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**ANALYSIS AND EVALUATION OF INTERWELL SEISMIC LOGGING
TECHNIQUES FOR RESERVOIR CHARACTERIZATION**

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OBJECTIVE

The objective of this three-year research program is to investigate interwell seismic logging techniques for indirectly interpreting oil and gas reservoir geology and pore fluid permeability. This work involves a balanced study of advanced theoretical and numerical modeling of seismic waves transmitted between pairs of reservoir wells combined with experimental data acquisition and processing of measurements at controlled sites as well as in full-scale reservoirs. This reservoir probing concept is aimed at demonstrating unprecedented high-resolution measurements and detailed interpretation of heterogeneous hydrocarbon-bearing formations.

SUMMARY OF TECHNICAL PROGRESS

Task 3 - Data Processing and Analysis

Geological and Petrophysical Analysis of the Interval From 800 to 1100 Feet in Five Wells at the Gypsy Test Site

INTRODUCTION

This part of the project is a geological and petrophysical analysis of the interval from 800 to 1100 feet in five wells at the Gypsy test site. A detailed analysis was made of the 9-7, 5-7, and 7-7 wells, and a preliminary analysis was made of the 1-7 and 11-7 wells. The study identified and characterized low velocity and high velocity zones that appear to be continuous across the test site. This data will be used to interpret the interwell seismic data acquired across the interval 800 to 100 ft., and to plan continuity logging measurements.

METHODOLOGY

1. Geological and petrophysical data available on the Gypsy test site were examined at the University of Oklahoma. Pertinent files were copied.
2. Digital log data were acquired. Floppies were obtained from Schlumberger's Logging Center in Denver. The University of Oklahoma (OU) has the data on 9-track tapes. However, because of the conversion routines necessary to put the data on floppies, it was necessary to acquire the data from Schlumberger. The data for the 5-7 well was not in Schlumberger's archives and it was not on OU's the 9-track tapes. As a consequence, the log curves were digitized by QC Data in Houston.
3. The following curves were loaded into the Terrasciences log analysis program: sp, gamma ray, phaser medium induction, phaser deep induction, unaveraged spherically focused, caliper, tension, bulk density, bulk density correction, density porosity, photoelectric factor, neutron porosity, Δt , Δt compression, and Δt shear. Δt long and Δt far were available for some wells.

4. The appropriate gamma ray and sonic curves were selected for analysis. Three gamma ray curves were available for each well (from the induction, density, and sonic log passes). Comparison of the curves showed the gamma ray from the density pass to have the best resolution (because of the slow logging speed and the tool being eccentered). Anywhere from 1 to 4 Δt curves were available for each well (Δt , Δt long, Δt far, and Δt compression). Comparison of the curves and discussions with a Schlumberger engineer resulted in the Δt curve being used for Δt compression. (This curve had a shorter transmitter-receiver spacing and therefore has less cycle skipping.) For the 5-7 well only one Δt curve was available (Δt compression).

5. The gamma ray curve was corrected for borehole diameter and mud weight. It was the only curve that required additional environmental corrections. Environmental constants were determined for each well and added to the log analysis program.

6. Shale volume was calculated from the gamma ray and sp curves. The gamma ray method gave more accurate shale volumes and was therefore used.

7. Density and neutron porosities were recomputed using a sandstone matrix.

8. Sonic porosity was calculated with both the Wyllie and Raymer-Hunt transforms.

9. Density, neutron, density-neutron crossplot, and sonic porosities were corrected for the effect of shale.

10. Core porosity and permeability were adjusted to the correct log depth by comparing the core gamma ray with the log gamma ray. The following adjustments were made: 104 feet was added to the core depths of the 1-7; 4.5 feet was added to the core depths of the 5-7; for the 7-7 well 4 feet was added down to a core depth of 972.5 feet, and 2 feet was added down to a core depth of 997.8 feet, the 9-7 was on depth, and for the 11-7 well 2 feet was added to the core depths down to 968 feet, and 1 foot was subtracted from the core depths below 968 feet.

11. Δt compression and Δt shear were converted to velocity (feet per second).

12. For the 5-7 well, the Δt compression values were invalid from 1038 to 1072 feet. The Δt compression values from the repeat pass were substituted for this interval.

13. Relative proportions of sandstone, shale dolomite, and porosity were calculated using Terrascience Petra Lithologic Analysis program. The program uses the overdetermined case condition:

$$N + 1 > M$$

where:

N = the number of log curves

M = the number of lithology and porosity equations solved for in the program.

TABLE I. CURVES AND LOG CONSTANTS USED TO CALCULATE LITHOLOGY

	Sandstone	Dolomite	Shale	Porosity
Gamma Ray (API units)	20.0	25.0	145.0	20.0
Bulk Density (g/cm³)	2.65	2.87	2.55	1.0
Neutron Porosity	-0.05	0.08	0.35	1.0

Dolomite was included because petrographic analysis of thin sections showed it to be present. Several combinations of constants and lithologies were computed. This combination was used because it was consistent with the geology of the section and it gave the lowest **sum deviation** in the Petra program. Sum deviation calculates how far the computed lithology departs from a mathematically perfect solution. Values generally ranged from 0.0 to 5.0 for these wells, which is an excellent fit. The gamma ray value for shale was 120 API units for the 11-7 and the 1-7 wells.

14. Three log displays were prepared for each of the five wells.

Display 1: sp, gamma ray, caliper, induction logs, core porosity, three shale corrected porosity curves (density-neutron crossplot and sonic porosity from the Wyllie and Rayner-Hunt transforms), and core permeability.

Display 2: calculated lithology, Δt , Δt shear, sonic compression velocity, sonic shear velocity, density-neutron crossplot porosity corrected for shale volume, core porosity, and caliper.

Display 3: core permeability, gamma ray, sonic compression velocity, density-neutron crossplot porosity corrected for shale volume, and core porosity.

15. Twelve graphs were constructed for the 9-7, 5-7, and 7-7 wells. A curve fitting routine was applied to the data only in those cases where there was some semblance of a meaningful relationship. For some graphs the log curves are also displayed. In the log column, core values appear as isolated lines. The data points within a boxed area on a graph are highlighted on the corresponding log curves as short horizontally lines. They are always the sandstones. The following graphs were constructed:

Sonic compression velocity (VE) vs. core permeability (PERM)

1. Regression of X vs. Y, X dependent
2. Regression of X vs. Y, Y dependent
3. Regression by Reduced Major Axis
4. Sonic compression velocity (VE) vs. density-neutron crossplot porosity corrected for shale volume (DNPISHC)
5. Sonic compression velocity (VE) vs. core porosity (PHI)
6. Sonic shear velocity (VS) vs. core permeability (PERM)
7. Sonic shear velocity (VS) vs. density-neutron crossplot porosity corrected for shale volume (DNPISHC)
8. Sonic shear velocity (VS) vs. core porosity (PHI)
9. Density-neutron crossplot porosity corrected for shale volume vs. core permeability (PERM)

Core porosity (PHI) vs. permeability (PERM)

10. Regression of X vs. Y, X dependent
11. Regression of X vs. Y, Y dependent
12. Regression by Reduced Major Axis
16. Two cross-sections were prepared of the interval from 800 to 1100 feet (9-7, 5-7, 7-7, and 1-7, 11-7, 7-7). Each cross-section contains the calculated lithology and the sonic compression velocity (VE). The distance from 9-7 to 7-7 is 210 meters; from 1-7 to 7-7 it is 150 meters. Five high velocity (HV) zones and four low velocity (LV) zones are correlated across each cross-section. Low velocity zone 3 and high velocity zone 3 are not present in every well. Table 2 contains the zone boundaries. The zones are also marked on log display 3.
17. The water saturation for each sandstone is 100%.

Interpretation

1. In general, the quality of the log data is good. The boreholes have very few washouts, except for some 1 to 12 inch washouts across some of the shale beds.
2. The quality of the main-pass sonic log is poor in the 1-7 well. However, there is a repeat pass which has better data.

3. The shear wave data is of poor quality for large portions of each well (log display 2). The intervals are usually the low velocity zones, which are shales. Shear velocities are attenuated so much by shale that the logging program is having a very difficult time picking the value. If necessary, the raw data could be reprocessed in an attempt to refine the shear velocities.
4. The Raymer-Hunt transform calculates sonic porosity values that are about 3 porosity units higher than the Wyllie transform. Overall, the fit of each porosity curves with the core porosities is the same.
5. The Gypsy sandstones contain a considerable amount of shale, as evidenced by the log analysis, core photographs, and limited petrographic analyses. This shale significantly affects the neutron and sonic porosity curves, but does not have much of an effect on the density porosity. Shale volume corrections significantly improved the accuracy of the porosity calculations.
6. The Gypsy sandstone interval (HV 4) is composed of a series of stacked channel sandstones, mudstones, and siltstones. Correlation of individual sandstone units between wells is uncertain and very difficult. Sandstone will probably be continuous somewhere within this interval between wells, but it will contain a number of sand bodies that may have different petrophysical properties.
7. There are, however, 6 intervals that have a very high degree of probability of being continuous between wells (HV 1, LV 1, HV2, LV 2, HV 5, and LV 4). Each high velocity zone is overlain with a low velocity zone. The velocity contrast between the two varies from 2,000 to 6,000+ feet per second. Unfortunately, none of these intervals was cored. However, the porosity and permeability of the low velocity zones, which are mudstones and siltstones, will be almost zero. The density-neutron crossplot porosity corrected for shale will give accurate porosities for the high velocity zones. HV 3 and LV 3 are continuous across many, but not all the wells.

TABLE 2. BED BOUNDARIES FOR THE HIGH AND LOW VELOCITY ZONES

	9-7	5-7	7-7	11-7	1-7
HV 1	1046-52	1069-72	1060-68	1062-72	1075-81?
LV 1	1028-46	1052-69	1044-60	1049-67	1060-75?
HV 2	1010-17	1029-38	1022-34	1027-36	1038-43?
LV 2	1001-10	1022-29	1015-22	1022-27	1025-38?
HV 3	-----	-----	1000-04	1006-12	1016-25?
HV 4	906-58	926-994	916-92	925-94	938-89
LV 3	904-06	-----	910-16	-----	935-38
HV 5	866-70	885-90	877-81	886-90	897-901
LV 4	854-66	873-85	865-77	874-86	885-97

8. There is a very good correlation between porosity (core or log) and permeability.

9. There is not a good correlation between sonic velocity (compression or shear) and porosity or permeability. The shale volume in the sandstones is a large contributor to this lack of correlation. It was therefore useless to run regression analysis on most of the graphs.

LIST OF FIGURES

- FIGURE 1. Crossplot for Dallas 9-7. Compressional wave velocity vs. density-neutron porosity. Both are corrected for shale volume.
- FIGURE 2. Crossplot for Dallas 5-7. Compressional wave velocity vs. density-neutron porosity. Both are corrected for shale volume.
- FIGURE 3. Crossplot for Dallas 7-7. Compressional wave velocity vs. density-neutron porosity. Both are corrected for shale volume.
- FIGURE 4. Cross-section through the Dallas 9-7, 5-7, and 7-7.
- FIGURE 5. Cross-section through the Dallas 1-7, 11-7, and 7-7.

FIGURE 1.

Well Name: DALLAS 9-7
 Date of X or Y: SONICUSC
 Date of X or Y: DNPISHC
 Date of X or Y: 111
 Date of X or Y: 15.26
 Date of X or Y: 11487.
 Date of X or Y: 15.26

FIGURE 2.

Well Name: DALLAS 5-7

TLOG 5.1 BHA 03/23/93 31

Slump: -.006 Incl: 84.723 Corr Out: -.869

Depth: 900.00 to 990.00 by .50 feet

SONICVSC --- Y Axis: DNPISHC 118 of 181 Plot pulled

Core Index: None

Plot interval 1

11497.

15.01

FIGURE 3.

Well Name: DALLAS 7-7

Depth: 915.00 ft

Time: 86.636

Date: 02/28/93

Corr Out: -.837

X Axis: SONICUSC Y Axis: DNPISHC 124 in 161 PLS plotted

Coordinate: Feet

Plot point 1

11497. 15.01

Well Name: DALLAS 9-7

Well Name: DALLAS 5-7

Well Name: DALLAS 7-7

CROSS-SECTION THROUGH THE DALLAS 9-7, 5-7, AND 7-7
Gypsy Test Site, Pawnee County, Oklahoma
(Selected zones that appear to be continuous between the three wells.)

Well Name: DALLAS 1-7

Well Name: DALLAS 11-7

Well Name: DALLAS 7-7

CROSS-SECTION THROUGH THE DALLAS 1-7, 11-7, AND 7-7
 Gypsy Test Site, Pawnee County, Oklahoma
 (Selected zones that appear to be continuous between the three wells.)

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		O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	Q2	Q3	Q4	Q1	Q2	Q3	Q4			a. Plan	b. Actual
101	Layered Model																										
102	Permeable Model																										
103	Plan Field Tests																										
104	Modify Equip't																										
105	Conduct Tests																										
106	Analyze Results																										
201	Numerical Model																										
202	Plan Field Tests																										
203	Conduct Tests																										
204	Analyze Results																										
301	Plan Field Tests																										
302	Conduct Tests																										
303	Analyze Results																										
107/205 304	Review Mtgs																										
108/206 305	Reporting																										
11. SIGNATURE OF PARTICIPANT'S PROJECT MANAGER AND DATE <i>Jose O. Ponce</i> April 15, 1993																											