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Structural Setting and Sequence Architecture of a Growth-Faulted Lowstand Subbasin, Frio Formation, South Texas

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Abstract

Much of the Oligocene Frio Formation was deposited as fourth- and fifth-order components within a third-order, lowstand wedge in the Red Fish Bay area, Texas. The third-order wedge resulted from a drop in relative sea level that caused a basinward shift of facies and deposition into deeper water. On the shelf, the fluvial systems were locked into incised valleys, and the expulsed sediment overloaded the seaward-lying distal slope. Slope failure initiated growth faulting, and a deepwater subbasin developed between the growth fault and the basinal shale ridge. Subsequent stabilization of the shale ridge ended the faulting. Upward-coarsening wireline-log facies patterns within the subbasin suggest lowstand deltaic sedimentation within a prograding wedge. Individual sands within adjacent, but diachronous, subbasins do not correlate. The lowstand wedge deltaic sandstones pinch out basinward and display potential updip rollover or fault closure.

Deposition occurred in the hanging wall block of a major growth-fault system. In the study area, two prominent growth faults dip southeastward and define the western and northern basin boundaries. Orthogonal to the western boundary fault is a younger fault, which did not influence the prograding wedge deposition. Syndepositional fault movement, rollover, and associated interval expansion occurred in the prograding wedge section. Crestal faults within the hanging wall block are a major control on trapping and compartmentalizing gas. Production and petrophysical analyses of prograding wedge reservoirs indicate gas-expansion drive north of the younger, orthogonal fault and water drive south of it. The best producing intervals are fifth- and sixth-order lowstand and transgressive sands having three- to four-way closures within the third-order, lowstand prograding wedge.

Introduction

A comprehensive study of the Oligocene Frio Formation was conducted in the Red Fish Bay area in South Texas incorporating wireline-log, seismic, and core data to establish a sequence stratigraphic model for lowstand growth-faulted subbasins. Red Fish Bay is located southeast of Corpus Christi in South Texas (Fig. 1). The Oligocene Frio Formation is one of the main producing units in the Gulf of Mexico basin (Fig. 2). Previous work has summarized the general structure, sand distribution, and regional sediment-thickness trends (Galloway et al., 1982; Galloway, 1986). Barnaby et al. (1998) conducted a detailed study of the upper and middle Frio transgression and highstand systems tracts in Red Fish Bay field. Edwards (1986) and Winker and Edwards (1983) addressed the effects of differential subsidence and growth faulting in the Gulf of Mexico, respectively. This paper is an outcome of several studies in the Corpus Christi area (Brown et al., in press; Brown et al., this volume; Trevino et al., 2003). Whereas previous papers focused on stratigraphy and reservoir development, this paper analyzes the sedimentary response to growth faulting initiated by third-order relative sea-level fluctuations and the resulting divisions into minibasins.

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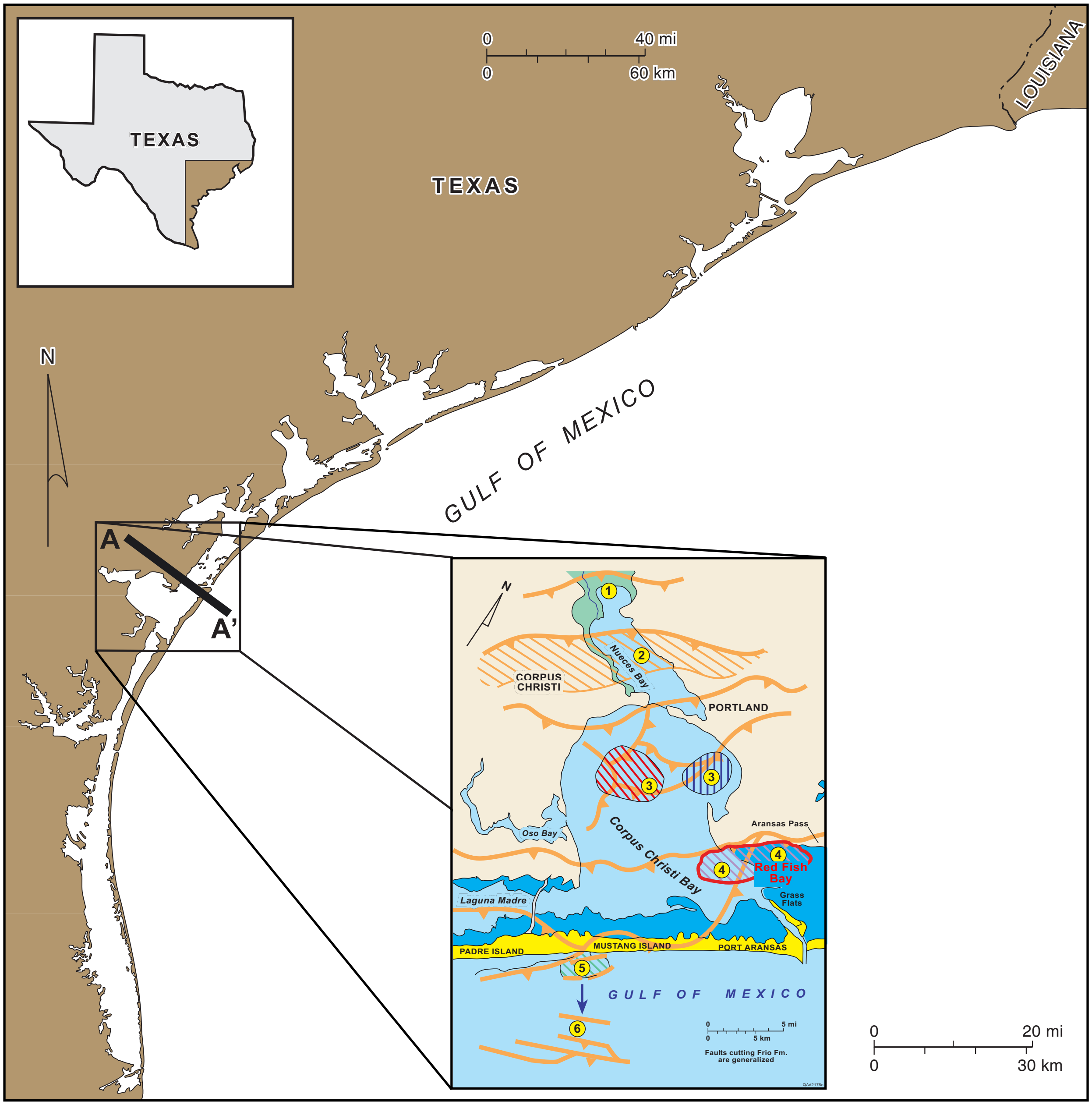

Figure 1. Study area showing location of Red Fish Bay in the Corpus Christi area, South Texas. Line A-A' represents regional cross section in Figure 2.

Reservoir Compartmentalization

Growth faulting is a common structural feature along the entire Gulf of Mexico, as well as the Texas Gulf Coast (Fig. 3). Hardin and Hardin (1961) described these growth faults as "contemporaneous faults" that formed as a result of normal structure-forming tectonic forces in the Gulf Coast during periods of rapid sedimentation. Winker and Edwards (1983) interpreted growth faults as the result of gravity sliding. Gravity sliding is the fault movement mechanism, but it does not explain what triggered the movement. Brown et al. (in press) interpreted the formation of growth faults as resulting from third-order sea-level falls where coarser grained sediments transported through incised valleys were shed from the exposed shelf and differentially loaded the slope, thus triggering growth-fault movement.

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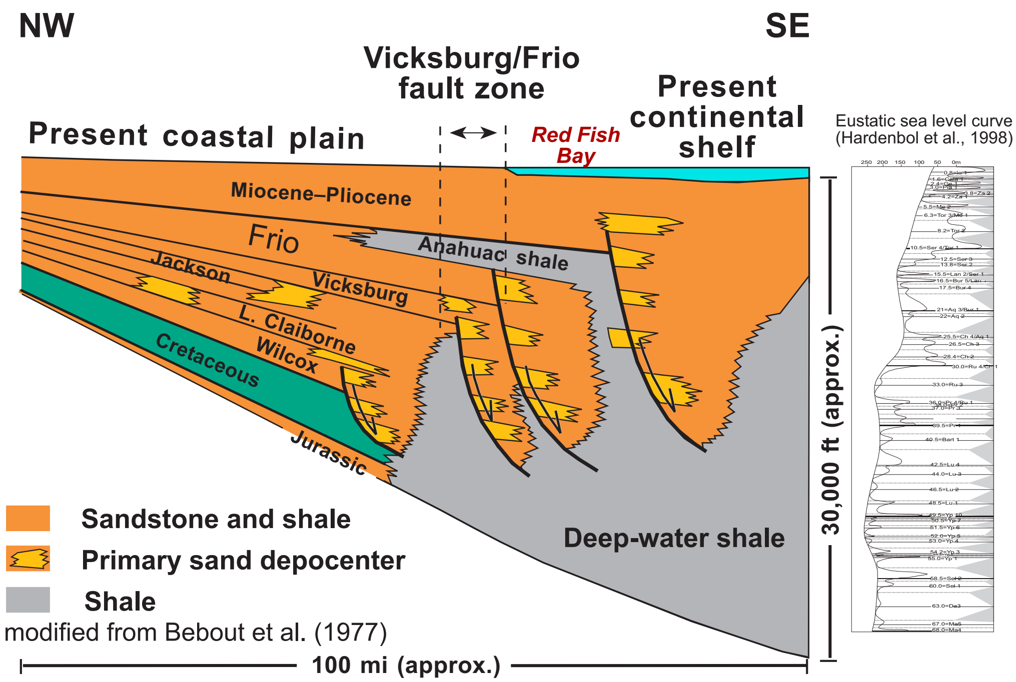
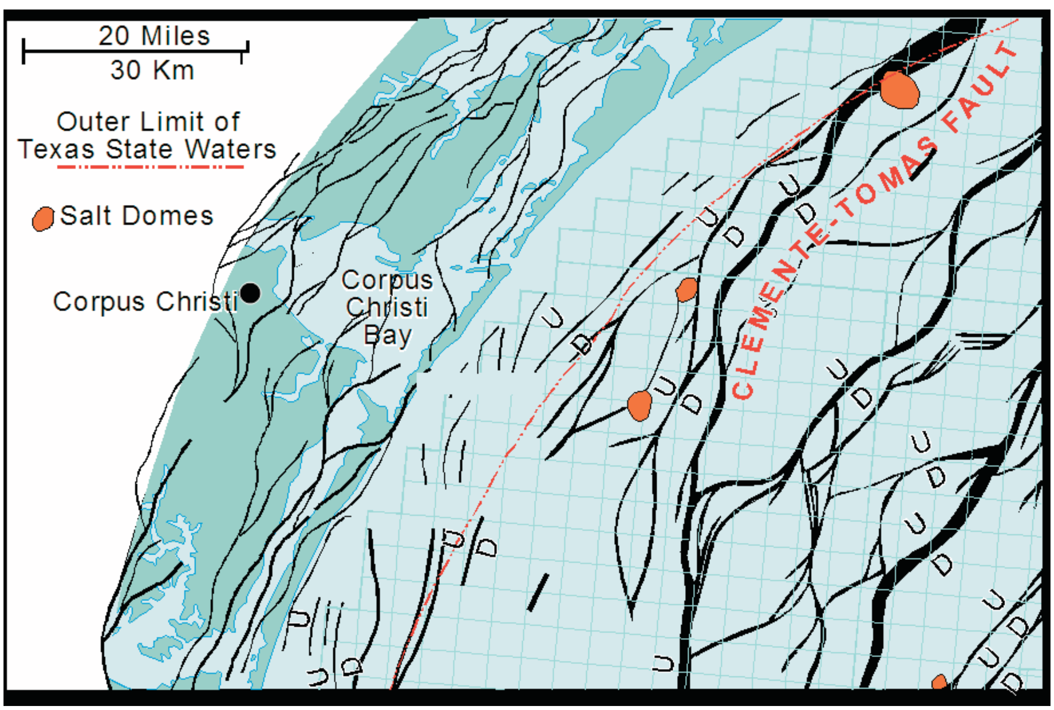


Figure 2. General stratigraphy and global Tertiary sea-level chart of the south Texas Gulf Coast. The Frio Formation is Oligocene in age. Sediments are composed of progradational transgressive and highstand on-shelf deposits and basinal gravity and suspension lowstand deposits (modified from Bebout et al., 1977).



modified from Trevino et al. (2003)

Figure 3. Regional tectonic map in the Corpus Christi area displaying growth faults that trend parallel to the coastline. Note the absence of salt (red) from study area. Instead, this area is dominated by mobile shale.

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Three-dimensional seismic data and well-log correlations were used to delineate the structural setting of the subbasin. The studied section was deposited in the hanging wall block of a major growth-fault system. Two prominent growth faults compose the growth-fault system that forms the western and northern boundary of the basin (Figs. 4 and 5). These faults subdivide the Red Fish Bay subbasin into three minibasins. Syndepositional fault movement, rollover, and associated interval expansion occurred in the prograding wedge section of the Frio Formation in this subbasin. Crestal, synthetic, and antithetic faults are common in the hanging wall and are the major control on trapping and compartmentalizing gas accumulations.

Orthogonal to the growth-fault system is a normal fault, which dips northeast (Treviño et al., 2004). The orthogonal fault's dip is in contrast to the main growth-fault system, which dips southeast. The orthogonal fault is younger than the growth-fault system and did not influence prograding wedge deposition. However, the throw on the orthogonal fault is as much as 400 ft within the prograding wedge. Production and petrophysical analyses of prograding wedge reservoirs contained within the subbasin indicate the existence of gas-expansion reservoir drives north of the orthogonal fault and water drives south of it. The best producing intervals are trapped by three- to four-way closures of smaller scale lowstand and transgressive systems tract sands of a third-order lowstand prograding wedge.

A variety of traps formed by the interaction of sedimentation and tectonics, such as anticlinal, fault, or stratigraphic closures. Anticlinal closures occur as rollovers and/or above shale ridges. Fault traps are sealed updip by either shale smears or juxtaposition against shale. Stratigraphic traps are closed updip by reservoir pinch-out. Gas charging occurs in anticlinal, combination, and fault traps until the gas-water contact breaches closure.

Sequence Stratigraphy

Sequence stratigraphic analyses indicate that the upper lowermost Frio stratigraphic interval was deposited in deltaic depositional systems as fourth- and fifth-order components of a third-order lowstand prograding wedge. The prograding wedge resulted from a drop in relative sea level, which caused a basinward shift in facies. Previous highstand fluvial systems incised and transported sediment all the way to the shelf edge. Sediments from the incised fluvial systems were deposited onto the slope (Mitchum et al., 1993). Differential loading on the underlying distal slope and basinal mud-dominated sediments with coarser grained sediments produced instability. Eventually, the slope failed, which resulted in the creation of the listric growth faults and the formation of a complex subbasin and a basinward shale ridge. Locking up of the shale ridge ended the syndepositional growth-fault movement. The overlying transgressive systems tract at a depth of approximately 10,000 ft and condensed section represent the regional seal and top of overpressure to Frio reservoirs (Fig. 6).

Architecture of a Third-Order Subbasin

Numerous growth-fault-bounded subbasins are aligned along the South Texas coast (Fig. 3). These subbasins are interpreted to have formed in response to successive third-order relative sea-level lowstands (Brown et al., in press). Within each subbasin are several minibasins related to the development of several smaller growth and normal faults that influenced deposition. These faults might be related to smaller scale sea-level fluctuations and/or to syndepositional structural movements influencing the sediment pathways and quantities that were shed into each basin.

Three minibasins were formed within the larger Red Fish Bay subbasin that exhibit similar vertical sediment patterns as the third-order lowstand systems tracts: basin-floor fan, slope fan, and prograding wedge described by Mitchum et al., 1993. Each of these minibasins exhibits different growth rates and sediment thicknesses in associated systems tracts (Fig. 7). The minibasin closest to the third-order growth fault in the southwest of the study area displays the thickest sedimentary column. Minibasins toward the northeast become progressively thinner with decreasing proximity from the growth-fault system. Thickness of slope and basin-floor-fan sections changes the most, whereas the prograding wedge section remained a constant thickness except where it is closest to the main growth fault.

Flooding surfaces were defined for the prograding wedge and correlated within the subbasin. The prograding wedge generally consists of upward-coarsening wireline-log facies that suggest deltaic sedimentation. Similar log facies are present in adjacent subbasins; however, individual prograding sequences are not correlative from one third-order subbasin to the next, but they are correlative from one minibasin to the other. Diachronous deltaic sandstone units pinch out basinward and also display potential updip rollover or fault closures.

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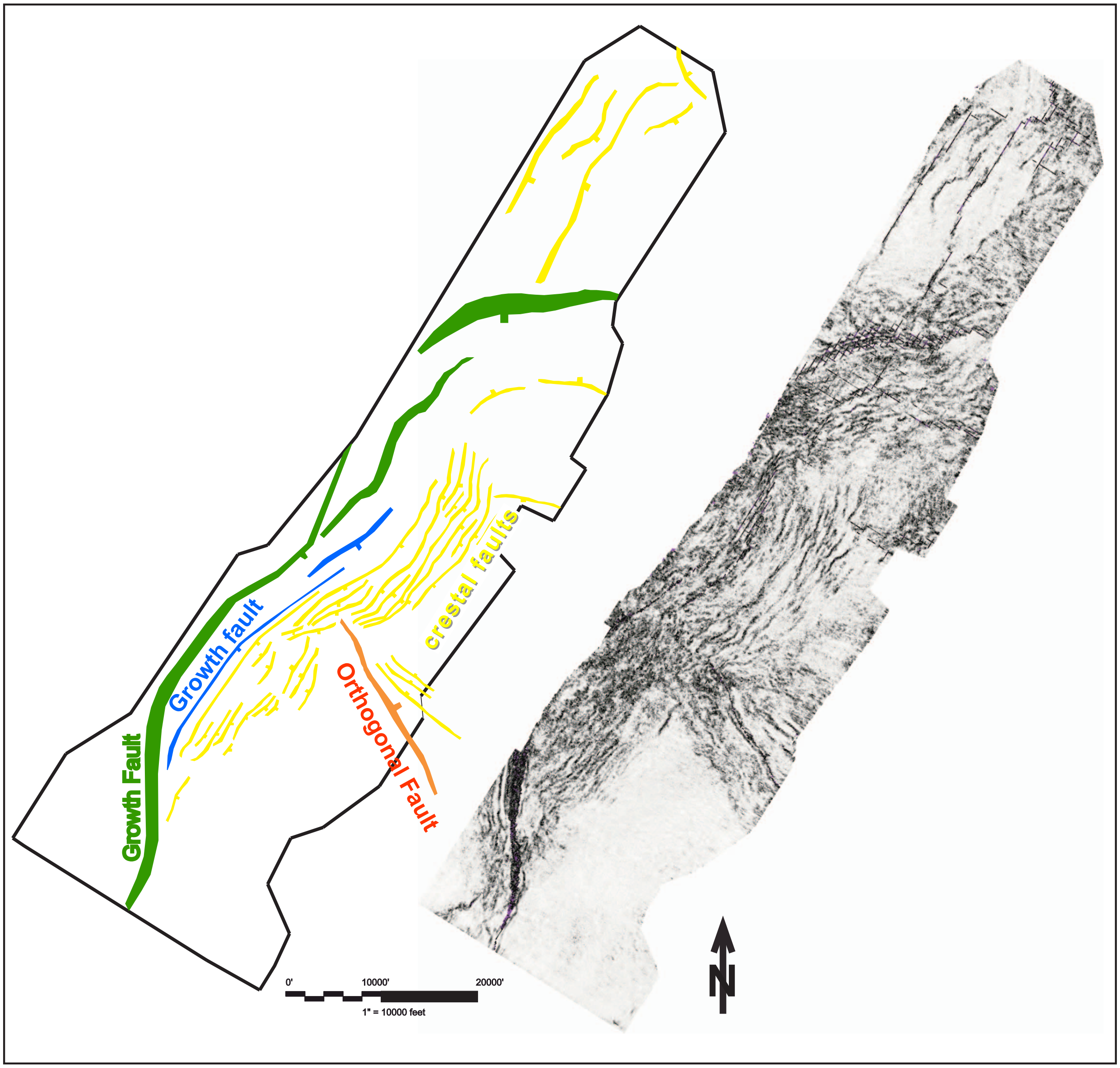

Figure 4. Illustration of major faults (left) and continuity map (right) within the Frio Formation in the field area. The blue and green faults belong to a major growth-fault system; the yellow faults are synthetic and antithetic crestal faults. The red fault is an orthogonal fault not exhibiting growth. Crestal faults add to compartmentalization of the reservoirs.

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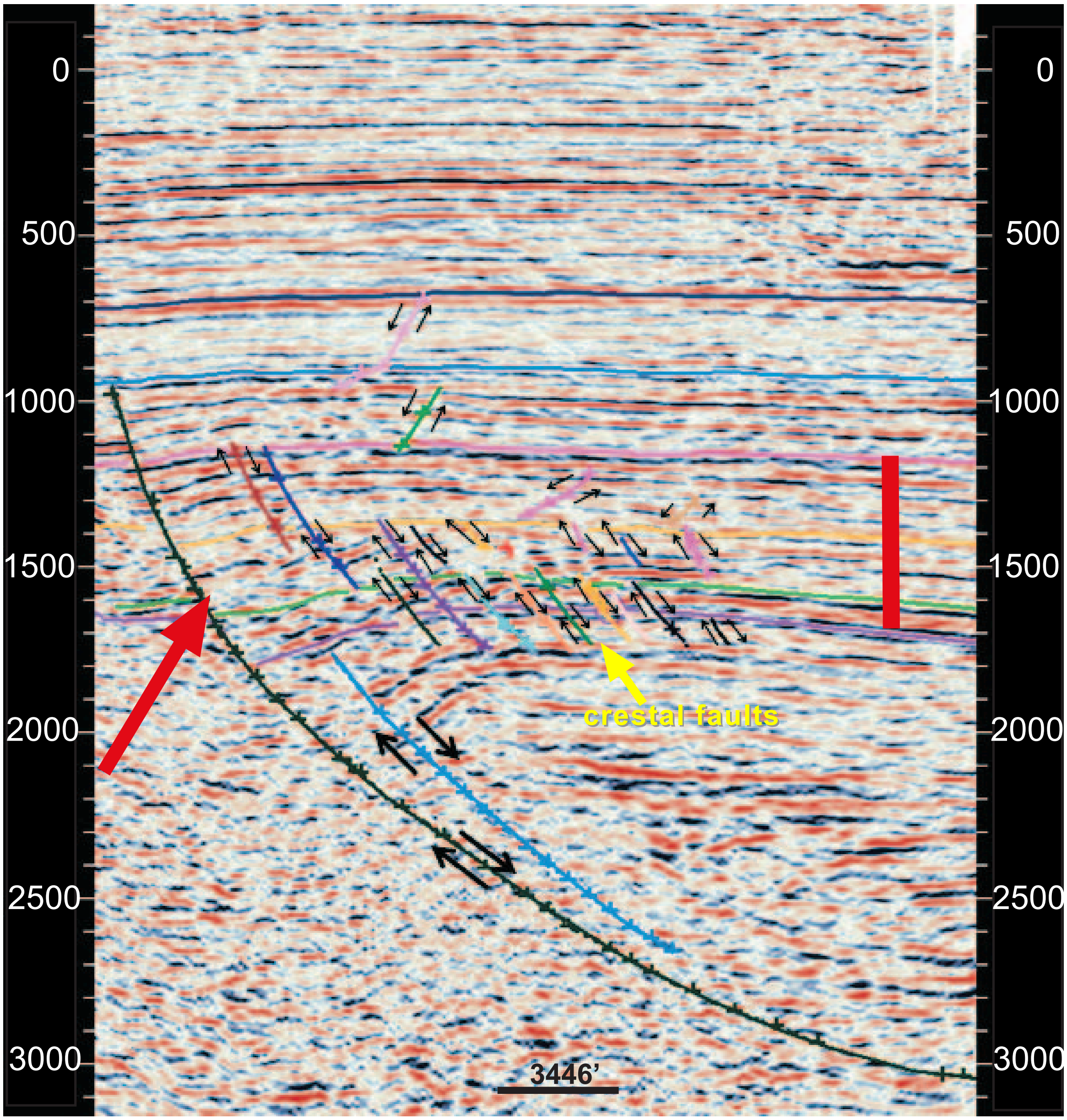

Figure 5. Seismic dip line exhibiting growth faults (blue, green) setting up the subbasin and antithetic and synthetic crestal faults. These faults compartmentalize the prograding wedge reservoirs (red bar). Note expansion of prograding wedge into growth fault (red arrow).

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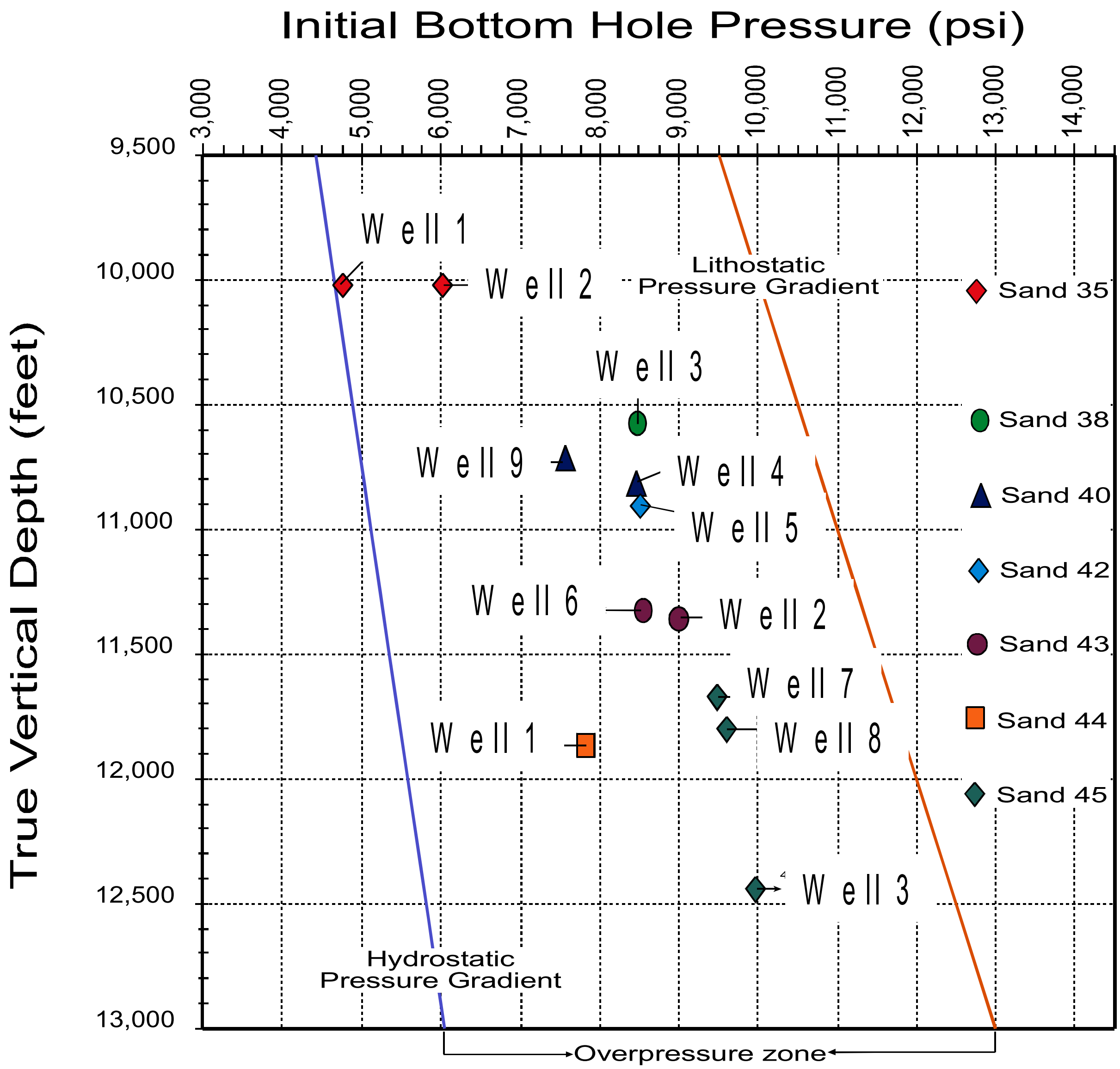

Figure 6. Initial bottom-hole pressure versus true vertical depth for selected wells and sands. Note that all wells are overpressured and pressure is increasing with depth.

The detailed study of faults within the third-order subbasin suggests a complex pattern of gravity tectonics and sedimentation (Figs. 7 and 8). The green fault represents the growth-fault system related to a third-order relative fall in sea level. The blue fault represents a subsidiary growth fault that, in concert with the green fault, set up two of the minibasins. A third minibasin was created by the green growth fault shown in Figure 4, which extends past the seismic survey in Red Fish Bay toward the northwest. Figure 8 displays an idealized model of several growth-faulted minibasins within a third-order subbasin. The schematic diagram emphasizes the complicated architecture of third-order lowstand subbasins as there are several faults that exhibit growth during the third-order lowstand duration. Apparently, expansion along the growth faults did not occur exactly at the same time or at the same rate, which resulted in varying thicknesses of the lowstand systems tracts among the different minibasins.

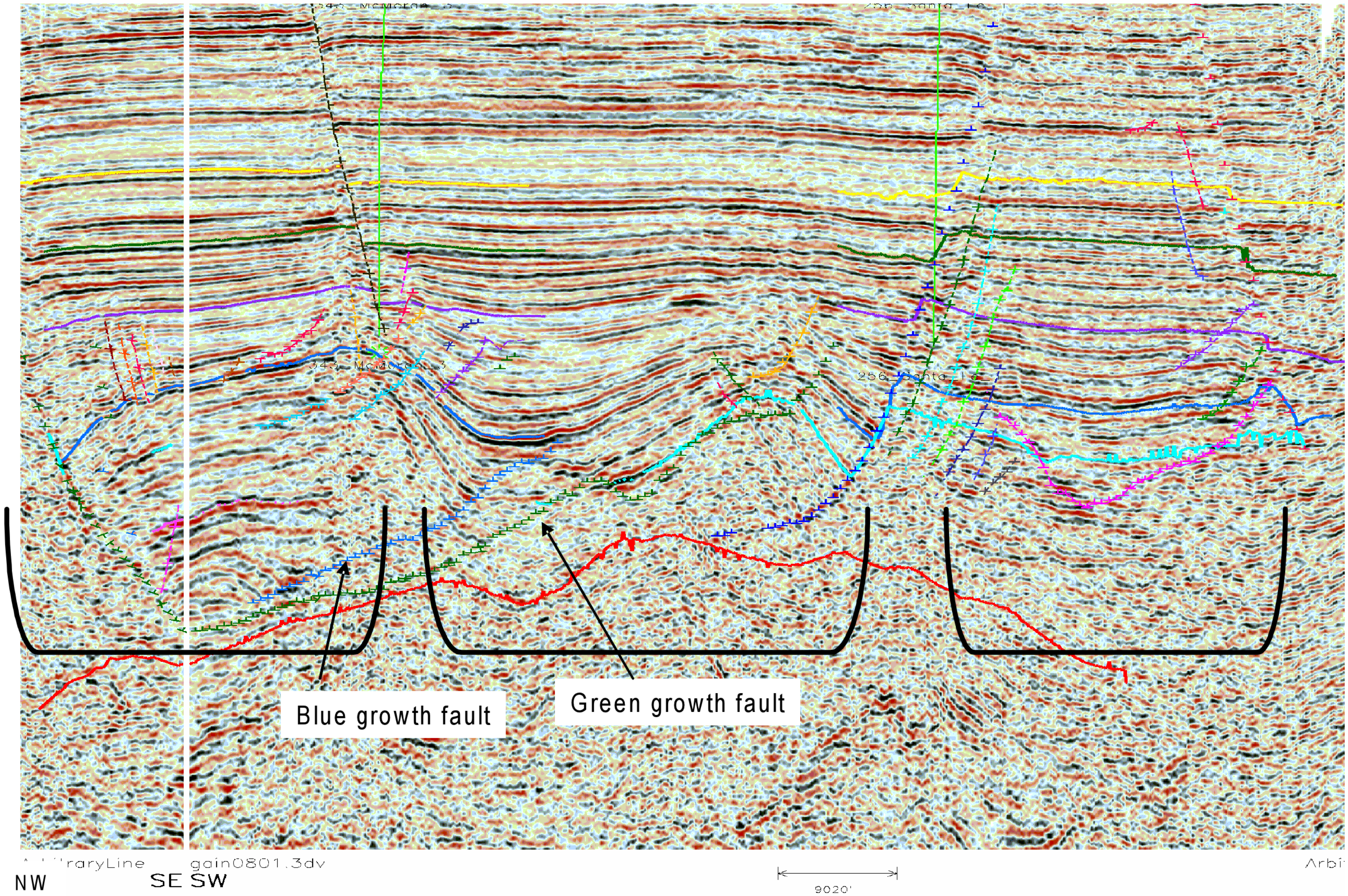

Figure 7. Arbitrary strike line trending NW-SE/SW-NE in field area. There are three minibasins (brackets) within the third-order subbasin each exhibiting different growth and sedimentation rates. Note that major growth fault (dark green) is parallel to section.

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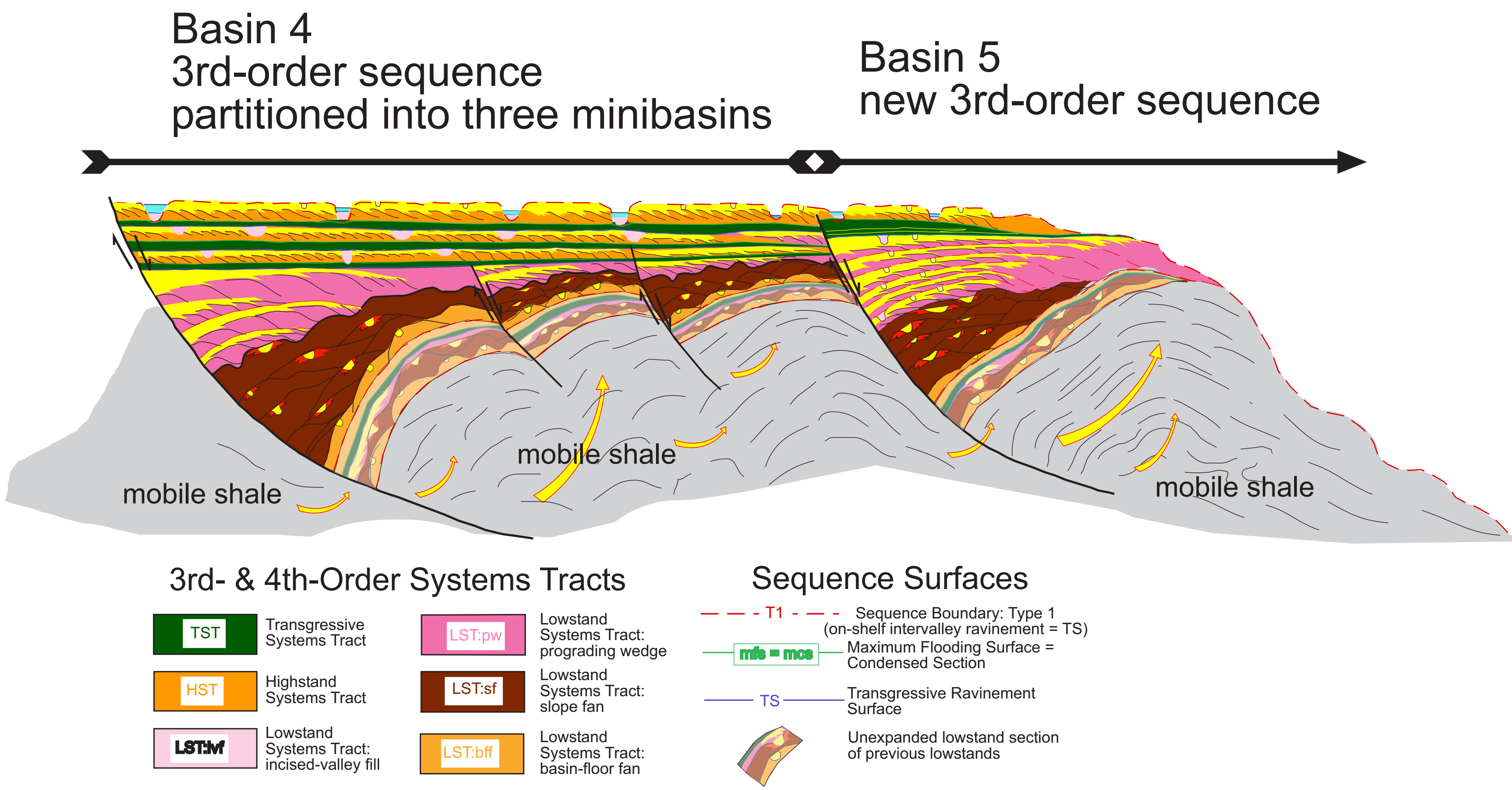

Figure 8. Idealized model of third-order subbasin development showing complexity of reservoirs and interplay of sediments and tectonics. Note that different minibasins exhibit varying thicknesses in lowstand systems tracts. Sediment thickness decreases with decreasing proximity from growth fault.

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Conclusions

Stratigraphic and structural analyses of a Red Fish Bay third-order subbasin suggest that the subbasin formed as a result of interaction between sedimentation and gravity tectonics. Minibasins developed because of differential subsidence, sediment supply, and growth-fault movements. Fault movement rates and hanging wall expansion varied slightly from one minibasin to another. The Red Fish Bay subbasin is one of several Frio lowstand subbasins that were created during third-order relative sea-level falls. The third-order subbasins are bounded on the landward side by growth faults and on the seaward side by shale ridges. Lowstand deposits within the subbasins are characterized by basin-floor and slope-fan deposits, which are overlain by prograding wedge deltaic sediments. These sediments were deformed by synsedimentary growth faults and later structural deformation. The primary growth-fault system defines the outline of the Red Fish Bay subbasin in the northwest and north. Subsidiary growth faults parallel to the main system partitioned the basin into several minibasins and structurally deformed parts of the lowstand systems tracts. Later structural deformation created compartmentalized reservoirs. Crestal (synthetic and antithetic) faults are common in the hanging wall block and are the major control on trapping and compartmentalizing hydrocarbon accumulations.

Acknowledgments

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