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TITLE: APPLICATION OF RESERVOIR CHARACTERIZATION AND ADVANCED TECHNOLOGY TO IMPROVE RECOVERY AND ECONOMICS IN A LOWER QUALITY SHALLOW SHELF CARBONATE RESERVOIR

Cooperative Agreement No.: DE - FC22 - 94BC14990

Contractor Name and Address: Oxy USA, Inc. (Oxy), Midland, Texas

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OBJECTIVES

The Class 2 Project at West Welch was designed to demonstrate the use of advanced technologies to enhance the economics of improved oil recovery (IOR) projects in lower quality Shallow Shelf Carbonate (SSC) reservoirs, resulting in recovery of additional oil that would otherwise be abandoned. Accurate reservoir description is critical to the effective evaluation and efficient design of IOR projects in the heterogeneous SSC reservoirs. Therefore, the majority of Budget Period 1 was devoted to reservoir characterization. Technologies being demonstrated include:

1. Advanced petrophysics
2. Three dimensional (3-D) seismic
3. Cross-well bore tomography
4. Advanced reservoir simulation
5. Carbon dioxide (CO_2) stimulation treatments
6. Hydraulic fracturing design and monitoring
7. Mobility control agents

DISCLAIMER

SUMMARY OF TECHNICAL PROGRESS

West Welch Unit is one of four large waterflood units in the Welch Field located in the Northwestern portion of Dawson County, Texas. The Welch Field was discovered in the early 1940's and produces oil under a solution gas drive mechanism from the San Andres formation at approximately 4800 ft. The field has been under waterflood for 30 years and a significant portion has been infilled drilled on 20-ac density. A 1982-86 pilot CO_2 injection project in the offsetting South Welch Unit yielded positive results. The recent installation of a CO_2 pipeline near the field allowed the phased development of a miscible CO_2 injection project at the South Welch Unit.

The reservoir quality is poorer at the West Welch Unit because of its relative location of sea level during deposition. Table 1 compares reservoir parameters between the two units and shows their ranking in relation to all SSC reservoirs listed in the TORIS database. Because of the proximity of a CO_2 source and the CO_2 operating experience that would be available from the South Welch Unit, West Welch Unit was an ideal location for demonstrating methods for enhancing economics of IOR projects in lower quality SSC reservoirs. This Class 2 project concentrates on the efficient design of a miscible CO_2 project based on detailed reservoir characterization from advanced petrophysics, 3-D seismic interpretations and cross wellbore tomography interpretations.

PETROPHYSICAL ANALYSIS

Initially, the productive San Andres interval at West Welch was divided into eight rock types based on geological analysis of thin sections prepared from core data across the field. As part of the West Welch Class 2 project, two observation wells were drilled in the demonstration area and core samples provided to D. K. Davies for detail petrophysical analysis. This analysis indicated four distinct rock types in the area of interest and this was confirmed by capillary pressure measurements which also indicated four rock types. These rock types are more correctly pore throat radius groupings distinguished by linear trends on plots of permeability versus a pore group relationship expressed as:

$$\text{pore group value} = \frac{\phi r^2}{4} \qquad (1)$$

Where ϕ = porosity, r = pore throat radius.

The slopes of the linear relationships are the Kozeny tau variables. Therefore a relationship should exist between permeability, cementation exponent and possibly the saturation exponent. The best results to date, have been obtained in the lower permeability ranges using the Nugent method with resistivity porosity instead of sonic porosity. The higher permeability ranges have been in error by a factor of two. This is probably because the higher permeability rock is more intermediate oil wet. Investigation in this area continues. Additional work was conducted on log data using

neural networks for the logs from the observation wells. Results of the neural network analysis also show four clusters indicating the methodology can be transferred to log analysis.

3-D SEISMIC INTERPRETATION

Oxy provided previously acquired 3-D seismic data over the study area which was subject to specialized processing to enhance the stratigraphic interpretability in the San Andres formation. To increase confidence in the correlation between 3-D seismic data and well data, vertical seismic profiles (VSP) were acquired in the two observation wells drilled for the project. The methodology used and the results of the stratigraphic interpretation and the estimation of log properties from seismic attributes has been previously reported. The 3-D seismic interpretation will be tied to the tomography interpretation once the tomographic processing is complete.

CROSS WELLBORE TOMOGRAPHY

An extensive area of cross wellbore tomography incorporating 15 lines has been acquired. The locations of the lines are shown in Fig 1. Compressional wave and shear wave data were acquired along with interwell seismic reflection profiles. Processing and interpretation of the data is ongoing.

Figure 2 shows a preliminary tomogram from a compressional wave velocity tomography line. Compressional wave tomography data has been used to create synthetic sonic logs at 50 ft intervals between wells. Fig 3 shows a comparison of an actual sonic log and the synthetic sonic log from tomography data. A difference in the absolute velocities of the tomography data and the sonic log have been noted. Although there are differences in absolute velocities, the tomography data appears to give a reasonable correlation with the sonic log from the tomography source well.

Vertical resolution of the tomography data is expected to be approximately 5 ft when processing is complete. Future efforts include combining the tomography, seismic and wellbore data to get a detailed reservoir description.

A problem was encountered with running the tomography tools in the sour gas environment of West Welch. The seismic tools had not previously been exposed to H_2S for extended periods. As a result, acquisition of tomography data took longer and cost more than expected. However, the first set of 15 lines was completed and data quality is excellent.

RESERVOIR SIMULATION

The design of an efficient miscible CO_2 project is largely dependent upon the predictive power of the reservoir simulator. The single most important aspect of the simulator will be the geological model which is the objective of the extensive reservoir characterization effort now underway. An important aspect of this process is the step

by step evaluation of the model as it becomes increasingly sophisticated. The initial geologic model was based on the correlation of well logs. This was improved by the use of sequence stratigraphy which allowed for the pinch-out of zone between wells. The geologic model was further improved by including the advanced petrophysical results as to rock types. Next, the 3-D seismic interpretation will be added to the model followed by the tomography interpretation. This step-wise approach will allow the advantages of a particular technology to be quantitative. It will also allow a "look back" approach to determining how the conventional wellbore data could be utilized to get a more accurate reservoir characterization.

CO_2 STIMULATION TREATMENTS

The performance results from the first four CO_2 stimulated wells have proven to be disappointing. The wells have exhibited little are no production increase as a result of the treatments which range from the injection of 5 to 10 MMCF of CO_2 followed by a several day soak period before the wells were flowed back. The results were a little more positive on the fifth well which was injected with 15 MMCF of CO_2 (largest treatment to date) toward the end of the first quarter of 1995. Injection surveys run on the fifth well show that the CO_2 was injected over most of the pay interval. Conversely projection surveys during flow back showed production coming from only the top portion of the pay interval. The reservoir characterization work now underway may help in understanding the results of the CO_2 stimulation treatments. Monitoring of the performance of all 5 wells is continuing.

HYDRAULIC FRACTURING

After 30 years of waterflood operations, the general orientation of inducted fractures in the formation is well understood and the injection patterns have been orientated accordingly. Part of the technology to be demonstrated in this project is the alignment of induced fracture wings along the row of injectors to create a more linear flood front to increase sweep efficiency along with injection rate. This requires the ability to design fracture treatments that will maximize the fracture wing length while keeping the fracture height within zone.

The initial fracture treatment was applied to Well No. 4807 in June, utilizing a frac design worked out jointly by Oxy and Halliburton. The sand was tagged with radioactive material for determining proppant placement and height. Passive seismic techniques were used to map the fracture. Post treatment logging indicated that the proppant was kept in zone. The passive seismic results are not yet available. The information gathered from this treatment will be used to further optimize fracture treatment design in preparation for the CO_2 injection project under Budget Period 2.

TECHNOLOGY TRANSFER

During this quarter, three presentations were made to industry groups concerning the geophysical/geological aspects of the project. In May, Mr. George

Watt made an informal presentation of the geophysical aspects of the West Welch demonstration project to the West Texas Geophysical Society. Also in May, Mr. Jim Justice made a presentation concerning the tomographic aspects of the project to a joint SEG/AAPC/SPE meeting in San Francisco. In addition, Mr. Justice included some aspects of the demonstration project in a SEG short course he taught in Lafayette, Louisiana in April.

TABLE 1

Comparison of Welch Study Area
with other
San Andres SSC Reservoirs
Based on Toris Database

Average Reservoir Parameter	West Welch Unit		South Welch Unit	
	Value	Ranking (%)	Value	Ranking (%)
Net Pay, ft.	65	40	101	20
Porosity, %	11.7	40	15.5	10
Permeability, md	1.7	90	4.4	60
Kh, md-ft.	110.5	80	444.4	30
Øh, ft.	7.6	40	15.65	10

(Ranking is percentage of reservoirs with higher values)

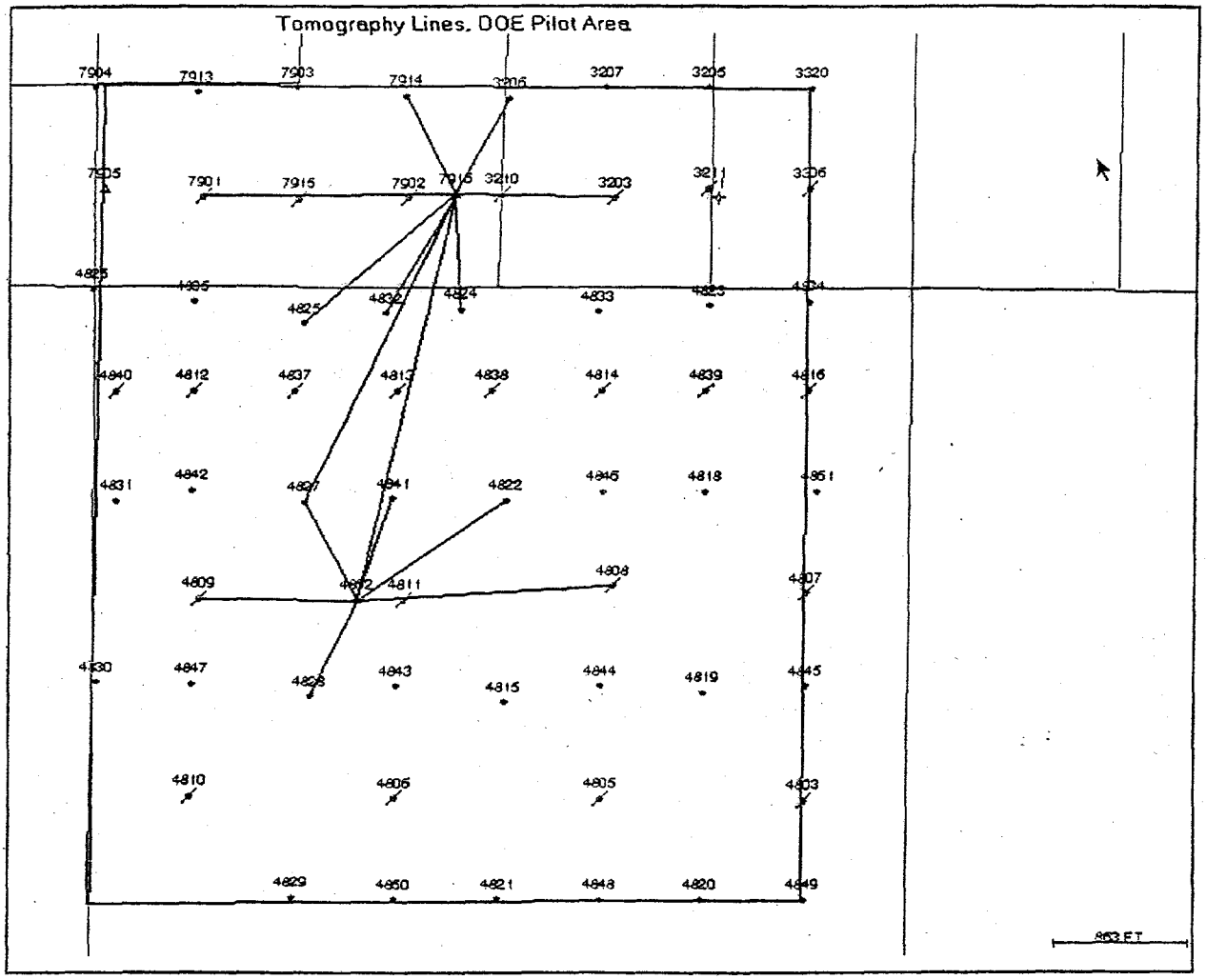


Fig. 1 Tomography Acquisition Lines - West Welch Demonstration Area

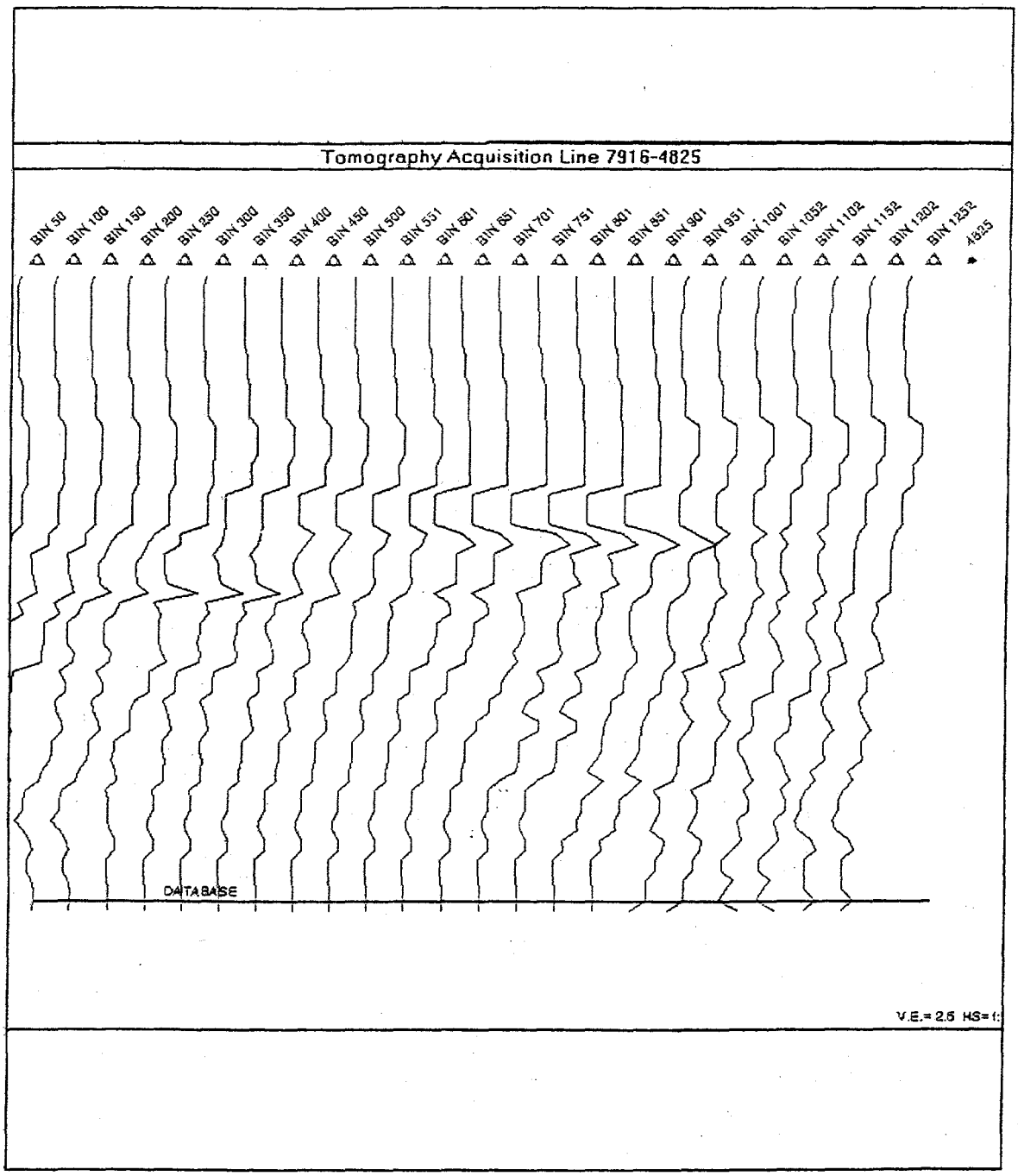
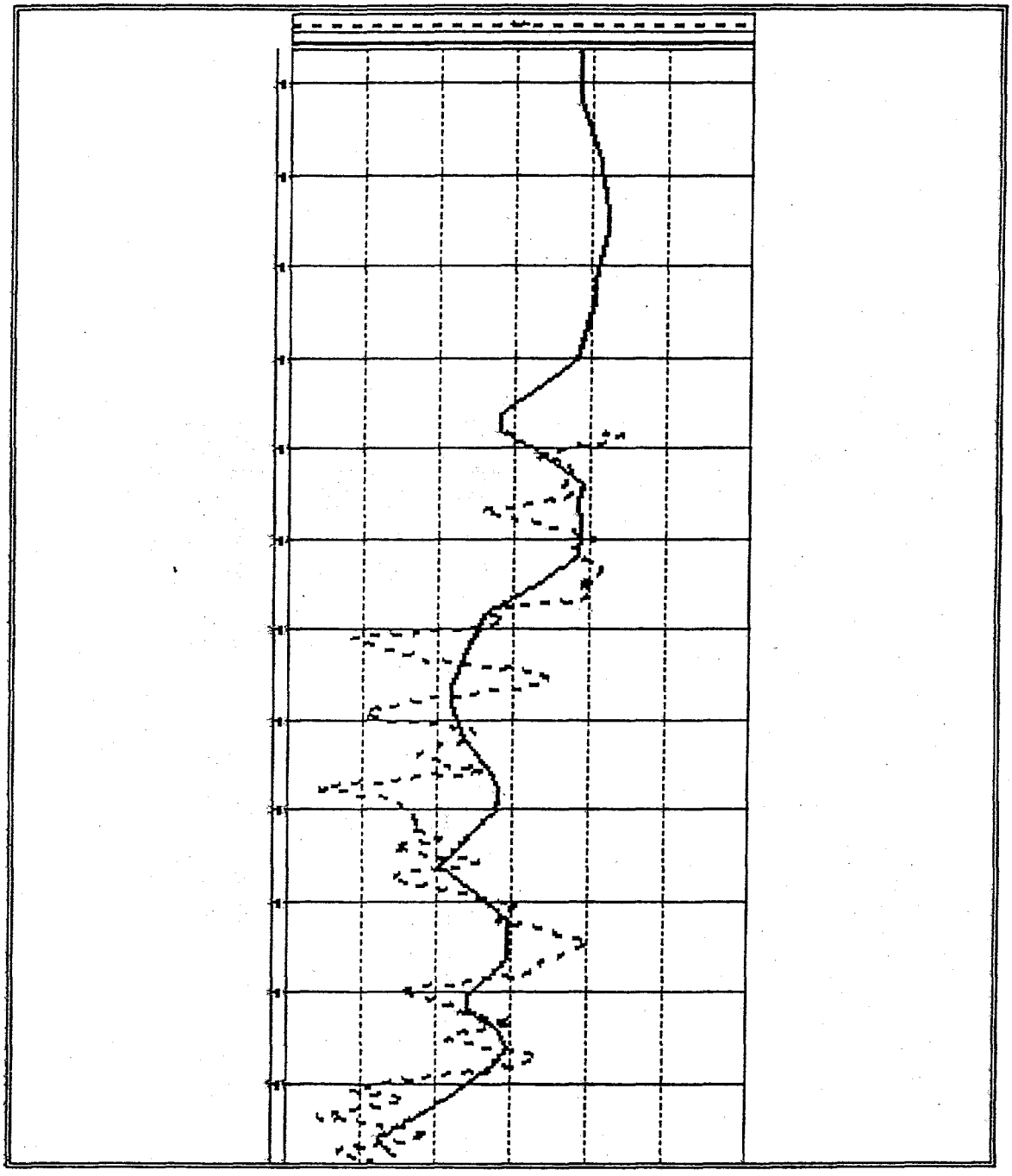


Fig. 2 Tomogram Across Pay Section (Line 7916-4825). Curves Spaced 50ft. Apart.



Synthetic Acoustic Log ----------
Wellbore Acoustic Log - - - - - -
Fig. 3 Synthetic Acoustic Log Across San Andres Pay Section