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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 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 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 second 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) tasks related to the transfer of the technologies to industry that aided in delineation. Text and figures have been prepared to support the geological-based compartment architecture and petrophysical analysis is being undertaken to provide a volumetric assessment of remaining resources and recoverable reserves.

Petrophysical work during this period has focused on Rincon field reservoirs because of the availability of core material for special core analysis. These analyses, completed during the previous quarter, have supported detailed study of modern and older well logs to provide accurate data for a three-dimensional (3-D) reservoir model of selected zones within Rincon field. The parameters identified by the combined core and modern log analysis of Rincon reservoirs are being used to improve the accuracy of petrophysical assessments of T-C-B reservoirs, where no core material was available. The result of this effort will be specific risk-weighted near-term reserve-growth opportunities in the form of recompletion and infill targets supported by rigorous volumetric and economic analysis.

Additionally, activity during the second quarter has been heavily weighted toward transfer of study results. A draft Topical Report[1] and two manuscripts[2-3] have been prepared that discuss the methods and results of detailed reservoir studies. Preparations have begun for short courses to be held in Corpus Christi and Houston, Texas, in the first half 1996, and a planning meeting has been held to outline the objectives and scope of a microcomputer-based Geological Advisor. During this period Bureau scientists have made invited presentations to a major operator that is active in the Frio Fluvial-Deltaic Play of South Texas.

Documentation of Untapped and Incompletely Drained Compartments and New Pool Reservoirs: Rincon Field Reservoir Studies

Reservoir compartment architecture has been identified in previous quarters and documented thoroughly during this quarter for the draft Topical Report due at the end of July. Petrophysical analysis of both modern and older logs is being undertaken with the benefit of special core analysis data to more accurately determine reservoir porosities and saturations for use in documenting recoverable reserves for recompletions and geologically targeted infill wells.

Analysis of Modern Logs

Modern well logs are uncommon in Rincon field. However, it is important to develop a methodology for their analysis because they provide data critical to the evaluation of the success of potential infill wells. A log suite including gamma ray, resistivity, density and compensated neutron porosity along with core data from 3 wells was analyzed in order to develop a strategy for wire-line petrophysics.

The work-flow scheme for analyzing modern logs includes depth shifting core data to wireline depths, determining a bulk shale volume indicator (Vsh), and developing a porosity algorithm. On the basis of correlation with other wells, and the significant presence of radioactive lithics within the sandstone, it was determined that the gamma ray log is not a good indicator of shale volume. Instead, the neutron log (CNL) is used as a shale indicator to calculate the shale fraction. The following equation is used to determine the shale volume:

$$V_{sh} = ((CNL * (CNL - CNL\ sand)) / DI)^{**} 0.5 \qquad (1)$$

where DI = CNL shale * (CNL shale - CNL sand), V_{sh} = bulk shale volume, CNL = CNL log value, CNL sand = the clean sand value read from the CNL log, and CNL shale = the pure shale value read from the CNL log. Shale determination is based on adjusting the CNL log reading between a pure sandstone and pure shale measurement. The clean sand and the pure shale values are respectively picked from local (Frio E reservoir) minimum and maximum values of the CNL log. For the particular well example the neutron clean sand value is 0.283 and the neutron shale value is 0.534, read directly from CNL log.

Porosity can be determined from the standard density-neutron crossplot applying a bulk volume shale correction. When calculating porosity, a clay density of 2.124 g/cc and a neutron clay response of 0.534 were chosen. These values were determined from density and neutron logs where the pure shale volume (100% of shale) occurs. It is noted that the value for the density of clay (2.124) g/cc corresponds closely to the published value of 2.120 for montmorillonite. The neutron log value for clay (0.534) is not very much different from the published value of 0.6 for montmorillonite and is close to the published value of between 0.519 and 0.500 for wet clay.

Correction for bulk volume shale is critical in determining correct porosity. The computed results for porosity without shale correction and shale corrected crossplot porosity have been compared with core porosity. Shale corrected crossplot porosity better represents core porosity than uncorrected crossplot data and uncorrected data predict overly optimistic porosity values. The shale-corrected crossplot porosity log ($\phi_{crossplot}$) generally agrees with the core porosity from E2 through E4 zones (3,974 ft - 4,015 ft); however, it underestimates porosity by 4 to 10 percent compared to the core porosity in the E1 reservoir (3,962 ft – 3,974 ft).

Analysis of Old Logs

Resistivity measurements are used to determine porosity from wire-line logs where modern porosity logs are not available. Several steps are needed to ascertain the resistivity-derived porosity (f_{sn}), which is a function of the volume of clay (V_{cl}), the near-borehole mixing zone resistivity (R_z), and the measured short normal resistivity (R_{sn}).

The first step in determining the bulk volume of shale is to calculate a clean sandstone SP response (SSP) for separate reservoirs. The need to derive a separate SSP for each reservoir is the result of each reservoir having a different R_w value. Before this can be done, however, an accurate mud filtrate resistivity (R_{mf}) may have to be calculated if it is not available from the well header, as is the case in many older logs. A value for R_{mf} is derived through Eq. (2), using mud resistivity (R_m), and a constant, C, which is equal to 0.847, when mud weight is less than 10.8 pounds.

$$R_{mf} = C^*(R_m)^{1.07} \tag{2}$$

The R_{mf} value is then used in Eq. (3), along with the measured spontaneous potential (SP) response, to determine SSP. When applying Eq. (3), R_w and R_{mf} must be at reservoir conditions and Tr represents reservoir temperature. The SSP value must then be tested to make sure it does not exceed the minimum measured SP response. If this discrepancy occurs, the variables in the equation must be adjusted to make the minimum SP equal to the SSP.

$$SSP = ((0.133^*Tr)+60)^*\log(R_w/R_{mf}) \tag{3}$$

Having a reservoir specific SSP allows the accurate determination of bulk volume shale (V_{cl}) from the SP wire-line curve. The simple calculation is made using Eq. (4).

$$V_{cl} = 1-(SP/SSP) \tag{4}$$

The near-borehole mixing-zone resistivity (R_z) is determined at formation temperature from formation water resistivity (R_w) and R_{mf}. For shallow invasion, R_z is calculated from Eq. (5).

$$R_z = 1/((0.1/R_w)+(0.9/R_{mf})) \tag{5}$$

When values for V_{cl} and R_z have been calculated, resistivity-derived porosity (f_{sn}) can then be derived from Eq. (6).

$$f_{sn} = (R_z/R_{sn})^{0.5}{}^*(1/V_{cl}) \tag{6}$$

This more accurate resistivity from older logs is then used to calculate reservoir compartment and drainage volumes in those portions of the reservoir where no core or modern well logs are available. The subsequent volumetric analysis and resulting evaluation of original in place and remaining resources is more accurate and reliable. Such accuracy is invaluable in reducing the uncertainty associated with predicting the economic risk of recompletions and targeted infill wells.

Documentation of Untapped and Incompletely Drained Compartments and New Pool Reservoirs: Tijerina–Canales–Blucher Field

Characterization studies in T-C-B field have focused on upper delta plain fluvial sandstone reservoirs of the Scott and Whitehill zones in the middle Frio, which range in depth from 6100 to 6300 ft. Stratigraphic studies of reservoir compartment architecture, supported by preliminary reservoir engineering studies of internal compartment heterogeneity, indicate that architecture and heterogeneity of these reservoirs are a function of the amount of sediment accommodation space (in this case, the potential height to which a delta plain can aggrade) existing during the time of their deposition[3]. This factor, controlled by changing relative sea level, consequently controls reservoir drainage efficiency. A spectrum of reservoir types results (**Figure 1**), from narrow, isolated, internally homogeneous channelbelts (sinuous isolated compartments with high drainage efficiency) deposited during low accommodation to broad, amalgamated, internally heterogeneous channelbelts (thicker laterally continuous reservoirs composed of many smaller compartments isolated by low-permeability layers at channel amalgamation surfaces, and having low drainage efficiency).

The Scott reservoir is the latter reservoir type and has been completed in most wells at the current spacing of 20 to 40 ac, recovering an estimated less than 10 percent of original oil in place. A series of infill opportunities have been identified for the Scott based on increasing the completion density to 10 ac. A petrophysical analysis of both modern and older well logs is in progress using carefully defined parameters from the Rincon field analysis to document reservoir volumetrics and mass balance. This data will be used in an economic analysis of various infill well geometries, including horizontal wells that might penetrate multiple isolated compartments within the overall laterally continuous reservoir. A proposal has been submitted to the Advanced Class Work program to undertake a detailed study of the Scott reservoir using (1) stratigraphic analysis of the available 3-D seismic data to attempt to image individual compartments at the between-well scale, (2) pressure pulse testing between well pairs to document the permeability-inhibiting nature of compartment boundaries, and (3) recompletion or infill drilling obtain production from an identified untapped or incompletely drained compartment. Such an accomplishment would clearly demonstrate to other operators of mature fluvial-deltaic reservoirs the benefits of advanced reservoir characterization.

The Whitehill reservoir represents the other end of the spectrum and consists of sinuous, internally homogeneous channelbelts isolated by floodplain mudstones (**Figure 1**). Despite its good drainage efficiency, it has not been extensively completed at present well spacings, and a number of recompletion opportunities exist. These have been tabulated and compared with current wellbore conditions to establish a prioritized list of reserve-growth opportunities (**Table 1**). Petrophysical analyses currently being conducted will refine the documentation of these opportunities by supplying volumes of recoverable hydrocarbons for each completion based on the volume of the compartment identified by geological characterization.

The operator in the study area is very active and is currently selecting two drilling locations based on (1) the interpretation of recently acquired 3-D seismic and (2) well log correlations established in a joint effort between operator and Bureau scientists. The primary focus of the operator is reservoirs below the Scott/Whitehill interval. However, infill locations identified by the Bureau could influence well location selection by providing low-risk up-hole secondary targets that improve the overall economics of the wells. Study findings will be validated if high oil saturations are encountered in the planned wells in Scott/Whitehill intervals identified by this study as containing untapped or incompletely drained compartments. Such confirmation will serve as valuable support of techniques developed in this study during technology transfer discussions with industry.

Table 1. Summary of recompletion opportunities in Whitehill reservoir, T-C-B field.

Well	Evidence of Productivity	Well Status	Risk
Blucher 23	Strong log show (11 ft @ >5 OHMM, peak of 6.5 OHMM).	Open to below Whitehill (idle in 21-B).	Low
Blucher 28	Strong log show (16 ft @ >5 OHMM, peak of 13 OHMM)	Open to below Whitehill (producing from Scott zone at 10 bopd).	Low
Blucher 51	Very strong log show (16 ft @ > 5 OHMM, peak of 17 OHMM).	Open to below Whitehill (idle in Sanford).	Low
Blucher 32	Strong Log show (12 ft @ > 5 OHMM, peak of 7.5 OHMM)	Open to below Whitehill (producing from Richard zone, 50 Mcfd).	Low-Moderate
Blucher 1	Strong log show (15 ft @ > 5 OHMM, peak of 15 OHMM)	Open to below Whitehill (idle in Imme zone).	Moderate
Blucher 42	High resistivity in thin bed (5 ft @ > 3 OHMM, peak of 4 OHMM)	Idle (Stray, 6030'), 4 plugs above Whitehill.	Moderate
Blucher 55	High resistivity (9 ft @ > 5 OHMM, peak of 8.5 OHMM) but low porosity (5 ft < 12%).	Open to below Whitehill (idle in Charles).	Moderate
Blucher 57	Good resistivity (22 ft @ > 5 OHMM, peak of 20 OHMM), 16% porosity, suppressed SP suggests tight but microlog indicates 8 ft of permeable reservoir	Open to below Whitehill (idle in Scott).	Moderate
Blucher 58	High resistivity (3 ft @ > 5 OHMM, peak of 6 OHMM), 18% porosity, RWA curve indicates 4 ft pay.	Open to below Whitehill (producing X from Carl).	Moderate
Blucher 59	Strong log show (20 ft @ > 5 OHMM, peak of 10 OHMM)	Open to below Whitehill (idle in Charles).	Moderate
Seeligson 7	High resistivity (5 ft @ > 5 OHMM, peak of 5.5 OHMM)	Open to below Whitehill (producing X from Alexander).	Moderate
Blucher 25	High resistivity (10 ft @ > 4 OHMM, peak of 4.5 OHMM)	Open to below Whitehill (producing X from Charles).	Moderate-High
Blucher 43	High resistivity (3 ft @ > 5 OHMM, peak of 5.2 OHMM).	Open to below Whitehill (idle in Jim Wells).	Moderate-High
Blucher 50	High resistivity (3 ft @ 5 OHMM), perforated and squeezed due to channeling.	Open to below Whitehill (idle in Richard).	Moderate-High
Blucher 52	High resistivity (4 ft @ > 5 OHMM, peak of 6 OHMM), 18% porosity.	Open to below Whitehill (idle in Arguellez).	Moderate-High
Blucher 53	High resistivity (7 ft @ > 5 OHMM, peak of 6 OHMM), 2 ft of weak RWA show	Open to below Whitehill (idle in Nicholas).	Moderate-High

Technology Transfer Activities

Increasingly, the focus of efforts in this project is the transfer of technologies developed or used during Phases I and II. During the second quarter, preparations were begun on a draft Topical Report summarizing techniques used in detailed reservoir characterization studies of Rincon field. This draft report will be completed and submitted by July 31. More direct transfer of these findings to operators in the Gulf Coast is being achieved through the preparation of two manuscripts that will be included in the Transactions volume of the 1995 Gulf Coast Association of Geological Societies (GCAGS). This volume will accompany oral presentations of findings at the 1995 GCAGS meeting in October. 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].

A vital part of the technology transfer activity is face-to-face meetings with the geologic staff of operators whenever feasible to impart the techniques of detailed reservoir characterization. Meetings with operator representatives from T-C-B field were held over the past project quarter in addition to numerous phone discussions with operators of both T-C-B and Rincon fields. Two separate visits to another operator included working discussions with geologists, geophysicists, and engineers responsible for South Texas field development, as well as presentations of playwide resource assessment and the sequence stratigraphic model to geoscientists working U.S properties.

Preparations are beginning for workshops to be held in Corpus Christi and Houston, Texas, in February and April of 1996. Preliminary contacts have been made with members of the geological societies in these cities that might host the workshops. Preparation of text and figures for short course notes has also begun. Finally, an initial planning meeting for the microcomputer-based Geological Advisor has been held. This software is intended to assist operators in decisions and studies related to characterization of mature fluvial-deltaic reservoirs.

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, the stratigraphic model of the Ferron was revised to include a highstand, lowstand, and transgressive systems tract. This revision is an important step toward improving the accuracy of the model for predicting reservoir architecture in fluvial-deltaic environments such as the Tertiary of the Texas Gulf Coast.

Deposits of the lowstand system tracts are very heterogeneous, consisting of heterolithic, river-dominated delta-front successions having a limited lateral extent and being isolated by marine shales associated with periods of delta lobe abandonment. By contrast, the highstand and transgressive systems tracts are relatively homogeneous, consisting of sand-rich, wave-modified to wave-dominated delta-front successions that form a sandstone body with a high degree of lateral connectivity and continuity. Heterogeneities are primarily related to lenticular, mud-filled channels that truncate and replace the upper portion of the sandstone body. Valley-fill deposits are preserved as narrow, isolated, shoestring-shaped sandstone bodies that crosscut preexisting delta-front strata. Although valley fills are volumetrically a minor component within the system, they may have an important impact on fluid flow by acting as conduits between laterally isolated system tracts and component delta lobes.

PLANNED ACTIVITIES

During the coming quarter, documentation of Phase II activities will be completed, logistics and preparations for short courses will continue, and work on the Geological Advisor will escalate.

Final documentation of Phase II activities will include final volumetric analysis of reservoirs to support specific near-term reserve-growth opportunities such as recompletion and geologically targeted infill wells. Preparation for short courses will involve logistical details such as scheduling the workshop sites and preparing advertising materials (preliminary advertising will begin during the final quarter). In addition, a workshop outline will be prepared and a course notebook planned. Finally, the specific goals of a Geological Advisor will be determined following several planning meetings with project scientists and programmers.

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: Transactions, Gulf Coast Association of Geological Societies, 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.*

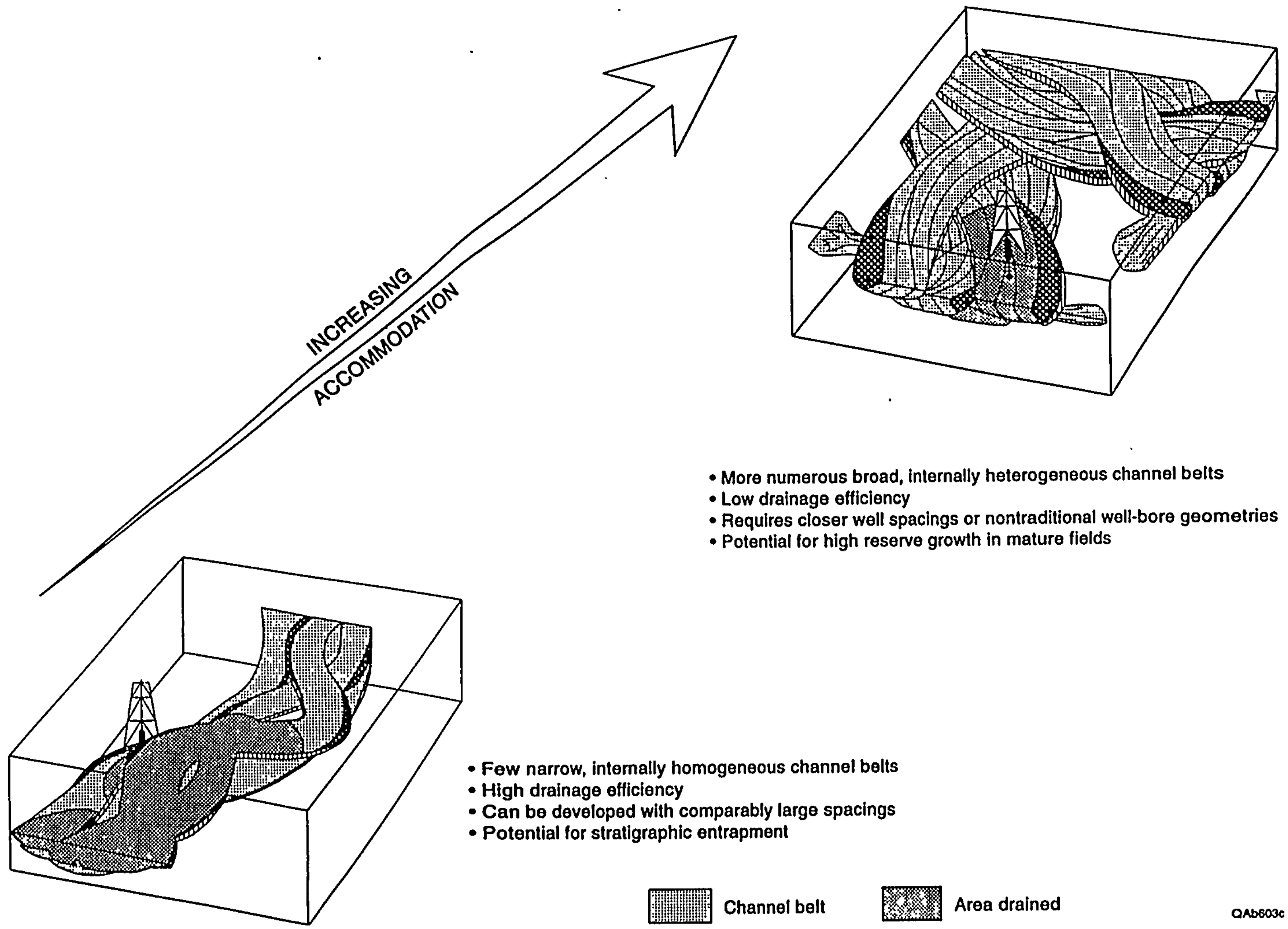

Figure 1. Spectrum of reservoir styles formed under conditions of increasing accommodation. End members have distinctly different compartment architecture, internal complexity, and reserve-growth potential and require different development strategies.