DOE/BC/14959--16

TECHNICAL PROGRESS REPORT

Title:	REVITALIZING A MATURE OIL PLAY: STRATEGIES FOR FINDING AND PRODUCING UNRECOVERED OIL IN FRIO FLUVIAL-DELTAIC RESERVOIRS OF SOUTH TEXAS
Cooperative Agreement No.:	DE-FC22-93BC14959
Institution:	Bureau of Economic Geology The University of Texas at Austin University Station, Box X Austin, Texas 78713-8924
Date of Report:	October 10, 1995
Award Date:	October 21, 1992
Anticipated Completion Date for this Budget:	August 31, 1996
Government Award for this Budget Period:	$817,911
Principal Investigators:	Noel Tyler and Raymond A. Levey
Technical Project Officer:	Edith C. Allison
Reporting Period:	July 1, 1995 – September 30, 1995

DISCLAIMER

OBJECTIVES

Advanced reservoir characterization techniques are being applied to selected reservoirs in the Frio Fluvial-Deltaic Sandstone (Vicksburg Fault Zone) trend of South Texas 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 characteristics 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 (1) screening fields within the play to select representative reservoirs that have a large remaining oil resource and that are in danger of premature abandonment and (2) 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 (III) and final phase 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 (1) to 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) to translate this understanding into more realistic, geologically constrained reservoir models to maximize recovery of hydrocarbons.

SUMMARY OF TECHNICAL PROGRESS

Project work during the third quarter of 1995 consisted of (1) documentation of Phase II tasks associated with the delineation of untapped and incompletely drained reservoir compartments and new pool reservoirs in selected Frio fluvial-deltaic sandstone intervals in Rincon and Tijerina–Canales–Blucher (T-C-B) fields, as well as (2) Phase III tasks related to the transfer of the technologies to industry that aided in delineation. Documentation of Phase II tasks has now concluded, and the bulk of the effort has turned toward technology transfer.

The process of multidisciplinary advanced reservoir characterization has been documented in a Topical Report accepted for publication by DOE. Reservoirs within Rincon field, Starr County, were used to illustrate the process of characterization and the potential for reserve growth in the mature reservoirs of the Frio Fluvial-Deltaic Play. Additionally, the operator of T-C-B field has begun a series of recompletions that have proved the validity of project recommendations and added incremental production from one of the reservoirs studied.

Results of the Frio fluvial-deltaic study have been used during the past quarter in two workshops developed by other programs at the Bureau of Economic Geology, The University of Texas at Austin, to reach management and geoscientists from a spectrum of operating companies ranging from small independents to large multinational corporations. Plans are also being made and schedules firmed up for two workshops specifically designed to transfer the results of the Frio fluvial-deltaic project to operators within the play. Finally, the ideas surrounding a microcomputer-based Geologic Advisor software package are maturing, and the minimum requirement targets for computers capable of running the software have been set.

Documentation of Untapped and Incompletely Drained Compartments and New Pool Reservoirs: An Example from Rincon Field

Reservoir compartment architecture and incremental recovery opportunities for selected reservoirs within the Frio Fluvial-Deltaic Sandstone (Vicksburg Fault Zone) Play have been identified in previous quarters, and final documentation was completed during this quarter. An example of this work has been accepted for publication by DOE as a Topical Report entitled "Strategies for reservoir characterization and identification of incremental recovery opportunities in mature reservoirs in Frio Fluvial-Deltaic sandstones, South Texas: An example from Rincon field, Starr County." The following brief summary illustrates the procedure used and the results obtained. An analysis of eight reservoirs in Rincon field indicates that 4.7 million barrels of mobile oil (MMBO) remain (Table 1, Fig. 1) and can be targeted by the methods used in this study.

Overview of Approach

The foundation for evaluating a reservoir and identifying remaining mobile oil is the recognition of compartmentalization within the reservoir. Although the effects of structural compartmentalization are widely appreciated, the contribution of stratigraphic variability is generally underrecognized. High-frequency stratigraphic correlation of fluvial-deltaic sequences within Rincon field shows that units as thin as 20 ft and thinner represent separate depositional episodes with consequently independent channel patterns and that these sandstone bodies act as partially or wholly isolated fluid-flow pathways or compartments. Interbedded floodplain or bayfill mudstones have permeabilities several orders of magnitude lower than the reservoir sandstones, and they hydraulically isolate reservoirs where as little as 2 ft of shale separates sandstones. Where vertically successive channel sandstones overlie one another, the sandstone-on-sandstone contact can still act to prevent or decrease fluid flow between sandstones because of the silty channel-top lithofacies of the underlying channel or the mudclast-rich lag deposits at the base of the overlying channel.

Because of these relationships, thick massive-appearing sandstones such as the D-4 through D-6 in the upper right of Figure 2 cannot be treated as a single reservoir. Instead, each depositional unit must be mapped separately to determine its reservoir volume and distribution. Past completions must then be tabulated for each unit as an indication of depletion. Areas of low completion density within each depositional unit present targets for potential recompletions or infill drilling.

The Rincon D-4 Reservoir

The D-4 reservoir in Rincon field is an example of how additional incremental oil production potential can be found in a mature reservoir. The D-4 is just one of four depositional units within the more massive-appearing D reservoir in the middle Frio Formation (Fig. 2). It is composed of a series of dip-oriented sandstone bodies (Fig. 3) that show an upward-fining log pattern. Regional relationships and sedimentary features in core from Rincon field support the interpretation that the D-4 represents the deposits of a fluvial channel system within an upper delta plain setting.

Figure 3 shows the net sandstone distribution, the oil–water and gas–water contacts (which parallel structure contours), and past completions within the D-4, as well as the past completions in the vertically adjacent D-5 unit. Of greatest import are the solid diamonds and squares indicating past completions within the D-4. Note the paucity of completions compared with those in the underlying D-5 unit (Fig. 4), which is more massive and was thus a preferred target for completions.

In the D-4, note the two crossing channel systems near the center of the producing area. The reservoir sandstones within each are likely to be laterally isolated from one another with respect to fluid flow by areas of floodplain mudstones (the areas of less than 5 ft of net sandstone) or, where the channels cross, by a layer of low-permeability mudclast rip-up conglomerate. The northeast and southwest channel segments (Fig. 3) have only had a total of three completions and likely represent incompletely drained compartments, whereas the northwest and southeast channel segments have not been exploited at all and remain as untapped compartments.

Testing of Identified Untapped and Incompletely Drained Compartments: Tijerina–Canales–Blucher Field

As reported in the last quarterly report (7/95), a series of recompletion and infill opportunities have been identified in the Scott and Whitehill reservoirs of T-C-B field, Jim Wells County, on the basis of a study similar to that illustrated for the D-4 reservoir. The opportunities in the Whitehill reservoir were tabulated and assigned a qualitative risk factor that took into consideration compartmentalization, past drainage, and measured resistivity.

The field operator has since recompleted one well that was categorized as moderate risk owing to intermediate resistivity values and proximity to a past completion that drained a large volume of gas from the reservoir. The well, Blucher No. 59, had maximum uncorrected resistivities from the ILD tool of 10 ohmm and is within 650 ft of the Blucher No. 3 well, which produced approximately 5 billion cubic ft (Bcf) of gas from the Whitehill reservoir (Fig. 5), within what is interpreted to be the same large compartment (well No. 59 postdates Blucher No. 3 production). Blucher No. 59 was completed in September 1995, flowing 268 thousand cubic ft per day (Mcfd) and 200 barrels of water (BW). The presence of gas and high water cut is interpreted as evidence of partial communication with Blucher No. 3, suggesting an incompletely drained compartment.

At least three other lower risk recompletion opportunities have been identified but remain untested. These wells are either producing at very economic rates from other reservoirs or produce low rates at low pressures but have flat decline curves. In these cases, the operator does not wish to jeopardize stable economic production by attempting a recompletion. In addition, 14 other recompletion opportunities with risk similar to or less than that of Blucher No. 59 have been identified in the Whitehill zone.

Technology Transfer Activities

The focus of efforts in this project has primarily turned to the transfer of technologies developed or used during Phases I and II. During the third quarter, a Topical Report[1] summarizing

techniques used in detailed reservoir characterization studies of Rincon field was submitted and accepted for publication by the DOE. More direct transfer of these findings to operators in the Gulf Coast is being achieved through the presentation of two technical papers at the annual meeting of the Gulf Coast Association of Geological Societies, to be held October 25–27 in Baton Rouge, Louisiana. The presentations will be accompanied by manuscripts[2,3] that will be included in the Transactions volume. These manuscripts address the detailed geological and engineering study done at Rincon field[2] and the sequence stratigraphic model for controls on reservoir architecture and heterogeneity developed at T-C-B field[3].

Other technology transfer activities during the third quarter included the presentation of project results in two outside workshops, planning for two workshops focusing exclusively on Frio fluvial-deltaic reservoir characterization, and tentative outlining of the Geologic Advisor microcomputer-based software. The following sections expand on each of these topics in turn.

Involvement in Associated Workshops

Results of this project were presented to two industry groups during this past quarter in workshops developed through related funding. One of the two groups included independent operators within the Frio, and the other group consisted of researchers, development geologists, reservoir engineers, and geophysicists from major domestic and foreign oil companies.

PTTC/TIPRO Workshop

The approach to reservoir characterization that was used in this project, along with results of the resource assessment for the Frio Fluvial-Deltaic Sandstone (Vicksburg Fault Zone) Play, was presented to operators of this play during August in Houston as part of a workshop developed jointly by the Bureau of Economic Geology, The University of Texas at Austin; the Petroleum Technology Transfer Council (PTTC); and the Texas Independent Producers and Royalty Owners (TIPRO). A total of 29 operators, geologists, engineers, and geophysicists attended.

The presentation was broken into three sections. The first part was an introduction to Texas Oil and Gas Plays and Reserve Growth Concepts. Sources and processes of reserve growth, play analysis, geological play determination, geologic provinces of the Texas Gulf Coast, and depositional systems models were some of the topics outlined in this section. The point was made that the future of activity in this play lies with reserve growth in already discovered reservoirs.

The second section was a slide presentation on Frio Fluvial-Deltaic Sandstone Play characteristics. Topics included an introduction to the play; an in-depth look at its depositional system makeup; and specific petrophysical attributes, fluid characteristics, and volumetrics of the play. Some of the questions asked concerned the use and resolution of 3-D seismic data as an exploration tool for this play.

The third section encompassed reservoir characterization methodology. Four steps were discussed, including determination of reservoir architecture, establishment of fluid flow trends, the integration of both, and identification of reserve growth potential. Specific field examples were incorporated into this portion of the talk with reference to the Rincon field of South Texas.

GRI Ferron Field Trip

The second workshop was developed by the Bureau of Economic Geology, The University of Texas at Austin, and the Gas Research Institute (GRI) to make geologists, engineers, and geophysicists aware of the breakthroughs in prediction of reservoir architecture within a sequence stratigraphic framework. The workshop consisted of a 3-day field trip to examine exposures of the Ferron Sandstone, Utah. In addition to representatives from the BEG and GRI, the trip was attended by 22 geoscientists from large independents, major integrated petroleum companies, and Latin American oil companies.

The initial work that made recent breakthroughs in reservoir architecture prediction possible was a detailed investigation of reservoir architecture, heterogeneity, and detailed petrophysical characteristics of the fluvial-dominated deltaic Ferron Sandstone of central Utah. This study was carried out by the Bureau of Economic Geology and sponsored initially by GRI and later cofunded

by an industrial associates group (see the section regarding the matching funding source). These concepts were used extensively during the investigation of compartmentalization within the Frio play. Paul Knox presented the results of a study of reservoir architecture in T-C-B field as an example of the application of concepts developed from the outcrop to subsurface studies. The talk underscored the practical utility of these emerging concepts and was well received.

Planning for Frio Workshops

Two workshops are being planned to transfer the techniques and results of this project. The workshops are intended primarily for independent operators and major operators, who control the great bulk of mature reservoirs in the Frio Fluvial-Deltaic Sandstone (Vicksburg Fault Zone) Play. Workshops will be held in two locations accessible to the identified audience. Discussions are currently being held with representatives from the South Texas Geological Society, San Antonio, and the Houston Geological Society. Both workshops will be given in the late winter–spring of 1996.

The workshops will begin with 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 the setting and characteristics of the Frio Fluvial-Deltaic Play will then be followed by a thorough discussion of integrated reservoir characterization methodology. Following lunch, examples from Rincon and T-C-B field reservoirs will be used to illustrate this methodology. Finally, a discussion of rules for prioritizing reservoirs for study will be followed by an introduction to the Geologic Advisor, which will be released in the summer of 1996. Throughout the day, cores from the Frio will be available for viewing during breaks, along with a demonstration of the Geologic Advisor and the display and sale of publications pertinent to the reservoir characterization process and the Frio Fluvial-Deltaic Play.

Geologic Advisor

A software package, "Geologic Advisor," is being developed to assist operators in planning and implementing an integrated reservoir characterization study. The software illustrates the flow path and technologies required in such studies and will include a hypertext-type help system. For example, the primary flow path for a study includes determining reservoir architecture. By activating a highlighted word or symbol, another panel with information on how to identify reservoir architecture will be displayed. Among the steps shown might be identification of depositional facies. By activating this phrase, a series of panels relating facies to typical log profile might be shown.

The approach to reservoir characterization will be a generalized summary of the process developed by the Bureau of Economic Geology, drawing on nearly 30 years of accumulated experience in this area. However, the details of the process will include characteristics inherent in the Frio fluvial-deltaic system. Petrophysical data gathered during this study will be incorporated, and specific examples of reservoir characterization studies from the play will be used.

Geologic Advisor uses a multimedia approach, incorporating text, graphics, animation, and application tools such as spreadsheets to guide the user through the four basic steps in identifying reserve growth potential. These steps are presented as separate modules in the Advisor, which build cumulatively: determining reservoir architecture, establishing fluid-flow trends, integrating architecture and fluid flow, and combining the results of previous steps to identify the reserve growth potential of the reservoir. Spreadsheets will allow the user to enter their reservoir-specific data and execute algorithms that create a quick-look ranking of reservoirs in terms of reserve growth potential or that calculate reservoir volumetrics and drainage areas.

Geologic Advisor is intended to be compatible with personal computers currently used by independent operators. As a consequence, it will be written for the PC-compatible platform, and its minimal requirements are a 386 CPU using Windows and an SVGA monitor to display the graphics and animation.

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 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.

One focus of this project is the Upper Cretaceous Ferron Sandstone, a fluvial-deltaic system deposited in a high-accommodation setting in Utah. During the past quarter, Mark Barton of the Bureau of Economic Geology led a field trip to the Ferron sandstone for the members of the Deltas Industrial Associates group. The goal of the trip was to document different styles of stratigraphic heterogeneity in outcrops of the Cretaceous Ferron Sandstone of central Utah. Styles and scales of reservoir heterogeneity are predictable and can be related to a stratigraphic framework. This predictive relationship reduces the amount of uncertainty associated with correlation and spatial distribution of small- and intermediate-scale features in poorly constrained stratigraphic systems. Being genetically based, this approach is not reservoir specific but is applicable to reservoirs from analogous stratigraphic, depositional, and diagenetic settings.

PLANNED ACTIVITIES

During the coming quarter, final dates and locations for two workshops will be established and preparations will begin on presentation materials and a notebook that will be provided to attendees. In addition, the selection of a source code for the Geological Advisor will be made and

initial writing will begin. Many of the figures for the Geological Advisor will be reformatted as necessary to be included.

REFERENCES

[1] McRae, L. E., and Holtz, M. H., 1995, Strategies for reservoir characterization and identification of incremental recovery opportunities in mature reservoirs in Frio fluvial-deltaic sandstones, Rincon field, South Texas: DOE report, in preparation.

[2] McRae, L. E., and Holtz, M. H., 1995, Strategies for optimizing incremental recovery from mature reservoirs in Oligocene Frio fluvial-deltaic sandstones, Rincon field, South Texas: Gulf Coast Association of Geological Societies, Transactions, v. 45, *in press*.

[3] Knox, P. R., and McRae, L. E., 1995, Application of sequence stratigraphy for prioritizing mature reservoirs for incremental growth opportunities, an example from Frio fluvial-deltaic reservoirs, T-C-B field, South Texas: Gulf Coast Association of Geological Societies, Transactions, v. 45, *in press*.

Table 1. Comparison of sandstone geometry and oil production among Frio D and E reservoir flow units.

	E-4	E-3	E-2	E-1	D-6	D-5	D-4	D-3
Sandstone architecture								
Stacking pattern	A	A	A-R	R	P	P-A	A	A
Mean net sand thickness	8.0	7.1	8.3	6.0	8.8	10.5	7.1	6.2
Reservoir acres	532	1843	1931	462	975	1734	532	294
Percent reservoir (acre/ft) in primary channel facies	77	92	83	---	---	99	78	57
Reservoir development								
Allocated MBO production (based on kH calculations)	486	1405	3453	23	583	2129	712	492
Number of completions	21	35	39	17	11	30	14	15
Percent completions in primary channel facies	50	71	62	---	---	68	71	73
Percent total oil produced from primary channel facies	96	91	66	---	---	94	93	99
Percent total oil produced from reservoir zone	7	31	51	1	19	62	16	3

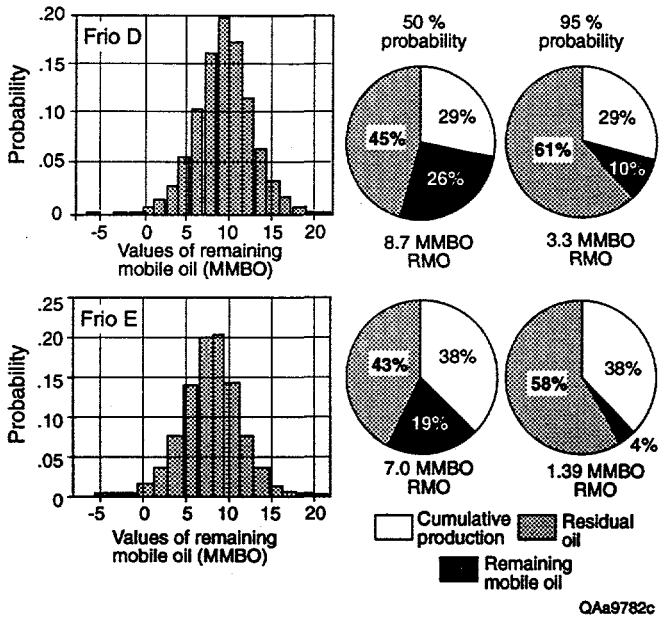


Figure 1. Mean (50% probability) and conservative estimates (95% probabilities) of remaining mobile oil in Frio D and E reservoir sandstones in Rincon field. Under conservative estimates, at least 4.7 MMBO remains in these two intervals.

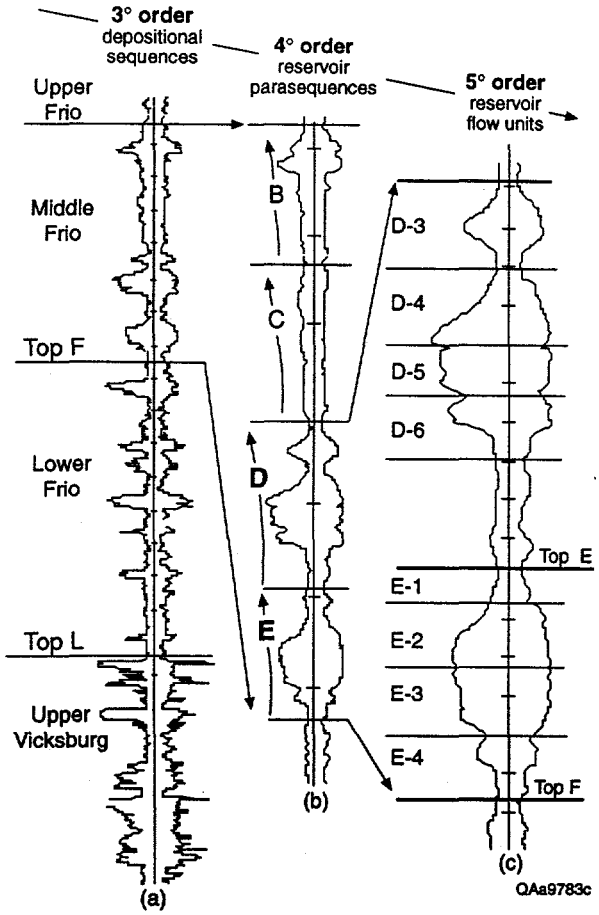
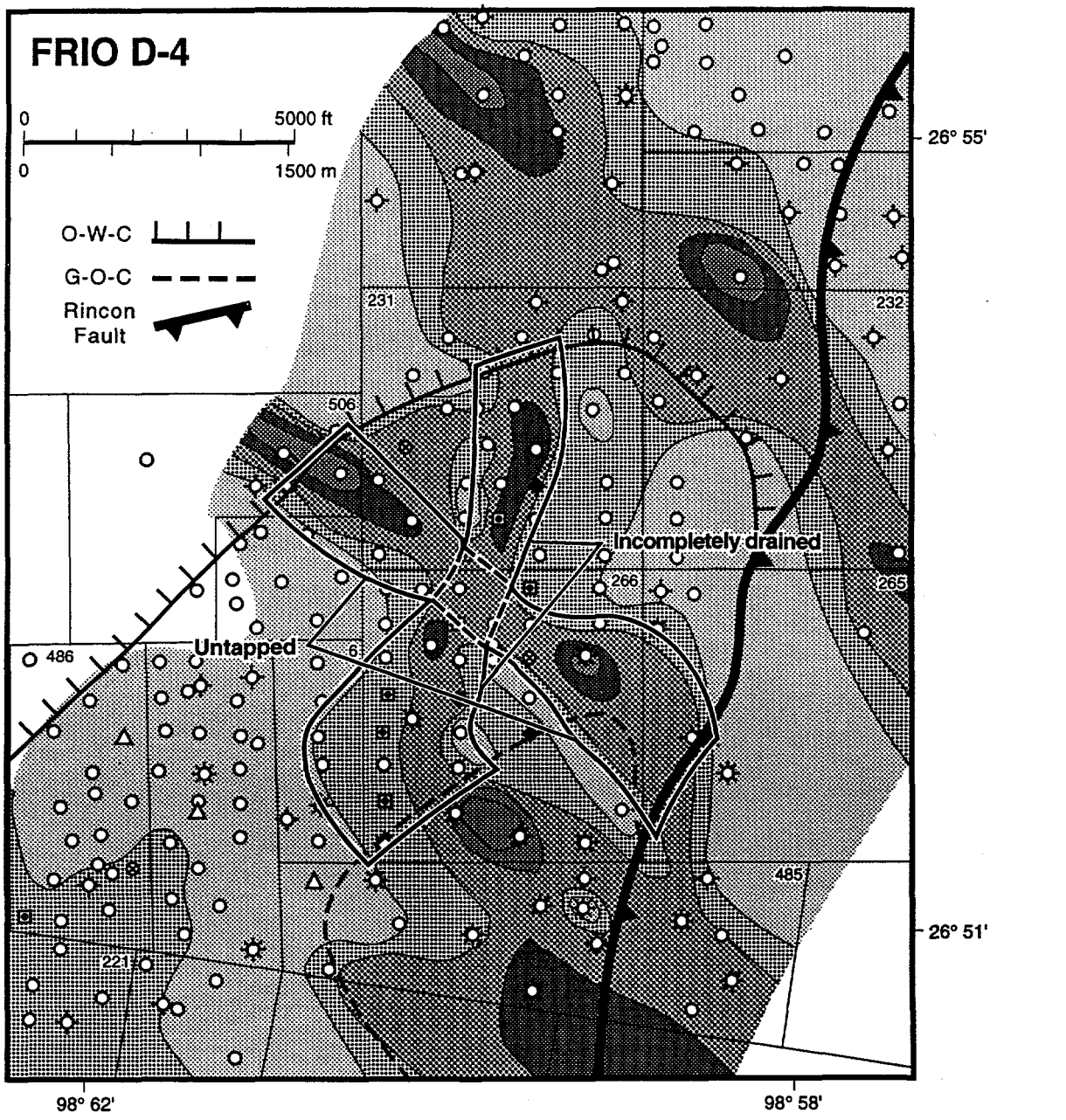


Figure 2. Type logs for Rincon field illustrating (a) the general depositional sequence for the productive Frio–upper Vicksburg reservoir interval, (b) the stratigraphic context of the middle Frio reservoir sequence, and (c) the reservoir nomenclature of individual producing units within the Frio D–E interval.



SANDSTONE THICKNESS (ft) AND RESERVOIR FACIES

- 0 (Floodplain/interdistributary facies)
- 0–5 (Channel/bar margin or overbank facies)
- 5–10 (Channel thalweg)
- 10–15 (Channel thalweg)
- 15–20 (Primary channel axis and/or point bar)

WELL STATUS

- ◆ Completion/production in zone
- ■ Completion/production in zone (watered out)
- ⊞ Completion/production in vertically adjacent sub-unit (D-5 zone)
- ⊗ Completion (no production)
- ○ Completion/oil production from another reservoir zone
- ☼ Completion/gas production from another reservoir zone
- ⊹ No production
- △ Water injection well

QAb1755c

Figure 3. Map illustrating sandstone thickness distribution, productive limits, past completions, and untapped and incompletely drained reservoir compartments in the Frio D-4 reservoir unit of Rincon field.

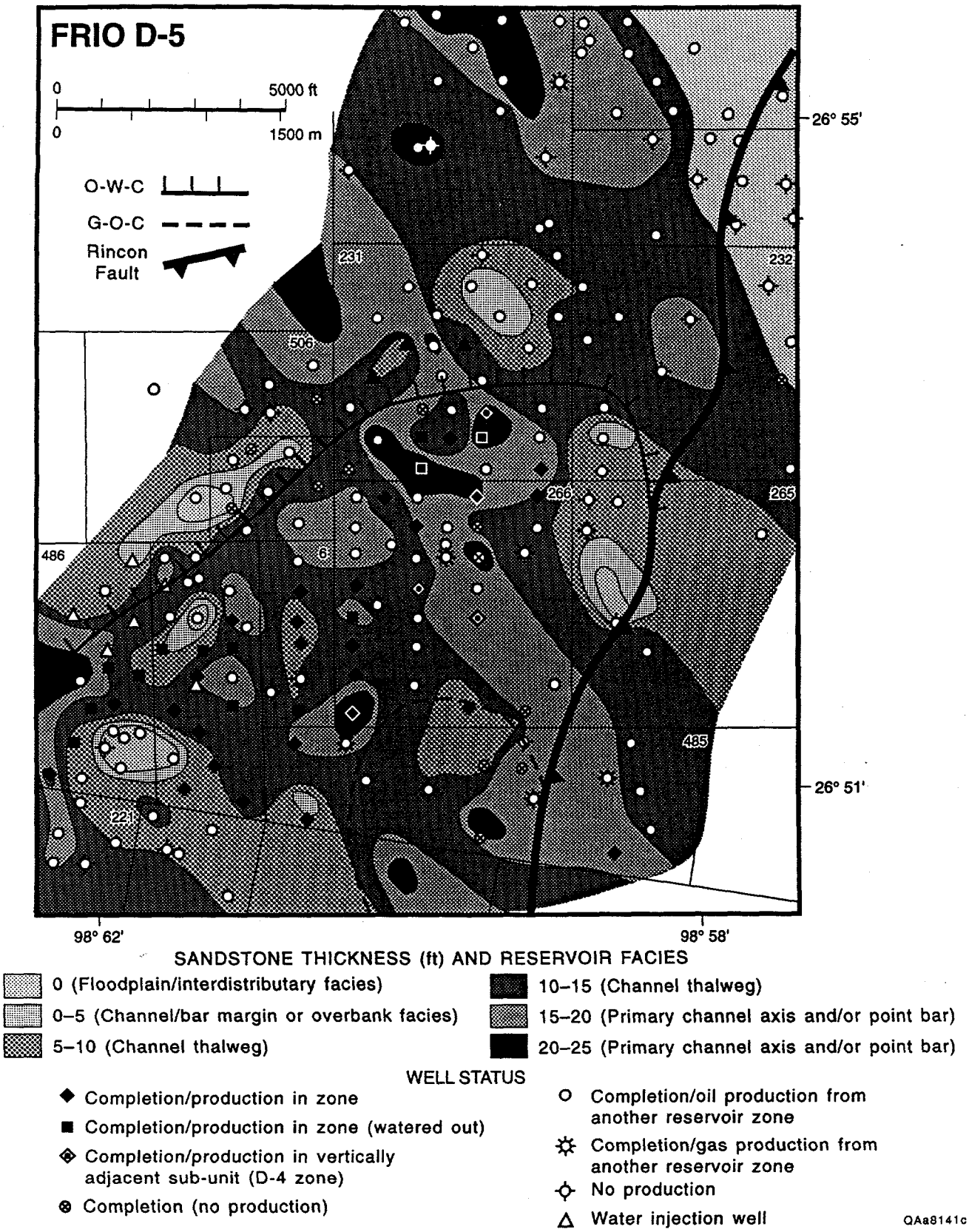


Figure 4. Map illustrating the sandstone thickness distribution, productive limits, and past completions within the Frio D-5 reservoir interval, Rincon field.

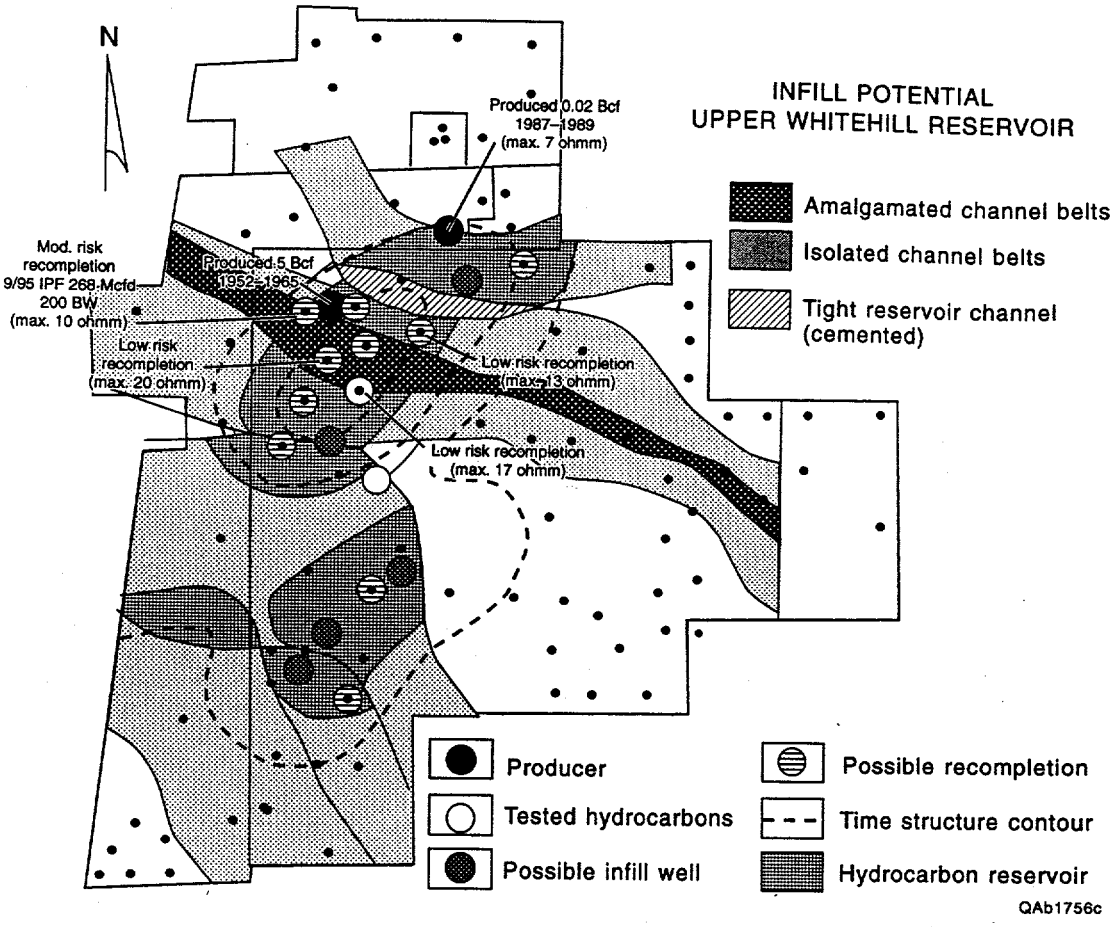


Figure 5. Map showing reservoir compartment distribution, productive limits, identified recompletion/infill opportunities, and results of one recompletion within the upper Whitehill reservoir of T-C-B field. Three recompletion opportunities evaluated as having lower risk than the current recompletion are annotated.

U. S. DEPARTMENT OF ENERGY
MILESTONE LOG

ELEMENT CODE	DESCRIPTION	PLANNED COMPLETION DATE	ACTUAL COMPLETION DATE	COMMENTS
I	**Reservoir selection and initial framework characterization**			
1	Screen play for suitable fields	2/28/93	2/26/93	100% complete
2	Identify potential for untapped reservoirs	10/21/93	10/21/93	100% complete
3	Identify potential for incompletely drained/compartmentalized reservoirs	10/21/93	10/21/93	100% complete
4	Identify potential for new pool reservoirs	12/31/93	12/22/93	100% complete
II	**Delineation of incremental recovery opportunities: targeting the advanced recovery resource**			
1	Delineate untapped reservoirs and assess volumetrics	12/31/94	12/31/94	100% complete
2	Delineate incompletely drained/compartmentalized reservoirs and assess volumetrics	12/31/94	12/31/94	100% complete
3	Evaluate potential for new pool reservoirs	12/31/94	12/31/94	100% complete
III	**Technology transfer and definition of extrapolation potential**			
1	Document distribution of untapped reservoirs for technology transfer	7/31/95	7/31/95	100% complete
2	Document distribution of incompletely drained/compartmentalized reservoirs for technology transfer	7/31/95	7/31/95	100% complete
3	Document distribution of new pool reservoirs for technology transfer	7/31/95	7/31/95	100% complete
4	Conduct technology transfer activities and extrapolate results within and between plays	6/30/96		50% complete
5	Develop computer-based advisor for recompletion and infill drilling and transfer to industry	8/31/96		21.5% complete

Phase III

U.S. DEPARTMENT OF ENERGY

DOE F1332.9
(11-84)

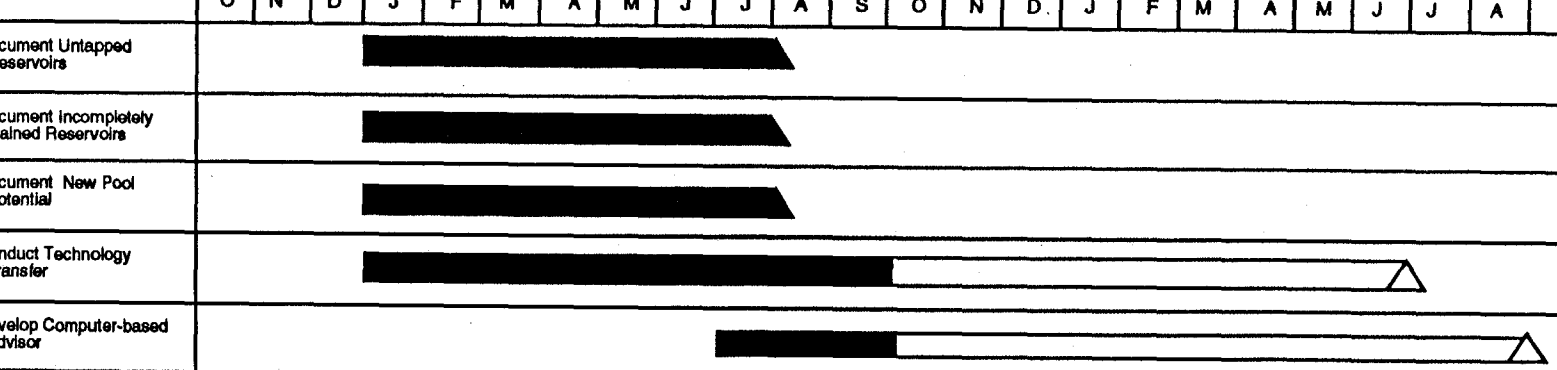
MILESTONE SCHEDULE ☐ PLAN ☒ STATUS REPORT

FORM APPROVED
OMB NO. 1900-1400

1. TITLE	2. REPORTING PERIOD	3. IDENTIFICATION NUMBER
Revitalizing a Mature Oil Play: Strategies for Finding and Producing Unrecovered Oil in Frio Fluvial-Deltaic Reservoirs of South Texas	January 1, to March 31, 1995	DE-FC22-93BC14959

4. PARTICIPANT NAME AND ADDRESS	5. START DATE	6. COMPLETION DATE
Bureau of Economic Geology The University of Texas at Austin P.O. Box X, University Station Austin, Texas 78713	January 1, 1995	August 31, 1996

7. ELEMENT CODE	8. REPORTING ELEMENT	9. DURATION FY95 O N D J F M A M J J A / FY96 S O N D J F M A M J J A / FY	10. PERCENT COMPLETE a. Plan	b. Actual
Phase III 1	Document Untapped Reservoirs		100%	100%
2	Document Incompletely Drained Reservoirs		100%	100%
3	Document New Pool Potential		100%	100%
4	Conduct Technology Transfer		50%	50%
5	Develop Computer-based Advisor		21.5%	21.5%



11. SIGNATURE OF PARTICIPANT'S PROJECT MANAGER AND DATE

Raymond A Levey 10/10/95

R. A. Levey