TECHNICAL PROGRESS REPORT

Title: REVITALIZING A MATURE OIL PLAY:
STRATEGIES FOR FINDING AND
PRODUCING UNRECOVERED OIL IN FRIO
FLUVIAL-DELTAIC RESERVOIRS OF
SOUTH TEXAS

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Objectives

Advanced reservoir characterization techniques are being applied to selected reservoirs in the Frio Fluvial-Deltaic Sandstone (Vicksburg Fault Zone) trend of South Texas (Fig. 1) in order to maximize the economic producibility of resources in this mature oil play. More than half of the reservoirs in this depositionally complex play have already been abandoned, and large volumes of oil may remain unproduced unless advanced characterization techniques are applied to define untapped, incompletely drained, and new pool reservoirs as suitable targets for near-term recovery methods. This project is developing interwell-scale geological facies models and assessing engineering attributes of Frio fluvial-deltaic reservoirs in selected fields in order to characterize reservoir architecture, flow-unit boundaries, and the controls that these factors exert on the location and volume of unrecovered mobile and residual oil. The results of these studies will lead directly to the identification of specific opportunities to exploit these heterogeneous reservoirs for incremental recovery by recompletion and strategic infill drilling.

Project objectives are divided into three major phases. Phase I, reservoir selection and initial framework characterization, consisted of the initial tasks of (a) screening fields within the play to select representative reservoirs that have a large remaining oil resource and are in danger of premature abandonment and (b) performing initial characterization studies on selected reservoirs to identify the potential in untapped, incompletely drained, and new pool reservoirs. Phase II involved advanced characterization of selected reservoirs to delineate incremental resource opportunities. Subtasks here included volumetric assessments of untapped and incompletely drained oil, along with an analysis of specific targets for recompletion and strategic infill drilling. The third and final phase (III) of the project consists of a series of tasks associated with documentation of Phase II results, technology transfer, and the extrapolation of specific results from reservoirs in this study to other heterogeneous fluvial-deltaic reservoirs within and beyond the Frio play in South Texas.

The goals of the Industrial Associates program that is the source of industry cofunding to this project are to (1) develop an understanding of sandstone architecture and permeability structure in a spectrum of fluvial-deltaic reservoirs deposited in high- to low-accommodation settings and (2) translate this understanding into more realistic, geologically constrained reservoir models to maximize recovery of hydrocarbons.

Summary of Technical Progress

Project work during the first quarter of 1996 consisted of Phase III tasks related to the transfer of technologies to industry. The two primary vehicles for transferring technologies evaluated in the Frio Fluvial-Deltaic Sandstone play (Vicksburg Fault Zone) are a series of two short courses and a microcomputer-based geologic advisor software program. The first of the two short courses was given during the first quarter, and a preliminary version of the software was demonstrated to industry for feedback. The second short course is scheduled for the second quarter, with release of the software planned for the third quarter. In addition, some technical work is ongoing to refine the interpretation of remaining hydrocarbons in the two field-study areas, thereby providing additional supporting evidence of opportunities to field operators. Finally, in addition to other technology transfer efforts, a manuscript has been completed that will accompany a presentation at a national technical conference during the second quarter.

In addition to technology transfer efforts, technical work in the two fields selected for detailed study, Rincon field in Starr Co., Tx., and Tijerina-Canales-Blucher (T-C-B) field in Jim Wells Co., Tx., is continuing in order to more clearly define reserve-growth opportunities for operators. In Rincon field, a three-dimensional (3-D) reservoir model is being constructed to more accurately calculate remaining volumes, and work during the first quarter focused on a sensitivity analysis of varying model parameters. In T-C-B field, horizon-slice analysis of the 3-D seismic data volume has been done in an attempt to image lateral reservoir extent, thereby helping to refine net sandstone maps and more clearly identify compartment boundaries.

Planned Short Course Series

The most critical task of this project is the transfer to operators of the reservoir characterization techniques found to be successful in this play. Short courses provide an opportunity to meet with the operators in person, present the material, and clarify difficult concepts through question-and-answer interaction. The rapport established between researchers and operators encourages operators to contact researchers if questions arise when operators put the techniques into practice. Two such short courses have been planned during this phase of the project.

The first scheduled short course was held on Monday, April 8, at The Bright Shawl restaurant in San Antonio, Texas, and was hosted by the South Texas Geological Society. The course was attended by a total of 25 professionals, including geologists, engineers, and geophysicists from the South Texas area. The agenda included special presentations by recognized experts in 3-D seismic interpretation and in the interpretation of old electric logs. Cost was kept to a minimum to attract staff from small independent operators. The fee of \$45 (\$50 at the door) covered lunch and included course notes and other materials.

The workshop began with a welcome by Dr. R. P. Major, Deputy Associate Director for Oil Resources, who provided an overview of fluvial-deltaic reservoirs, their importance as a U.S. energy resource, and the need for multidisciplinary advanced reservoir characterization studies. An overview of Frio fluvial-deltaic play characteristics and integrated reservoir characterization methodologies was then presented by Mark Holtz, petroleum geologist at the Bureau. The geologic advisor software was then introduced by program developer Gerry White, and a live demonstration followed in an adjacent workroom.

A short break allowed workshop participants to view cores from Rincon field, selected Bureau publications, and a live demonstration of the geologic advisor software. Following this break, Andrew Scott discussed sequence stratigraphic concepts and gave an introduction to facies identification in deltaic systems. Participants were given an exercise to reinforce the concepts of

subregional well log correlation and interpretation of depositional setting from logs. Andrew concluded the morning session with a talk on the geological identification of reservoir architecture, illustrating the process with examples from reservoirs in both of the fields (Rincon and T-C-B) studied in this project.

Following an onsite lunch, engineering applications in reservoir characterization, such as the evaluation of reservoir pressures and fluid-flow history and the interpretation of old electric logs, were presented. The afternoon session began with a presentation on the interpretation of old electric logs by Dr. George Asquith, the well-known author of a log interpretation book and an old e-log advisor software program. He was followed by Mark Holtz, who spoke about Frio fluvial-deltaic petrophysical characteristics, including porosity, permeability, capillarity, residual oil saturation, and relative permeability.

Dr. Bob Hardage, a well-known expert in the field of 3-D seismic, followed with a discussion on the power and benefits of 3-D seismic. Dr. Hardage presented suggestions for optimizing acquisition parameters to obtain the best data possible in a particular reservoir of interest. He was followed by Dr. Jeff Paine, who discussed the application of geophysics and geology to the identification of reservoir compartment boundaries and sighted specific examples from T-C-B field, a field studied in detail during this project.

After a short break, Mark Holtz concluded the short course by pointing out the importance of developing the reservoir model through the integration of geology, geophysics, and engineering. This integration of reservoir architecture and fluid-flow trends was discussed as the final step to identifying the location and volume of remaining resources.

Overall, the short course ran very smoothly and was well attended. Participants were given a three-ring notebook that contained copies of the materials presented; an exercise; Bureau of Economic Geology Report of Investigations No. 227, "Identification and Assessment of Remaining Oil Resources in the Frio Fluvial-Deltaic Sandstone Play, South Texas"; DOE Contract Report DOE/BC/14959-17, "Revitalizing a Mature Oil Play: Strategies for Finding and Producing

Unrecovered Oil in Frio Fluvial-Deltaic Sandstone Reservoirs of South Texas"; and an annotated bibliographic index of the Frio Fluvial-Deltaic Sandstone play.

The Geologic Advisor

The geologic advisor software package is another technology transfer tool that has the potential of reaching a larger audience than the short courses. It will illustrate the technologies and approaches presented in the short courses. However, because it can be used by the operator repeatedly, when the operator chooses, and in the operator's office, it is more accessible than the short courses.

The advisor is being designed to provide operators with an illustrated microcomputer-based guide to the reservoir characterization process, which leads to identifying reserve-growth potential. The geologic advisor will include hypertext links to enable rapid definition or illustration of terms or concepts and will contain algorithms to calculate reservoir volumetrics and reservoir priority on the basis of operator-supplied data. To enable the majority of operators within the play to use it, the software will run on an IBM-compatible personal computer model 386 (or faster) with a VGA monitor (or better) and mouse, will use Windows 3.1 or higher, and will be distributed in diskette form.

The geologic advisor has now reached the beta stage of development and is being demonstrated to reviewers, both at BEG and outside the University, for feedback. The screen design has been established and is considered readable and easy to use. A recent version was demonstrated at the first short course on April 8 in San Antonio, and the feedback was favorable: screen layout, usability, and project scope were all lauded by Society members in attendance.

The advisor comprises five main modules. Four modules illustrate separate tasks of reservoir characterization, and one module provides a Quicklook analysis for prioritizing reservoirs for detailed study. The most complete module is the Quicklook analysis package, into which an operator enters several numerical parameters for each of a group of reservoirs being evaluated for possible detailed reservoir characterization. The numerical parameters are then used to calculate a

value that is related to the estimated potential of the reservoir to contain remaining mobile hydrocarbons.

Parameters entered for a reservoir in the data entry screen (Fig. 2) include relative volumetric importance (an estimate of the original hydrocarbons in place relative to the other reservoirs being evaluated), percent gas—the volume of the reservoir that originally contained gas (a measure of hydrocarbon mobility), current well spacing in acres, depth, structural heterogeneity, and stratigraphic heterogeneity (measures of how well a reservoir has been drained). Many of these are subjective parameters, and the advisor represents a way to quantify and combine each subjective aspect into a quickly calculated ranking of reservoirs. It offers a mechanism with which to quickly form an 'educated opinion' about a series of reservoirs by using both concrete and subjective information. The accuracy of the evaluation is constrained by the amount of information currently available about a reservoir without undertaking a time-consuming detailed study of each reservoir.

A separate screen (Fig. 3) displays the calculated value and subsequent ranking for each reservoir, along with the entered parameters for a user-selected reservoir. Values for each parameter can be edited here and the ranking recalculated and displayed instantly. Similarly, the rank of a given reservoir will be displayed in the lower right corner of the data-entry screen (Fig. 2) and will be automatically updated if the user changes the value of any parameter.

Continued Technical Support

Following the conclusion of Phase II tasks, technical efforts in reservoir characterization have continued in order to provide additional supporting evidence to operators of the validity and risks associated with specific reserve-growth opportunities. In Rincon field, this includes construction of a 3-D reservoir visualization model, with initial work focusing on the sensitivity of the model to changing parameters. In T-C-B field, continued technical work this quarter has been directed toward stratigraphic analysis of selected layers to aid in the definition of compartment boundaries.

Rincon Field

A 3-D reservoir visualization model was built to refine the understanding of the location and volume of remaining oil. The outcome of such a model is a consequence of the approach used to establish flow-unit geometries and extrapolate petrophysical characteristics from well locations. A sensitivity analysis was undertaken that considered the method of describing flow units that thin laterally (either proportionally or by onlap onto an underlying surface); whether a directional bias should be applied in the extrapolation of petrophysical characteristics, potentially reflecting a preferential directional fabric within the reservoir; and whether a facies template should be used, such that petrophysical characteristics are stochastically extrapolated within a deterministic framework established by geologic facies mapping (that is, values are extrapolated between two adjacent wells in a channel facies, but values from these wells are not used to extrapolate to a third adjoining well located in a floodplain facies).

Table 1 shows the results of the sensitivity analysis for five cases. On the basis of geological knowledge about the reservoir in question, case 1 is the most accurate but complex case, wherein layers are thinned proportionally and a facies template is used without any directional bias applied. Successive cases consider situations in which flow units are thinned by onlap and in which petrophysical characteristics are distributed with or without a facies template, with directional bias either applied or not applied. The fourth and fifth columns of Table 1 show the resulting calculated original oil in place (OOIP) and the percent difference from the ideal case (case 1). The largest factor affecting the outcome seems to be the method used to describe the thinning of the flow units, perhaps because it so substantially affects reservoir volume. The difference between proportional thinning and onlap made a greater-than-20-percent difference in the calculated OOIP. Using a facies template improved the accuracy of the calculation by three percent in cases in which directional bias was applied (case 3 versus case 4) and in which it was not (case 2 versus case 5). In this analysis, the application of directional biasing of petrophysical characteristics actually decreased the accuracy by two percent (case 2 versus 3 and case 4 versus 5). This may be a

consequence of the complexly multidirectional nature of depositional trends in the fluvial (upper delta-plain) reservoir used in the analysis.

TABLE 1

Results of a sensitivity analysis of the Rincon field reservoir model.

Experiment	Layer method	Directional bias	Facies template	OOIP (STB)	% Change
Case 1	Proportional	No	Yes	10,392,900	—
Case 2	Onlap	No	Yes	8,231,690	-21%
Case 3	Onlap	Yes	Yes	7,957,790	-23%
Case 4	Onlap	Yes	No	7,662,200	-26%
Case 5	Onlap	No	No	7,855,270	-24%

T-C-B Field

A reprocessed three-dimensional seismic data set donated by Mobil Exploration and Producing U.S. Inc. is being analyzed to better understand stratigraphic controls on reservoir compartments. Despite a relatively low useful frequency range of 10 to 50 Hz that limits vertical resolution, numerous stratigraphic features that affect reservoir geometry are visible in the data set. Seismic analysis has focused on an interval between the 13A and 21D (Fig. 4) horizons that is relatively unaffected by faulting. These strata are mostly upper delta-plain deposits of the middle Frio Formation. Time-depth relationships have been established using two checkshot surveys, seven synthetic seismograms constructed from acoustic and density logs, and a vertical seismic profile collected during reprocessing.

Thirteen key stratigraphic horizons have been picked within the data volume. Maps of two-way time and reflector amplitude constructed from these horizons and more than 50 maps derived from these key horizons are yielding additional information that allows us to refine facies and net sandstone maps constructed from well logs only. For example, a horizontal time slice from the

21B zone in the north-central part of the seismic data set (Fig. 5) shows an amplitude high that forms a channellike feature in the shape of a flattened "S." A generalized version of the same feature is evident on a net sandstone map of the same geographic area and stratigraphic interval (Fig. 6). The greatly increased level of detail visible on the seismic image attests to the benefits of better lateral resolution in the seismic data set than in the well log data set. These horizon mapping techniques are being combined with other advanced seismic analysis tools, such as amplitude thickness mapping, to locate likely stratigraphic targets for enhanced hydrocarbon recovery.

Other Technology Transfer Activities

In addition to the presentation of the short course and the initial public demonstration of the geologic advisor, a manuscript³ was completed and preprints published to accompany a presentation to the Society of Petroleum Engineers/DOE Improved Oil Recovery Conference to be held April 22, 1996, in Tulsa, Oklahoma.

Characterization of Heterogeneity Style and Permeability Structure in a Sequence Stratigraphic Framework in Fluvial-Deltaic Reservoirs (Matching Funds Source)

Because of the worldwide importance of resources in fluvial-deltaic reservoirs, a consortium of oil companies is funding research at the Bureau of Economic Geology, The University of Texas at Austin, aimed at reservoir characterization of fluvial-deltaic depositional systems. The goals of this program are to develop an understanding of sandstone architecture and permeability structure in a spectrum of fluvial-deltaic reservoirs and to translate this understanding into more realistic, geologically constrained reservoir models. Our approach is to quantify the interrelationships among sequence stratigraphy, depositional architecture, diagenesis, and permeability structure through detailed outcrop characterization. This Industrial Associates program is the source of the 50-percent cofunding for the Bureau's Class I Oil Project.

Subsurface interpretation of reservoirs is hindered by the fact that data are derived primarily from wells. In relatively homogeneous reservoirs, the continuity of reservoir units between wells may be relatively easy to determine. In more complex fluvial-deltaic reservoirs, continuity of sandstone bodies may be much less than the average well spacing. A fundamental problem in characterizing complex subsurface reservoirs is the determination of the three-dimensional architecture of depositional and diagenetic facies and their relationship to the spatial distribution of reservoir properties that control fluid flow.

The investigation of this general set of reservoir description and modeling problems continued during the reporting period. The goal of this task is to build descriptive and distinct spatial models for both seaward- and landward-stepping elements of the Upper Cretaceous Ferron sandstone, a fluvial-deltaic system deposited in a high-accommodation setting in Utah. The results will be used to quantify differences in recovery behavior between the two architectural styles. The models will be constructed using deterministic and stochastic approaches that are consistent with outcrop observations, geological inference, and data quality. The combination of statistical data and stacking rules provides the basis for developing object-based models for flow simulation. The permeability data and sample analysis, in turn, provide information for modeling the effective reservoir properties of these objects. In addition, the permeability data will provide information useful in conducting more geostatistically based reservoir simulations.

During this quarter, tabular and gridded versions of the Ferron outcrop data were translated into formats that can be imported into the commercial flow simulator Eclipse. The geometric and petrophysical accuracy and consistency of these models are being verified. Each stratum in the outcrop image is translated to one or more simulation grid layers. All layers are divided into cells by intersecting this stratigraphic coordinate system with a series of evenly spaced vertical lines. The cell boundaries are then defined by the intersection of the vertical lines with stratigraphic surfaces. The (x,z) coordinates of these intersections are used to specify the "corner-point geometry" for the simulator. These corner points are also used to determine the cell center and to interpolate facies descriptions and petrophysical properties. The corner-point geometry and rock

properties are written to large "include" files, which can be parsed by the commercial preprocessing, simulation, and visualization programs. Ultimately, this will facilitate dissemination of detailed architectural data from the Ferron outcrop study.

Planned Activities

During the coming quarter, the second workshop will be given, a completed "beta" version of the geologic advisor will be released, and presentations of project results will be made at national technical conferences of the Society of Petroleum Engineers and the American Association of Petroleum Geologists. The content of the second workshop, to be held June 6 in Houston, Texas, will be modified slightly to reflect audience feedback from our initial presentation, as well as any additional technical progress made in the course of operator support. The "beta" version of the advisor will be released to selected operators for review and feedback at the end of June, with modifications and distributions of the final product by the end of August.

Technical work on Rincon and T-C-B reservoirs will continue so that specific reserve-growth opportunities can be further clarified for operators. Refinement of the 3-D reservoir model of Rincon intervals will also continue, as will interpretation of 3-D seismic data in T-C-B reservoirs.

References

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- ²Kosters, E. C., Bebout, D. G., Seni, S. J., Garrett, C. M., Jr., Brown, L. F., Hamlin, H. S., Dutton, S. P., Ruppel, S. C., Finley, R. J., and Tyler, Noel, 1989, Atlas of major Texas gas reservoirs: The University of Texas at Austin, Bureau of Economic Geology Special Publication, 161 p.
- ³Holtz, M. H., Reservoir characterization methodology to identify reserve growth potential: SPE/DOE Improved Oil Recovery Conference, April 22, Tulsa, Oklahoma, Transactions, *in preparation*.

Fig. 1 Map of South Texas showing location of fields within the Frio Fluvial-Deltaic Sandstone play along the Vicksburg Fault Zone. This project included detailed studies of Rincon and T-C-B fields, located in the southern and northern parts of the play, respectively. (Modified from Gallo-way and others,¹ and Kosters and others.²)

Enter Data for a New Reservoir

Reservoir Name:

Depth: feet

Percent Gas: %

Well Spacing: acres

Drive Mech:

Operator Bias

☐ Gas Production

☒ Oil Production

Relative Volumetric Importance

Low
Med
High

68%

Stratigraphic Heterogeneity

Heterogeneity:

Structural Heterogeneity

Heterogeneity:

Entry Status

Priority:

Rank:

Total:

Get help on using the Advisor

Fig. 2 Reservoir data-entry screen for the Quicklook module of the geologic advisor. Reservoir parameters such as the percent of the reservoir that contains gas, the current well spacing, relative volumetric importance, and reservoir heterogeneity can be entered to allow a comparison of reserve-growth potential between several to many different reservoirs. Displays for stratigraphic and structural heterogeneity help the operator make an estimate of these values by showing cartoons of reservoirs that have greater or lesser heterogeneity as the 'up' and 'down' arrows are activated.

Reservoirs Ranked by Reserve Growth Potential

View the prioritized list of reservoirs below. Click on a reservoir name to examine its criteria.

Rank	Value	Reservoir Name	Evaluation Criteria Review
1	14117	Reservoir #1	<p>*** Seeligson Zone 19-B ***</p> <p>Well Spacing: 120</p> <p>Percent Gas: 30</p> <p>Depth (ft): 6600</p> <p>Volumetric Importance: 20</p> <p>Structural Heterogeneity: 8</p> <p>Stratigraphic Heterogeneity: 8</p> <p>Hydrocarbon Bias: Oil</p> <div style="display: flex; justify-content: space-around; margin-top: 10px;"> Edit Delete New </div> <p>Click here to view the equation the reservoir rank</p>
2	4646	Reservoir #4	
3	3959	Randall Co. #9	
4	2762	Midland Oil Co.	
5	2590	Walker #41	
6	2560	Walker #42	
7	2424	Smith and Jones #44	
8	2409	Hamilton Pool #33	
9	2215	Jones #77	
10	1971	Seeligson #44	
11	1875	Seeligson Zone 19-B	
12	1260	Kelsey Zone 21	
13	860	Very Long Reservoir Name	
14	458	Avalon	
15	393	Midland Oil #1	

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Fig. 3 'Results' screen for the Quicklook module of the geologic advisor. After data for several reservoirs are entered on the data-entry screen (Fig. 2), the ranking of the reservoirs (calculated automatically) is displayed in the box on the left side of the screen (the second column is the actual value calculated—the higher the value, the higher the estimated reserve-growth potential of a reservoir). The user can highlight a particular reservoir and be shown the parameters that were entered for it in the area to the right. These values can be edited here, and the ranking will automatically be recalculated and displayed.

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Fig. 4 Type log for the T-C-B field showing the relationship between formation, reservoir sandstone name, and genetic unit top markers. Stratigraphic analysis of the 3-D seismic data has focused on the interval from the 13A marker to the 21D marker.

Fig. 5 Amplitude map for the genetic unit below the 21B marker, with higher amplitudes (lighter colors) indicating greater sandstone volumes. An apparent meandering sandstone thick is present in this portion of the study area. Figure 6 shows the corresponding net sandstone map drawn using only well control.

21-B-2 NET SANDSTONE

EXPLANATION Net sandstone (ft)

> 10
5 to 10
0 to 5
No sand

0 0.5 mi

QA63728c

Fig. 6 Net sandstone map for the 21-B-2 reservoir. Contoured using only well data, this map suggests two separate, relatively straight channels with narrow to wide areas of levee or overbank. The amplitude map that includes this interval, shown in Fig. 5, suggests that the deposits of this unit may instead be the result of a single meandering channel. If accurate, this would provide a much clearer picture of the distribution of high-quality reservoir rock, thereby reducing the geologic risk associated with any infill drilling that targets this unit.