AIIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910

301/587-8202

Centimeter

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 mm

1 2 3 4 5

Inches

1.0 2.8 2.5 3.2 2.2 3.6 2.0 4.0 1.1 1.8 1.25 1.4 1.6

MANUFACTURED TO AIIM STANDARDS
BY APPLIED IMAGE, INC.

1 of 1

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 78713-7508
Date of Report:	March 31, 1994
Award Date:	October 21, 1992
Anticipated Completion Date for this Budget:	December 31, 1994
Government Award for this Budget Period:	[redacted]
Principal Investigator:	Noel Tyler and Shirley Dutton
Technical Project Officer:	Edith C. Allison
Reporting Period:	January 1, 1994 - March 31, 1994

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 screening fields within the play to select representative reservoirs that have a large remaining oil resource and are in danger of premature abandonment and performing initial characterization studies on selected reservoirs to identify the potential in untapped, incompletely drained, and new pool reservoirs. Phase II will involve advanced characterization of selected reservoirs to delineate incremental resource opportunities. Subtasks here include the 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 will consist of a series of tasks associated with 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.

SUMMARY OF TECHNICAL PROGRESS

Project work during this first quarter of 1994 consisted of the continuation of Phase II tasks associated with identification and delineation of incremental recovery opportunities in selected Frio fluvial-deltaic sandstone reservoirs. The present focus has been on defining interwell stratigraphic heterogeneity of individual reservoir zones in Rincon field through detailed stratigraphic correlations and analysis of abundant wireline core data.

A digital database for Rincon field consisting of log curves for over 200 wells has been refined and updated to include production data and reservoir tops, log facies type, thicknesses, net sandstone, percentage sandstone, and core porosity, permeability, and water saturation for individual reservoir zones. Digitized log data has been depth-adjusted to correspond with core analysis values. Maps illustrating distribution of oil production, initial potential, net sandstone thickness, percentage sand, and permeability-thickness have been generated for several separate reservoir zones.

In addition to these ongoing tasks, final revised versions of the annual contract report and a topical report were completed and submitted to DOE for publication and distribution. Two papers were prepared for presentation: one for the 1994 American Association of Petroleum Geologists Meeting in June and a second for the Gulf Coast Association of Geological Societies Meeting in October. Two trips to Mobil were made by project personnel to obtain additional reservoir production data.

Characterization of Rincon field reservoirs

The stratigraphic positions of important reservoir units in Rincon field within the context of the larger scale genetic stacking sequence were evaluated to assess the importance of reservoir stratigraphy on hydrocarbon production, recovery efficiency, heterogeneity style, and the potential for compartmentalization of additional oil resources. Oil reservoirs in Rincon field represent deposition in aggradational fluvial channels, mixed aggradational/progradational fluvial and distributary channels, and progradational deltaic facies. The differing stratigraphic context of these reservoirs results in different engineering attributes and degrees of internal heterogeneity that affect reservoir quality, hydrocarbon recovery efficiency, and therefore their potential for additional recovery. Further integration of past reservoir production behavior with detailed studies of geologic facies heterogeneity within individual reservoir units are being used to identify the location of significant additional reserves in unproduced reservoir compartments. Details of the reservoir stratigraphic framework, the current distribution of hydrocarbon production, and summarized petrophysical attributes for Rincon field oil reservoirs are described below.

The stratigraphic subdivisions between upper Vicksburg, lower Frio, and middle Frio reservoirs are identified on a representative log shown in Figure 1. Wireline core data representing more than 1,500 analyses from more than 100 wells in the Rincon field study area were assigned to individual reservoir subunits and evaluated to assess heterogeneity within each of the major reservoir units. A summary of reservoir attributes for each of the productive Frio reservoir sandstones is shown in Table 1. Distributions of values for core porosity and permeability for reservoirs representing upper Vicksburg, lower Frio, and middle Frio are illustrated in histograms shown in Figure 2.

Upper Vicksburg reservoirs

Sratigraphic framework and reservoir facies

Vicksburg reservoirs in Rincon field include the L sandstone unit shown at the base of the log interval illustrated in Figure 1. These reservoirs consist of thick progradational (seaward-stepping) deltaic sandstone deposits that occur in packages 50 to 150 ft thick and are separated by 50- to 200-ft-thick intervals of mudstone. Primary reservoir facies are channel-mouth-bar sandstones that are interbedded with prodelta mudstone and siltstone. Individual upward-coarsening channel-mouth-bar deposits are generally less than 50 ft thick and stack to produce repetitive cycles that can reach 150 to 200 ft in thickness.

Reservoir attributes

Deltaic reservoirs from the upper Vicksburg have distinctly lower porosity and permeability (mean ϕ = 20.3 percent, median k = 8.2 md) than Frio reservoirs (Figure 2, Table 1), probably reflecting the interbedded sandstone/mudstone alternations characteristic of these stacked progradational units. These reservoirs are responsible for a total of 21% the total oil production from Rincon field.

Vicksburg reservoirs in Rincon field are not targets for resource delineation and additional recovery in this project because their deposition was strongly influenced by faulting associated with the development of the Vicksburg Fault Zone (Coleman and Galloway, 1990, 1991), and correlations necessary to document depositional heterogeneity and stratigraphic compartmentalization in these reservoirs are difficult. Our reservoir studies will focus on the structurally uncomplicated Frio reservoir interval where there is better potential for identifying lateral facies heterogeneity and stratigraphic compartmentalization, and there is also much more data available.

Frio reservoirs

Sratigraphic framework and reservoir facies

Subdivisions within main Frio reservoir producing zones are illustrated in Figure 1, along with cumulative oil and gas production for each zone, and the relative position of each reservoir within a genetic stratigraphic stacking hierarchy developed for the Rincon field section. Low-resistivity shale markers separate the primary reservoir sandstone zones, and two significant low-resistivity markers interpreted to represent maximum flooding surfaces have been identified at the top of a transgressive bar sandstone complex (B and F units). Each transgressive sandstone complex that occurs below a major flooding surface (Frio B and F units) produces mostly gas and is not an important oil reservoir. Aggradational channel sandstones (e.g., Frio D, E, and G units) located below each transgressive unit are primarily oil reservoirs, the most significant accumulations occurring in the sands immediately below the main gas reservoir. This observation suggests that these flooding surfaces may act as important sub-regional seals.

The Frio G–J (lower Frio) reservoir interval is interpreted to correspond to an interval of mixed progradational and aggradational sedimentation, whereas the Frio C, D, and E sandstone zones (middle Frio) represent deposition in a purely aggradational setting. The F shale marker is taken to mark the boundary between these two contrasting styles of deposition. Reservoir facies in the lower Frio interval are interpreted to represent predominantly delta-plain distributary-channel sandstones. Distributary channels are distributed as elongate, dip-parallel belts. Individual, upward-fining channel sandstone packages range from 5 to 20 ft thick, and commonly stack to produce amalgamated units that have vertical thicknesses of 10 to 50 ft. These stacked sandstone packages commonly display an upward-thickening trend. Sandstone body continuity is generally less than in Middle Frio fluvial channels, as distributary channel-fill sandstones are narrower and are flanked laterally by sand-poor interdeltaic facies. Low-permeability mudstone facies locally encase and compartmentalize or isolate individual reservoir sandstones. These reservoir compartments are primary targets for additional oil recovery in the lower Frio interval.

Middle Frio reservoir facies consist primarily of dip-elongate fluvial channel-fill sandstones and are separated by non reservoir facies that include levee siltstones and floodplain mudstones. Productive middle Frio reservoirs in Rincon field occur both as individual narrow channel-fill units isolated vertically and laterally by low-permeability overbank and floodplain facies and as large channel complexes with multiple sandstone lobes that combine into a single large communicating reservoir. Sandstones have individual thicknesses ranging from 5 to 30 ft but are commonly stacked into composite units with gross thicknesses between 20 and 60 ft. Low-permeability subfacies within the channel fill are responsible for the development of multiple reservoir compartments that may represent significant opportunities for additional recovery.

Reservoir attributes

There are distinct distributions of reservoir porosity and permeability illustrated by core data from lower and middle Frio reservoir units (Figure 2). Channel sandstone reservoirs in the mixed progradational/ aggradational lower Frio interval exhibit higher porosity and permeability values (mean ϕ = 27.1 percent, median k = 85 md) than their counterparts in the aggradational middle Frio (mean ϕ = 25.7 percent, median k = 38 md). In addition, the porosity and permeability values of middle Frio reservoirs appear normally distributed, whereas the distribution of values in lower Frio units is not. Different frequency distributions for reservoir attributes have been documented to have important implications in estimates of recovery efficiency when average values of non-normally distributed data are used to calculate reservoir volumes (Holtz and McRae, 1994).

Core porosity and permeability values were crossplotted to identify variability within individual Frio reservoir zones. Examples of these data from a middle Frio aggradational channel sandstone (Frio E), a transgressive bar sandstone (Frio F), and a lower Frio mixed aggradational channel sandstone (Frio G) are shown in Figure 3. Core data measured from sands in Frio E and Frio G dip-oriented channel oil reservoirs exhibit a greater range of values than the Frio F gas reservoir. This most likely reflects the greater variability of depositional facies present within the fluvially dominated reservoir zones and may also be partly an artifact of slightly higher textural maturity of the reworked bar sandstone units. The Lower Frio G sandstone unit also exhibits greater variability, and a weaker relationship between porosity and permeability, than the Frio E sandstone unit, its channel counterpart in the Middle Frio interval.

Production behavior

Production histories for the most important Frio oil reservoirs in Rincon field were examined to identify relationships between the stratigraphic position and porosity and permeability characteristics of Rincon reservoirs and their ability to produce hydrocarbons. Evaluation of production data including a reservoir's response to waterflooding and overall recovery efficiency will be used in conjunction with studies of facies architecture to identify zones with highest potential for containing compartments with unproduced oil.

The Frio E sandstone, the most prolific reservoir zone in the field, has produced nearly 12 MMSTB of oil since production began in 1940. Secondary waterflooding in the Frio E reservoir zone has accounted for 2.5 MMSTB, or nearly 21 percent of total E zone production. Using average reservoir values of 26.5 percent porosity and 37.5 percent water saturation, Frio E reservoirs have been estimated to have an overall recovery efficiency of 34 percent.

Frio D sandstones have similar reservoir attributes as Frio E reservoirs (average porosity of 25.2 percent, Sw of 40.5 percent, and estimated OOIP of approximately 35 MMSTB) but a lower recovery efficiency of 28 percent. Frio D reservoirs have produced nearly 10 MMSTB oil since 1940. Waterflooding attempts in this reservoir zone accounted for secondary recovery amounting to only 2 percent of total D production. These disappointing results were attributed in part to the heterogeneous nature of the D sandstone interval.

The Frio G reservoir zone also began production in 1940 and has produced a total of 5.4 MMSTB oil to date. Unsuccessful waterflooding in the G reservoir zone accounted for less than 2 percent of total production. Mean porosity and permeability values of G sandstones (ϕ = 27.4 percent, k = 96.9 md) are greater than those of Frio D and E sands. G sandstones, as shown in Figure 3, also exhibit the greatest variability in porosity and permeability. Approximately 29 percent of the original-oil-in-place has been recovered from the G reservoir zone.

Planned Activities

The Frio D, E, and G reservoirs in Rincon field are the current focus of more detailed studies to characterize the heterogeneity of the various productive reservoir facies. Detailed mapping of the internal physical architecture of individual reservoir flow units should explain why these reservoir zones have produced differently and may identify the location of untapped and incompletely drained reservoir compartments that may have significant potential for additional oil recovery. In conjunction with these efforts, studies of whole core from the D and E reservoir zones in Rincon field will begin during the next project quarter. Evaluation of production data and identification of heterogeneity style in selected reservoir zones from T-C-B field is also continuing.

Table 1. Summary of general reservoir attributes for individual productive Frio sandstone zones within Rincon field.

Zone	Depositional Environment and Sandstone Geometry	Depth (subsea)	Pay	Mean ϕ (%)	Mean k (md)	Net sand	% sand	Cum prod. MMCF	Cum prod. MBO	% total oil	% aband. zones
Middle Frio aggradational reservoirs											
Frio B	Strike-elongate bar sands	3164	Gas	27.0	62.9	12.9	13	11774	138	0.4	81
Frio C	Thin narrow channels	3248	Oil	n/a	n/a	2.5	3	1558	124	0.4	100
Frio D	Broad dip-elongate fluvial channel system	3350	Oil	25.3	56.9	21.1	27	14126	8311	24.7	95
Frio E	Dip-elongate fluvial channel system	3449	Oil	26.6	67.6	18.2	22	29103	14066	41.9	86
		Interval totals:		----	----	47.6'	13	56561	22639	70.6	---
Lower Frio mixed aggradational/progradational reservoirs											
Frio F	Strike elongate bar sands minor dip-elongate channels	3517	Gas	24.7	25.8	25.5	0.18	6647	96	0.3	
G zone	Dip-elongate channels	3633	Oil	27.4	96.9	18.4	0.17	10457	5356	15.9	86
H- zone	Broad dip-elongate channels	3712	Oil & Gas	27.9	55.6	16.8	n/a	14840	873	2.6	100
I zone	Thin dip-elongate channels	3852	Oil	25.6	30.8	13.0	n/a	12285	2057	6.1	94
J zone	Narrow channel sands	3928	Oil	24.7	89.1	16.1	n/a	3051	645	1.9	100
K zone	Strike-elongate bar sands	3969	Oil	26.9	62.5	9.0	n/a	21433	421	1.3	100
		Interval totals:		----	----	98.4	25%	68713	9448	29.4	---

Mean porosity and permeability values based on wireline core analyses
Mean reservoir depth, net and % sand, and cumulative production data for study area (see location map)
% abandoned zones calculated from total completions and remaining active (producing and shut-in) zones as of 1991.
Values listed as n/a reflect limited data available

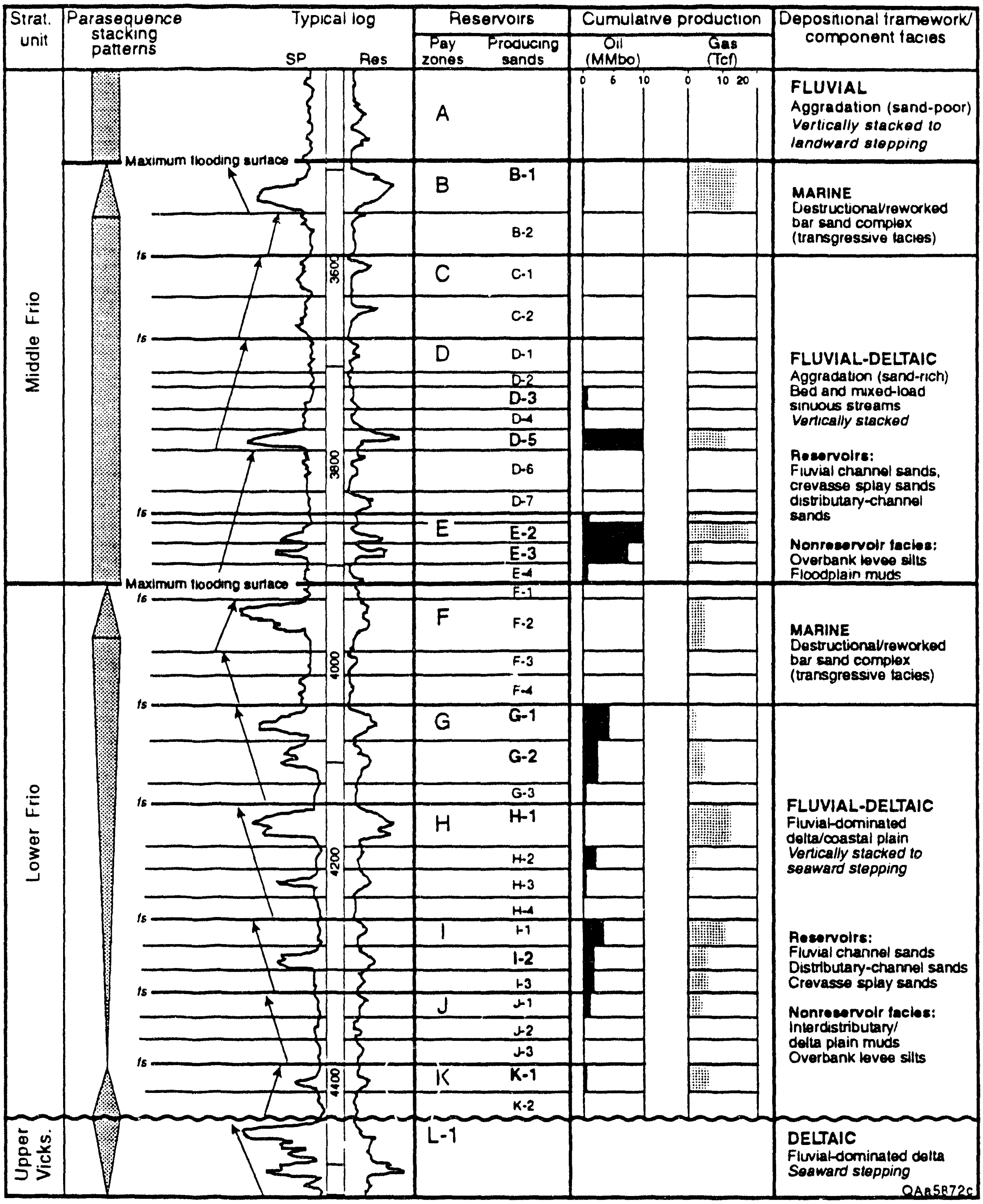

Figure 1: Representative log from Rincon field illustrating general stratigraphy, reservoir nomenclature, and the stratigraphic distribution of oil and gas production of individual producing units in the rio Fluvial-Deltaic Sandstone Play productive reservoir interval.

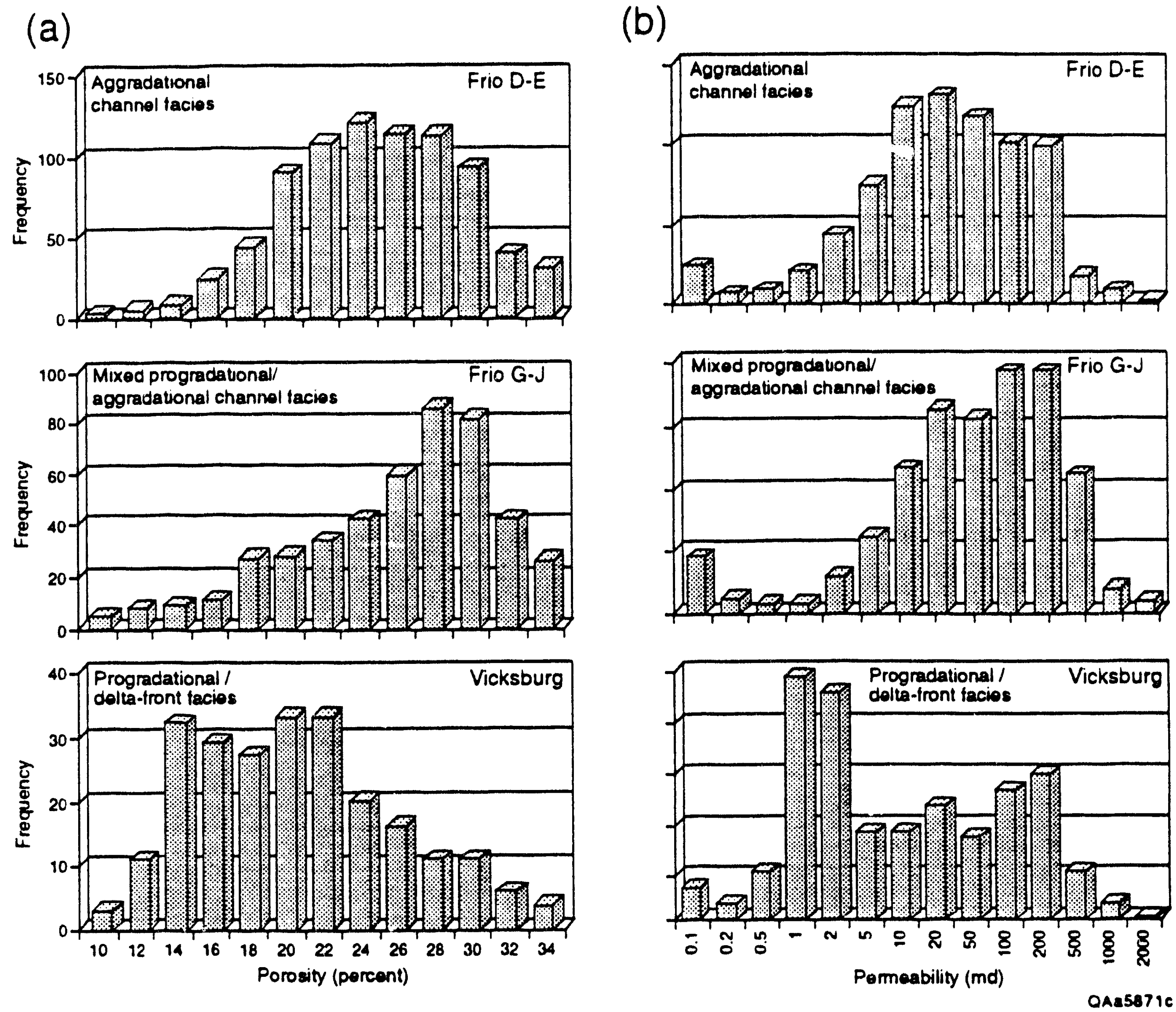

Figure 2: Histograms showing frequency distributions for values of core porosity and permeability from various fluvial-deltaic reservoir groups within the productive Frio-Vicksburg stratigraphic interval.

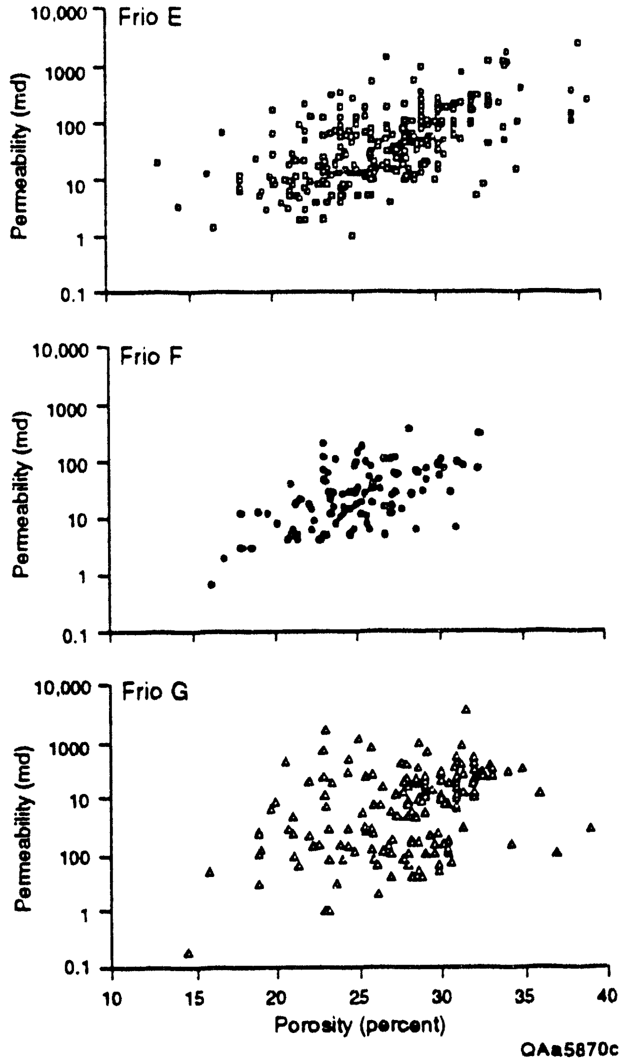

Figure 3. Crossplots of porosity and permeability values measured from wireline cores in representative Frio reservoirs in Rincon field. Dip-elongate channel sandstone oil reservoirs from the E and G units represent deposition in middle and lower Frio intervals, respectively. The F unit is a strike-elongate transgressive unit that exhibits significantly less variability in porosity and permeability values than the E and G channel reservoir facies above and below it. The F sandstone is a minor gas reservoir and is shown for comparison purposes only.

DATE

FILMED

7/18/94

END