The Class Act

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# Going Underground to Spy on MEOR Microbes & Finding Many MEOR Barrels of Incremental Oil

by Lewis R. Brown and A. Alex Vadie, Mississippi State University, and James O. Stephens, Hughes Eastern Corporation

## Successful but Mysterious

The high success rate and low cost of microbial enhanced oil recovery (MEOR) should make this process very popular. Even though some operators report success rates as high as 80% for the recovery of additional oil and quote costs as low as $2 per barrel of incremental oil, many operators remain skeptical of MEOR. The skeptics lack the scientific proof that microorganisms are indeed responsible for the increased oil production. This DOE-sponsored project demonstrates how adding appropriate nutrients to the injection water of a waterflood will *cause microbial growth* that *alters flow patterns*, thereby *enhancing sweep efficiency*.

Using microorganisms to enhance oil recovery was first suggested by Beckman in 1926, but it was not until the 1940s that ZoBell and his coworkers began to apply the concept. The MEOR process depends upon growth and/or the production of by-products such as acids, gases, polymers, solvents, or surfactants by microorganisms that are present in the reservoir or are injected. Compared to other oil recovery processes, MEOR becomes even more attractive at low oil prices.

## A Field in Decline

The field chosen for this MEOR demonstration project is the **North Blowhorn Creek Unit** (NBCU) in Lamar County, Alabama. The NBCU was discovered in 1979 and produced from the Carter formation at the 2,300-foot level. The field was unitized in 1983, in-fill drilled to 40-acre spacing, and waterflooded. Production peaked in 1985 and then declined steadily. Of the 16 million barrels (bbl) of original oil in place (OOIP), only 5.5 million bbl had been recovered by 1995.

At the start of this project in 1994, there were 20 injector wells and 30 producer wells in operation. Estimates projected that the field would be abandoned with 10 million barrels of oil remaining unless MEOR could increase recovery. No other recovery method was economically practical.

## Lab Tests on Live Cores

In order to formulate the amounts and schedule for adding nutrients to the injection water, coreflood experiments were conducted in the laboratory using live cores obtained from two new wells drilled in an area of the field where bypassed oil was expected. Based on data from the coreflood experiments, two different feeding regimes were designed. One feeding regime supplemented injection water with potassium nitrate and sodium dihydrogen phosphate; the

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other regime also added molasses.

The experimental design for the field demonstration follows:

1. Add nutrients into four test injector wells and measure the results in the producer wells surrounding each injector.
2. Measure the results in the producer wells surrounding each of four control injector wells receiving injection water alone.
3. Compare the results of the four test injector wells with the results of the control injection wells.

This design also enabled researchers to compare the results to historical data for the test wells. A tracer study conducted in test pattern 1 showed that evidence of microbial activity could not be expected for 7–12 months.

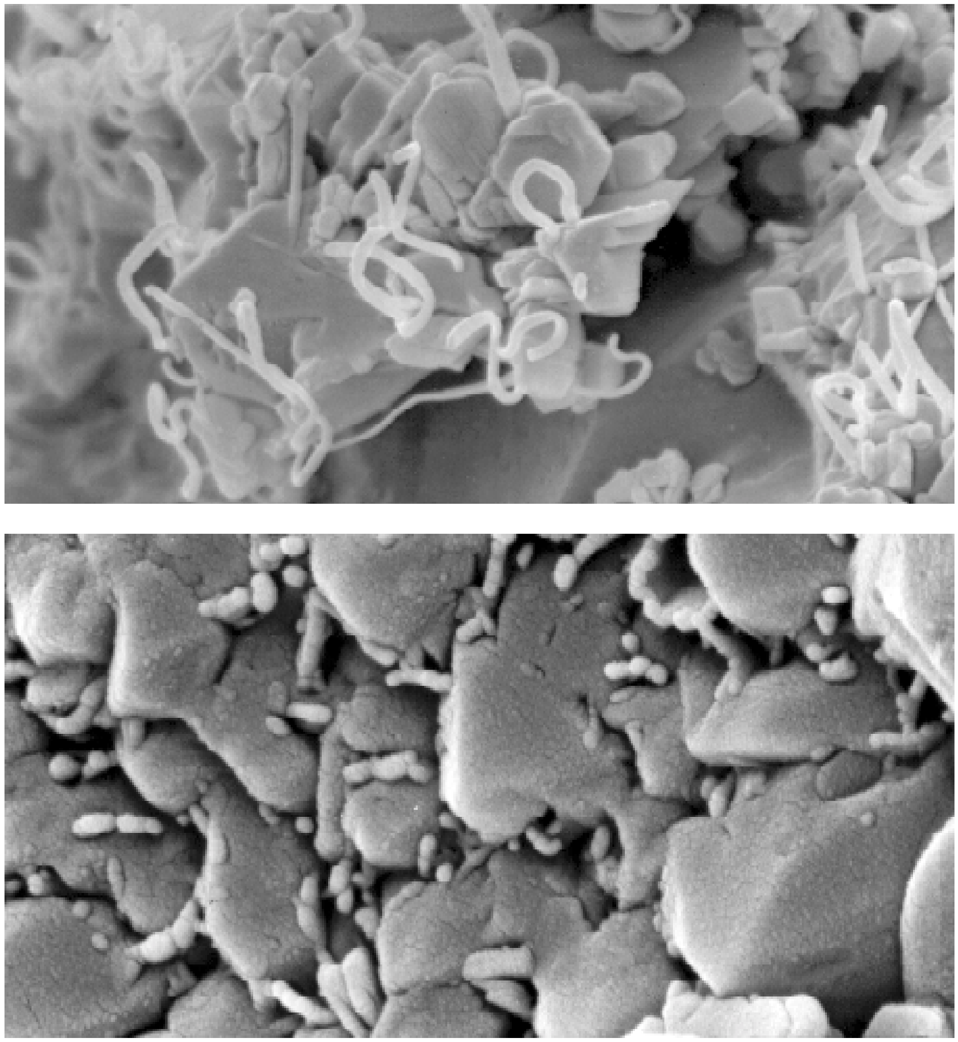

**Figure 1** Electron microscopic examination of core sections revealed many microbial cells, as shown by these two samples

## Add Nutrients, Stir...

To add nutrients to the injection water, dry chemicals were placed in a hopper, water was added, and the solution was mixed with a stirrer inside a mixing tank. Molasses was added directly to the mixing tank. The chemical solution was then metered into the injection water over a 24-hour period. Injection of nutrients into the first test injector well was begun on November 21, 1994, followed by injection into test injector 2 on February 27, 1995, test injector 3 on January 16, 1995, and test injector 4 on February 17, 1995.

## Positive Well Response

As of July 1995 (30 months after the nutrients had been added to the test injectors), 8 of the 15 producers in test patterns have shown a positive response, whereas 6 of the 8 producers that are in control patterns continued their natural decline.

In addition to collecting production data, the study is monitoring fluids for various chemical, microbiological, and petrophysical characteristics. Tests have shown:

1. The sulfide content of the produced water from all wells is lower (at the 5% level of probability) after more than 6 months of nutrient injection. This bonus was not a surprise. Nitrate inhibits its sulfate-reducing bacteria in the reservoir, as do increasing numbers of nitrate-reducing bacteria.

**The *Class* Act** is a quarterly newsletter devoted to providing information about the Department of Energy's (DOE's) Reservoir Class Program. The newsletter is produced by BDM-Oklahoma, which manages the National Oil Program for the DOE National Petroleum Technology Office in Tulsa, Oklahoma.

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2. Gas chromatographic data suggested that the oil coming from one test producer is less degraded than the oil that emerged at the start of nutrient injection, suggesting that "new" oil is being recovered.

3. Gas production from the reservoir has risen over the last seven months and could reflect microbial action or the phenomenon of "new" areas of the reservoir being swept by the waterflood.

## Microbes in Action

In order to help evaluate the progress of microbial activity in the reservoir, three new wells were drilled in the field during the fall of 1996. The wells encountered 24 ft, 21 ft, and 36 ft, respectively, of net Carter sand. Much oil appeared to remain in the low permeability rock, whereas the high permeability rock appeared better swept by the waterflood.

Chemical analyses of five sections of core from each well showed the presence of nitrate ions in four of the five sections from Well 1, three of five sections from Well 2, and all five sections from Well 3. Phosphate ions were present in three sections from Well 1, none of the sections from Well 2, and one section from Well 3. Electron microscopic examination of sections of the cores revealed many microbial cells in some of the samples as shown in Figure 1.

Although the analyses of cores from the three newly drilled wells are incomplete, the nutrients being injected into the test wells clearly are being widely distributed in the reservoir. Plus, an abundance of microbial cells in samples suggests that microbes are actively multiplying in the reservoir formation.

## Results Are Barreling In

In summary, these results were observed during the 30 months of the MEOR field demonstration:

- More than half the wells in test patterns–8 of the 15 wells–have shown a positive response whereas 6 of 8 wells in control patterns continued their natural decline.
- Three recently drilled wells have shown that nutrients added to test injector wells are widespread in the reservoir, and cores from the new wells revealed large numbers of microorganisms.
- To date, 41,000 barrels of incremental oil have been recovered as a result of the MEOR process. Plus, if treatment of the field were to stop today, a projected total of more than 200,000 bbl of extra oil would be recovered.

Figure 2 shows oil production from all of the original wells in the field and the projection of what production would have been without MEOR. The projection indicates that production would have fallen below economic limits by October 1998, but because of MEOR, production is projected to continue through July 2001. These results should reassure operators seeking proof that MEOR can help boost incremental oil recovery.

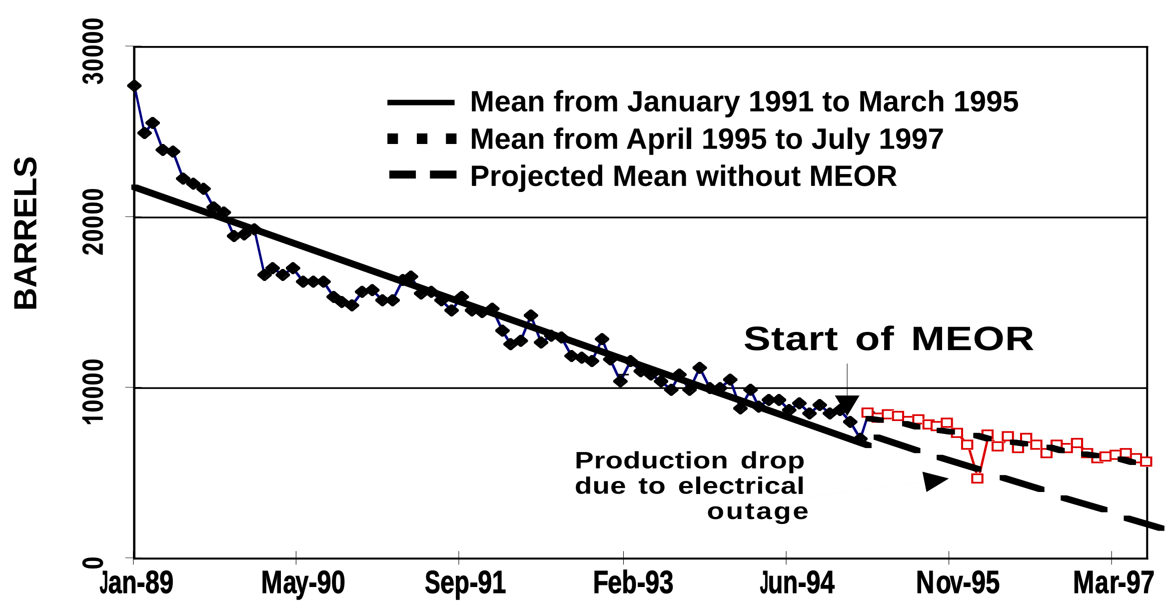


**Figure 2** Oil production from all of the original wells in North Blowhorn Creek Unit, plus the projections with and without MEOR

# New IOR Process of Air Injection Boosts Oil Recovery in Gulf Coast Salt Dome

byTravis Gillham, Amoco Production Company

## Trying to Boost Recovery in Light Oil Reservoirs

The West Hackberry Tertiary Project sets a milestone as the first improved oil recovery (IOR) project to demonstrate that air injection can increase oil recovery in light oil reservoirs in a Gulf Coast salt dome oil field. The project is one of four Class I Midterm Projects that have been implemented to develop advance recovery technologies in fluvial-dominated deltaic reservoirs.

**West Hackberry Field** is located about 30 miles southwest of Lake Charles in Southwestern Louisiana. At West Hackberry, Amoco and DOE have teamed up to test a new tertiary recovery process which combines low-cost air injection with the double displacement process.

## Double Displacement to Induce Gravity Drainage

The double displacement process uses gas to displace a water-invaded oil column to obtain tertiary oil recovery through gravity drainage. In many light oil high-permeability dipping reservoirs, gravity drainage can recover 80%–90% of the original oil in place (OOIP), whereas water drive recovers only 50%–60% of OOIP. The double displacement process suggests that gas can be injected into a watered out reservoir to form or expand a gas cap, thereby creating an environment conducive to gravity drainage. The target for tertiary oil recovery is the incremental oil between the 50%–60% water drive recoveries and the 80%–90% gravity drainage recoveries.

In the West Hackberry project, air injection is split between the higher-pressure (2500–3300 psi) reservoirs on the west flank and the lower-pressure (300–600 psi) reservoirs on the north flank. To date, air injection in the higher-pressure reservoirs on the west flank have not yielded production, as the gas caps have not yet expanded enough for the oil rims to reach the producing wells.

The low-pressure oil reservoirs on the north flank are characterized by steep bed dips, large low-pressure gas caps, thin oil rims, and slow water encroachment. A cross section of a low-pressure air injection reservoir appears in Figure 1. The dynamics for the movement of the thin oil rim in a steeply dipping reservoir is explained in Figure 2.

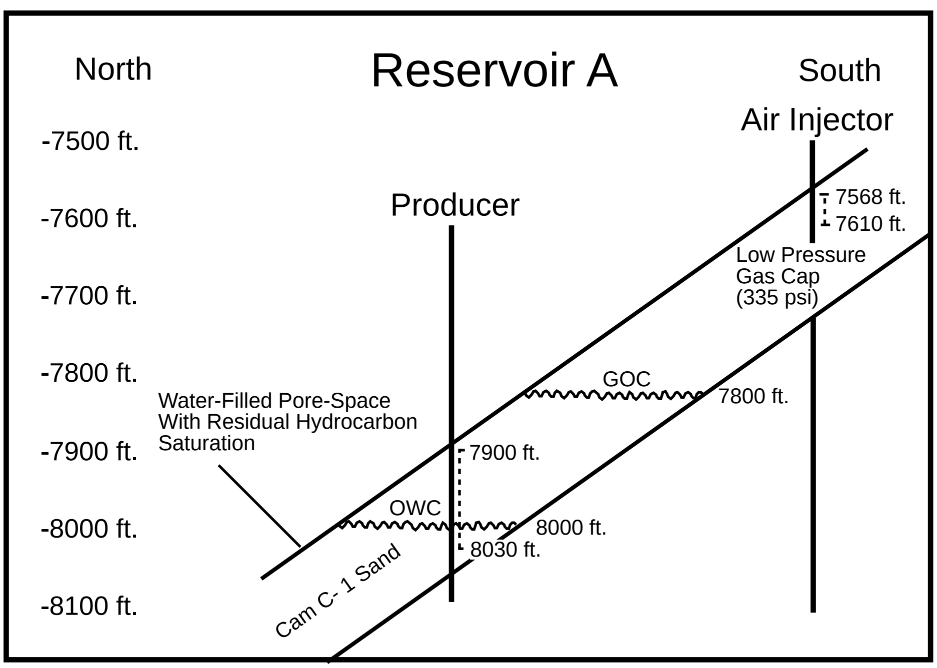


**Figure 1** Cross-section of a low-pressure air injection reservoir

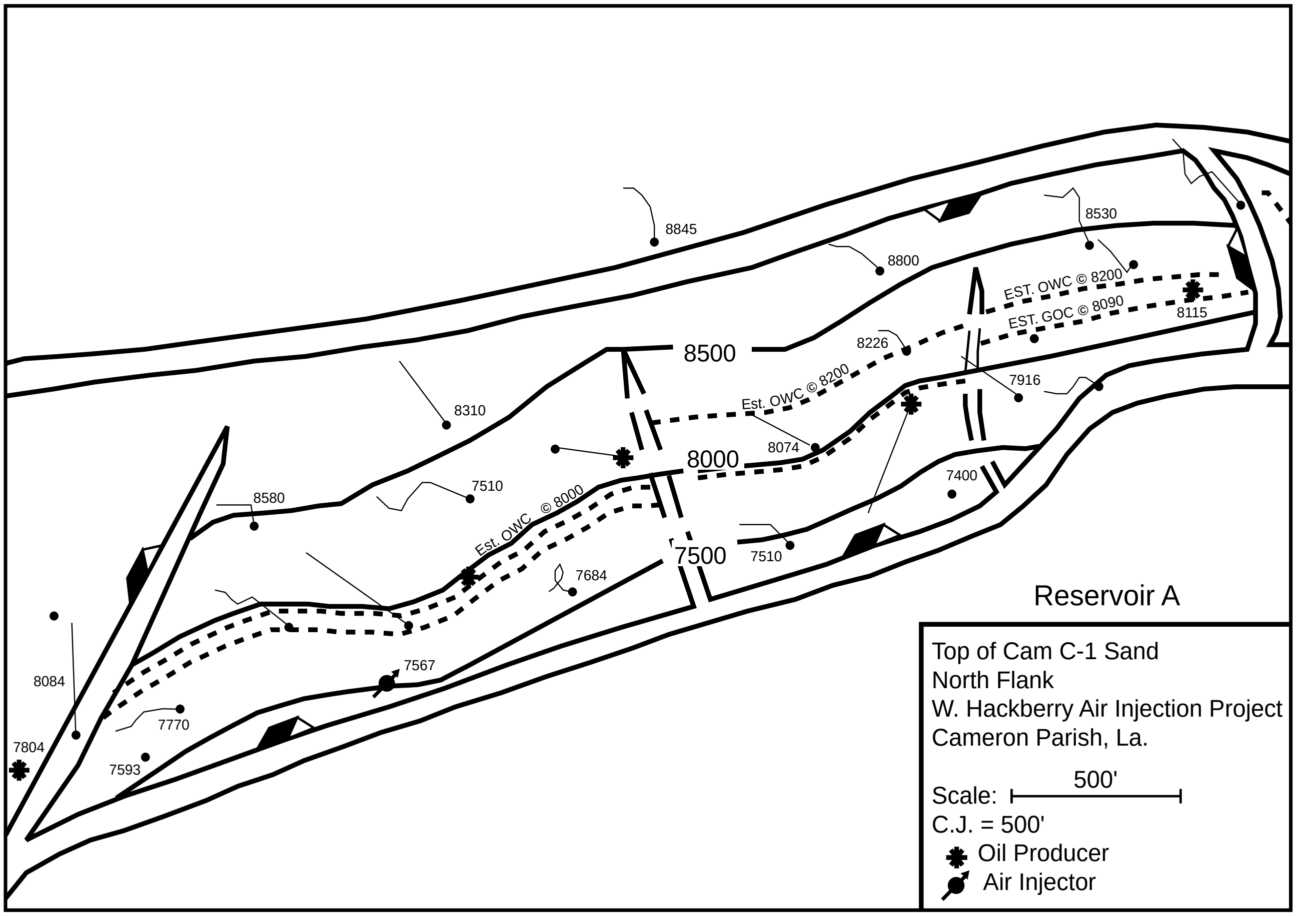


**Figure 2** A thin oil rim on a steeply dipping reservoir occupies a narrow area. As slow water encroachment pushes the oil rim upstructure, the oil rim becomes trapped between the downstructure wells that have watered out and the upstructure wells in the gas cap. The result is little or no production.

Injecting water into downstructure wells to push the oil rim upstructure to the wells in the gas cap can result in a loss of reserves, as the oil rim will dissipate as it is pushed into the gas cap.

Rather than injecting water into a downstructure well, a gas can be injected into an upstructure well. Injecting a gas into the gas cap of a low-pressure oil reservoir increases oil recovery by:

- Pushing the oil rim downstructure to the location of existing wellbores
- Repressurizing the reservoir
- Obtaining tertiary oil recovery through the double displacement process

## Gas Choices & Risks

Among the choices for injection gas, such as nitrogen, carbon dioxide, air, flue gas, or natural gas, air costs the least. On the other hand, air injection is associated with certain risks.

The greatest risks stem from the presence of oxygen in both the reservoir (bacterial growth and emulsions) and the production equipment (corrosion and explosions). Such risks are reduced by selecting reservoirs with sufficient temperature for oxygen consumption in the reservoir through spontaneous in-situ combustion.

Laboratory tests have indicated that the West Hackberry reservoirs targeted for air injection have sufficient temperature to consume oxygen. Also, evidence of in-situ combustion has been seen in analyses of produced gas that finds the nitrogen content as high as 77 mole percent and the oxygen content as low as 1 mole percent.

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## 180 BOPD Produced above the Normal Decline

Air injection began in July 1996 in the low-pressure reservoirs on the north flank. By June 1997, oil production had increased in two low-pressure reservoirs to 420 barrels of oil per day (BOPD) or 180 BOPD above the normal decline. From June 1996 to July 1997, air injection increased production by 58,500 barrels above the normal decline. A production plot can be found in Figure 3.

## Costs and Payback

With the production increase seen to date, the West Hackberry project can be used as a case study of the economics of low-pressure air injection. To evaluate the economics of a purely low-pressure air injection project, a price quote was secured from a compressor operating company for the cost of providing 2 million standard cubic feet per day at 1,000 psi. The vendor's price for compressed air was about $0.49 per thousand cubic feet (including natural gas fuel, assuming that the gas is available at $2 per million BTU).

During the first 13 months of operations, more than $300,000 in before-tax cash flow have been generated. The money comes from $800,000 in cash receipts (on 58,500 barrels of incremental oil), less $500,000 in investments and operating expenses.

Because of the success of the first two low-pressure reservoirs, the air injection project was expanded to a third low-pressure reservoir during the fourth quarter of 1997.

## The Potential to Revive Depleted Salt Domes

When DOE selected the West Hackberry Tertiary Project for funding under the Class I Program, both Amoco and DOE foresaw that successful implementation of a new low-cost tertiary process would have the potential to spread to many nearly depleted salt dome oil fields throughout the Gulf Coast.

The results recorded to date demonstrate the potential of that vision.

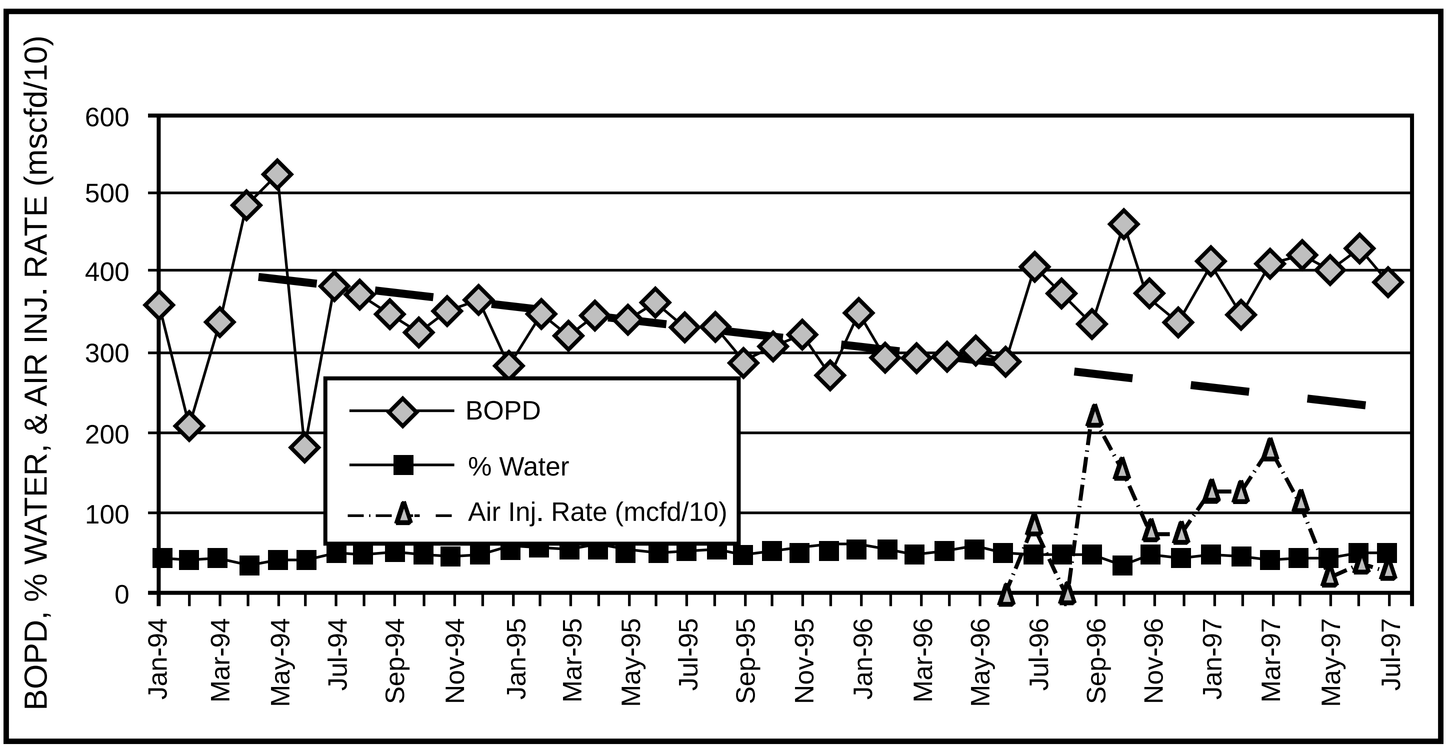


**Figure 3** Composite production plot for the north flank low pressure reservoirs of the West Hackberry air injection project

# C A L E N D A R

## JANUARY

**Jan. 13,** Advanced Applications of Wireline Logging for Improved Oil Recov. Workshop, Denver, CO:
- "Applying Integrated Formation Evaluation to Advanced Reservoir Characterization in CA's Monterey Formation Siliceous Shales" (Chevron Class III). T. A. Zalan et al.
- "Use of Dipole Shear Anisotropy, Dual Burst Thermal Decay Time, & Isotope Tracer Logs for Recompletion Design & Post-Recompletion Evaluation in Complex Reservoirs" (Utah Geol. Survey, Class II). C. Morgan.
- "Acoustic Logging to Detect Hydrocarbons through Casing" (City of Long Beach Class III). D. Moos.

**Jan. 14,** Michigan Basin Geol. Soc., Acme, MI: "Reservoir Geology of Crystal Field" (Mich. Tech U. Class II). H. Wines.

**Jan. 15,** Permian Basin Well Log Society, Midland, TX: "Petrophysics of the Ramsey Sandstone, Ford Geraldine Unit, Reeves & Culberson Co., Texas" (BEG UT Class III). G. B. Asquith.

**Jan. 20,** SEPM Monthly Meeting, Midland, TX: "Characterization of Spraberry Fractures from the O'Daniel #28 Horizontal Core" (Parker & Parsley Class III). M. Cater.

**Jan. 23,** Basin Research Institute Meeting, Monteleone Hotel, New Orleans, LA. "West Hackberrry Air Injection Project" (Amoco Class I). T. Gillham.

## FEBRUARY

**Feb. 8-10,** SPE 6th Archie Conference, Improving Reservoir Productivity Using Static & Dynamic Delineation Methods, Kerrville, TX:
- "Reservoir Characterization of the Siliceous Shale, Buena Vista Hills, CA, Using Crosswell Seismology" (Chevron Class III). R. T. Langan.
- "Incorporation of Core Data into Reservoir Characterization of a Deep-Water Channel-Levee & Lobe Deposit, Ford Geraldine Unit, Delaware Basin" (BEG UT Class III). S. P. Dutton.

**Feb. 26,** DOE Core Workshop, Midland, TX. For info, contact Bob Trentham, 915-686-9692.
- "Core from Nash Draw Brushy Canyon Pool, Eddy County, NM" (Strata Class III). S. Speer.
- "Reservoir Characterization of a Deep-Water Channel-Levee & Lobe System, Bell Canyon Form., Ford Geraldine Unit, W. TX. (Delaware Basin)" (BEG UT Class III). S. P. Dutton.

## MARCH

**Mar. 13,** U. of Las Vegas Seminar, Las Vegas, NM: "Using Microorganisms to Improve Oil Recovery" (Hughes Eastern Class I). L. Brown.

**Mar. 23–26,** Permian Basin Oil & Gas Recovery Conference, Midland, TX:
- "Using Reservoir Characterization Results at the Nash Draw Pool to Improve Completion Design & Stimulation Treatments" SPE 39775 (Strata Class III). B. Stubbs.
- "Reservoir Characterization as a Risk Reduction Tool at the Nash Draw Pool", SPE 38916 (Strata Class III). D. Martin.
- "Fracture Characterization Based on Oriented Horizontal Core from the Spraberry Trend Reservoir: A Case Study" SPE 38664 (Parker & Parsley Class III). P. McDonald.
- "Integrated Study of Imbibition Waterflooding in the Naturally Fractured Spraberry Trend Reservoirs" SPE 39801 (Parker & Parsley Class III). P. McDonald.
- "Use of Single Well Test Data for Estimating Permeability & Anisotrophy of Naturally Fractured Spraberry Trend Reservoirs" SPE 39807 (Parker & Parsley Class III). P. McDonald.
- "Compositional Simulations of a $CO_2$ Flood in Ford Geraldine Unit, Texas" SPE 39794: (BEG UT Class III). M. A. Malik.

## APRIL

**Apr. 8–9,** Southwestern Petroleum Short Course, Lubbock, TX:
- "Field Implementation of a $CO_2$ Flood in a Small Waterflood-Depleted Carbonate Unit" (Phillips Class II). K. Dollans et al.
- "Fracture Characterization Based on Oriented Horizontal Core from the Spraberry Trend Reservoir: A Case Study" SPE 38664 (Parker & Parsley Class III). P. McDonald.

**Apr. 10–12,** SPE/DOE 11th Symposium on Improved Oil Recovery, Tulsa, OK:
- "Low Cost IOR: An Update on the W. Hackberry Air Injection Project"(Amoco Class I). T. Gillham.
- "Seismic Analysis of the Grayburg/San Andres Forster & S. Cowden Fields, TX"(Laguna Class II). R. Weinbrandt.

**Apr. 29–May 1,** AAPG Pacific Section Convention, Ventura, CA: "Advanced Reservoir Characterization of the Siliceous Shale, Buena Vista Field, CA" (Chevron Class III) booth & presentation on 3-D Visualization/Geologic Modeling. M. Morea.

## MAY

**May,** West Texas Geol. Society: "Project Update on the Grayburg/San Andres in Foster & S. Cowden Fields, TX" (Laguna Class II). R. Trentham, luncheon speaker.

**May 10–13,** SPE Western Regional, Bakersfield, CA: "Applying Integrated Formation Evaluation to Advanced Reservoir Characterization in CA's Monterey Formation Siliceous Shales" (Chevron Class III). T. A. Zalan et al.

**May 18,** AAPG Salt Lake City: "Horizontal Drilling in Old Fields of Michigan's Dundee Formation" Poster (Mich. Tech U. Class II). J. Wood et al.

**May 17–20,** AAPG Annual Convention, Salt Lake City, UT:
- "Optimization of Heavy-Oil Production by Steamflood from a Shallow Sandstone Reservoir, Midway-Sunset Field, South San Joaquin Basin, CA" (U. of Utah Class III). S. Schamel et al.
- "2nd Field Demo. of Completion Techniques in a Fluvial-Dominated Deltaic Lacustrine Reservoir, Uinta Basin, Utah" (Utah Geol. Survey Class I). C. Morgan.
- "Reservoir Characteristics of a Heterolithic Carbonate Mound, Runway Field, Paradox Basin, Utah" (Utah Geol. Survey Class II) poster. T. Chidsey.
- "Significance of Depositional and Early Diagenetic Controls on Architecture of a Karsic-Overprinted Mississippian (Osagian) Reservoir, Schaben Field, Ness County, KS" (U. of Kansas Class II). E. K. Franseen et al.
- "Influence of Lithology & Pore Geometry on NMR Prediction of Permeability & Effective Porosity in Mississippian Carbonates, KS" (U. of Kansas Class II). W. Guy et al.
- "Application of Cost-Effective PC-Based Reservoir Simulation & Management—Schaben Field (Mississippian), Ness County, KS" (U. of Kansas Class II). P. Gerlach et al.
- "Reservoir Characterization of the Siliceous Shales, Buena Vista Hills, CA, Part 2: Reservoir Modeling & Visualization" (Chevron Class III). D. C. Beeson et al.
- "Acoustic Anisotropy Measurements in the Siliceous Shale, 653Z-26B Well, Buena Vista Hills Field, CA" (Chevron Class III). A. W. Britton et al.
- "Regional Tectonic Synthesis of the S. San Joaquin Valley" (Chevron Class III). D. J. Campagna.

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- "Advanced Reservoir Characterization of the Siliceous Shales, Buena Vista Hills, CA, Part 1: Integration of Geological, Geochemical, & Petrophysical Data" (Chevron Class III). M. Morea et al.
- "Applying Integrated Formation Evaluation to Advanced Reservoir Characterization in CA's Monterey Formation Siliceous Shales" (Chevron Class III). T. A. Zalan et al.
- "Ramsey Sandstone Channel-Levee & Lobe deposits: Deep-Marine Clastic Reservoirs in the Bell Canyon Formation, Delaware Basin, TX" (BEG UT Class III). S. P. Dutton.

**NOVEMBER**

**Nov. 2–6,** SPE Sixth International Oil & Gas Conference & Exhibition, Beijing, China: "Transient Test Analysis Case History for Two Horizontal Miscible Gas Injection Wells" (Phillips Class II). T. F. McCoy et al.

# *A N N O U N C E M E N T S*

**Advanced Applications of Wireline Logging for Improved Oil Recovery,** a one-day workshop, will draw on logging technologies developed and applied in DOE's Reservoir Class Program. The workshop will emphasize practical selection and use of advanced logging technologies and tools, as well as the economic successes and failures encountered. Topics will include rock typing using conventional logs, borehole imaging tools, and other advanced wireline tools (e.g., pulsed acoustic logs). The workshop is funded by DOE and organized by PTTC Rocky Mountain Region and BDM-Oklahoma. It will be held on January 13, 1998, 7:45 am–5:30 pm at the Denver Athletic Club, Denver, CO. For registration information, contact Sandra Mark at 303-273-3107; fax 303-273-3859. For technical information about the program, contact Susan Jackson at 918-337-4465; fax 918-337-4365; email: sjackson @ bdmok.com.

**Oxy Class II** expanded the project demonstration area of West Welch Field, south of the current site, to drill 14 additional wells. This will further demonstrate the seismic guided mapping technique.

**Oklahoma Geological Survey/PTTC, Focused Technology Waterflood Workshop,** Norman, OK, March 1998; Tulsa, OK, May 1998. Contact Michelle Summers at 405-325-3031.

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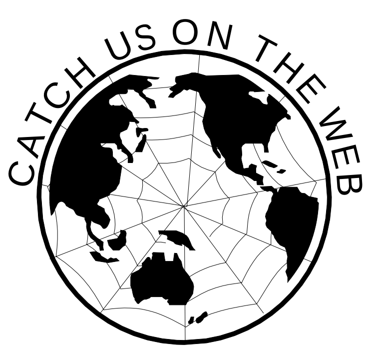


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