4-D High-Resolution Seismic Reflection Monitoring of Miscible CO_2 Injected into a Carbonate Reservoir

DE-FC26-03NT15414

Goal
A primary goal of this project is to seismically delineate the non-linear movement of a miscible CO_2 floodbank through a thin carbonate petroleum reservoir with sufficient resolution to identify reservoir heterogeneities and their influence on sweep uniformity and efficiency.

Performer
University of Kansas Center for Research
Kansas Geological Survey
Lawrence, KS

Results
Differences interpreted on consecutive time-lapse seismic horizon slices are consistent with CO_2 injection volumetrics, match physical restraints based on engineering data and model amplitude response, and honor production data. Textural characteristics in amplitude envelope images appearing to correspond to non-uniform expansion of the CO_2 through the reservoir honors both the lineaments identified on baseline data and changes in containment pressures. Interpretations of a set of time-lapse seismic images can be correlated to a mid-flood alteration of the injection/production scheme intended to improve containment and retard excessive northward movement of the CO_2.

Benefits
Continued success seismically monitoring CO_2 movement through this reservoir will reveal critical components and considerations necessary for routine incorporation of 3-D high-resolution seismic monitoring with CO_2 enhanced oil recovery (EOR) programs in thin, relatively shallow, mature carbonate reservoirs. Changes in production schemes possible by incorporating nearly real-time monitoring data into CO_2 injection EOR programs could dramatically impact both the efficiency and economics of that technology in many Mid-continent fields. Refinements to 3-D high-resolution reflection imaging coming from this study also could provide assurances essential for routine sequestration of CO_2 in depleted oil/gas reservoirs or brine aquifers.

Background
Time-lapse 3-D, or 4-D, seismic reflection profiling has been proven an effective tool during the last decade to evaluate the effectiveness of conventional EOR programs. Consistency and repeatability of 3-D surveys has been the most persistently identified problem associated with time-lapse monitoring of reservoir production. Seismic monitoring has been considered viable only for the most prolific fields, which possess the greatest potential for significant returns with the identification of stranded reserves. The vast majority of Mid-continent reservoirs would not be considered candidates for 4-D monitoring using historical criteria.

The potential of seismically monitoring the injection of miscible CO_2 into thin carbon-ate reservoirs only recently has been studied. Field tests to date of this technique have used conventional approaches with-out significant regard to the economics of routine application or spatial and temporal sampling necessary for application to most Midcontinent reservoirs. Changes in reservoir characteristics between baseline and one or at most two monitoring surveys have previously assumed linearity and have not been designed to be incorporated into the production scheme.

Summary
This project is designed to address questions related to both EOR flood management and CO_2 sequestration in mature, shallow, and thin carbonate reservoirs. Important aspects related to flood management include delineating preferential CO_2 pathways, enhancing sweep efficiency, locating areas of bypassed oil, and defining the mechanisms controlling CO_2 movement.

As a secondary component, assessing the feasibility of this methodology for applications in CO_2 sequestration includes identifying preferential pathways for CO_2 movement, delineating features that might influence long-term containment of CO_2, detecting movement of CO_2 outside containment at a high enough resolution to provide the necessary public assurances, and defining the minimum survey requirements for effective long-term monitoring.

Efficiency of EOR programs relies heavily on accurate reservoir models. Movement of miscible CO_2 injected into a thin (~5 meters), shallow-shelf, oomoldic carbonate reservoir around 900 meters deep in Russell County, KS, is being monitored successfully with high-resolution 4-D time-lapse seismic techniques. High-resolution seismic methods show great potential for incorporation into CO_2 flood management, thus highlighting the necessity of frequently updated reservoir-simulation models, especially for carbonates. Use of an unconventional approach to acquisition and interpretation of the high-resolution time-lapse/4-D seismic data was key to the success of this monitoring project.

Twelve 3-D seismic reflection surveys will be conducted over 6 years to develop and refine appropriate methodologies for monitoring the injection and containment of miscible CO_2 in a thin carbonate reservoir in central Kansas.

Project highlights include the following:

• Interpretations of geologic features from seismic data have provided critical location-specific reservoir properties that appear to strongly influence fluid movement in this production interval.

-Distribution and geometries associated with similarity-seismic facies and seismic lineament patterns are suggestive of a complex ooid shoal depositional motif, consistent with oolitic lithofacies being the known reservoir in this field.

• Weak-anomaly enhancement of selected non-inversion, 4-D seismic attribute data represented a significant interpretation development and proved key to seismic monitoring of CO_2 movement.

-Amplitude envelope attribute data possess changes in texture, interpreted as related to CO_2 movement that are generally consistent with expectations and CO_2 volumetrics.

-Time-lapse seismic monitoring of this EOR CO_2 flood revealed weak anomalies in the thin carbonates that represent the reservoir below temporal resolution.

-Spatial textural—rather than spatially sustainable magnitude—time-lapse anomalies were observed and should be expected for thin, shallow carbonate reservoirs.

• Lineaments identified on seismic sections likely (based on time-lapse monitoring and production data) play a role in sealing and/or diverting flow through the reservoir.

-Advancement of the CO_2 from the injector seems to honor both the lineaments identified on baseline data and changes in containment pressures.

• Flow models after simulator updating added by seismic data (sealing lineaments and preferential permeability manifested by faster progression of the CO_2 bank) show great improvement in detail and pro-vide excellent correlation with the material balance.

- Predictions of breakthrough at Well No. 12 and the delay at Well No. 13—based on seismic data alone, without the aid of any production data after the second monitor survey—were consistent with the actual production data and injection volumetrics.

-Interpretation of a permeability barrier between Wells No. 13 and CO_2 injector No. 1, and northward movement of CO_2 is consistent with all field data.

-Time-lapse seismic monitoring results can be made available to field engineers with sufficient lead time to allow reservoir-simulation and flood-management adjustment even on very short-lived, small-field EOR programs.

Current Status (July 2006)
The injection of CO_2 was halted, and water injection began as part of a water-alternating-gas scheme in July 2005. At that time, seven 3-D surveys were completed (six monitor and one baseline) within about 18 months. The first monitor survey after water injection was conducted in January 2006. Based on flood simulations, water injection should severely alter the pressure and fluid distribution across the entire field within six months. Results from the January 2006 survey should provide uniquely different images of the reservoir relative to the last year of CO_2 injection.

Funding
This project was selected from submissions to DOE's sole-source proposals program.

Publications (partial list)
KGS project website: www.kgs.ku.edu/Geophysics/4Dseismic.

Miller, R.D., Raef, A.E., Byrnes, A.P., and Harrison, W.E., Technical progress report, year 2, and plan for year 3: 4-D high-resolution seismic reflection monitoring of miscible CO2 injected into a carbonate reservoir, Kansas Geological Survey Open-file Report 2005-32., 2005.

Miller, R.D., Raef, A.E., Byrnes, A.P., and Harrison, W.E., 4-D seismic— Application for CO2 sequestration assurances (abstract), AAPG Mid-Continent Section meeting, Oklahoma City, OK, September 10-13, 2005.

Byrnes, A.P., Miller, R.D., and Raef, A.E., Evolution of reservoir models incorporating different recovery mechanisms and 4-D seismic—Implications for CO2 sequestration assurances, poster presented at the annual conference of the American Association of Petroleum Geologists, June 19-22, 2005, Calgary, AB, Canada.

Raef, A.E., Miller, R.D., Byrnes, A.P., Harrison, W.E., and Franseen, E.K., Rock physics and seismic modeling guided application of 4-D seismic attributes to monitoring enhanced oil recovery CO2 flood in a thin carbonate reservoir, Hall-Gurney field, Kansas, U.S.A. (abstract), annual conference of the American Association of Petroleum Geologists, June 19-22, 2005, Calgary, AB.

Project Start: September 1, 2003
Project End: August 31, 2009

Anticipated DOE Contribution: $2,304,327
Performer Contribution: $577,529 (20% of total)

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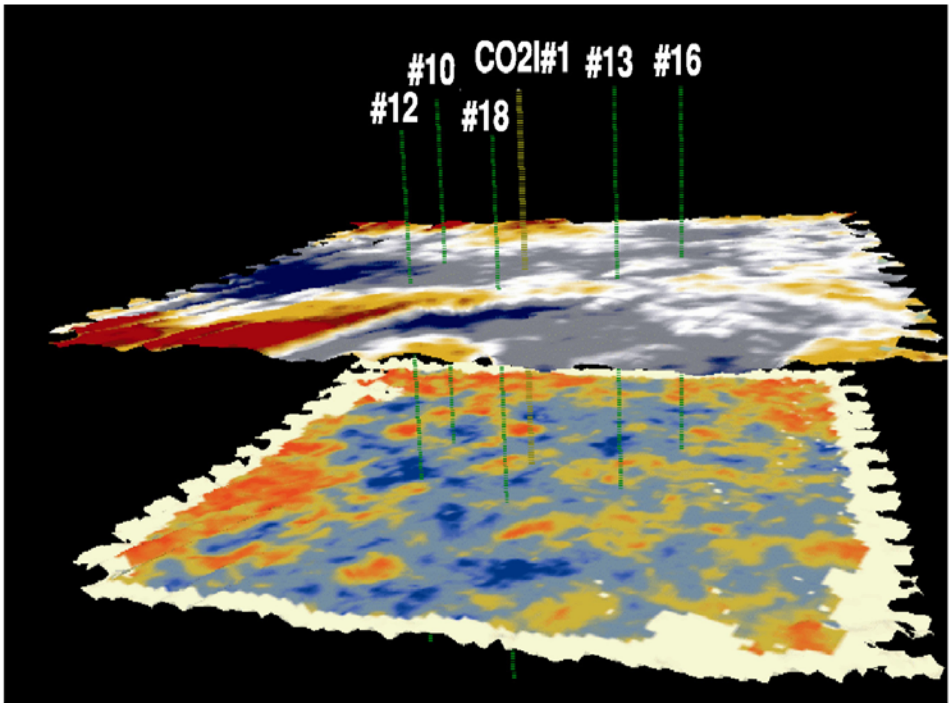
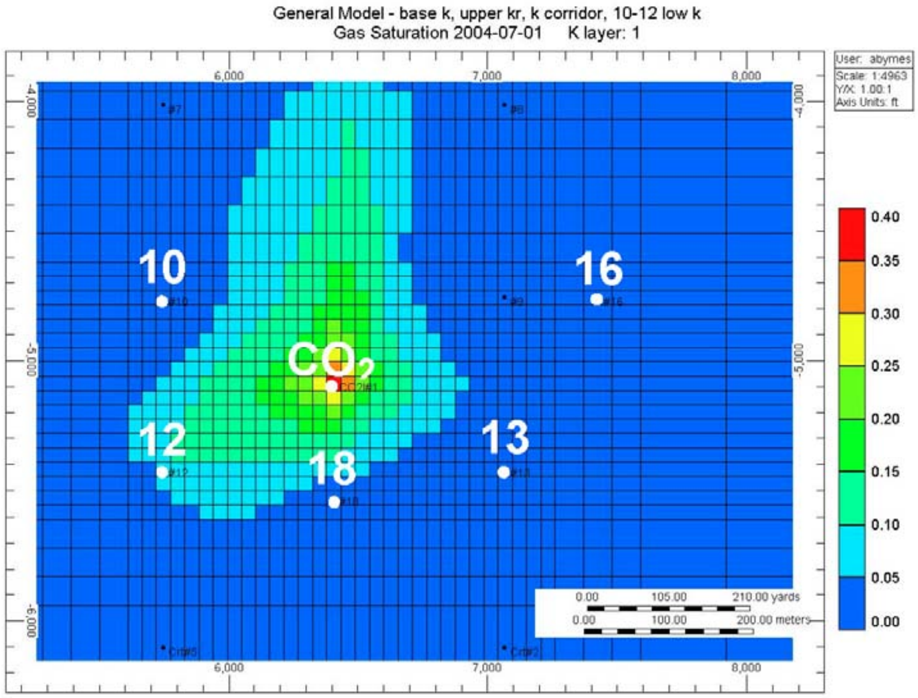


Time-structure map over similarity facies map.



Interpreted amplitude envelope, third monitor survey.