely with the axial trace of the Chittim anticline. This correlation may, however, be more an artifact of well control than real as seismic control suggests that the trend of Lower Glen Rose porosity has a much stronger east-west component than does the Chittim anticline and insufficient well control exists to definitively locate the downdip limit of production. It is also important to note that the Chittim anticline did not exist as a positive element during Lower Glen Rose time and therefore could not have influenced the deposition of Lower Glen Rose grainstones. However, tectonic activity related to formation of the anticline may have influenced migration and implacement of hydrocarbons.

The Lower Glen Rose pay section can be observed in the Aztec Petroleum Barclay No. 71-1. Completed in August, 1983,

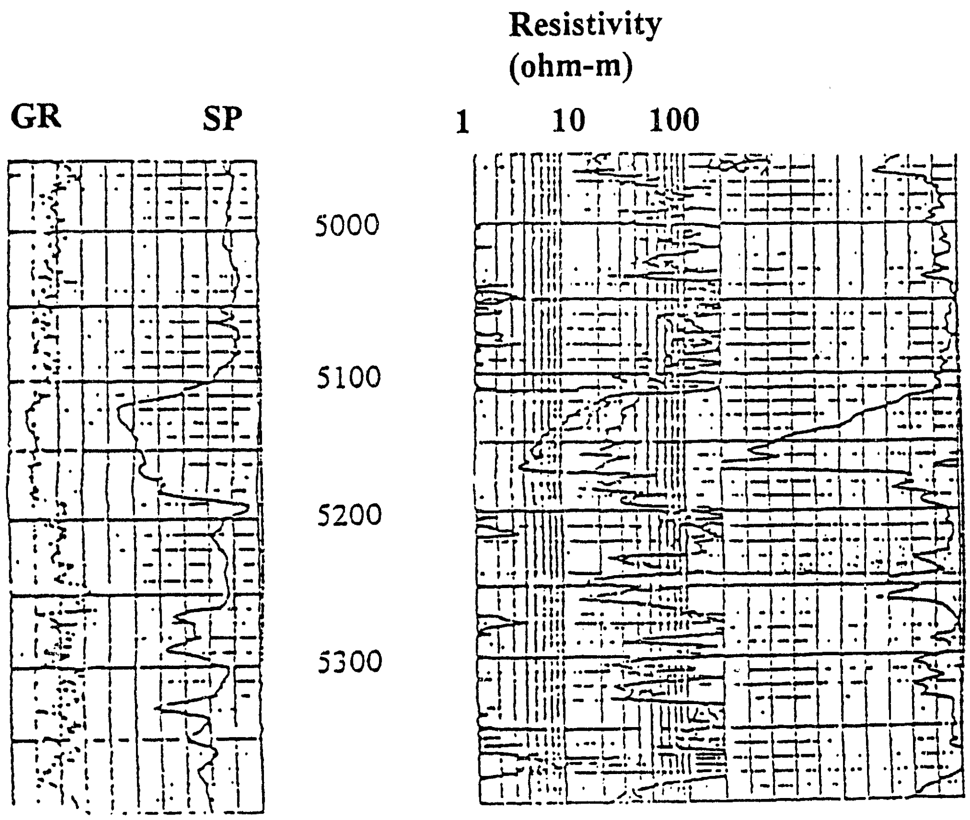

Figure 5. SP, Gamma Ray, and Induction Resistivity Logs, Aztec Petroleum Barclay No. 71-1. Datum = Surface Elevation

this well produces gas and condensate from perforations in the Lower Glen Rose from 5,116 feet to 5,124 feet subsurface.Gamma ray, SP, and induction resistivity logs are presented in Figure 5. Gamma ray, caliper, and a compensated neutron-density porosity log are presented in Figure 6. The typical upward-coarsening character of the Lower Glen Rose porosity can be clearly seen in the SP signature in Figure 5, from about 5,115 feet to about 5,185 feet. Porous and permeable Lower Glen Rose can be observed on the induction log from 5,115 feet to about 5,170 feet. Below 5,170 feet the induction and porosity logs suggest the formation is tight. Taking the average of the neutron and density porosity estimates suggests porosities in the 8% to 9% range. Note also the absence of a "gas-effect" neutron-density signature in the pay zone.

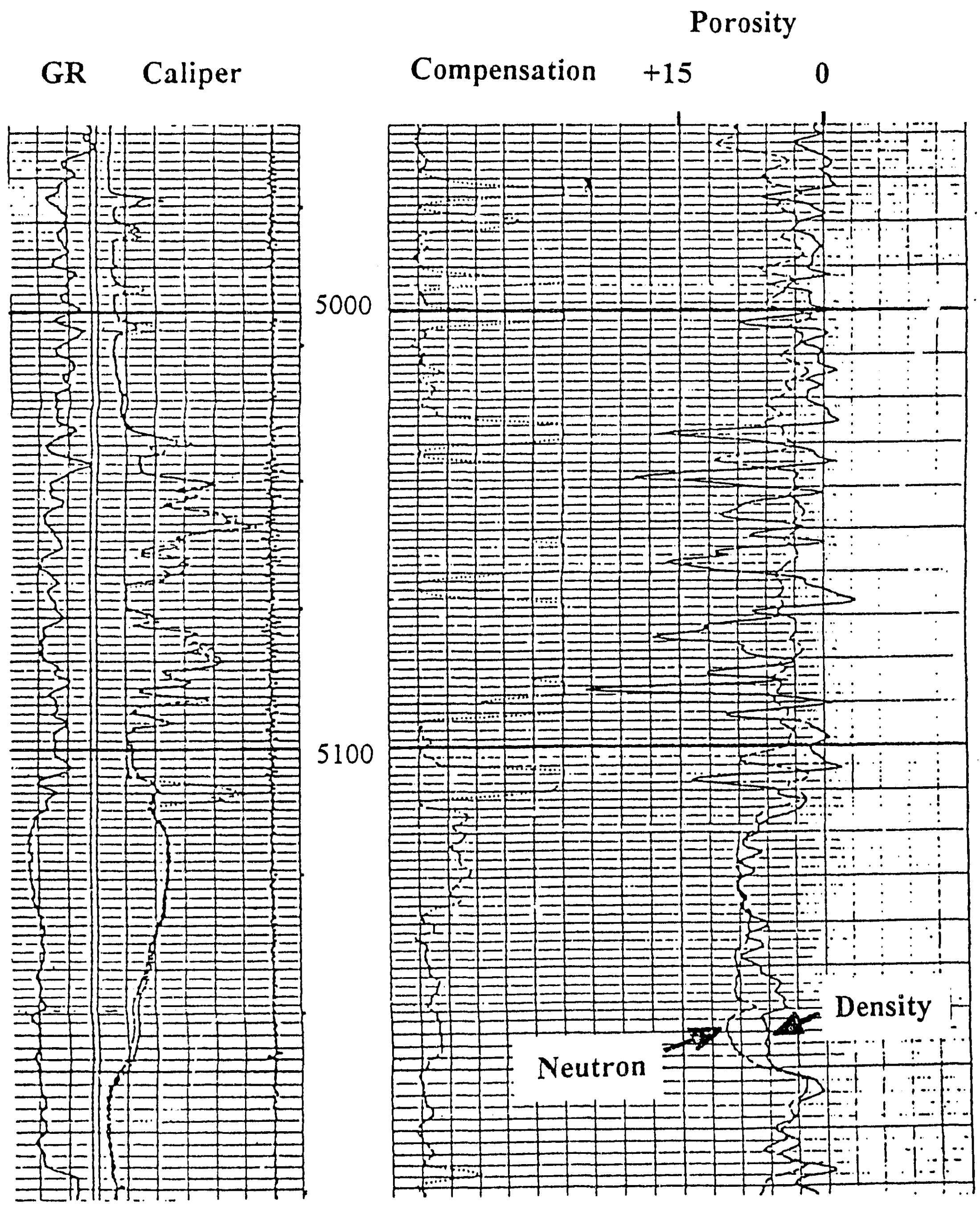

Figure 6. Gamma Ray, Caliper, and Compensated Neutron - Density Log, Aztec Petroleum Barclay No. 71-1. Datum = Surface Elevation

No saturation profile has been calculated for the Aztec Barclay 71-1. However, decreasing resistivity of the pay zone with depth, combined with the SP and porosity log responses, qualitatively suggests increasing water saturation with depth.

Drilling data in the Chittim field shows that several porosity developments contain some water downdip. However, no Lower Glen Rose gas producers in the Chittim field are known to have produced more than a few BBLS of water per day. It is also important to note that different porous bodies tend to have different water resistivities, which suggests that the water is unique to the individual porous bodies and not part of a regional water table (James Sigmon, The Exploration Company, personal communication).

Production history through mid-1991 is presented in Figure 7 for the Aztec Barclay 71-1. This well is projected to cum approximately 0.85 BCF and about 10,400 BBLS of condensate by the time it reaches its projected economic limit in late 1996. With reserves of 0.85 BCF, the Aztec Barclay 71-1 ranks in approximately the 75th percentile of gas reserves in the 49-well study. Other wells of interest on the PrimeEnergy acreage are the Zinke & Philpe (Z&P) 72-1 and the Sullivan Rycade No. 5. A schematic map of the PrimeEnergy acreage block and well locations is presented in Figure 8.

The Zinke & Philpe 72-1 is projected to cum only about 355 MMCF. It is probable that the Zinke & Philpe 72-1 is producing from one of the thinner "storm" deposits but no logs were available to confirm this. The Sullivan Rycade No. 5 is one of the earliest wells drilled in the Chittim field. It is reported to have flowed 7 MMCF per day open-flow but was abandoned due to lack of a gas market.

Seismic Results

Servos Exploration Associates of Houston, Texas have shown, through their extensive seismic work in the Chittim field, that a characteristic seismic amplitude anomaly can be observed in the vicinity of wells with a thick, highly porous Lower Glen Rose section. Additionally, this work has led to the refinement of acquisition techniques using a vibroseis source which are both effective and economical. This work has also confirmed that the porous Lower Glen Rose facies is only locally developed as bank and/or bar deposits; typically on paleotopographic features (Gary Servos, personal communication). These areas of enhanced porosity tend to be elliptical in plan view, ranging in area from a few tens of acres to on the order of a thousand acres. Such a target can present a difficult and risky target for vertical drilling. However, considerable empirical evidence suggests that high-quality seismic data may significantly reduce dry hole risk and can, therefore, be an important tool in the well siting process.

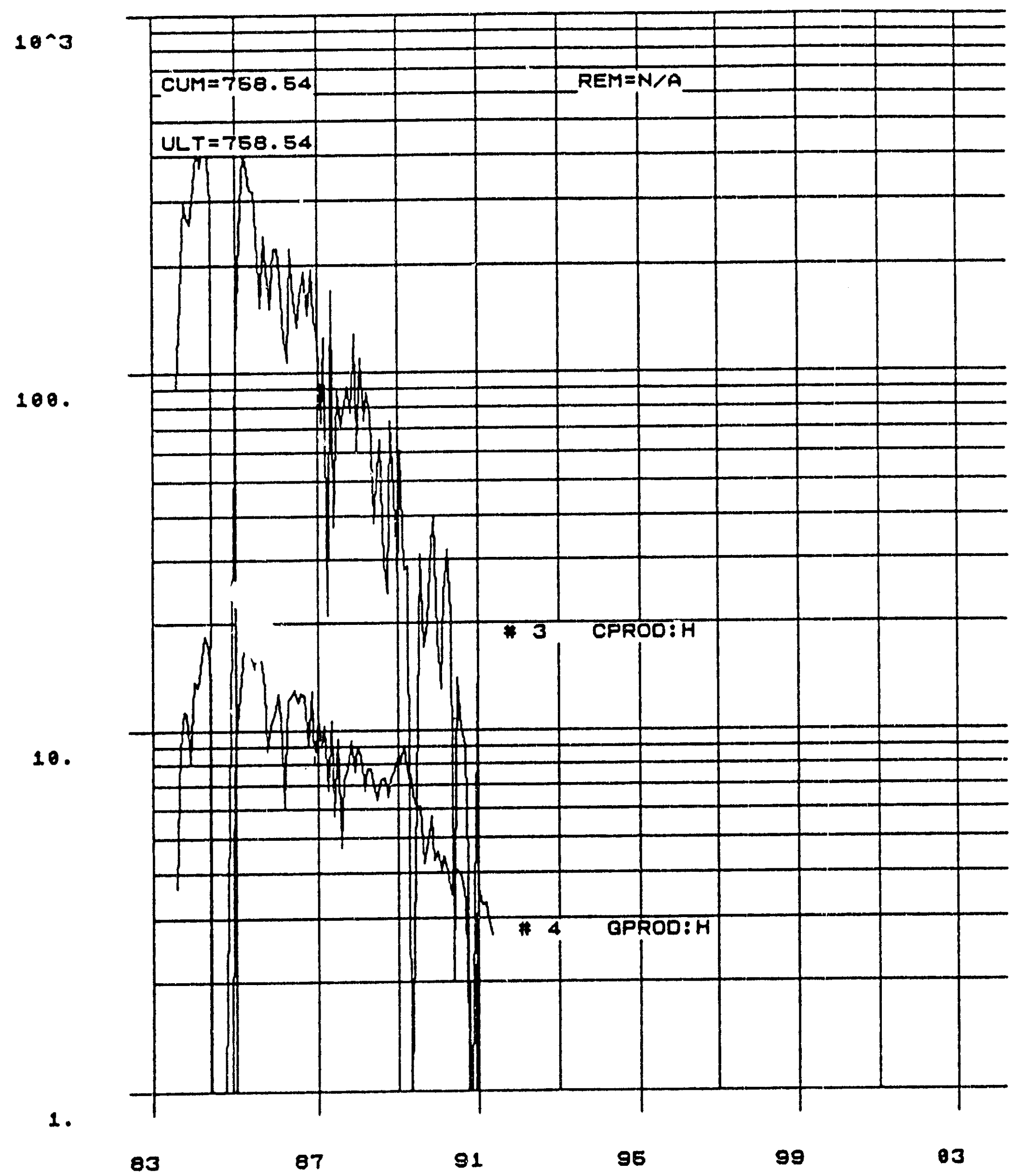

Figure 7. Production History, Aztec Petroleum Barclay 71-1. Top Curve = Condensate Production in BBLS/Month. Bottom Curve = Gas Production in MMCF/Month

Table 2. Acquisition Parameters - Lines 13 and 14

Contractor: Western Geophysical	
Instruments: DFS III	Date Recorded: December, 1978
Energy Source: Dynamite	Format: SEG A
Charge Weight: 20 Lbs.	Record Length: 6 Seconds
Shot Hole Depth: 70 - 90 Feet	Sample Rate: 2 MS
Shot Point Interval: 300 Feet	Geophone Type: Mark 10 HZ
Geophone Interval: 100 Feet	Channels/Record: 92
Field Filter: 12 - 124 HZ	Geophones/Trace: 12
Notch: In	CDP Coverage: 15-Fold

Spread:

Trace:	1	92	SP
Distance:	-9,300	-200	X Feet

The location of existing and in-progress seismic coverage can be seen in Figure 8. Seismic lines 13, 14, and 1-A are relatively deep shot-hole, 15-fold, dynamite data shot in the 1970s, primarily for resolution of deep structure. Lines 13, 14, and 1-A are approximately 12, 14, and 14.6 miles long respectively. They extend approximately 1.5 to 2 miles north and approximately 6 miles south of the PrimeEnergy acreage and provide full 15-fold coverage throughout the PrimeEnergy acreage. Only portions of the lines on or adjacent to the PrimeEnergy acreage are shown in Figure 8. Lines 13, 14, and 1-A have recently been re-processed using processing technology more amenable to the resolution of stratigraphic targets. Field acquisition parameters for lines 13 and 14 are listed in Table 2.

Despite their vintage, Lines 13 and 14, in particular, are very high quality data and clearly show a number of Lower Glen Rose porosity developments. However, only one of those porosity developments is within the PrimeEnergy acreage block. A schematic representation of that porosity development can be seen between shot points 2467 and 2443 in Figure 8. Line 1-A was recorded with an analog system, and hence, is of a lesser quality. Still, it too shows evidence of Lower Glen Rose porosity development.

Migrated and relative amplitude (RAP) seismic sections are presented for Line 13 in Figures 9 and 10 respectively. On the horizontal axis of Figures 9 and 10 are shot point numbers which correspond to

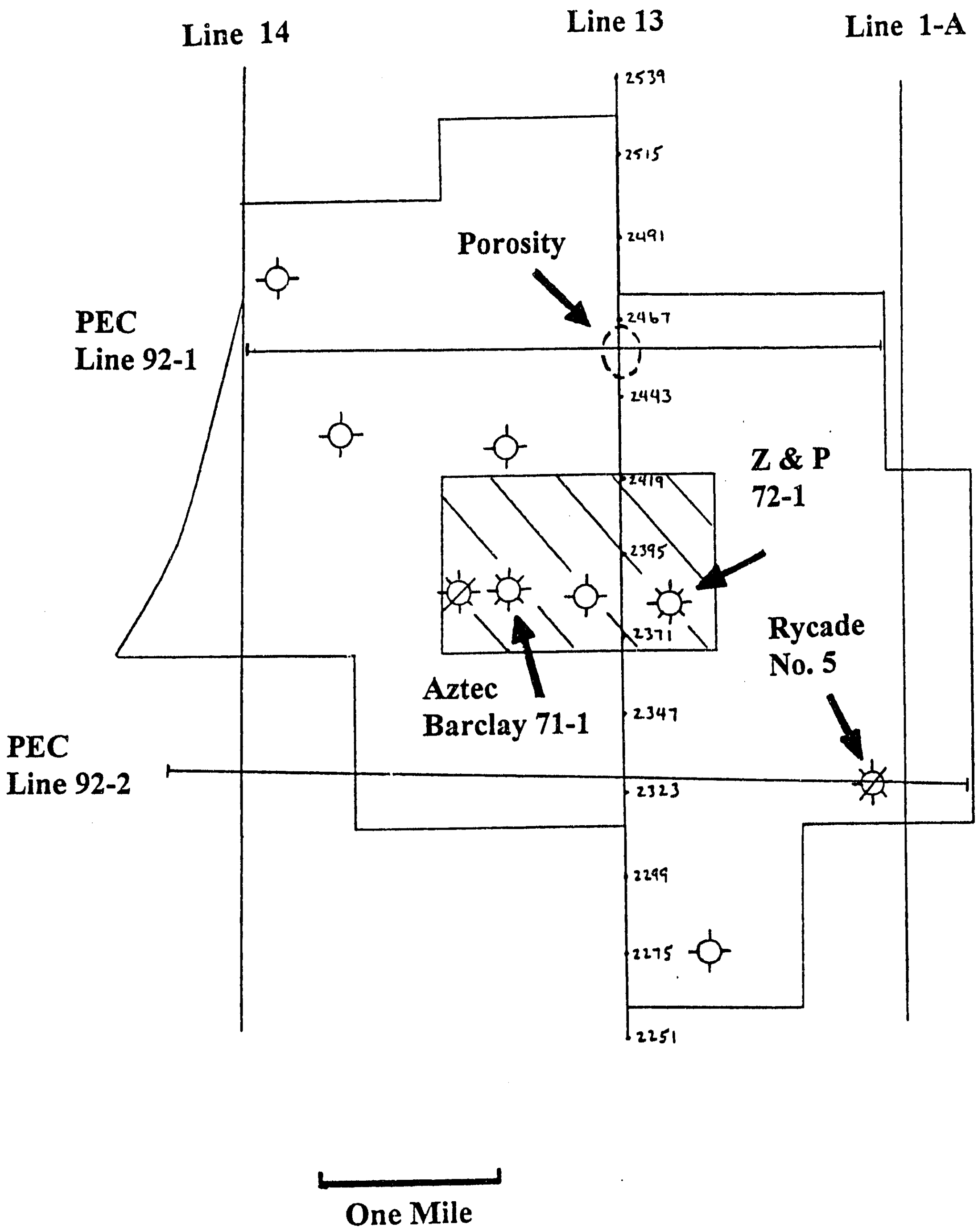

Figure 8. Acreage and Seismic Line Location Schematic with Lower Glen Rose Well Control and Known Lower Glen Rose Porosity Developments. Hachured Area = Held By Production. Vertical = North

those plotted in Figure 8; vertical axes are two-way travel time. Also marked on the sections are the top of the Lower Glen Rose (LGR) and selected other formations.

The migrated seismic data presented in Figure 9 have been processed as outlined in Table 3. The RAP-processed data presented in Figure 10 are not migrated and have had no automatic gain control applied. The RAP-processed data have been processed through steps 1 through 15 of Table 3.

Table 3. Processing Sequence for Line 13

1. Demultiplex
   Gain Correction
2. Trace Edit
3. Common Depth Point Gather
   Datum = 800 Feet
   V(E) = 8500 Feet/Second
4. Deconvolution
   Spike
   Zero Phase Output
5. Velocity Analysis
6. Initial Normal Moveout Correction
7. Initial First Break Correction
8. Automatic Statics
   Surface Consistent
   Window: 200 - 2000 MS
9. Receiver Edit
10. Velocity Analysis
11. Final Normal Moveout Correction
12. Final First Break Suppression
13. Automatic Statics
    Surface Consistent
    Window: 200 - 2000 MS
14. Stack
    15-Fold
15. Spectral Equalization
    10 - 110 HZ
    10 HZ Bands
16. FX Deconvolution
17. Migration
    Finite Difference
    100% Velos.
18. T/V Filter

HZ.	Time
15 - 95	0.0
12 - 85	0.6
12 - 75	1.2
10 - 55	2.0

19. Balance
    500 MS Window
20. Datum Adjustment
    Datum = 900 feet
    V(E) = 8000 Feet/Second

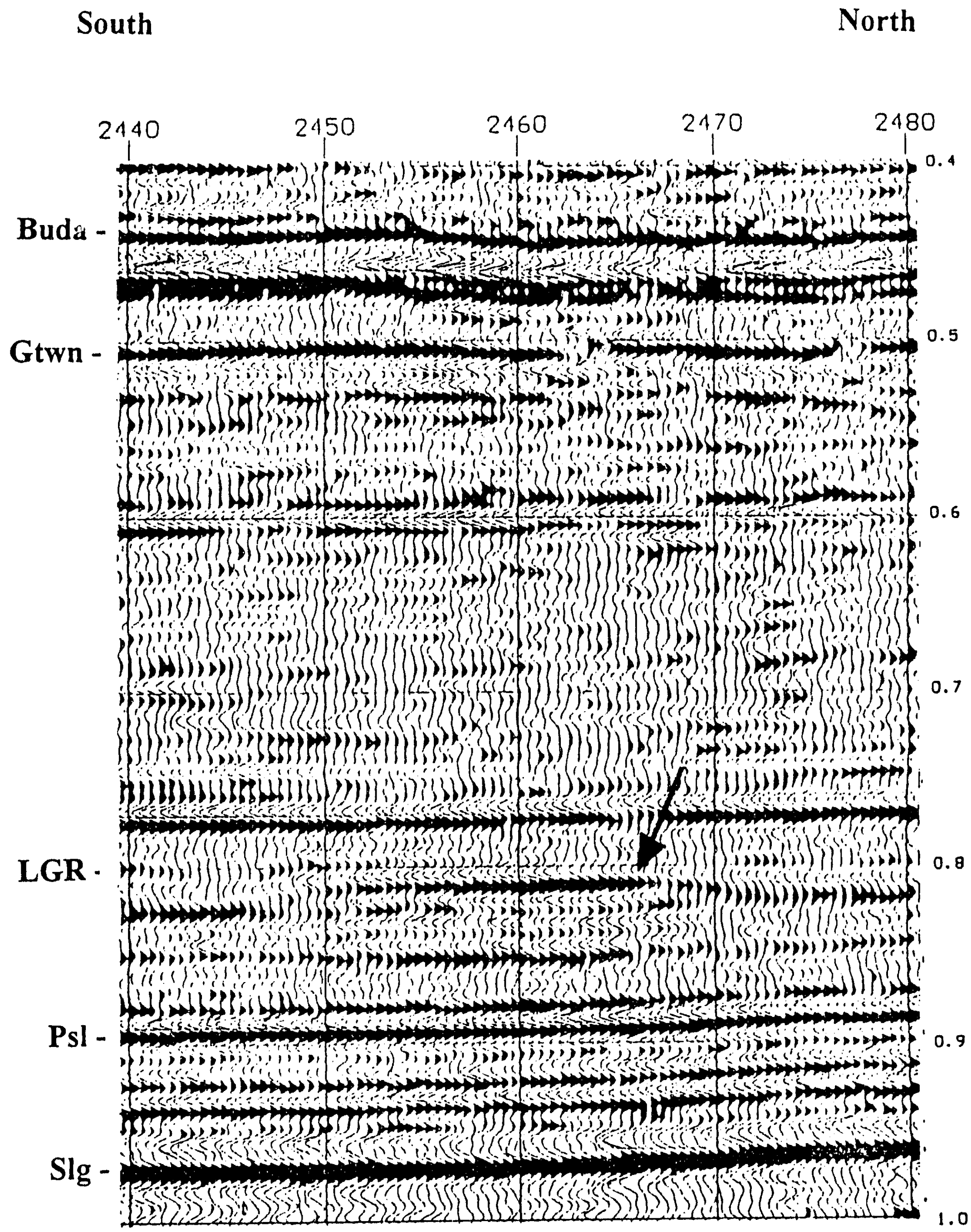

Figure 9. Migrated Seismic Section - Line 13. Horizontal Axis = Shot Point Number. Vertical Axis = 2-Way Travel Time in Seconds. Gtwn = Georgetown, LGR = Lower Glen Rose, Psl = Pearsall, Slg = Sligo

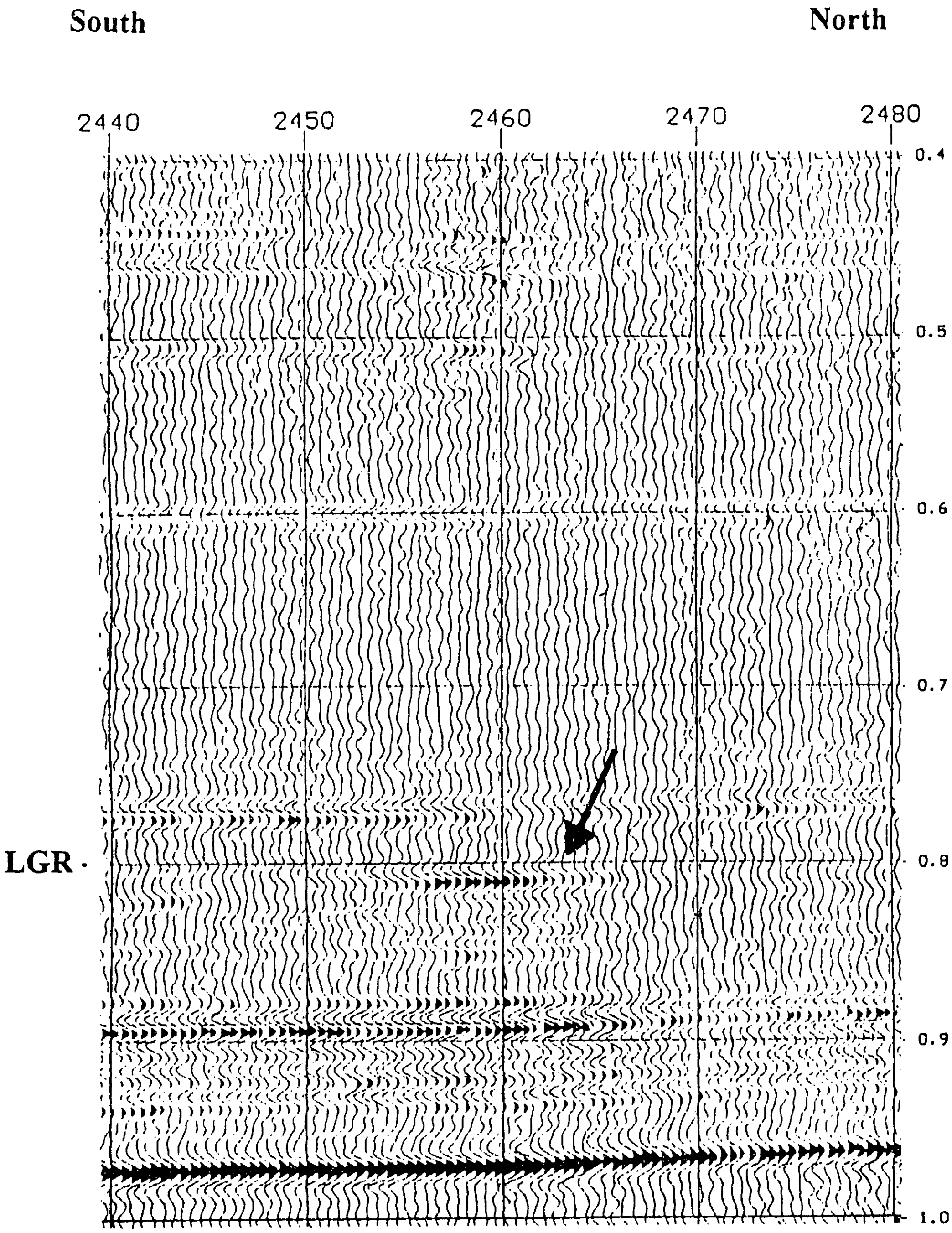

Figure 10. Relative Amplitude Processed Seismic Section - Line 13. Horizontal Axis = Shot Point Number. Vertical Axis = 2-Way Travel Time in Seconds. LGR = Lower Glen Rose

Since there has been no automatic gain control applied to the RAP-processed data, all seismic amplitudes have been uniformly amplified by the recording field amplifier. The data are gained down so that the largest amplitude on the section is not clipped. This results in a display where amplitudes are expressed relative to the largest amplitude on the section, which allows the interpreter to see more clearly lateral changes in seismic amplitudes such as those indicated by the arrows in Figures 9 and 10.

The anomaly resolved by Line 13 is centered two or three traces south of shot point 2460. This anomaly appears smaller than most of the known porosity developments outside of the PrimeEnergy acreage but is characteristic in essentially all other respects. The anomaly is characterized by a relatively large negative amplitude event followed by a relatively large positive amplitude event corresponding roughly with the top and the bottom of the porous zone respectively. See Stanulonis and Tran (1992) and Morgan, et al (1982) for excellent case studies of porosity identification using seismic amplitude data.

Processing of PEC (PrimeEnergy) lines 92-1 and 92-2 is in progress at the time of this writing. PEC Lines 92-1 and 92-2 utilize a Vibroseis source with acquisition parameters developed by Servos Exploration Associates. Those parameters are outlined in Table 4. The processing sequence for PEC Lines 92-1 and 92-2 is similar to that outlined in Table 3.

Table 4. Acquisition Parameters - PEC Lines 92-1 and 92-2

Contractor: Western Geophysical
Instruments:
MDS-16 with fiber optic distributed recorder with summer and correlator
Energy Source:
Vibroseis system utilizing four LRS-15 (23.5 ton) vibrators with Pelton Advance I electronics
Vibrator Interval: 165 Feet
Geophone Interval: 82.5 Feet
Sweeps/Vibrator Point: 12, non-linear
CDP Coverage: 30-Fold

Field Filter: 8 - 128 HZ
Notch: Out
Format: SEG - B
Record Length: 17 Seconds
Sample Rate: 1 MS
Geophone Type: Geospace 20D 10 HZ
Channels/Record: 120
Geophones/Trace: 24
Sweep Length: 12 Seconds

Spread:

Trace:	1	-	60	VP	61	-	120	
Distance:	-6,820		-330	X	330		6,820	Feet

One objective of PEC lines 92-1 and 92-2 is to further define the size and shape of the porous body centered near shot point 2460 on Line 13 as it is possible that the porous body is larger than is sketched in Figure 8. Other objectives are to tie to the Sullivan Rycade No. 5 well and to search for additional porosity developments on the PrimeEnergy acreage between existing well control.

FUTURE WORK

Drilling Location Selection

If one or more significant porosity developments are resolved by PEC Lines 92-1 and 92-2, a north-south-oriented vibroseis line will be shot over the largest of them to further define it. If no favorable locations are defined by PEC Lines 92-1 and 92-2 and provided that the anomaly at shot-point 2460 on Line 13 is too small to be of interest, PrimeEnergy will attempt to obtain a location adjacent to the existing 10,218-acre farmout, on one of the porous bodies already known from existing seismic coverage.

The following discussions of drilling, completion, and logging plans are excerpts from the PrimeEnergy - Grace, Shursen, Moore & Associates drilling program (modified after Rich Carden, 1992).

Drilling

Because the exact depth and thickness of the Lower Glen Rose porosity cannot be derived from the seismic data, the well will be drilled vertically through the Glen Rose pay and then logged. Open hole logs will be used to precisely define the target interval for the horizontal section of the wellbore. The borehole will have an azimuth approximately perpendicular to the long dimension of the targeted porous body and will cross the target interval as far updip as is practical. Seismic control in Chittim field suggests that the porous bodies are typically oriented with their long dimensions approximately north-south. It is currently thought that the azimuth of the horizontal section will be between approximately 225 and 270 degrees.

After open hole logging, the hole will be plugged back to the intermediate casing point and kicked off building angle at 12.5 degrees per 100 feet of measured depth. The target is expected to be at least 20 to 30 feet thick but will be refined with the results of open hole logging.

The horizontal section will be drilled with water as circulating fluid to minimize the the possibility of formation damage. Virgin reservoir pressure is greater than the hydrostatic gradient and so the well may be drilled underbalanced. It is also possible, due to local production, that reservoir pressure may be less than the fresh water gradient. The drilling rig fluid system will be rigged to drill flowing should it become necessary.

A wellbore schematic is presented in Figure 11. The Texas Water Commission requires that fresh water at 225 feet be isolated with surface casing. A string of 10 3/4-inch surface casing will be set at 400 feet to isolate the fresh water. An intermediate casing string will be required

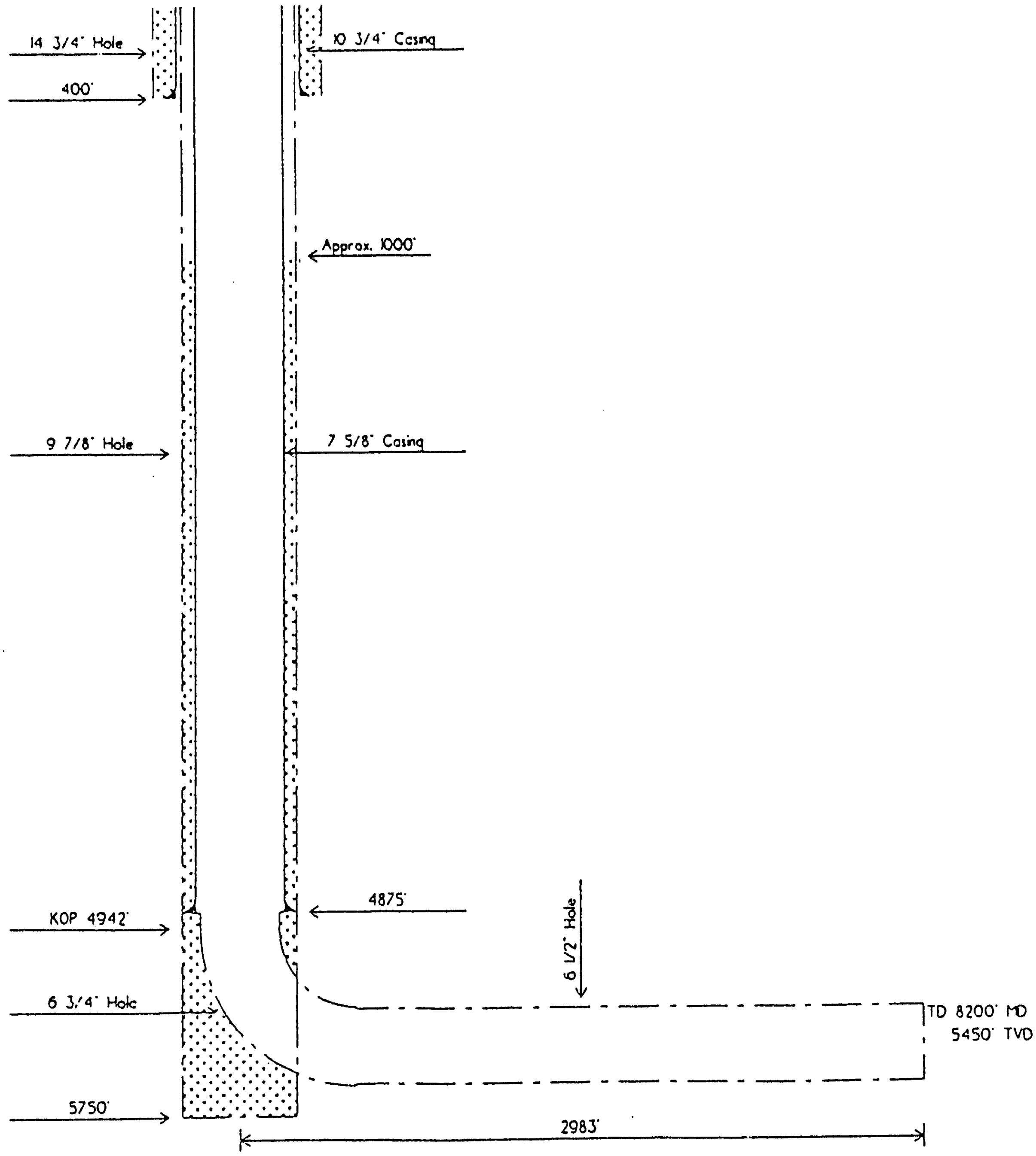

Figure 11. Wellbore Design Schematic

just above the kickoff point to isolate shale sections. It will also provide a sufficiently high frac gradient should the well be drilled underbalanced. The 7 5/8-inch intermediate casing will be set at approximately 4,875 feet with the exact depth to be determined with open hole logs.

After setting surface casing, a 9 7/8-inch hole will be drilled to approximately 5,800 feet and open hole logs will be run. Once the well is logged, it will be plugged back to a depth of approximately 4,942 feet and kicked off. A 6 3/4-inch angle-build section will then be drilled. A 50-foot true vertical depth tangent section is planned at 60 degrees to allow for small differences in planned and actual build rates. The hole size will be reduced to 6 1/2-inches in the horizontal section to minimize required reaming. The horizontal section will be drilled from a total measured depth of approximately 5,762 to 8,200 feet, or completely out of the Lower Glen Rose porosity, whichever is less. This will provide up to approximately 2,400 feet of horizontal section in the target zone.

After reaching total depth, the well is to be logged. No casing will be placed in the horizontal section until the well has been tested open hole. The open hole tests will be designed to show gas entry points. The exact completion strategy will depend upon the volume of gas entering the borehole and the location of the entry points. Total time to drill the well is expected to be 28 days from spud to rig release as is shown in Figure 12.

Completion

The current plan is to test the Lower Glen Rose as an open hole completion. The test would allow the overall productive capability of the formation to be evaluated. If flow rates are greater than 2 MMCF/Day, the pay zone will not be stimulated at least until sustained production has been evaluated. During the flow test, a temperature survey will be run to determine where the gas is entering the wellbore. The temperature survey will be correlated with the open hole logs and a completion strategy will be devised. Until the well has been tested and the logs evaluated, it is not possible to determine the best completion strategy. By initially utilizing an open hole completion all options are left open. Those options would be:

(1) Continue to produce open hole. Limited stimulation capabilities are available with an open hole straddle packer assembly. Acidizing isolated zones would be the preferred stimulation method.

(2) Run a slotted liner. No individual zone isolation and stimulation would be possible. An acid wash would be the only alternative.

(3) Run a 4 1/2-inch production string and cement it in place. Perforate and stimulate individual zones. Perforating would be very expensive. Stimulation would involve acidizing and/or fracturing.

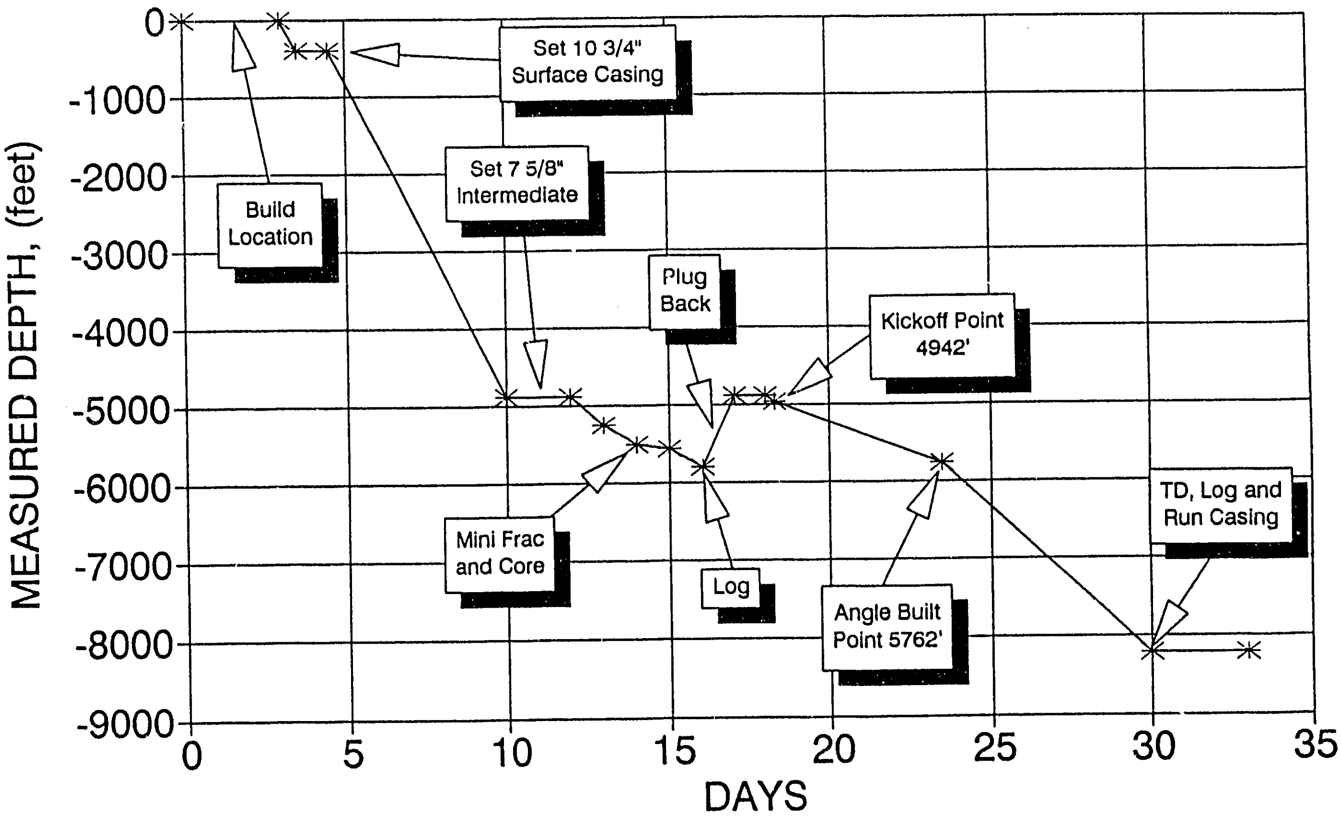

Figure 12. Drilling Schedule - Measured Depth vs. Days. PrimeEnergy/DOE La Paloma Horizontal Drilling Project

(4) Run a 4 1/2-inch production string with external casing packers and port collars. Stimulate individual zones by acidizing and/or fracturing.

Logging Program

The Logging program is designed to determine the potential productivity of the Lower Glen Rose as well as to provide data for seismic modeling and tying the well to the seismic data base. Since the primary production comes from porosity and permeability, porosity logs will be most useful. Resistivity logs will indicate water saturations and the sonic and density tools will provide the link with the seismic database. The logging program is listed by hole section below in Table 5.

Table 5. Logging Program

Surface to 400 feet	No logs
Intermediate hole to 5,750 feet	Dual Induction Gamma Ray SP Dual Spaced Neutron Spectral Density Sonic Caliper
Horizontal wellbore to 8,200 feet	Dual Induction Gamma Ray SP Dual Spaced Neutron Spectral Density Sonic Caliper

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