The *Class* Act

DOE's Reservoir Class Program Newsletter
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Coming Soon - A Shallow Shelf Carbonate Workshop

by Mike Fowler

On May 15, 1996, in Midland, Texas, the DOE, BDM-Oklahoma, Inc., and the Center for Energy and Economic Diversification (CEED) will conduct a workshop titled: "Improving Production from Shallow Shelf Carbonate (Class 2) Reservoirs" (see Figure 1).

- The focus will be on the decision-making process that matches a potential technology to a reservoir and optimizes its application.
- Representatives from Class 2 projects will address economics, unexpected problems, successes, and lessons learned.
- Methodologies for evaluating and selecting reservoir description technologies as well as cost-effective techniques for selecting and implementing improved recovery technologies will be emphasized.
- For each Class 2 project, a brief (20-minute) presentation will emphasize the methodologies that led to project development and the project's progress. Presentations will stress the application of reservoir management aspects of pursuing improved recovery in shallow shelf carbonate reservoirs.
- An exhibit session will follow project presentations in the afternoon. In this session, more information about each

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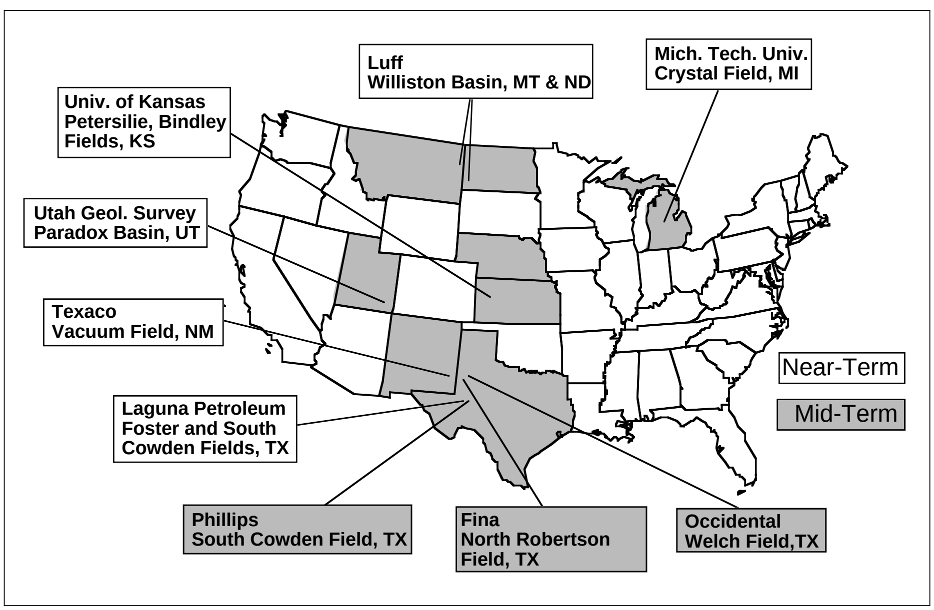

Figure 1 Location of Class 2 Projects

The *Class* Act is a quarterly newsletter devoted to providing information about DOE's Reservoir Class Program. The newsletter is produced by BDM-Oklahoma, which manages the National Oil Program for the Department of Energy (DOE) and operates the National Institute for Petroleum and Energy Research (NIPER), a DOE petroleum research laboratory in Bartlesville, Oklahoma.

For further information on Class Program projects, contact DOE's Bartlesville Project Office (BPO):
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project will be available, and workshop participants can freely discuss details of the projects' technologies and methods with the presenters.

How Do I Sign Up?

For more information or to make reservations, contact CEED in Midland at 915/552-2430. A nominal registration fee is being requested to cover the cost of lunch, snacks, and drinks. If the workshop is oversubscribed, it may be repeated on May 16 to accommodate additional registrants.

Class 2 Background

Shallow shelf carbonate reservoirs contain about 22% of all light oil originally in place in U. S. reservoirs, according to the DOE's Tertiary Oil Recovery Information System (TORIS) database. Two-thirds (over 45 billion barrels) of the oil originally contained in these reservoirs remains in the ground in mature, often marginally economic fields. Substantial portions of this potential resource are being lost as marginally economic reservoirs are abandoned.

In 1994, the Department of Energy initiated nine industry cost-shared field demonstration research projects in Class 2 reservoirs. These projects have an average anticipated length of five to six years to develop and demonstrate technologies that can cost-effectively improve recovery and delay abandonment of shallow shelf carbonate reservoirs. DOE and the project participants (reservoir operators, universities, state surveys, and other research organizations) firmly believe that millions of barrels of incremental oil can be produced profitably from Class 2 reservoirs by following the examples set by these research projects.

The Class 2 Projects at a Glance

- Five of the nine Class 2 projects intend to demonstrate targeted infill drilling through improved reservoir characterization.
- At least three of the projects are evaluating horizontal wells or deep horizontal completion techniques.
- Three of the projects are attempting to show that innovative application techniques can revitalize CO_2 economics.
- All the projects are placing heavy emphasis on reservoir characterization to assure optimum economic application of improved recovery technologies. Reservoir characterization technologies being employed run the gamut from very simple, conventional approaches to state-of-the-art tools such as 3-D seismic, which is being evaluated in four of the projects.

Michigan Technological University is demonstrating that using reservoir characterization to target horizontal wells can recover additional oil, even from currently unproductive fields. The study focuses on the Devonian Dundee formation in the Michigan Basin. A 60-foot core has been obtained, and evidence suggests that the top of the Dundee may be a karst surface.

The **University of Kansas** is improving reservoir characterization and reservoir management to help target infill wells to cost-effectively recover incremental oil from two Mississippian reservoirs in western Kansas. The project has generated simple spreadsheet-like PC-based log analysis software and is also making field data (and some analytical capabilities) available over the Internet.

The **Utah Geological Survey** is demonstrating how reservoir characterization can be used to select appropriate advanced secondary recovery techniques for five small fields in the Pennsylvanian Paradox formation in Utah's Paradox Basin.

Luff Exploration Company is using advanced reservoir characterization technologies, including 3-D seismic, to optimally locate infill wells and apply laterally extensive horizontal perforations in Mississippian and Ordovician reservoirs in the Williston Basin of Montana and the Dakotas. Their findings indicate a need to re-evaluate conventional thinking about well density.

Laguna Petroleum Corporation is applying integrated reservoir characterization, including 3-D seismic, to target infill wells and optimize mature waterflood operations in the South Cowden and Foster field Grayburg/San Andres reservoir in the Permian Basin. They have found that within a horizontal time slice, the distribution of instantaneous amplitudes

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shows a good match with a map of initial well potentials.

Fina Oil and Chemical Company is focusing on improved reservoir description to define economically optimal infill locations in the Glorieta/Clear Fork at the Permian Basin's North Robertson Unit. As the project enters its implementation phase, projections indicate a substantial economic advantage for targeted infill drilling versus the "blanket" approach.

Phillips Petroleum Company is investigating the use of appropriately targeted horizontal CO_2 injection wells to improve recovery. The process will use less CO_2 than conventional flooding techniques in the South Cowden field Grayburg/San Andres reservoir in the Permian Basin. The project is now performing final optimization of injection locations.

Occidental Oil Company is demonstrating the use of cyclic CO_2 stimulation to improve recovery and economics in the Permian Basin's Welch field San Andres reservoir. They have developed a transformation that predicts permeability from log data through an intermediate prediction of constants for the Carman-Kozeny equation relating porosity and permeability through capillary pressure data.

Texaco Exploration and Production, Inc. is employing a CO_2 huff-(n)-puff technique to improve CO_2 economics in the Vacuum field's Grayburg/San Andres reservoir in the New Mexico part of the Permian Basin.

Although Class 2 projects began in 1994, many have already made substantial progress in the reservoir descriptive phase of the project, Budget Period 1 (see Figure 2). Many of the important decisions concerning selection and implementation of improved recovery technologies in Budget Period 2 have already been made. Decision-making methodologies in both project phases will be the primary focus of the upcoming workshop in Midland.

The Class 3 Permian Basin Projects

The May workshop will also present poster session exhibits of three Permian Basin Class 3 (slope basin and basin clastics) projects.

Strata Production Company is targeting the Brushy Canyon formation in the Nash Draw field in the southeast New Mexico part of the Permian Basin to demonstrate that improved reservoir description, when used to optimally locate vertical and horizontal infill wells, can significantly increase oil recovery.

Parker and Parsley Development Company, through laboratory tests and field demonstration, is investigating the use of CO_2 injection to improve recovery from the highly fractured Spraberry reservoir. The technology, as yet untested in the Spraberry, is one which "conventional wisdom" suggested would not be applicable.

The University of Texas **Bureau of Economic Geology** is employing advanced reservoir characterization, including 3-D seismic, to selectively target infill wells and strategize field development in Delaware Mountain Group reservoirs in the Geraldine Ford and West Ford fields.

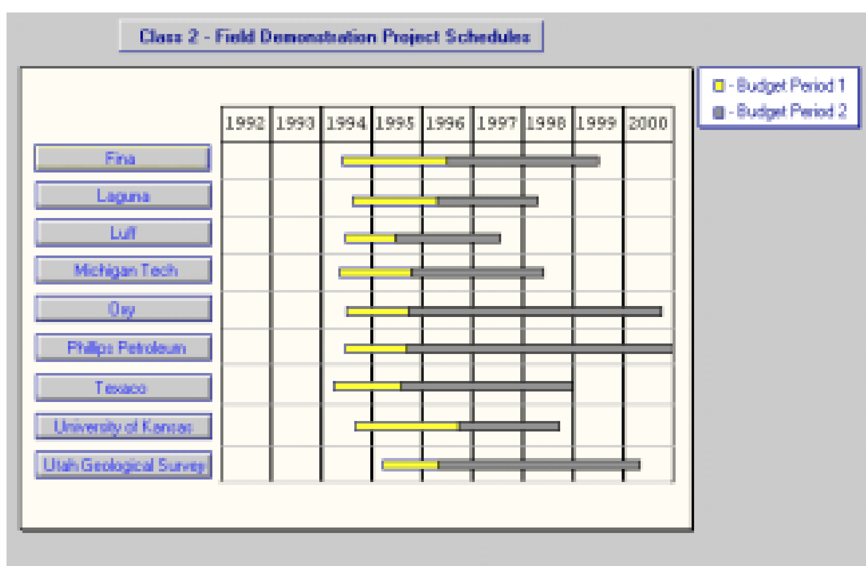

Figure 2 Class 2 Project Schedules

Budget Period 1 is Reservoir Description and Budget Period 2 is Field Implementation.

Improved Reservoir Characterization Influences Field Development Plans

by Lance Cole

Recovering More Oil and Avoiding Unnecessary Field Development Costs

The value of improved reservoir characterization is most often judged on the basis of incremental oil produced as a result of better understanding the reservoir. With increased understanding, operators can revise field development plans to achieve the best economic performance. Often, these revised plans *avoid costly investments or activities* which, according to technical analysis, would not have exhibited adequate financial return.

These avoided costs are as much a benefit of improved reservoir characterization as increased oil recovery. The following three examples from DOE's Class 1 program illustrate this point well:

- University of Kansas/NARCO Stewart Field Project
- University of Tulsa/Uplands Resources Glenn Pool Field Project
- Texaco Port Neches CO_2 Flooding Project

Polymer Unnecessary According to Simulation

The University of Kansas and North American Resources Company (NARCO) are performing a Class 1 near-term project in the Stewart field, located in southwestern Kansas. Production is from the Morrow sandstone. Although the field was discovered in 1967, the majority of field development activities took place from 1985 to 1994 with total field development resulting in 43 producers and 14 dry or abandoned wells. Primary production dropped rapidly after full field development. Operators in conjunction with the University of Kansas proposed a Class 1 project defining the reservoir and evaluating the most efficient and economical improved oil recovery process. Field-wide unitization was integral to implementing any improved oil recovery process. Polymer flooding initially was thought to be attractive.

Available log, core, pressure, and production data were analyzed and a reservoir model developed which closely matched historical data. Geological modeling of production and pressure data contributed to the improved reservoir description. Operators, confident in the reservoir description, relied heavily on appropriate reservoir simulation packages to estimate future performance under waterflood and polymer flood. Modeling results, (see Fig. 3) based on data from an 80-acre 5-spot using the Polymer Flood Predictive Model developed by Scientific Software Intercomp, indicated that polymer flooding would ultimately recover more oil. However, the increased oil recovery would not occur until after 10 years of flooding negating any economic benefit from the higher cost polymer flood.

Technology-based answers influenced the field development plan. Waterflooding is being implemented, and the higher costs associated with polymer flooding are being avoided.

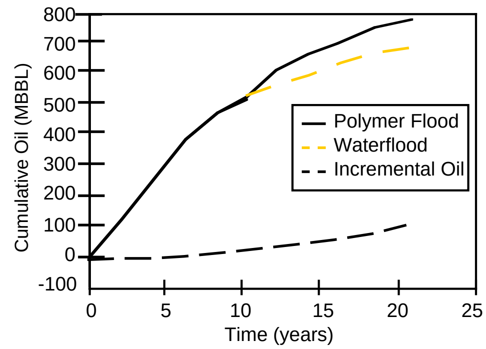

Figure 3 Comparison of cumulative oil production from polymer flooding and waterflooding in the Stewart Field Project From Class1 Technology Workshop, Feb., 1996.

Recovery Increased Without Infill Drilling

The University of Tulsa and Uplands Resources, Inc. are performing a Class 1 near-term project in the Self Unit, located in the southeast portion of the Glenn Pool field near Tulsa, Oklahoma. Production is from the Pennsylvanian age Bartlesville "Glenn" sand. Since first lease production in 1906, the field has experienced several waves of activity including gas repressurizing, waterflooding, and redrilling. Despite this extensive history, recovery through 1993 was still less than 22% of the OOIP. The University of Tulsa/Uplands Resources, Inc. Class 1 project proposed a comprehensive reservoir characterization effort as part of improved reservoir management. Initially, waterflooding with horizontal injection wells was thought to be an attractive option.

Cross borehole tomography, modern log analysis, integrated geological description, and geostatistics were used to refine reservoir models. Reservoir characterization identified additional recovery potential in the D and E intervals. Future performance for existing wells, additional vertical wells, or a horizontal injection well were estimated using reservoir simulation. Simulation used uniform relative permeability values modified from Glenn Pool reservoir data, variable initial water saturations, and assumed completion in the D and E intervals. Results are illustrated in Figure 4.

Estimated production increases were only marginally higher with drilling of either a horizontal injection well or vertical producers so existing wells are being reworked rather than costly drilling. Drilling costs for the horizontal well option would have been about $400,000. A rework program on only six wells has already increased production by 35 bopd. If similar successes are realized as the program is implemented lease wide, increased oil production should exceed the initial estimate.

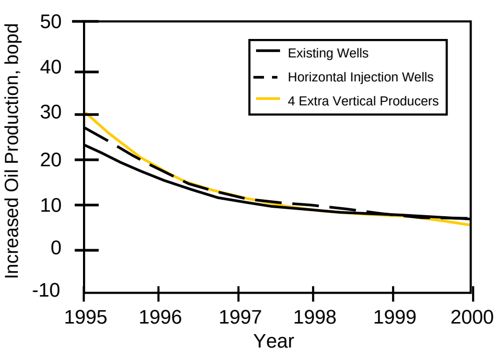

Figure 4 Comparison of incremental production from horizontal injection wells, existing wells, and extra vertical producers in the Glenn Pool Field Project. From Annual Report DOE/BC/14951-10, May 1995.

Revised Reservoir Volume Alters CO_2 Injection Scheme in 2nd Fault Block

Texaco's Class 1 mid-term project in the Port Neches field in southeast Texas involves CO_2 flooding of a pressure-depleted Marginulina sand that was previously extensively waterflooded. The project area includes a reservoir within two fault blocks (see Fig. 3). Initial operations focused on the larger Area 1 fault block. The project involves injecting salt water to raise reservoir pressure, then CO_2 flooding the reservoir using both vertical injection wells and a horizontal injection well. As the project proceeded, Texaco collected 3-D seismic and bottomhole pressure data. Interpretation of this data confirmed separation of Area 1 and 2, but indicated that reservoir volume in Area 2 is less than originally thought. The smaller target oil volume does not justify CO_2 flooding, so drilling injection well Polk B-39 was cancelled. Instead, CO_2 huff-(n)-puff treatments are being evaluated in Polk B-5. Improved reservoir definition using pressure and 3-D seismic data avoided the costs of drilling a CO_2 injection well and CO_2 flooding of the smaller fault block.

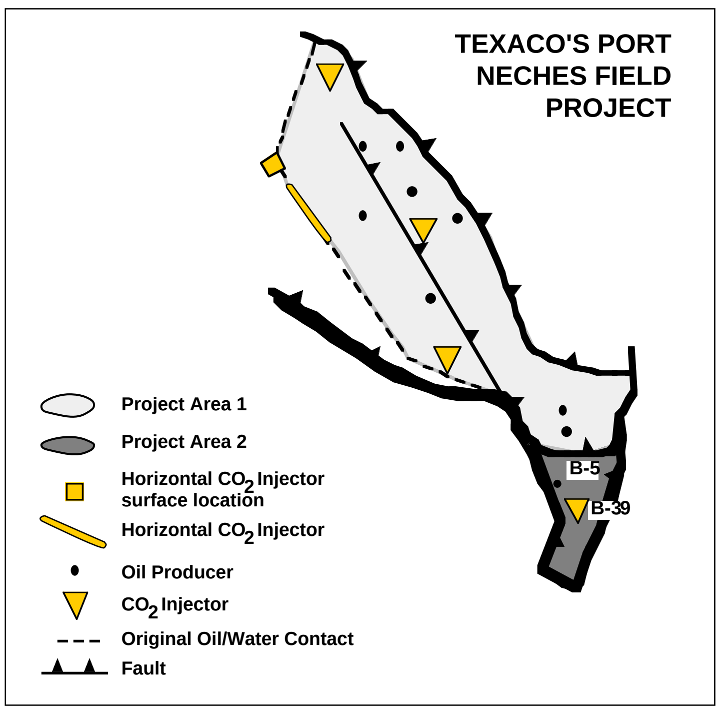

Figure 5 Texaco's Port Neches Field CO_2 Project area (map not to scale). Modified from Annual Report DOE/BC/14960, October 1994.

CO_2 Processes Applied in Class Projects

by Mike Fowler and Eugene Safley

Immiscible and miscible CO_2 processes are being investigated in six of the Class projects. The projects are being conducted in a variety of reservoir types including clastic fluvial deltaic (Class 1), carbonate shallow shelf reservoirs (Class 2), and clastic slope/basin (Class 3) reservoirs (Table 1). Information on the use of CO_2 flooding in the Class projects was provided by the project participants.

In miscible displacement processes, CO_2 is dissolved into the oil. At sufficient pressure, interfaces between the gas-rich and the oil-rich phases disappear and miscibility results. CO_2 injected under miscible conditions displaces the oil left in the water-swept portion of the reservoir. At pressures below that required for miscibility, displacement efficiencies are lessened, but recovery through the important mechanisms of oil swelling and viscosity reduction is still realized.

Immiscible Processes

Texaco Exploration and Production, Inc. is investigating the use of a CO_2 huff-(n)-puff technique in the Vacuum field in the New Mexico part of the Permian Basin. Cyclic or huff-(n)-puff processes involve CO_2 injection into a single wellbore. The well is shut-in for up to four weeks allowing the oil to absorb the CO_2. Oil viscosity and interfacial tensions are reduced and the relative mobility of the oil increased, allowing the oil to flow into the production well. Huff-(n)-puff has been used successfully in sandstone reservoirs of the Gulf Coast, but has been underutilized in carbonate reservoirs. The successful demonstration of the technique with its expected quick recoveries and early cash flows may provide producers in both large and small Permian Basin carbonate reservoirs a cost-effective alternative to large scale CO_2 floods.

Occidental Oil Co. is investigating the advantages of coupling cyclic CO_2 stimulation of production wells with CO_2 flooding to improve economics and recovery efficiency in the previously waterflooded, low -permeability San Andres formation in West Welch field in the Permian Basin.

The CO_2 flooding technology was selected based on laboratory and field tests that included standard PVT analysis and minimum miscibility tests. Core flooding experiments showed the residual oil after waterflooding to average 35% of floodable pore volume. Capillary pressure data combined with the relative permeability tests were used to distinguish four rock types. As in the Texaco project discussed above, cyclic CO_2 will result in early recovery and cash flow.

Field implementation is expected to begin in late 1996. A 10% increase in oil recovery amounting to an estimated 2.7 MMBO from the 520 acre project area is anticipated. If the CO_2 flood is successfully expanded to the rest of the unit, recovery of 10% (up to 29 MMBO) of the OOIP could result.

Cyclic CO_2 treatments on five wells have resulted in increased recovery from two of the wells. One well, which received the largest volume of CO_2, has been shown to be economic based on pipeline cost for CO_2.

Chevron is evaluating a CO_2 project in the fractured Monterey siliceous shales in California's Buena Vista field. CO_2 will be injected to reestablish reservoir pressure and improve sweep efficiency. Phase behavior and coreflood measurements will be input into a simulation model. Injection profiles and tracer tests will be run to determine fracture characteristics and optimum injection rates. Chevron expects to recover an additional 5 to 15% of the original oil-in-place.

Miscible Processes

Texaco is evaluating the use of a horizontal injection well to improve oil recovery. Miscible CO_2 design studies included standard PVT work and tests to determine miscibility conditions of the reservoir oil with CO_2.

Reservoir modeling studies indicated that water injection prior to CO_2 had little or no effect on the miscible CO_2 performance, but did increase the flow rates in producing wells due to higher reservoir pressure.

A horizontal injection well penetrated 250 feet of reservoir to improve reservoir sweep efficiency. CO_2 is being injected at the oil-water contact. The project has been in operation since 1993, and has recovered 270 MBO of tertiary oil to date. Total CO_2 injection in the reservoir to date is 4.2 BCF.

Current project assessment indicates mixed results. Positive results include the increase of well production rates by three to four times by using CO_2 flooding.

Application of a WAG (water alternating gas) process resulted in an improvement of the reservoir production rate and increased ultimate recovery. Water injected simultaneously or in small slugs alternating with gas (WAG), causes the CO_2 to sweep the reservoir more efficiently.

Problems that have affected both ultimate recovery and production rates are: lowered minimum displaceable oil saturation (MDOS), water blockage, reservoir complexity, and wellbore mechanical problems. These issues will be discussed in more detail in a paper that will be presented at the SPE/DOE symposium in Tulsa, OK., April, 1996.

Phillips Petroleum Company is using horizontal injection wells to improve the economics of CO_2 flooding in the Grayburg/San Andres reservoir in the South Cowden field in the Permian Basin. This technique is expected to improve recovery 25% compared to typical vertical wells, and will use less injectors by one-third, eliminate the need for an extensive CO_2 distribution system, and reduce capital costs. Lab tests are analyzing foaming surfactants for CO_2 mobility control and gelled polymers for profile modification. Increased recovery from the Grayburg/San Andres at South Cowden field as a result of applying this technology could be as much as 3 MMBO.

The Paradox basin in Utah also has significant potential for miscible CO_2 flooding. **The Utah Geological Survey** is evaluating the CO_2 potential of five fields in the Paradox basin. Seismic and outcrop data are being used in the reservoir description.

Parker and Parsley plan to inject CO_2 in the Spraberry trend in Texas to produce oil by gravity drainage. The presence of natural fractures is the dominant influence on performance in the Spraberry's slope-basin and basin clastic reservoirs. Waterflooding was initiated in the Spraberry in the 1950s, but recovery of additional oil from this process has been relatively poor and only marginally economic. Less than 10% of the 10 billion bbls of OOIP in the Spraberry Trend has been recovered.

CO_2 injection in the Spraberry has never been attempted. It has always been assumed the low viscosity of the injected CO_2 combined with the inability of the CO_2 to be spontaneously imbibed would cause rapid channeling of CO_2 to production wells via the fracture network.

Parker and Parsley will attempt to show that when carbon dioxide is injected into the Spraberry reservoir under near miscible pressure conditions, gravity becomes the dominant force in the recovery mechanism as the interfacial tension (IFT) between phases approaches the point of miscibility. Based on previous laboratory work with analog fluids and scaling theory, the predominance of gravity near the critical point suggests efficient recovery processes may be designed for vertically fractured reservoirs by injection of CO_2.

Success of the proposed technology could improve production in the pilot study area by 85 barrels of oil per day resulting in an incremental recovery of 31 thousand barrels of oil. Extrapolated to the Spraberry trend as a whole, this technique might allow access to a substantial national resource in what has often been referred to as the largest uneconomic field in the world. If successful, the potential incremental oil recovery from the Spraberry could be over 125 million barrels.

Table 1 Class Projects Addressing CO_2 Flooding

Contractor	Principal Investigator	Class	Field/State	Formation
Texaco	Sami Bou-Mikael	1	Port Neches /TX	Marginulina
Texaco	Scott Wehner	2	Vacuum /NM	Grayburg/San Andres
Oxy USA	Archie Taylor	2	Welch /TX	San Andres
Phillips	D.R. Wier	2	South Cowden /TX	Grayburg/San Andres
Utah Geol. Survey	M. Lee Allison	2	various/UT	Paradox
Chevron	Stan Cook	3	Buena Vista /CA	Monterey
Parker & Parsley	Paul McDonald	3	various /TX	Spraberry/San Andres

C A L E N D A R

MARCH

March 1, *Michigan Tech Class 2 Horizontal Drains Project,* Core exam., Crystal Field, Dundee Fm., by apptmnt, Houghton, MI (call J. Wood 906/487-2894) and Kalamazoo, MI (call W.B. Harrison 616/387-5488)

March 1-2, *Michigan Tech Class 2 Horizontal Drains Project,* "Oil Recovery Using Horizontal Drains—Dundee Formation, MI," Poster session, Alma, MI (call S.D. Chittick 906/487-2531)

March 8-10, Brushy Canyon Field Trip (related to Class 3), in conjunction with SW Section Annual Meeting AAPG, El Paso, TX (call Bill Basham 915/697-7560)

March 10-12, *Laguna Petroleum Class 2 Project,* Permian Basin G/SA Integrated Study, Oral presentation & poster, AAPG SW Section meeting, El Paso, TX (call Hoxie Smith 915/682-7356)

March 21-22, *Oxy Class 2 Welch Field CO_2 Project,* "Improved Reservoir Characterization Through Integrated Core, Well Log and 3-D Seismic Data Applied to the Permian San Andres Carbonate Reservoirs in the Welch Field, Dawson County, Texas," SIPES 1996 National Conv., Addison, Texas (call George Watts 915/685-5666)

March 26-27, *OGS Platform Carbonates in the Southern Midcontinent* (related to Class 2, supported by DOE funding) (call Michelle Summers 405/325-3031)

— ***Occidental Class 2 Welch Field CO_2 Project,*** "Seismic Prediction of Reservoir Properties in a San Andres Reservoir, Welch Field, Dawson County, Texas" and "Improved Reservoir Characterization Through Integrated Log and Core Analysis: Example from the Welch Field, Dawson County, Texas" (call George Watts 915/685-5666)

March 27-29, *SPE Permian Basin Oil & Gas Recovery Conference,* Midland, TX

— ***Laguna Petroleum Class 2 Project,*** Permian Basin G/SA Integrated Study (call Hoxie Smith 915/682-7356)

— ***Texaco Class 2 Permian Basin Project,*** "CO_2 Huff-(n)-Puff Process in a Light Oil, Shallow Shelf Carbonate Waterflooded Reservoir" (call Scott Wehner 915/688-2954)

— ***Occidental Class 2 Welch Field CO_2 Project,*** "Fracture Monitoring Using Low Cost Passive Seismic," "Characterization of Rock Types with Mixed Wettability Using Log and Core Data," "Case Study—CO_2 Stimulations of Five San Andres Producers" (poster session) (call Archie Taylor 915/685-5677)

APRIL

April 8, *Texas BEG Class 1Frio Fluvial Deltaic Project,* "Identifying Opportunities for Reserve Growth in Mature Fields of the Frio Fluvial/Deltaic Play, Vicksburg Fault Zone, South Texas," Short course hosted by South Texas Geological Society, San Antonio, TX (call Ray Levey 512/471-7313)

April 17-18, *Laguna Petroleum Class 2 Project, Permian Basin G/SA Integrated Study, Short course and oral presentation,* Southwest Petroleum Short Course, Lubbock, TX (call Hoxie Smith 915/682-7356)

April 18, *Oklahoma Geological Survey Class 1 Project,* "FDD Workshop: The Layton and Osage-Layton Play," Oklahoma City, OK (call Michelle Summers 405/325-3031)

April 21-24, *Technical Papers at SPE/DOE Tenth Symposium on Improved Oil Recovery,* Tulsa, OK

— ***Laguna Petroleum Class 2 Project,*** Permian Basin G/SA Integrated Study (call Hoxie Smith 915/682-7356)

— ***Amoco Class 1 West Hackberry Project,*** "Economics of Light Oil Air Injection Projects" (call Travis Gillham 713/366-7771)

— ***Hughes Eastern Class 1 Microbial Project,*** "Utilization of Indigenous Microflora in Permeability Profile Modification of Oil Bearing Formations" (call James Stephens 601/969-6600)

— ***Texaco Class 2 Permian Basin Project,*** "CO_2 Huff-n-Puff Process in a Light Oil, Shallow Shelf Carbonate Waterflooded Reservoir" (call Scott Wehner 915/688-2954)

— ***Texaco Class 1 CO_2 Project,*** "Post Waterflood CO_2 Miscible Flood in Light Oil Fluvial Dominated Deltaic Reservoirs" (call Sami Bou-Mikael 504/593-4565)

— ***Occidental Class 2 Welch Field CO_2 Project,*** "Preliminary Results of Cross Wellbore Tomography and Comparison to Borehole Logs, DOE Project, San Andres Reservoir, Welch Field, Dawson County, Texas" (call Greg Hinterlong 915/685-5667)

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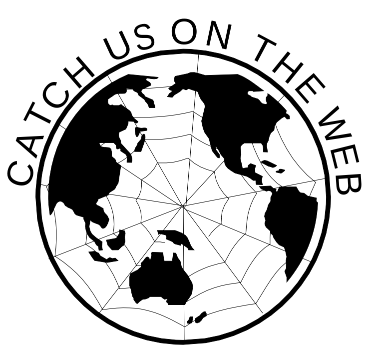

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