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Application of Reservoir Characterization and Advanced Technology to Improve Recovery and Economics in a Lower Quality Shallow Shelf San Andres Reservoir

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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 left in the reservoir at project abandonment. 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 (CO₂) stimulation treatments
6. Hydraulic fracturing design and monitoring
7. Mobility control agents

SUMMARY OF TECHNICAL PROGRESS

West Welch Unit is one of four large waterflood units in the Welch Field 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 infill-drilled on 20-ac density. A 1982-86 pilot CO₂ injection project in the offsetting South Welch Unit yielded positive results. Recent installation of a CO₂ pipeline near the field allowed the phased development of a miscible CO₂ injection project at the South Welch Unit.

The reservoir quality at the West Welch Unit is poorer than other San Andres reservoirs due to its relative position to sea level during deposition. Because of the proximity of a CO₂ source and the CO₂ operating experience that would be available from the South Welch Unit, West Welch Unit is 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 CO₂ project based on detailed reservoir characterization from advanced petrophysics, 3-D seismic interpretations and cross wellbore tomography interpretations.

During the quarter, simulation history matching was made using the seismic integrated geologic model. Cross well seismic work continued, using the revised processing software.

3-D SEISMIC INTEGRATION

The seismic data over the project area has been used to generate porosity and porosity thickness maps for the two main pay intervals¹. These properties were then distributed to the geologic model layers using the average porosity distribution from the closest available wellbores for the distribution of porosity at the particular bin location². Initial simulation runs using this enhanced model resulted in a good match with historical total fluid production, indicating that the integration of seismic data improved the characterization of rock properties such as porosity and permeability. However, the forecasted water/oil ratio was low to the historical rates (i.e. oil production too high and water production too low) suggesting a problem with relative permeability and/or floodable pay.

The seismic-generated maps were used in an attempt to determine locations of barriers to waterflooding. Areas on the maps that showed rapid decreases in porosity were interpreted as barriers to flow. These apparent barriers were inserted in layers 1 through 4 in the geologic model, but they had little impact on the forecasted oil recovery. Next, the barriers were extended through additional layers. The final simulation results reduced the model's oil production by only 500-600,000 bbls of oil which still did not match actual performance.

difference ?

Another approach to locating barriers was tried using the seismic cross-sections to determine where flat spots or unusual reductions in the seismic troughs occurred. This approach gave results similar to the seismic-generated map method, both in terms of the barriers location and the reduction in the simulator forecasted oil production.

Barriers are not the only parameters controlling the water/oil ratio, so the accuracy of the barrier location from seismic data can not be judged at this time. However, if 500-600,000 bbls of oil is being trapped in the formation due to a lack of continuity, it would create an infill drilling opportunity that will be pursued further.

CROSS WELL SEISMIC

Due to the nature of the recording and source for reflection surveys, the ray path is actually bent or curved leading to problems in placing the reflection event at the proper depth. Changes to the processing software corrected this curvature, allowing the reflections and calculated velocities to be placed at the proper depth which improved the correlation of seismic and wellbore data.

Because the reflected signals are very weak, additional work to remove noise and interfering wave train components has improved the reflection surveys. Examples of the most recent results are shown in Figs 1 and 2 which display the images for an interval from 4800 ft to 5000 ft below ground level, referenced at the source well. Traces are shown at one-foot lateral spacing and are zeroed above 4800 ft. Figure 1 is in the north between wells 7916 (source) and the 7914 (receiver) where the reservoir quality is poorer and more heterogeneous. The section shown starts about 200 ft from well 7916 and extends about 100 ft to the northwest. In general, the reflection peaks match the dense zones and troughs match the porous zones on the 7916 neutron-density log. The density log shows negative porosity values in the same depth range as the amplitude peaks on the seismic. There is also a general correlation between the seismic section and the porosity log on well 7914.

Figure 2 covers a reservoir interval that is considered to be more uniform than the section in Fig 1. The same 4800 ft to 5000 ft interval and one-foot lateral trace spacing are shown. The images suggest a more uniform reservoir section than Fig 1.

NUMERICAL SIMULATION

As discussed in the 3-D Seismic Integration Section, the base geologic model was enhanced by incorporating seismic data to define the interwell properties. Since the seismic traces were on approximately the same spacing as the model grids, reservoir properties of porosity and permeability were available at each grid block. The multipliers to porosity and/or permeability were not applied as in the previous model which only used wellbore values. This enhanced model produced the correct volumes of total fluid, but the wrong water/oil ratio. Therefore, further changes to the geologic model were limited to pay continuity, relative permeability and net-to-gross pay multipliers.

The first change attempted was the addition of flow barriers based on seismic data as previously described. This did not produce sufficient change in the produced fluid ratio, so net-to-gross pay ratio was investigated. Dimensionless type curve analysis³ indicated that a net-to-gross pay multiplier needed to be applied to certain wells in the project area. The analysis gave good results when the production or injection wells were operating under reasonably stable conditions which prevent the generation of "noise." Injection wells were generally operated at injection pressures of 1600-1800 psig, creating stable enough operating conditions for the type curve

analysis to be usable. Noise in producing wells is usually created by mechanical problems, i.e. scale problems, workovers etc. which interrupt capacity production. Some producing wells were found suitable and others too "noisy" for the technique to work.

Combining relative permeability adjustments with the net-to-gross pay multipliers allowed the model to produce at the correct water/oil ratio. The changes required to get more water production and less oil produced created a higher oil saturation at the start of the CO₂ flood. The last adjustment to the relative permeability curves assigned one rock type to the entire area. The resulting water relative permeability curve had a residual oil saturation-to-waterflood of 45% and a slightly higher water relative permeability than the type one relative permeability curve used in the old simulation model. Available core saturation data support the higher residual oil to waterflood. Due to these changes, forecasted oil production during tertiary recovery should be higher than previously shown. The field results will be the ultimate check of this approach. X

PROJECT AREA PREPARATION

One well was drilled and is currently waiting to be fracture treated. The well is being produced for a short period before fracturing to deplete the pressure around the wellbore. This will help contain the fracture to the proper interval. X

Facilities engineering work covered design and specifications for distribution and gathering facilities. The design and sizing of the CO₂ distribution system for the project area injection wells was completed. The routing of gas gathering and re-injection lines were planned. Sizing of both lines was done using existing simulation forecasts. However, since changes to the model result in more oil being produced during the CO₂ flood, the revised forecast will be made of injection and production volumes for facilities design. Work on preparing specifications for CO₂ metering station at the Este pipeline and requisitions for wellheads and other wellhead equipment was also undertaken.

ECONOMIC ANALYSIS

Additional economic analysis will be performed on the forecasts resulting from the enhancement of the geologic model.

TECHNOLOGY TRANSFER

On March 2, Archie Taylor and Greg Hinterlong made a presentation before the Fourth Annual Reservoir Characterization Conference "Use of Multiple Log Curves to Predict Permeability in a Dolomite Reservoir." A poster session was also conducted at the Conference.

The Rocky Mountain Association of Geologists and the Denver Geophysical Society held their Third Annual 3-D Seismic Symposium in Denver on February 27, 1997. George Watts presented "Seismic Description of a Complex Carbonate Porosity System, Welch Field, Permian Basin, Texas" at this meeting.

During the quarter, revisions to the Budget Period One Final Report were made and submitted.

REFERENCES

1. Watts, G.P., Hinterlong, G.D. etal, "Seismic Estimate of Porosity in the Permian San Andres Carbonate Reservoir, Welch Field, Dawson County, Texas," March 1996 Proceedings: Oklahoma Geological Society Workshop on Platform Carbonates of the Southern Midcontinent.
2. A. R. Taylor, and G. D. Hinterlong, etal, Application of Reservoir Characterization and Advanced Technology to Improve Recovery and Economics in a Lower Quality Shallow Shelf Carbonate Reservoir, DOE contract No. DE-FC22-94BC14990, *Quarterly Report*, October 1-December 31,1996.
3. L. E. Doublet, T. A. Blasingame, Decline Curve Analysis Using Type Curves: Water Influx/Waterflood Cases, paper SPE30774 presented at the 1995 Annual Technical Conference and Exhibition, Dallas, Tex., October 22-25,1995.

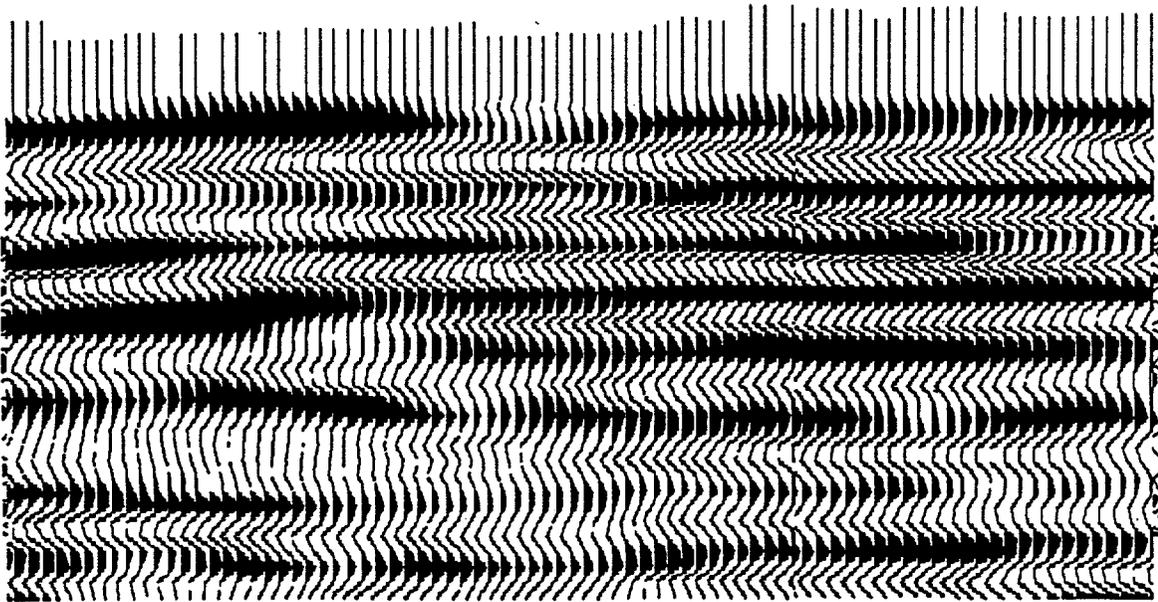


Figure 1 Portion of the cross well reflection survey between wells 7916 and 7914.

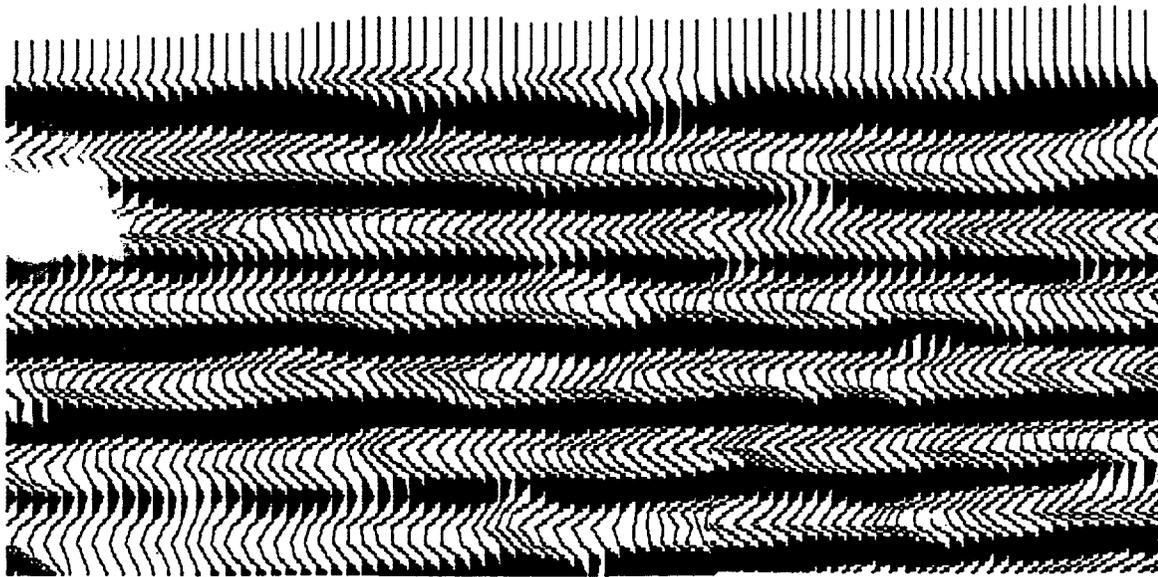


Figure 2 Portion of the cross well reflection survey between wells 4852 and 4809.