

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/287536627>

Pre-Holocene geological evolution of the northern Gulf of Mexico basin

Article · January 2009

CITATIONS

4

READS

106

1 author:



[William E. Galloway](#)

University of Texas at Austin

194 PUBLICATIONS 8,881 CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:

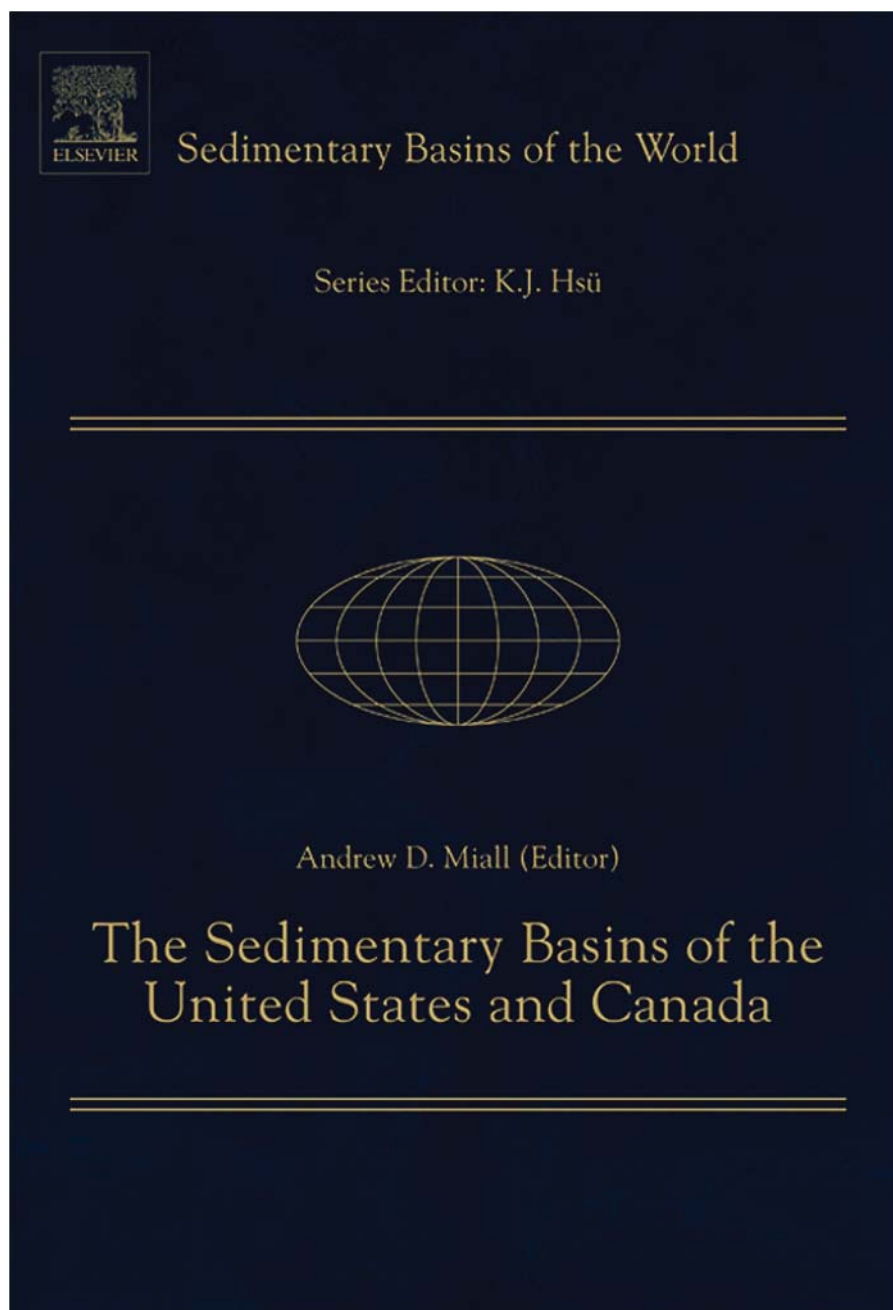


Source-to-sink analysis of the lower Miocene strata in the Gulf of Mexico Basin [View project](#)



Gulf of Mexico Depositional Systems [View project](#)

This chapter was originally published in the book *Sedimentary Basins of the World*, published by Elsevier, and the attached copy is provided by Elsevier for the author's benefit and for the benefit of the author's institution, for non-commercial research and educational use including without limitation use in instruction at your institution, sending it to specific colleagues who know you, and providing a copy to your institution's administrator.



All other uses, reproduction and distribution, including without limitation commercial reprints, selling or licensing copies or access, or posting on open internet sites, your personal or institution's website or repository, are prohibited. For exceptions, permission may be sought for such use through Elsevier's permissions site at: <http://www.elsevier.com/locate/permissionusematerial>

From William E. Galloway, Depositional Evolution of the Gulf of Mexico Sedimentary Basin.

In: K.J. Hsü, editor: *Sedimentary Basins of the World*, Vol 5, *The Sedimentary Basins of the United States and Canada*, Andrew D. Miall.

The Netherlands: Elsevier, 2008, pp. 505–549.

ISBN: 978-0-444-50425-8

© Copyright 2008 Elsevier BV.

Elsevier

DEPOSITIONAL EVOLUTION OF THE GULF OF MEXICO SEDIMENTARY BASIN

William E. Galloway

Contents

1. Introduction	506
2. Crustal Structure and Basin Origin	507
2.1. Subsidence mechanisms and history	509
3. Structural Framework	509
3.1. Basement structures	509
3.2. Gravity tectonic structures	510
3.3. Growth structure domains	511
3.4. Structural growth history	514
4. Depositional Framework	514
4.1. Depositional episodes and sequences	514
5. Depositional History and Paleogeography	516
5.1. Middle Jurassic–Earliest Cretaceous (Bathonian–Berriasian) depositional episodes	516
5.2. Early Cretaceous (Valanginian–Cenomanian) depositional episodes	520
5.3. Late Cretaceous (Cenomanian–Maastrichtian) depositional episodes	525
5.4. Cenozoic depositional episodes	528
5.5. Laramide depositional episodes	529
5.6. Middle Cenozoic volcanism and related depositional episodes	531
5.7. Miocene depositional episodes	533
5.8. Early Pliocene–Quaternary depositional episodes	536
6. Patterns and Generalizations in Gulf Depositional History	538
6.1. Sediment supply: Sources and drainage history	538
6.2. Climate and oceanography	539
6.3. Continental margin evolution	541
7. Energy Resources	543
Acknowledgments	544
References	544

Abstract

The Gulf of Mexico is a small ocean basin lying between the North American plate and the Yucatan block. Following initiation in the Middle Jurassic, sea-floor spreading continued approximately 25 Myr. Spreading was asymmetric, creating a broad area of attenuated transitional continental crust beneath the northern basin. Initially, widespread, thick salt deposits accumulated across much of the basin; mobilization of this salt by subsequent sedimentary loading has created a complex suite of gravity tectonic structures. Most salt is now allochthonous, forming extensive stocks and canopies. By the end of the Mesozoic, thermal subsidence had created a deep basin floor, flanked by continental shelves. The resultant basin contains a succession of Late Jurassic through Holocene strata that is as much as 20 km thick. Sediment supply from the North American continent has filled nearly one-half of the basin since its inception, primarily by offlap of the northern and northwestern margins. Depositional history can be generalized in seven phases: (1) Middle-Late Jurassic evaporite and carbonate deposition in a broad, shallow, restricted to open marine basin. (2) Latest Jurassic-Early Cretaceous sand-rich clastic progradation from the northern margins. (3) Late-Early Cretaceous development of a rimmed carbonate shelf. (4) Late Cretaceous mixed clastic and carbonate aggradation of the continental margins. (5) Resurgent Paleogene clastic progradation and filling centered in the NW basin. (6) Miocene progradation and basin filling centered in the central and NE Gulf. (7) Late Neogene climatically and eustatically influenced progradation along the central Gulf margin. In contrast

to the broad, progradational sediment wedge of the northern Gulf, the Florida margin is a primarily aggradational carbonate platform.

1. INTRODUCTION

The Gulf of Mexico is a small ocean basin lying between the North American plate and the Yucatan block. It contains within its depocenter a succession of Jurassic through Holocene strata that is as much as 20 km thick. Sediment supply from the North American continent has filled nearly one-half of the basin since its inception, primarily by offlap of the northern and northwestern margins. This chapter will focus on the history of this northern fill.

The fundamental geologic principal that “the present is the key to the past” has found wide application and success in the Gulf basin. The modern basin (Figure 1) has a central abyssal plain that generally lies at >3 km depth (Bryant et al., 1991). The eastern Gulf floor is dominated by the morphology of the Late Quaternary Mississippi fan. The continental slope of the northern Gulf margin displays a bathymetrically complex morphology that terminates abruptly in the Sigsbee escarpment to the west and merges into the Mississippi fan to the east (Steffens et al., 2003). The hallmark of the central Gulf continental slope is the presence of numerous closed to partially closed, equi-dimensional, slope minibasins. In contrast, the Florida platform forms a broad ramp and terrace that terminates at depth into the nearly vertical Florida escarpment. The western Gulf margin displays intermediate width and it too is bathymetrically complex. Here, numerous contour-parallel ridges and swales dominate the mid- to lower slope morphology. The modern shelf edge, as reflected by a well-defined increase in basinward gradient, generally lies at a depth of 100–120 m. Landward, the northwestern, northern, and eastern Gulf of Mexico is bounded by broad, low-gradient shelves that range from 100 to 300 km in width (Figure 1). Today, and throughout its history, the Florida and Yucatan platforms, which bound the basin on the east and south, persist as sites of carbonate deposition.

On shore, the northern and northwestern Gulf margin displays a broad coastal plain (Figure 1). The lower coastal plain, a flat, low-relief surface, is underlain by Neogene and Quaternary strata. The upper coastal plain displays modest relief of less than about 100 m created by Quaternary incision into older Neogene, Paleogene,

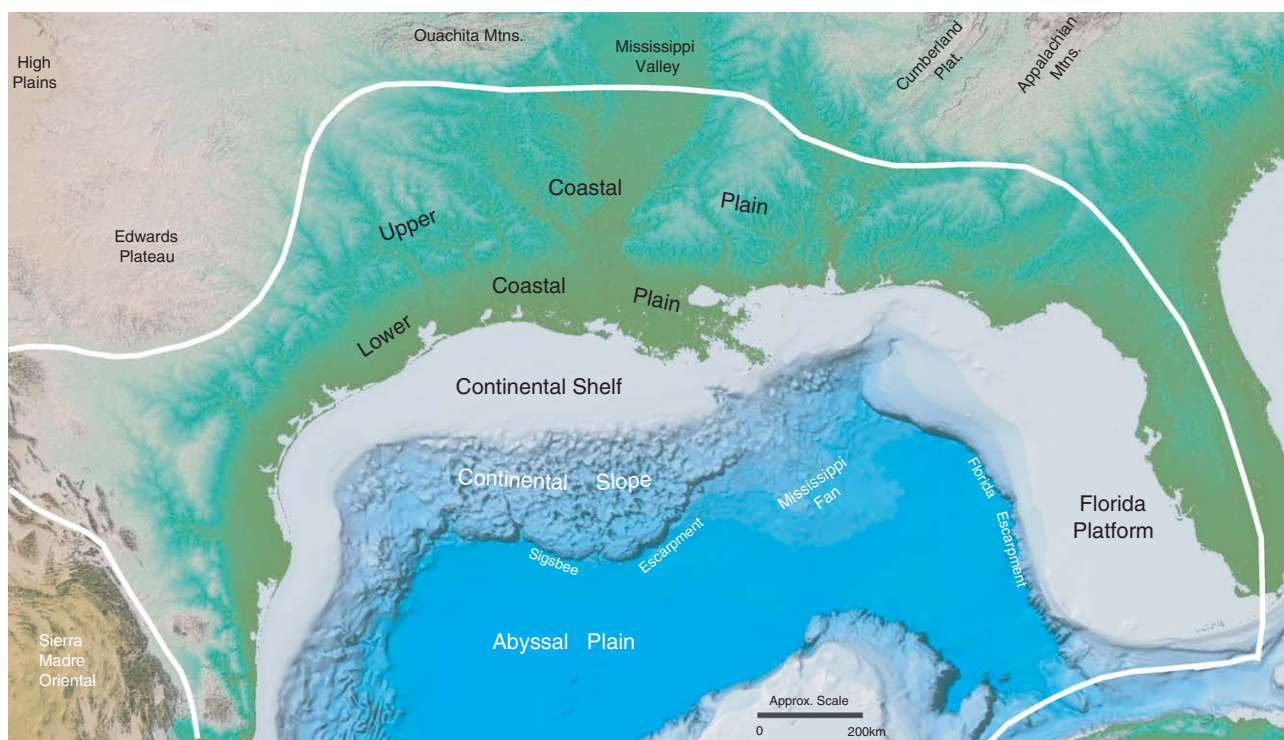


Figure 1 Principal physiographic elements of the Gulf of Mexico basin and adjacent North America. White outline shows approximate geological limits of the Gulf basin. Bathymetry from GEBCO (2003, The GEBCO digital atlas-Centenary edition, British Oceanographic Data Centre); topography from International Centre for Tropical Agriculture (CIAT) (2005), Void-filled seamless SRTM data V2, <http://srtm.csi.cgiar.org>. Image created using IVS3D Fledermaus.

and Late Cretaceous strata by numerous large and small rivers. The basin is bounded by a variety of Cenozoic, Mesozoic, and remnant Paleozoic uplands, including the Sierra Madre Oriental of Mexico, the Trans-Pecos mountains of West Texas, the Lower Cretaceous limestone-capped Edwards Plateau, Ouachita Mountains of southern Arkansas (Miall, Chapter 8, this volume), and the Cumberland Plateau and southern Appalachian Mountains of northern Mississippi and Alabama (Ettensohn, Chapter 4, this volume). The northeast Gulf basin merges into the southern Atlantic coastal plain across northern Florida (Miall et al., Chapter 14, this volume); however, the structural basin boundary is generally placed near the current west coast of the Florida peninsula.

The geology of the Gulf of Mexico has been reviewed by numerous authors. Two syntheses stand out. Grover Murray's 1961 *Geology of the Atlantic and Gulf Coastal Province of North America* summarized classic mid-20th century stratigraphic and structural understanding of the basin. The Geological Society of America's 1991 *Geology of North America* volume J, *The Gulf of Mexico Basin*, edited by Amos Salvador, provided a synthesis of all facets of basin geology and resources integrated through the initial applications of modern concepts of crustal tectonics, depositional systems, genetic stratigraphy, deep-marine studies, and gravity tectonics. The objective of this chapter is to incorporate the wealth of new ideas and information that has been published in the decade since the GSA volume into a succinct description of the stratigraphic framework and depositional history of the northern margin and related deep Gulf of Mexico basin.

2. CRUSTAL STRUCTURE AND BASIN ORIGIN

The Gulf of Mexico basin was created by an episode of crustal extension and sea-floor spreading during the Mesozoic breakup of Pangea (Salvador, 1987; Sawyer et al., 1991; Buffler and Thomas, 1994; Harry and Londono, 2004; Jacques and Clegg, 2002). Origin of the basin is reflected in the distribution and nature of the basement crust (Figure 2). The Gulf basin is largely surrounded by normal continental crust of the North American plate. Most of the structural basin is underlain by transitional crust that consists of continental crust that was stretched and attenuated by Middle to Late Jurassic rifting. Two types of transitional crust are differentiated (Figure 2). The basin margin is underlain by a broad zone of *thick transitional crust*, which displays modest thinning and typically lies at depths between 2 and 12 km subsea depth (Sawyer et al., 1991). The area of thick transitional crust consists of blocks of near-normal thickness continental crust separated by areas of stretched crust that has subsided more deeply. The result is a chain of named arches and intervening embayments and salt basins around the northern periphery of the Gulf basin (Figure 2). Much of the present inner coastal plain, shelf, and continental slope is underlain by relatively homogeneous *thin transitional crust*, which is generally less than half of the 35 km thickness typical of continental crust and is buried to depths of 10–16 km below sea level. More recent reconstructions of deep seismic traverses (Peel et al., 1995) indicate that basement may lie below 20 km in the central depocenter beneath the south Louisiana coastal plain and adjacent continental shelf. The deep, central Gulf floor is underlain by an arcuate belt of basaltic oceanic crust that was intruded during Late Jurassic through Early Cretaceous sea-floor spreading. The exact nature and actual distribution of this crust is problematic; Figure 2 illustrates the general shape and distribution of oceanic crust suggested by most authors. That central Gulf crust lacks the magnetic signature typical of oceanic crust, compounds interpretation difficulties.

The broad history of plate tectonic movements that culminated in the Gulf basin is generally understood (Marton and Buffler, 1999; Pindell and Kennan, 2001; Jacques and Clegg, 2002; Harry and Londono, 2004; Bird et al., 2005), if not fully agreed upon in detail. The Gulf of Mexico opened by the separation of the North and South American plates as rifting spread southward along the Atlantic spreading ridge. A long period of Late Triassic through Early Jurassic extension that created a series of basement grabens and half grabens filled with terrestrial red beds and volcanics presaged the main phase of Late Jurassic–Early Cretaceous Gulf rifting. Recognition of potential seaward-dipping reflectors in the northeastern Gulf suggests an early phase of subaerial volcanism during the initial spreading phase (Imbert, 2005). Continued stretching in Bathonian and Callovian time initiated a broad sag, which opened to the Pacific Ocean. Widespread deposition of thick Louann Salt and associated evaporites, a defining event for the later structural evolution of the Gulf sedimentary fill, spread across the shallow, hypersaline basin centered above the thinned continental crust. Salt thickness was greatest above the marginal crustal embayments and basins and, regionally, above the evolving thin transitional crust (Figure 2). The regional unconformity beneath the evaporite layer separates localized syn-rift from blanket post-rift deposits and is widely taken as the base of the Gulf of Mexico sedimentary basin fill (Sawyer et al., 1991; Buffler and Thomas, 1994).

Rotational spreading along a generally east-west trend extending from a pole centered beneath NW Cuba continued through Late Jurassic to as late as the Valanginian (Pindell and Kennan, 2001). Opening of the Gulf entailed approximately 500 km of extension accompanied by southward migration and counter-clockwise

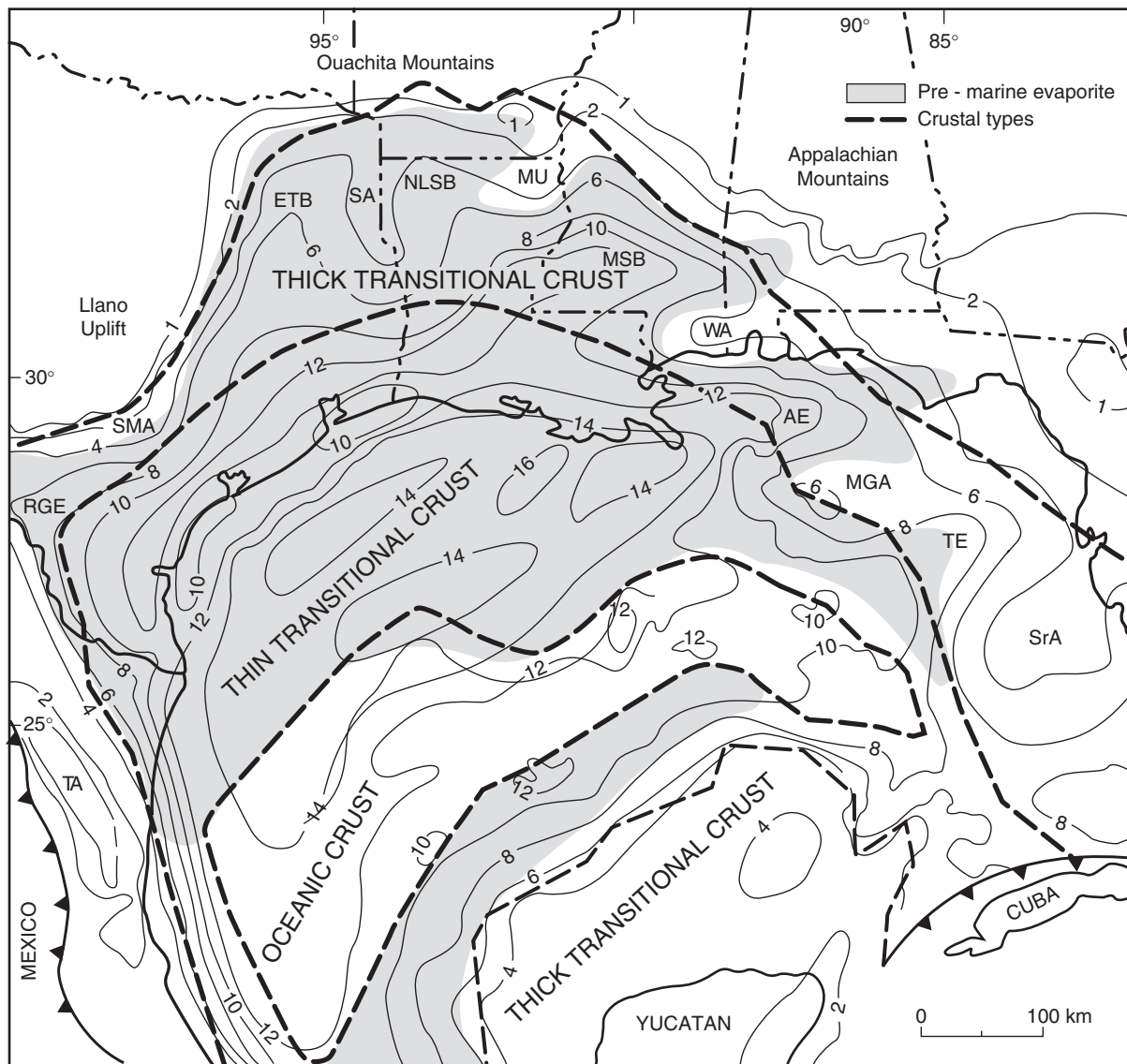


Figure 2 Crustal types, depth to basement (km), and original distribution of Jurassic Louann pre-marine evaporite beneath the Gulf of Mexico basin. Principal basement structures include: SrA, Sarasota arch; TE, Tampa embayment; MGA, Middle Ground arch; AE, Apalachicola embayment; WA, Wiggins arch; MSB, Mississippi salt basin; MU, Monroe uplift; NLSB, North Louisiana salt basin; SA, Sabine arch; ETB, East Texas basin; SMA, San Marcos arch; RGE, Rio Grande embayment; TA, Tamaulipas arch. Modified from Sawyer et al. (1991). Note that modern reconstructions suggests crustal depths of >20 km beneath the north-central Gulf depocenter.

rotation of the rigid Yucatan block to its present position and by extensive NNW-SSE shear along the west flank of the basin (Martin and Buffler, 1999; Pindell and Kennan, 2001; Jacques and Clegg, 2002). Crustal rupture and emplacement of basaltic crust began by the Oxfordian and continued until the termination of spreading in the latest Berriasian or Early Valanginian. Salt deposition ended with onset of sea-floor spreading, and the Louann salt basin was split into northern and southern Gulf segments overlying transitional crust (Figure 2). Jacques and Clegg (2002) suggest two phases of rotation about differing poles. With shift of further inter-plate spreading to the Atlantic and proto-Caribbean basins, cooling and subsidence of the stretched continental and oceanic crust-dominated basin development. By the end of the Early Cretaceous, combined deposition of rimming carbonate platforms and subsidence had created the modern outline and morphology of the Gulf Basin (Winker and Buffler, 1988). Late Cretaceous and, especially, Cenozoic history was dominated by loading subsidence, complicated by intrabasinal gravity tectonics.

The history of Gulf spreading created four distinctly different basin margin types. The northern margin is a relatively simple divergent margin with a broad zone of stretched continental crust separating oceanic and continental crust. The Yucatan margin, to the south, is also a divergent margin, but juxtaposes thick transitional crust closely to the oceanic crust. This pronounced asymmetry suggests a simple-shear model for extension

(Marton and Buffler, 1993; Watkins et al., 1995). The Mexico and Florida margins primarily reflect displacement of crustal blocks along a series of transfer faults. To the west, the crustal boundary is characterized by an elongate gravity high and narrow zone of primarily Late Cenozoic growth faults (Ambrose et al., 2005; Bird et al., 2005). On the east, the margin was formed by a series of rhombohedral crustal blocks that rotated between two parallel transfer faults that generally conform to the Florida-Bahamas and the Cuban Fracture Zones (MacRae and Watkins, 1996). The family of basement arches and sags that extends from the Mississippi Salt Basin southeast to the Sarasota Arch (Figure 2) were produced in this transtensional domain (Watkins et al., 1995; Marton and Buffler, 1999; Pindell and Kennan, 2001; Stephens, 2001).

2.1. Subsidence mechanisms and history

Like other oceanic basins, total subsidence of the Gulf basin is the sum of crustal stretching, cooling, and loading subsidence. Combined stretching and cooling as crust migrated away from the axial spreading center and then cooling after spreading ceased caused a total tectonic subsidence of 5–7 km of the central thin transitional and oceanic crust (Sawyer et al., 1991). Initially, stretching and cooling subsidence created a starved basin that subsided more rapidly than sediment was supplied. The marine basin expanded and deepened. Subsequent depositional loading of the crust, which soon followed and has continued through the Holocene, has further depressed the crust to its current 10–20 km (Figure 2) below sea level. Loading subsidence has dominated Cenozoic history of the basin.

Additional Mesozoic and Cenozoic tectonic phases have further influenced local to sub-regional subsidence history of the Gulf. Several of the marginal highs, including the San Marcos arch, Sabine arch and Monroe uplift display short pulses of uplift of as much as a few hundred meters, creating angular unconformities in Middle Cretaceous and Lower Eocene strata (Laubach and Jackson, 1990). These pulses generally correlate to phases of Laramide thrusting, in turn related to changing rates of Pacific margin plate convergence and changing intracratonic compressional stress. Extensive crustal heating across northern Mexico and the southwestern United States (Gray et al., 2001) uplifted and tilted Mesozoic and Early Cenozoic strata of the western Gulf.

Cenozoic mobilization of thick bodies of intrabasinal salt has created as much as 1–2 km of often rapid subsidence of the overlying outer shelf and upper slope sediments at numerous times along segments of the northern Gulf continental margin (Diegel et al., 1995; Galloway et al., 2000). Such salt evacuation has been a major process for creation of local to regional sediment accommodation volume.

3. STRUCTURAL FRAMEWORK

The depositional history of the Gulf of Mexico Basin is best understood in the context of both the basement structure, which subtly influenced sediment supply and accumulation patterns, and gravity tectonic structure, which reflects dynamic interactions among depositional loading, sediment and salt mobilization, creation or loss of accommodation space, and deformation.

3.1. Basement structures

Basement structures and their influence on overlying stratigraphy are most readily apparent around the periphery of the basin underlain by thick transitional crust. They include the halo of embayments (epicratonic basins that open to the central Gulf) and basins and intervening arches and uplifts (Ewing, 1991) (Figure 2). The basins and embayments typically contain a significant thickness of Louann salt and thicker sequences of Jurassic and Early Cretaceous strata relative to the adjacent arches and uplifts. Salt-floored basins, including the East Texas basin, North Louisiana salt basin, Mississippi salt basin, and Appalachicola embayment (also known as the DeSoto Canyon salt basin) contain well-described families of salt domes and related structures (e.g., Seni and Jackson, 1984).

Deep crustal structures of the thin transitional and oceanic crustal domains are less easily defined. Gravity and magnetic data, changes in basement topography and rates of subsidence, and salt distribution all suggest a family of NW-SE trending basement transfer faults created during Atlantic and Gulf extension and spreading phases (Watkins et al., 1995; Huh et al., 1996; Stephens, 2001).

In the Late Cretaceous (60–100 Ma), intrusive and extrusive volcanism occurred around the northern and northwestern periphery of the Gulf Basin (Byerly, 1991; Stephens, 2001). Principal volcanic clusters lie around the inner edge of the central and south Texas coastal plain, and in southern Arkansas and the adjacent Monroe

uplift of northern Louisiana and adjacent Mississippi. Igneous lithologies include basalt, nephelene syenite, phonolite, and peridotite.

3.2. Gravity tectonic structures

The Gulf of Mexico basin fill displays one of the best-described and most complex assemblages of gravity tectonic structures to be found in the world (Worrall and Snelson, 1989; Nelson, 1991; Diegel et al., 1995; Jackson, 1995; Peel et al., 1995; Watkins et al., 1996a; Jackson et al., 2003). The combination of a thick, basin-flooring Louann salt substrate, rapid sediment loading, and offlap of a high-relief, continental-margin sediment prism has resulted in mass transfer of salt and overpressured mud up section and basinward throughout Gulf history. The resultant panoply of structures and related features includes:

1. Growth-fault families and related structures (Winker, 1982; Watkins et al., 1996b). Growth faults tend to nucleate and grow during active deposition at the continental margin. Here, extension results from basinward gravitational gliding or translation of the sediment wedge along a detachment zone, typically found within salt or overpressured deep-marine mud (Rowan et al., 2005). Extension creates a family of features, including primary synthetic growth faults, splay faults, antithetic faults, and rollover anticlines (Figure 3A).
2. Allochthonous salt bodies, including salt canopies and salt sheets (Diegel et al., 1995; Fletcher et al., 1995; Peel et al., 1995; Jackson et al., 2003). Loading of the Louann salt has resulted in regional extrusion of salt basinward and up section. Salt canopies typically develop beneath the continental slope, where salt rises as a series of coalescing diapirs or as injected tongues. Salt may also be extruded to the surface, forming salt sheets, or nappes, that move basinward much like salt glaciers.
3. Salt welds (Jackson and Cramez, 1989; Jackson et al., 1994). Welds (Figure 3B and C) are surfaces that juxtapose discordant stratigraphies. They form where nearly complete expulsion of salt stock feeder dikes, salt tongues, or salt canopies has occurred.
4. Roho fault families (Rowan, 1995; Schuster, 1995; Jackson et al., 2003). Lateral salt tongue extension by gravity spreading creates a linked assemblage of extensional faults and compensating, down-slope compressional toe faults, anticlines, and salt injections in the overlying sedimentary cover (Figure 3B).
5. Salt diapirs and their related withdrawal synclines and minibasins (Seni and Jackson, 1984; Rowan, 1995; Fletcher et al., 1995; Rowan and Weimer, 1998; Jackson et al., 2003). In the Gulf-margin basins and embayments, salt diapirs rise directly from the autochthonous Louann “mother” salt. Basinward, depositional loading of salt canopies and sheets beneath shelf and slope areas causes renewed salt stock evacuation, creating

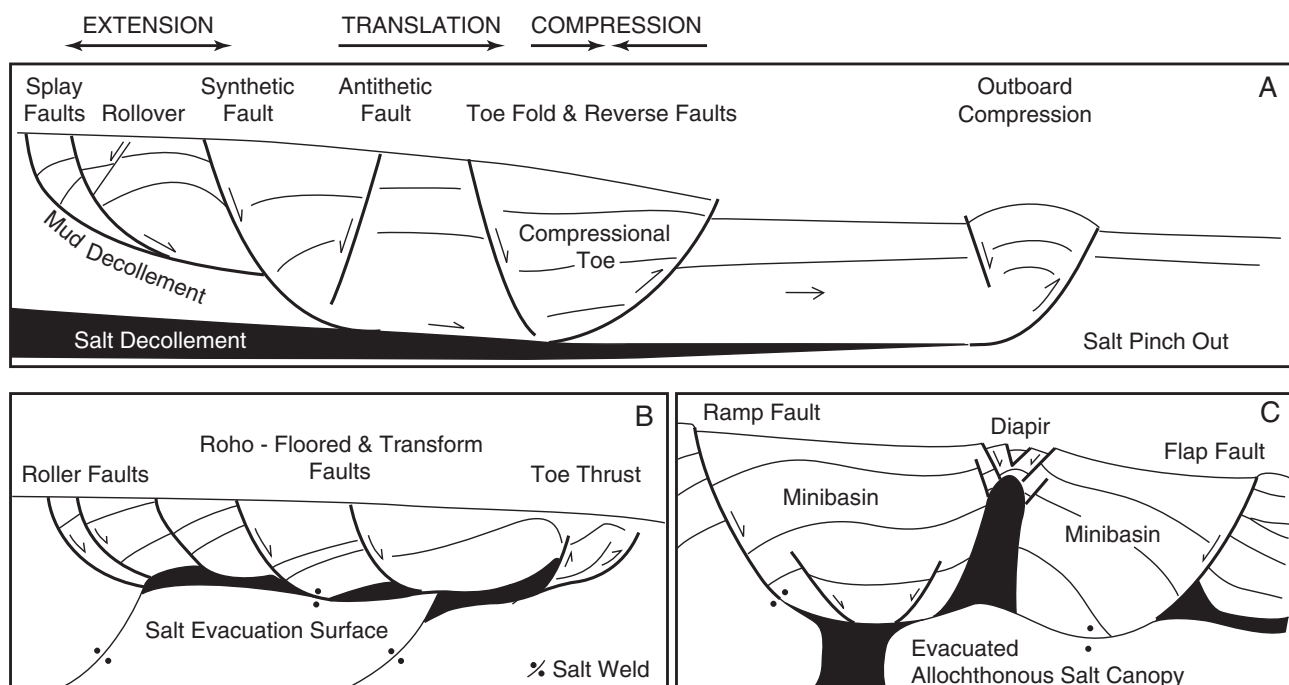


Figure 3 Typical intrabasinal gravity tectonic structural styles and features of the northern Gulf margin. (A) Linked salt- and shale-based detachments. (B) Salt-based detachment fault system, or Roho structure. (C) Salt-withdrawal minibasin. Modified from Karlo and Shoup (1998).

high-relief salt diapirs and intervening depressions (Figure 3C). Progressive salt evacuation creates shifting, localized sites of extreme subsidence and sediment accumulation. Resulting features include (Figure 3C) withdrawal synclines created by local evacuation of salt from diapir flanks, bathymetric depressions, called minibasins, that form local depocenters, turtle structures, and local fault families including down-to-basin ramp faults, counter-regional flap faults, and crestal faults above salt bodies.

6. Basin-floor compressional fold belts (Weimer and Buffler, 1992; Fiduk et al., 1995; Trudgill et al., 1999; Hall et al., 1998). Basinward gravity spreading or gliding along a detachment zone, and resultant updip extension, requires compensatory compression at the toe of the displaced sediment body. Compressional features include anticlinal toe folds and reverse faults (Figure 3A). They commonly form at the base of the slope, but also can extend onto the basin plain where a stepped discontinuity or termination of the decollement layer occurs.

3.3. Growth structure domains

The most complex and complete array of gravity tectonic structures lies within the Cenozoic sedimentary wedge of the northern Gulf of Mexico basin (Figure 4). Principal structural features include an inboard series of strike-aligned growth-fault families beneath the coastal plain, complex fault families beneath South Louisiana and its adjacent continental shelf, a broad zone of relatively shallow salt stocks and coalesced autochthonous canopies beneath the continental slope, a base-of-slope salt nappe, forming the Sigsbee escarpment, and several sub-slope and basin floor compressional fold belts (Figure 4). Sediment loading of the salt canopy has created a series of largely filled shelf minibasins and closed bathymetric lows, called slope minibasins, on the continental slope.

This mosaic of gravity tectonic features can be grouped into genetically related structural domains (Peel et al., 1995) (Figure 5). Each domain had a finite time span of primary growth that can be associated with one or more successive episodes of clastic sediment accumulation in the Gulf. Domains generally become younger basinward, beginning with the Middle Cretaceous Louann detachment domain and culminating in the Plio-Pleistocene minibasin and salt canopy domains of the continental slope. The Oligocene-Lower Miocene and Miocene compressional domains are exceptions to this general pattern.

In addition, the full array of gravity tectonic structure domains of the northern Gulf basin includes the salt diapirs and related structures of the East Texas, North Louisiana, Mississippi, and DeSoto Canyon salt basins, which lie around the northern basin periphery, and a series of peripheral grabens, including the Luling-Mexia-Talco, State Line, and Pickins-Gilberton fault zones, that delimit the landward extent of

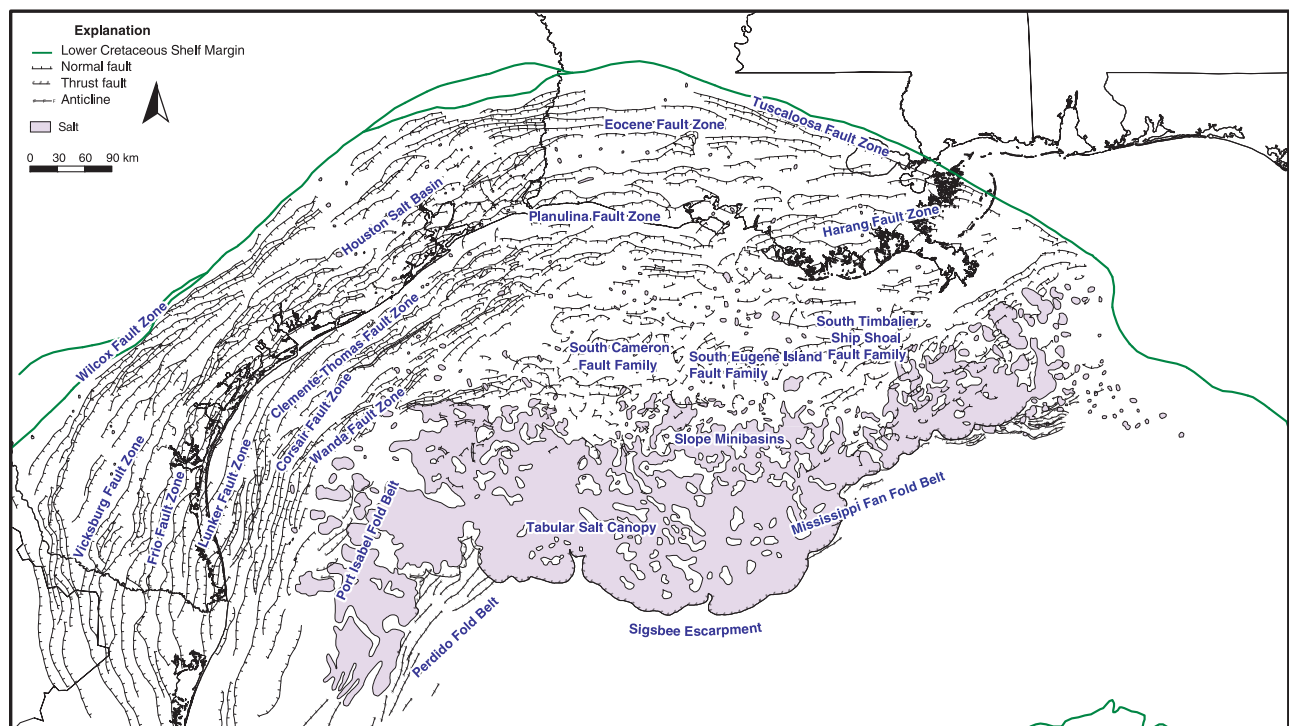


Figure 4 Structural features of the northern Gulf of Mexico. Compiled from Watkins et al. (1995) and numerous additional sources.

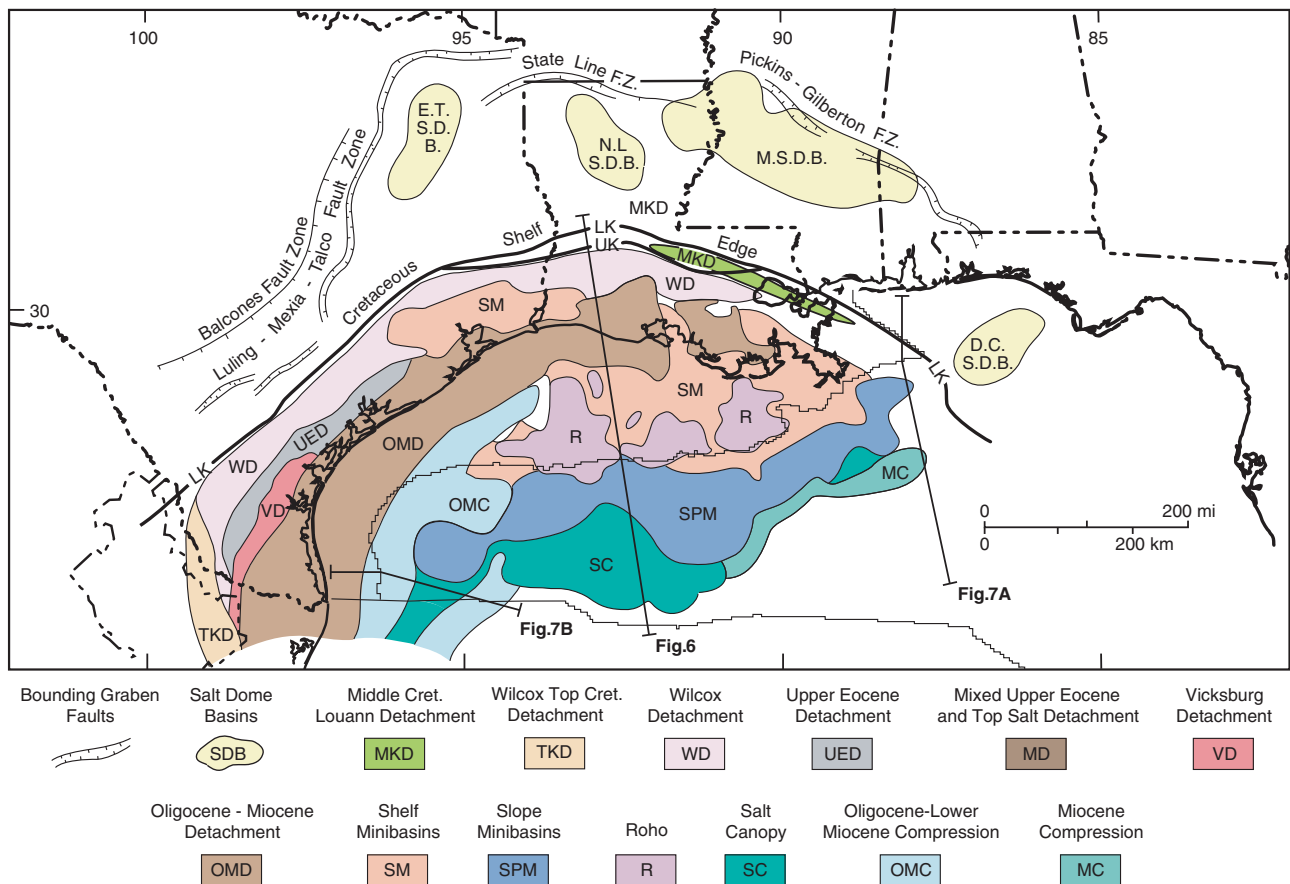


Figure 5 Structural domains of the northern Gulf of Mexico. Compiled from Ewing (1991), Diegel et al. (1995), and Karlo and Shoup (1998).

autochthonous Louann salt (Figure 5). Growth of structures within these inboard domains occurred largely in Mesozoic time.

The three-dimensional structural and stratigraphic architectures of the northern basin are illustrated by a regional N-S section across the north-central basin fill (Figure 6). The boundary between thick and thin transitional crust is reflected by a subsidence hinge that became the focus for development and stabilization of the Cretaceous continental shelf margin, most clearly marked by an extensive reef system. Basinward, the thick Cenozoic sedimentary prism overlies thin transitional crust, which has been depressed more than 16–20 km by sedimentary loading. The prism extends beneath the coastal plain and shelf, reaching its thickest point near the present continental margin. The continental slope extends basinward to about the position of the transitional/oceanic crust boundary. Beneath this sediment prism, most of the autochthonous Louann salt has been expelled, forming a primary salt weld on the basal Jurassic unconformity that is a principal decollement zone for growth faults.

Paleogene and Neogene deposits form an off-stepping series of sediment wedges. Paleocene through Miocene wedges are expanded and deformed by a succession of growth-fault families included within the Wilcox and mixed Upper Eocene and top salt detachment provinces. Cretaceous and Early Tertiary fault extension was accommodated by detachment at the Louann Salt; Oligocene — Recent extension typically detached on allochthonous salt canopies or in marine shales (Rowan et al., 2005). The off-stepping deposition acted as a giant rolling pin, pushing salt upward and basinward into three major salt canopies. The inboard canopy was loaded and largely evacuated by subsequent deposition, forming the vast central Gulf shelf minibasin and roho domains. Beneath the continental slope, a shallow salt canopy forms the slope minibasin and salt canopy domains, which terminate in the Sigsbee scarp. However, at the east end of the slope mini-basin province, salt rose directly from the autochthonous level. The base of the canopy rises through flat-lying basinal Cretaceous and Cenozoic strata to the final salt sheet, which is intruded into Pleistocene strata (Figure 6A).

Transects through the NE and NW Gulf margins (Figure 7) illustrate features of additional structural domains and general basin stratigraphy. In the NE Gulf (Figure 7A), the total basin fill is relatively thin, depressing the crust only to depths between 7 and 11 km. The crustal boundary again pins the location of the Mesozoic shelf margin,

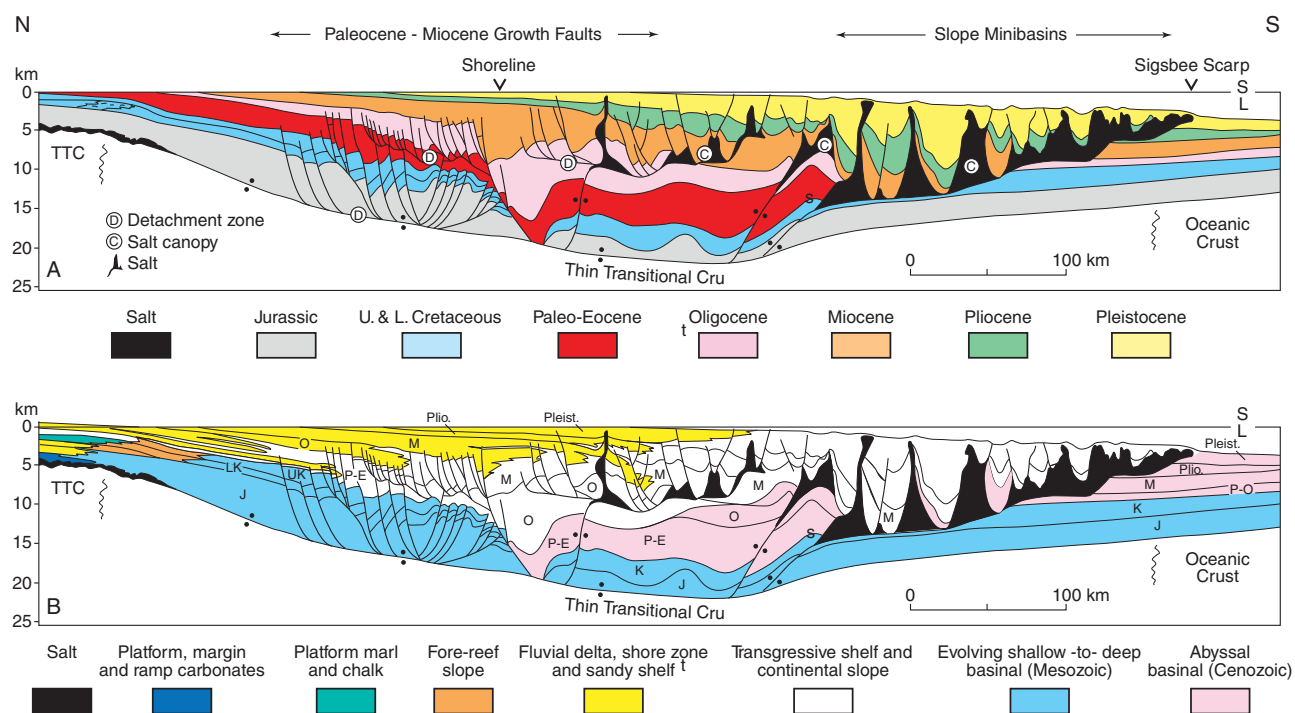


Figure 6 North-south (dip) cross-section of the northern Gulf of Mexico continental margin. (A) Crustal types, generalized stratigraphy, and structural elements including major salt canopies and detachment zones. (B) Principal facies associations (J, Jurassic; K, undifferentiated basinal Cretaceous; LK, Lower Cretaceous; UK, Upper Cretaceous; P-E, Paleocene–Eocene; O, Oligocene; M, Miocene; Plio., Pliocene; Pleist., Pleistocene). For location see Figure 5. Modified from Peel et al. (1995).

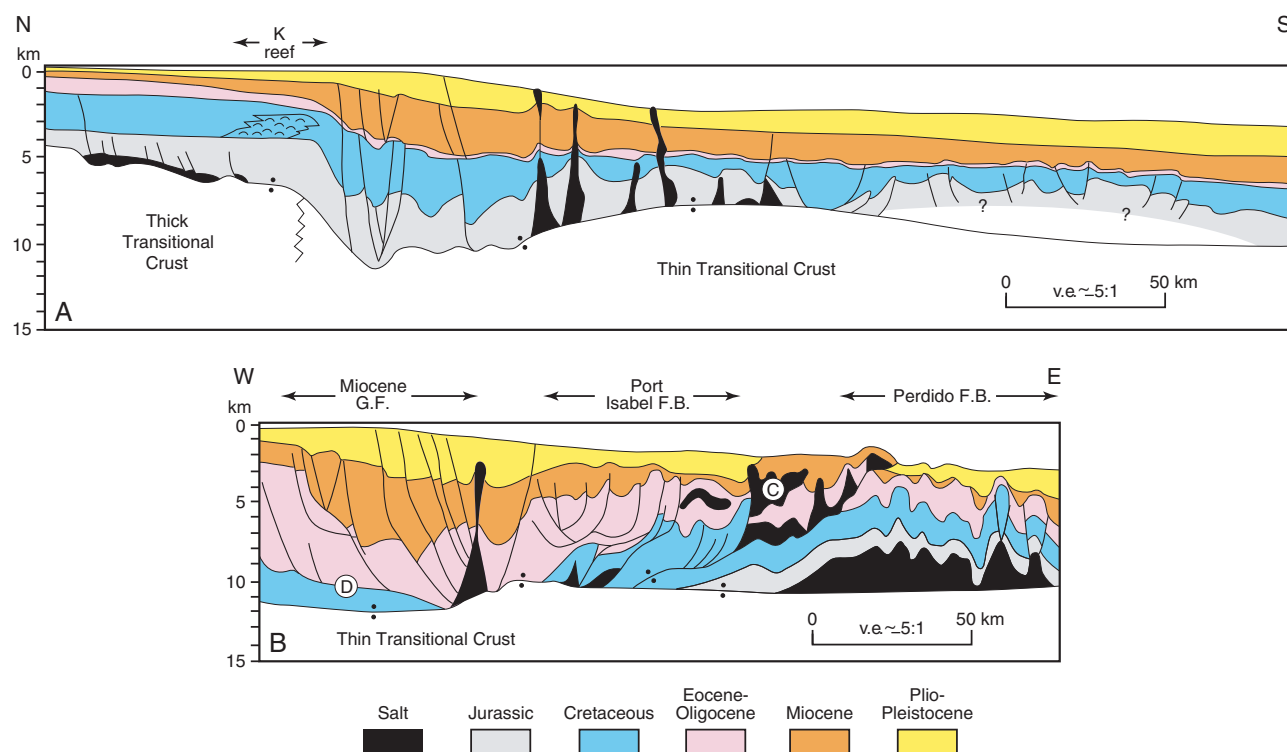


Figure 7 Dip cross-sections of the northeastern (A) and northwestern (B) Gulf of Mexico continental margins. For location see Figure 5. Modified from Peel et al. (1995).

which has been built further basinward only about 50 km by Neogene deposition. Growth faults are few. Limited salt stocks, which rise from the largely evacuated autochthonous Louann, define the eastern margin of the slope minibasin domain. However, the basinal toe of the section illustrates compressional features of the east end of the Miocene compression domain. The NW Gulf transect (Figure 7B) illustrates the structure of the basin depocenter located beneath the continental shelf and slope. The Oligocene–Miocene detachment province is rooted in a decollement located within deep basinal muds of indeterminate age. Basal Louann salt has been evacuated both upward as isolated stocks and basinward to the toe of the continental slope and beyond, leaving a primary weld. In contrast to the central and NE Gulf, the NW Gulf displays broad, complex Middle Cenozoic compressional domains, including the Perdido and Port Isabel fold belts. The Port Isabel fold belt is linked by a decollement to the Miocene Clemente–Thomas, Corsair, and Wanda fault zones of the Oligocene–Miocene detachment province (Figures 4 and 5) (Hall et al., 1998). Like the Mississippi fan fold belt, the Perdido fold belt is located at the depositional limit of basal Louann salt (Fiduk et al., 1995). Additional contraction was accommodated by the compound salt canopy that has been injected up into Oligocene and Miocene section.

3.4. Structural growth history

Backstripping of regional cross-sections (Figure 8) reveals the dynamic interplay between deposition, wholesale mass transfer of salt, development of growth structures, and outbuilding of the Gulf margin that has characterized the basin's history (Diegel et al., 1995; Peel et al., 1995; McBride, 1998). Late Jurassic accumulation of up to 4 km of Louann salt extended across the subsided thinned transitional crust. By the end of the Cretaceous, deposition had loaded and expelled much of the landward part of the autochthonous salt basinward, beneath the paleo-continental slope toe and northern basin floor (Figure 8B). Extension of the upper slope was accommodated by compressional deformation at the slope toe. A remnant layer of autochthonous salt provided the decollement horizon for basinward gravity spreading. By the end of the Oligocene (Figure 8C), successive pulses of Paleogene deposition had prograded the continental margin over the Cretaceous slope, deflating the thick salt under-layer by intrusion of salt stock canopy complexes under the advancing continental slope and further inflation of the abyssal salt sheet. The Oligocene Frio growth–fault zone migrated basinward with the prograding continental margin; here decollement occurred within Upper Eocene mud as well as in the deeper salt. The resultant continental slope was a mix of sediment and near-surface salt bodies. Miocene–Pliocene deposition loaded the salt canopies, triggering passive diapirism and further gravity spreading, creating roho fault systems and isolated salt stocks separated by welds (Figure 8D). Thick minibasin fills separate the salt stocks. Loading also initiated extrusion of a salt sheet at the toe of the slope. Pleistocene deposition has filled updip minibasins and built the continental slope onto the distal salt sheet, where incompletely filled minibasins dominate present slope topography (Figure 8E).

4. DEPOSITIONAL FRAMEWORK

The stratigraphic architecture of the northern Gulf of Mexico Basin displays many elements typical of divergent continental margins (Winker, 1982, 1984; Winker and Buffler, 1988). (1) Above a break-up unconformity, initial strata onlapped the subsiding basin margin. (2) Following this onlap phase, sediment supply overcame subsidence, and margin aggradation accompanied by offlap-dominated. A deep, sediment-starved basin center became separated from the marginal coastal plain and shelf by a clearly defined shelf edge and slope. (3) Further deposition created a succession of offlapping stratal units constructing a broad coastal plain and continental shelf. This nearly continuous depositional record, which covers more than 160 Ma of geologic time and continues today, produced a succession of regionally correlative stratigraphic units that are separated by major marine flooding horizons, sediment-starvation surfaces, and erosional unconformities.

4.1. Depositional episodes and sequences

Northern Gulf basin stratigraphic framework, chronology, and nomenclature were established during the early- to mid-20th century using conventional stratigraphic concepts. The thick, monotonous, siliciclastic Cenozoic section was subdivided using the fossiliferous marine shale tongues that record regional transgressions across the northern basin. This concept of transgression-bounded genetic units was formalized in a seminal paper by D.E. Frazier in 1974. Frazier argued that the Gulf Cenozoic fill recorded a succession of *depositional episodes*, each characterized by a foundation of progradational marine and coastal facies, overlain and replaced landward by

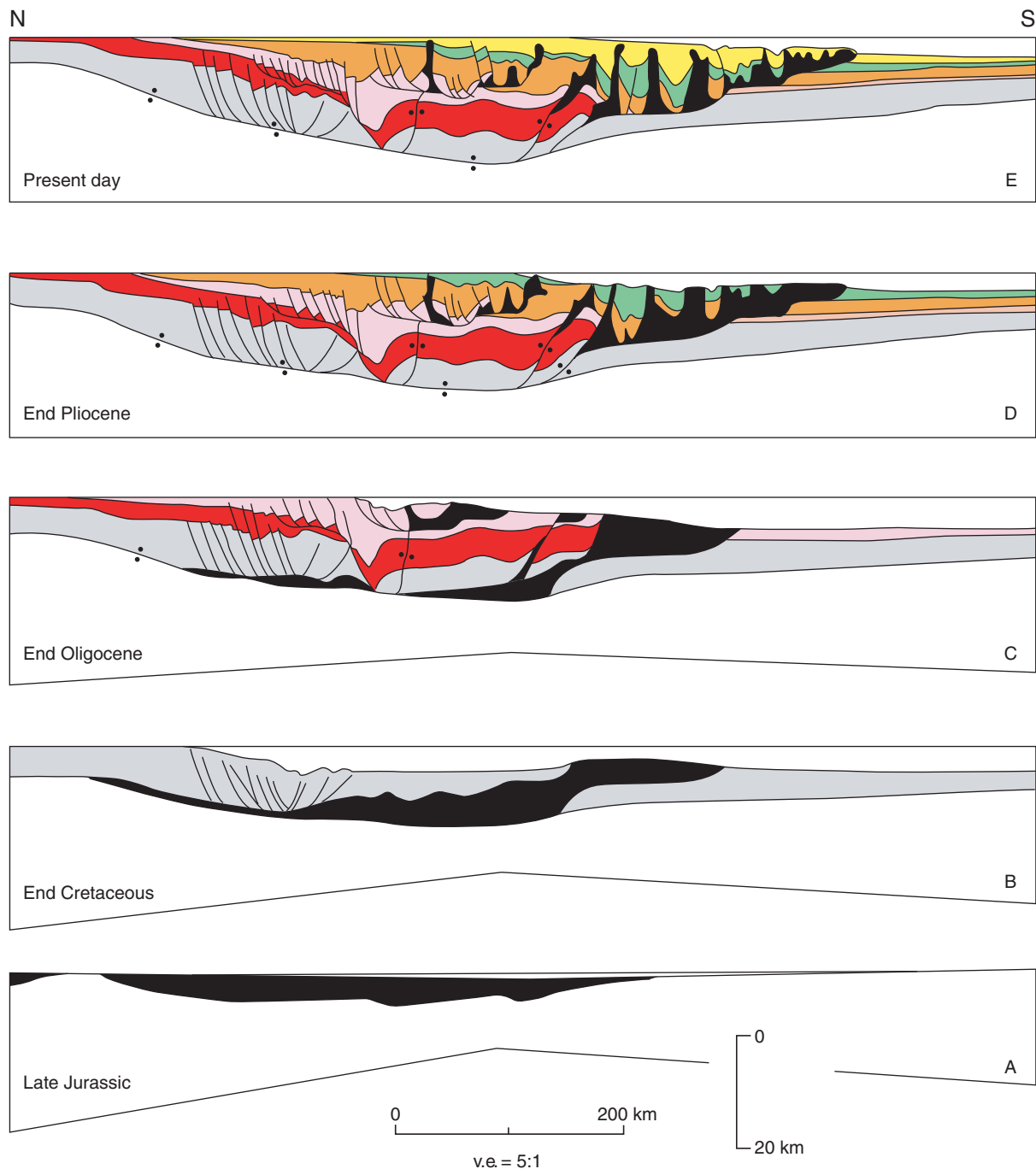


Figure 8 Reconstruction of the regional north-south cross-section of the Gulf continental margin showing evolution of salt canopies and fault complexes. Modified from Peel et al. (1995).

aggradational coastal plain and fluvial facies. Both facies successions were capped by a relatively thin succession of transgressive or back-stepping coastal and marine shelf facies. The “Frazierian” genetic unit is bounded basinward by submarine starvation surfaces (condensed beds) created during and soon after transgressive retreat of coastal depositional systems. If relative or eustatic sea-level fall further punctuates the history of a depositional episode, the genetic unit will contain an internal subaerial unconformity within its updip strata.

Using the Frazierian depositional model, Galloway (1989a) defined the *genetic stratigraphic sequence* as a fundamental unit of Gulf of Mexico Cenozoic stratigraphy. The genetic sequence consists of all strata deposited during an episode of sediment influx and depositional offlap of the basin margin. It is bounded by a family of surfaces of marine non-deposition and/or erosion created during transgression, generalized as the *maximum flooding surface*. This pattern is readily recognized in the Paleogene section, where transgressive marine shelf mudstone and glauconitic sandstone units extend to outcrop (Galloway, 1989b). It also applies in Neogene strata,

where prominent transgressive markers record glacioeustatic sea-level rise events (Galloway et al., 2000). Thus, genetic sequences typically correspond closely to widely used stratigraphic nomenclature.

The *depositional sequence* paradigm, which uses subaerial erosion surfaces as sequence boundaries, provides an alternative to the traditional Gulf basin lithostratigraphic framework and has been applied by several authors (e.g., Yurewicz et al., 1993; Mancini and Puckett, 1995; Lawless et al., 1997) especially to Late Neogene strata that are strongly influenced by glacioeustasy (Weimer et al., 1998; Roesink et al., 2004). Depositional sequence models for carbonate and mixed successions, which are appropriate for the Mesozoic Gulf fill, are summarized and illustrated by Handford and Loucks (1993).

The synthesis of Gulf depositional history and physical stratigraphy as presented here largely utilizes the traditional lithostratigraphic framework of the Mesozoic and Paleogene sections and the regional marine flooding horizons characterized by widely identified faunal markers within Neogene strata. Building upon the syntheses of Winker and Buffler (1988), Galloway (1989b), Morton and Ayers (1992), and Galloway et al. (2000), I propose a genetic stratigraphic framework that groups strata into a succession of 29 principal Gulf of Mexico depositional episodes (Figures 9–12). First and foremost, each episode records a long-term (ca. 2–12 Ma) cycle of sedimentary infilling, typically accompanied by shelf-margin offlap, of the northern Gulf basin. Deposits of each episode are characterized by lithologic composition (sandstone, mudstone, carbonate, evaporite), vertical stacking of lithofacies and parasequences, and relative stability of sediment dispersal systems and consequent paleogeography. Almost all of the depositional episodes terminated with a phase of deepening and/or basin-margin transgression (Figures 10 and 12). Deposits of episodes are bounded by prominent, widely recognized, and well-documented stratigraphic surfaces (Figures 10 and 12). Bounding surfaces variously include marine starvation and condensed horizons, maximum flooding surfaces, marine and subaerial erosional unconformities, and faunal gaps that are described and interpreted by multiple authors. Such depositional episodes conform to the basic definition of a sequence as a contiguous suite of genetically related strata bounded in part by unconformities. In fact, most of the Mesozoic depositional episodes described here correspond to seismic or depositional sequences identified by one or more authors (e.g., Yurewicz et al., 1993; Dobson and Buffler, 1997; Goldhammer and Johnson, 2000). They are widely recognized as fundamental stratigraphic building blocks of the basin fill. At the same time, a depositional episode framework is sufficiently flexible and robust to accommodate stratigraphic units that were variously dominated by tectonic deformation, sediment supply and composition histories, or eustatic sea-level change.

5. DEPOSITIONAL HISTORY AND PALEOGEOGRAPHY

The stratigraphy, depositional system framework, and paleogeographic evolution of the northern Gulf basin will be discussed in the context of the 29 depositional episodes. These episodes logically cluster into Bathonian–Berriasian (Middle–Late Jurassic and earliest Cretaceous), Early Cretaceous, Late Cretaceous, and Cenozoic families.

Each episode is recorded by a genetic sequence of strata that is constructed of the facies of a suite of carbonate and/or terrigenous clastic depositional systems. These systems, in turn, record geologically long-lived paleogeographic features that constituted the physical geography of the northern Gulf of Mexico. The depositional system classifications (Figure 13) follow those of Galloway and Hobday (1996) and Handford and Loucks (1993).

5.1. Middle Jurassic–Earliest Cretaceous (Bathonian–Berriasian) depositional episodes

The Upper Jurassic and lowest Cretaceous Louann, Norphlet, Smackover, and Cotton Valley episodes form a tectonostratigraphic megasequence bounded below by the break-up unconformity and above by a prominent intra-Valanginian unconformity, which records the termination of sea-floor spreading (Todd and Mitchum, 1977; Winker and Buffler, 1988; Wu et al., 1990; Salvador, 1991b; Dobson and Buffler, 1997; Marton and Buffler, 1999).

Initial breakup created a shallow Gulf basin with a connection to the Pacific Ocean across central Mexico. Widespread deposition of Louann salt and associated anhydrite blanketed subsiding transitional crust (Salvador, 1987, 1991a, 1991b; Dobson and Buffler, 1997). As much as 4 km of nearly pure halite, deposited over a span of almost 10 Ma, buried the underlying topography and overlapped northward onto the structural margin of the Gulf (Salvador, 1987) (Figure 2). Salt accumulation was replaced, in the Oxfordian, by deposition of a relatively thin, widespread siliciclastic-dominated sequence that is best known around the northern and northwestern Gulf margin as the Norphlet Formation. The boundary between the Louann and Norphlet sequences is poorly

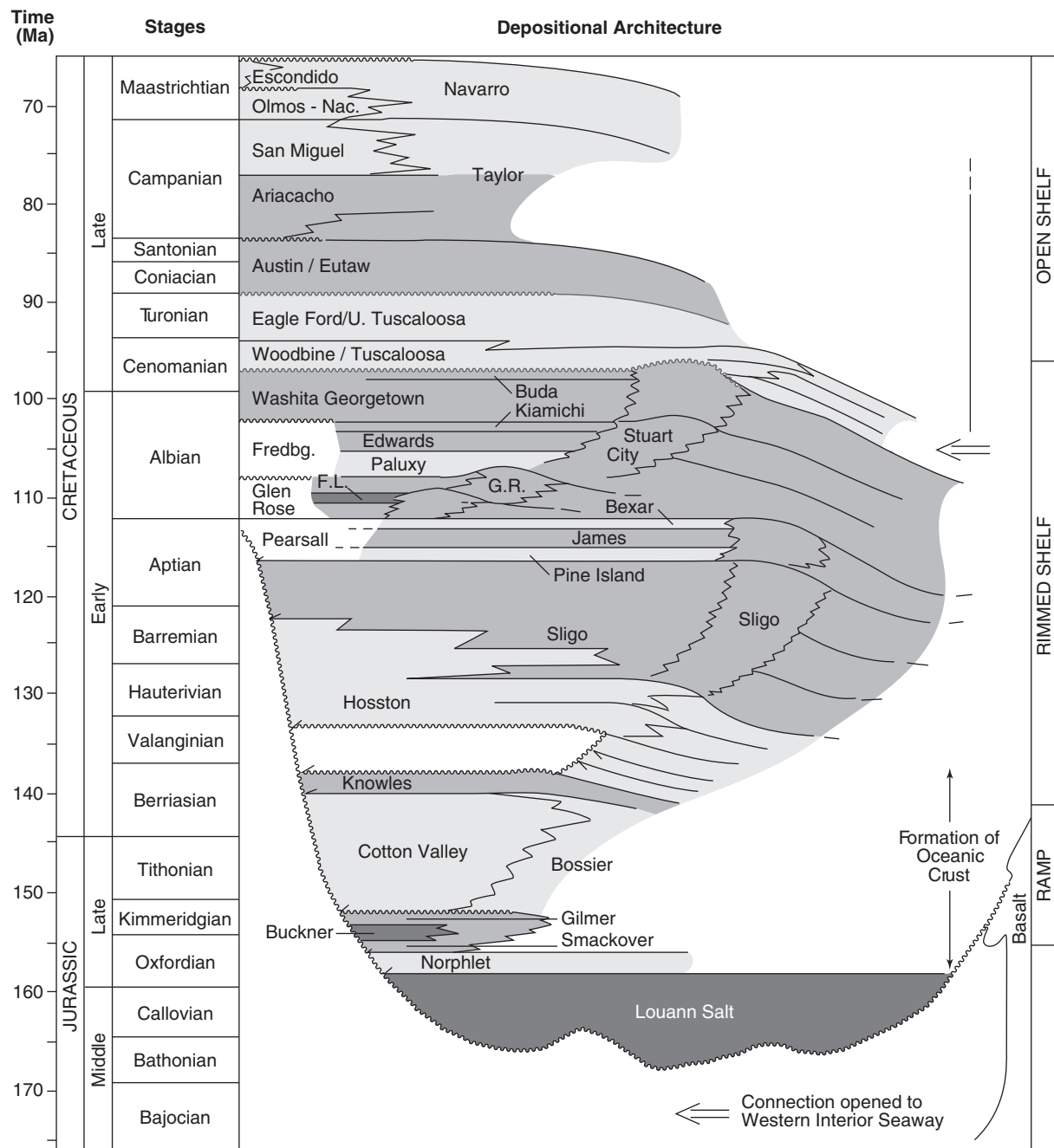


Figure 9 Generalized Mesozoic stratigraphic succession and architecture of the Northern Gulf of Mexico basin. Time scale of Berggren et al. (1995). Modified from Winker and Buffler (1988).

defined; deposition may have been continuous or disconformable (Salvador, 1991a). In either case, the Norphlet deposits further onlapped the break-up unconformity, especially in the structural embayments of the northeast Gulf margin. There, several small alluvial fan, braidplain, and delta systems created local depocenters up to 300 m thick. Eolian, sabkha, and playa deposits are also abundant, indicating continued aridity. Basinward, siliciclastics grade into marine shale and limestone. Although I have differentiated the Louann and Norphlet as two episodes, based on the prominent lithologic change and evidence of a pulse of clastic input, the Norphlet might alternatively be considered the transgressive cap of a single, evaporite-dominated Louann sequence (Goldhammer and Johnson, 2000).

Continued Oxfordian transgression onto the stable basin margin initiated the first carbonate-dominated depositional episode of the Gulf. Together, the Smackover, Buckner, and Gilmer Formations record a ca. 5 Ma cycle generally bounded above and below by transgressive flooding surfaces (Salvador, 1991b; Prather, 1992; Dobson and Buffler, 1997; Goldhammer and Johnson, 2000; Mancini and Puckett, 2005) (Figure 9). Initial

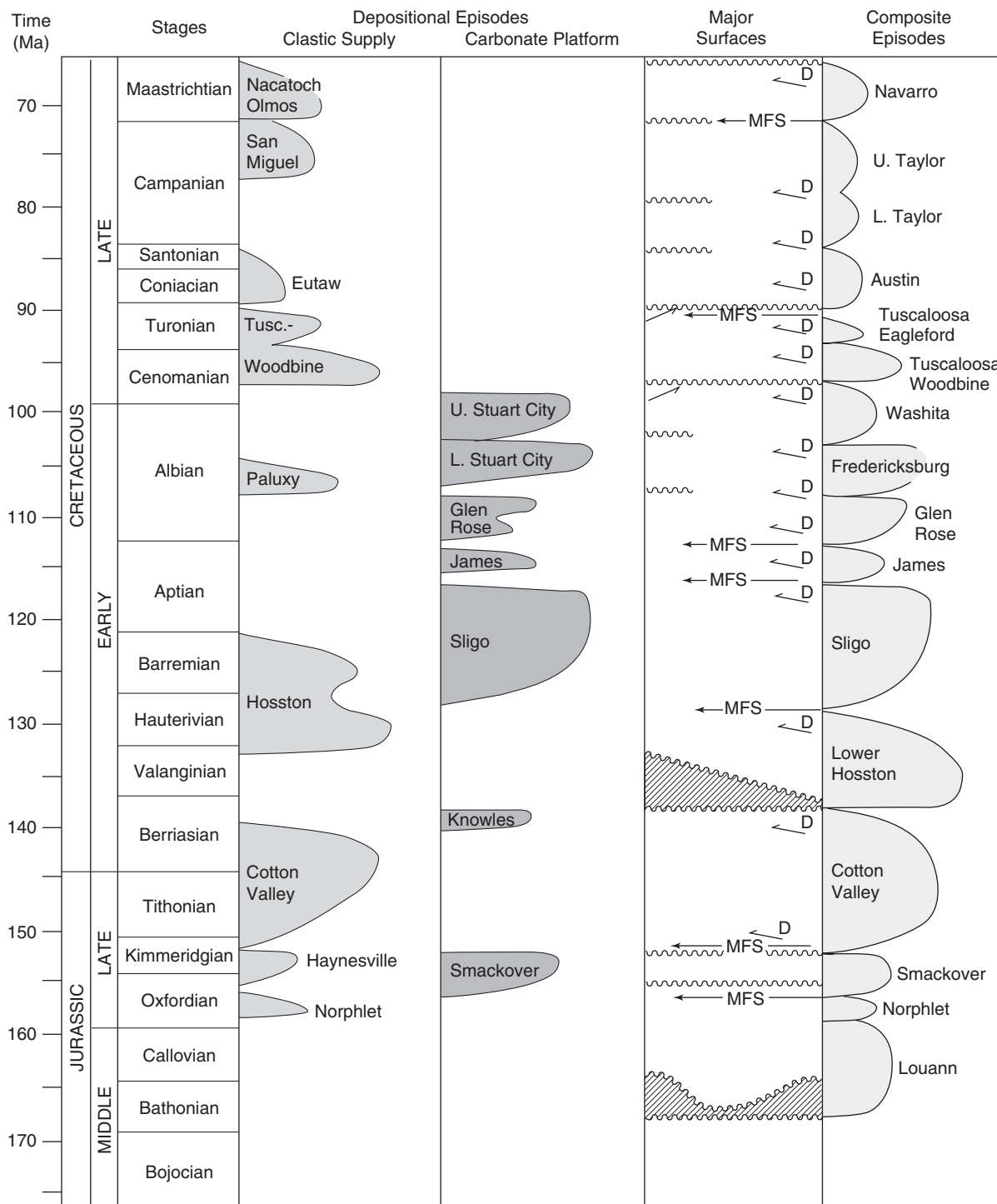


Figure 10 Mesozoic depositional episodes as reflected by major phases of siliciclastic and carbonate sediment accumulation in the northern Gulf basin. Major stratigraphic surfaces include basin-margin unconformities, deepening events (D) and associated ravinement, and maximum flooding disconformities (MFS). Composite episodes reflect regionally concordant stratigraphic units bounded by major surfaces and a relatively stable paleogeography.

deposits consisted of fine-grained, dark, carbonate ramp sediments, which were succeeded by a heterogeneous assemblage of carbonates, including prominent ramp-edge grain shoals. These banks aggraded and coalesced to form a broad shoal system around the northwest and west-central Gulf (Figure 14) (Budd and Loucks, 1981; Moore, 1984). In the northeastern Gulf, grain shoals formed around the emergent basement arches. In mid-episode, evaporites of the Buckner Formation accumulated on the shoal-restricted, shallow inner platform. Seaward, carbonate muds formed a broad carbonate ramp, or, to the east, a nascent carbonate slope. Clastic influx was minor. Small delta and flanking shore-zone systems (the Haynesville Formation) prograded onto the

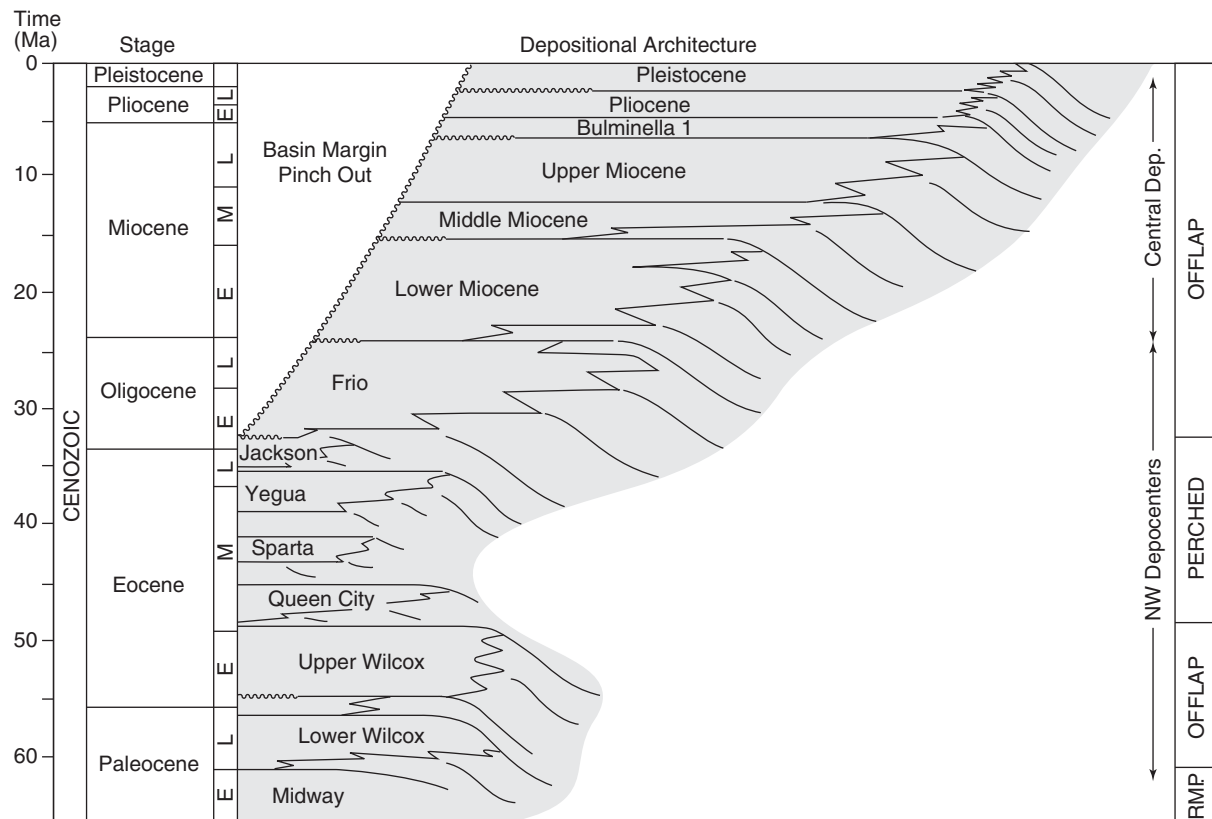


Figure 11 Generalized Cenozoic stratigraphic succession and architecture of the Northern Gulf of Mexico basin. Time scale of Gradstein et al. (1995).

northeastern Gulf margin. The episode ended with terminal flooding and deposition of the transgressive Gilmer Limestone. The pulse of clastic sediment input along the northeastern Gulf margin (Figure 10), which coincided with the later part of the episode, limited transgressive Gilmer carbonate deposition to the outer ramp and basin.

Sandstones of the Cotton Valley depositional episode (Figures 9 and 10) abruptly overrode the transgressive Gilmer and Haynesville strata (Salvador, 1991b; Prather, 1992; Dobson and Buffler, 1997; Goldhammer and Johnson, 2000; Klein and Chaivre, 2002). Locally, patterns of reflection and stratal terminations suggest the presence of a disconformity associated with transgression or maximum flooding or clastic burial of the Smackover ramp. The dramatic change from carbonate-dominated to siliciclastic-dominated deposition across the entire northern Gulf basin indicates that continental uplift or climate change rejuvenated adjacent North American source areas. Large, sandy delta systems prograded from major fluvial axes centered in the East Texas basin, Mississippi salt basin, and Apalachicola embayment. Suspended sediment spread basinward to form a broad, muddy, marine shelf platform that built basinward beyond its older Jurassic foundations. As deposition progressed, a distinct shelf/slope break emerged. On this platform, marine reworking connected the delta systems with sandy shore-zone and shelf systems. This major episode of clastic input and progradation lasted more than 10 Ma, and deposited more than 300 m of sediment around much of the northern Gulf. It terminated with a relatively brief phase of carbonate accumulation, creating the back-stepping Knowles Limestone (Figure 9). This carbonate blanket marks the terminal transgression of a clastic-dominated episode; together, the Cotton Valley and Knowles form a major transgression-bounded sequence.

Although the Cotton Valley depositional episode ended with the conventional record of transgression, its deposits are separated from strata of the overlying Lower Cretaceous Hosston episode by a singularly prominent unconformity throughout the northern Gulf divergent margin (Salvador, 1991b; Goldhammer and Johnson, 2000) (Figure 10). Updip, this unconformity records the entire Valanginian (about 5 Ma); basinward, until strata become concordant beyond the Cotton Valley progradational margin. Here, Valanginian strata form a fore-shelf lowstand wedge (Figure 9). The unconformity records subaerial exposure and erosion, which clearly reflect progressive uplift and basinward tilting of the northern Gulf margin. Coincidence of the unconformity with termination of sea-floor spreading in the Gulf and its medial location within a 25 Ma phase of coarse clastic sedimentary influx to the northern basin indicate that it is a direct consequence of intraplate stress regime changes

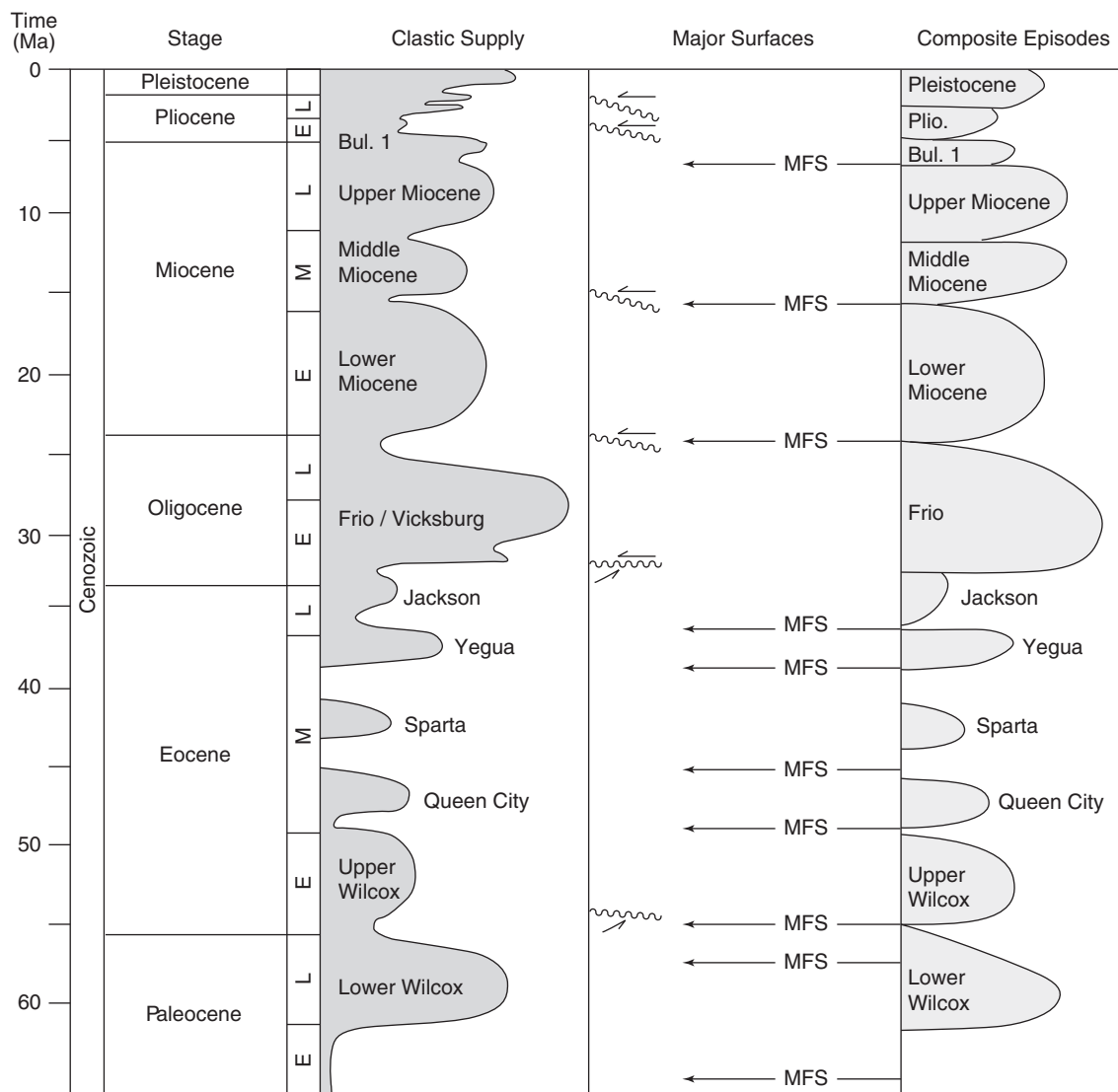


Figure 12 Cenozoic depositional episodes as reflected by major phases of siliciclastic sediment accumulation in the northern Gulf basin. Major stratigraphic surfaces include basin-margin unconformities and maximum flooding disconformities. Composite episodes reflect regionally concordant stratigraphic units bounded by major surfaces and a relatively stable paleogeography. Neogene episodes incorporate multiple glacioeustatic cycles and their resultant high-frequency sequences.

and resultant deformation of the North American plate. Together with the sub-salt unconformity, the Valanginian unconformity bounds the syn-drift strata of the early Gulf.

5.2. Early Cretaceous (Valanginian–Cenomanian) depositional episodes

Following termination of Gulf spreading, a succession of six composite depositional episodes (Figure 10, Lower Hosston–Washita) provides a record of diminishing continental source area relief and basin-margin stabilization (Winker and Buffler, 1988; McFarlan and Menes, 1991; Scott, 1993; Yurewicz et al., 1993; Marton and Buffler, 1999; Goldhammer and Johnson, 2000; Kerans and Loucks, 2002; Badali', 2002; Mancini and Puckett, 2005). The climatic setting remained tropical and arid. Clastic input decreased and carbonate deposition came to dominate the northern GOM (Figure 9). Two phases of regional progradation of the reef-rimmed carbonate margin, separated by a regional Early Albian flooding event (Figure 9), produced a well-defined shelf edge separating open to restricted, shallow platform depositional systems from steep slope and deep basinal equivalents. Following this distinctive phase of Early Cretaceous deposition, which lasted for nearly 40 Ma, the intra-Cenomanian unconformity and subsequent resurgent clastic deposition marked a basin-scale reorganization of regional depositional patterns. Continental uplift and erosion that supplied clastics was focused on the Mississippi embayment and has been associated with subcrustal passage of the Bermuda hotspot (Cox and Van Arsdale, 2002).

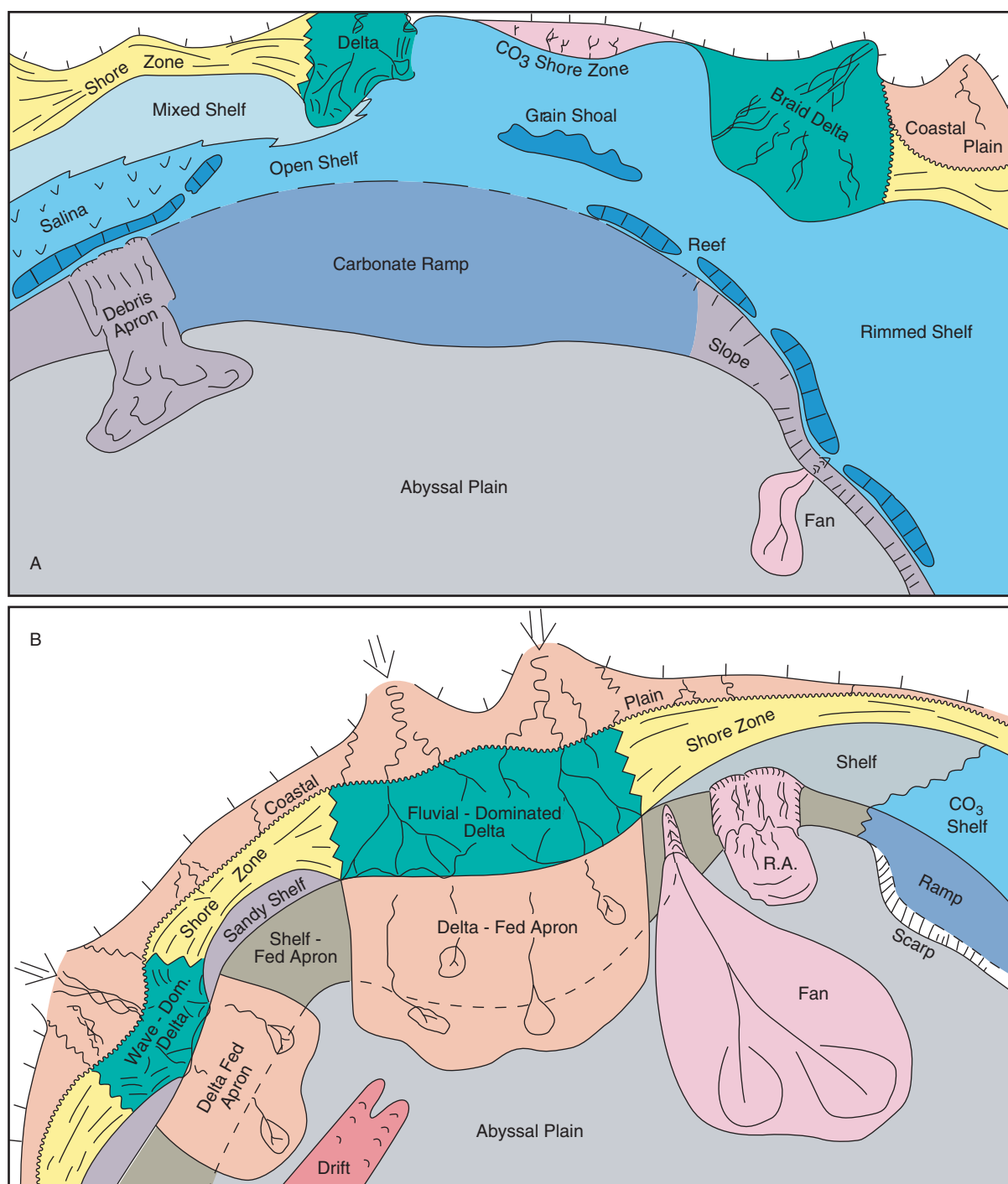


Figure 13 Generalized paleogeographies of (A) carbonate-dominated and (B) siliciclastic-dominated episodes of deposition within the northern Gulf of Mexico. Principal depositional systems are distinguished using this format on the following paleogeographic maps.

Clastic sediment supply continued to dominate Valanginian and Hauterivian deposition. The conglomeratic, sandy Hosston (eastern Gulf margin) and Travis Peak (Texas) formations record this siliciclastic influx. Hosston stratigraphy is complex, however, and displays three depositional styles. Basal Hosston deposits form a shelf-margin prograding wedge that records coastal plain and shelf bypass during formation of the Valanginian unconformity (Yurewicz et al., 1993). Beginning in Late Valanginian, Lower Hosston strata were buried as subsidence of the basin margin and northward expansion of the Gulf basin resumed (Figure 9). During the Hauterivian, Hosston strata onlapped the northern Gulf margin, aggraded the shelf, and prograded the shelf edge basinward of the lowstand wedge. In the Late Hauterivian, deepening and transgressive flooding interrupted depositional offlap. Together, the lowstand wedge and overlying aggradational and progradational Lower Hosston

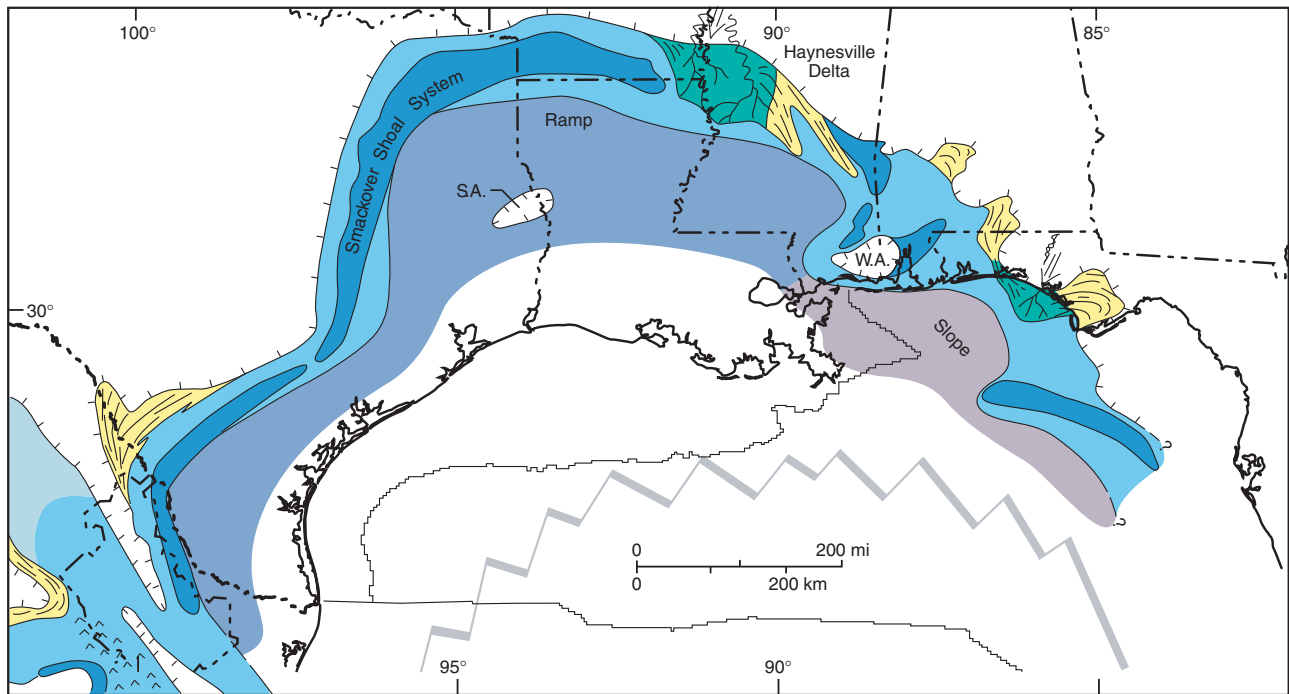


Figure 14 Paleogeography and principal depositional systems of the Upper Jurassic Smackover depositional episode. Depositional elements reflect lower Smackover facies distribution.

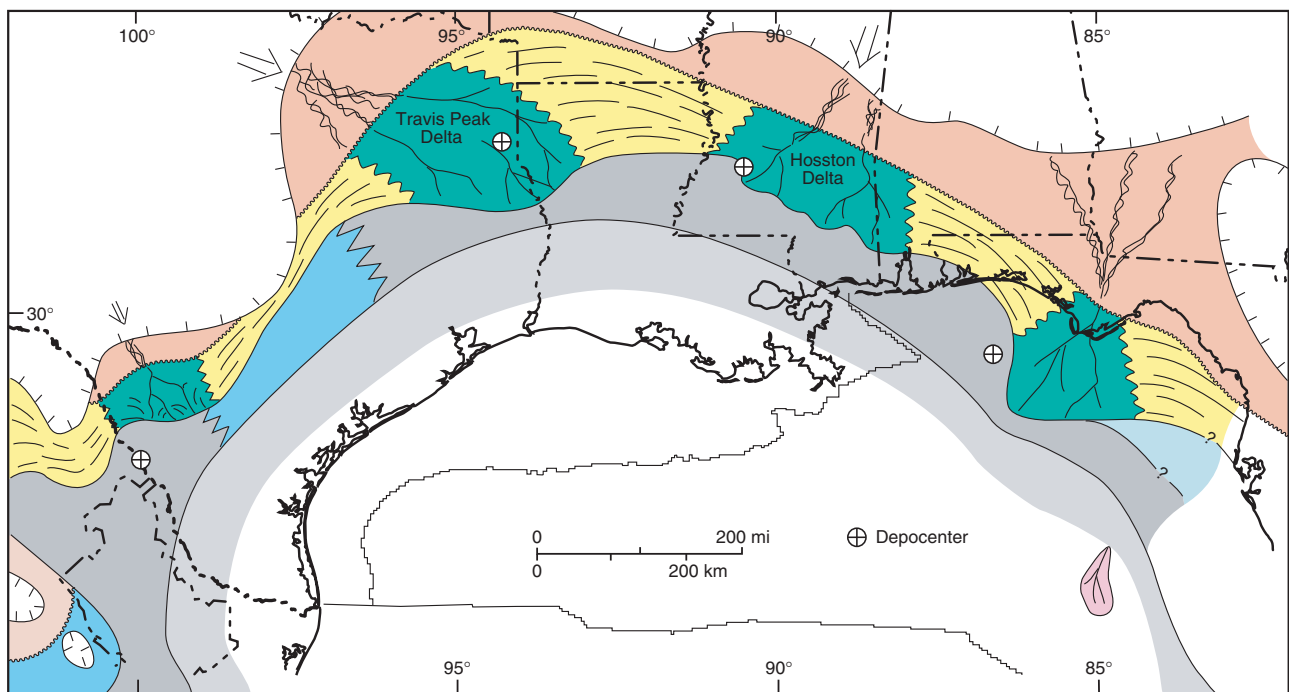


Figure 15 Paleogeography and principal depositional systems of the Lower Cretaceous Lower Hosston depositional episode.

deposits form a compound depositional episode that was initiated by tectonically forced regression and terminated by transgression and onset of carbonate deposition on the outer shelf (Figure 10).

Four deltaic depocenters—dominated Lower Hosston accumulation (Figure 15) (McGowen and Harris, 1984; Dutton, 1987; McFarlan and Menes, 1991). Source areas located to the northeast and northwest coalesced into four sandy bedload fluvial systems that prograded marine-modified braidplains and deltas into the Apalachicola embayment, Mississippi salt basin (Hosston delta), East Texas basin (Travis Peak delta), and Rio Grande embayment. Extensive wave reworking of sandy delta fronts nourished a series of interdeltaic strandplain and

barrier/lagoon systems and associated shallow sandy shelves. Suspended sediment spread from deltas to form a muddy, prograding outer shelf and slope across the northern Gulf. Only the interdeltic shelf above the San Marcos arch, in central Texas, was carbonate-dominated.

Following Late Hauterivian flooding, a mixed carbonate/clastic depositional episode inaugurated the reef-rimmed carbonate margin progradation that is the hallmark of the Lower Cretaceous GOM section (Kauffman and Johnson, 1997). Landward, siliciclastic Upper Hosston deposition continued, but progressively decreased in geographic extent through the Barremian (McGowen and Harris, 1984; Bebout et al., 1981, McFarlan and Menes, 1991). At the same time, carbonate-forming open platform, reef, and grain shoal systems of the Sligo Formation expanded landward across the outer shelf and created a well-organized shelf-margin reef system that stretched from northern Mexico to the southern Florida platform (Bebout, 1977). Coral-like rudistids built these and later Lower Cretaceous reefs and banks. After modest progradation, the barrier reef-rimmed shelf margin stabilized and aggraded along a narrow belt located above the boundary between thin and thick transitional crust. This shelf margin, which persisted until the Early Cenozoic, reflects a hinge line between the two crustal subsidence domains (Sawyer et al., 1991). By Early Aptian, the carbonate environments extended to the depositional limits of the basin, reducing clastic facies to a thin, undifferentiated muddy “ring” around the basin fringe. The shallow northern Gulf shelf formed a broad, open carbonate platform upon which local rudistid banks and grain shoals accumulated (Bebout and Loucks, 1974; Bebout et al., 1981). Shoals, patch reefs, and banks are particularly abundant over residual basement highs, such as the Sabine and San Marcos arches.

After nearly 10 Ma of carbonate platform growth and consolidation, abrupt Aptian deepening terminated the Sligo depositional episode (Figure 10). The northern Gulf shelf was blanketed by the thin, widespread Pine Island Shale (Figure 9). Temporary shoaling and rejuvenation of carbonate-forming environments resulted in a brief (1–2 Ma) episode of carbonate platform and margin deposition, forming the James Limestone (Figure 9). A second, more extensive drowning event is recorded by the Bexar Shale and terminated the James depositional episode. The shales, thin sandstones, and limestones of the James depositional episode are characteristically dark and fine-grained. Together, the Pine Island–James–Bexar interval, which form the Pearsall Group of the Texas Gulf margin, constitute a punctuated, retrogradational stratigraphic systems tract that culminated with a basin-wide flooding surface. Following this flooding, the rimmed margin that was initially re-established by Albian depositional episodes was displaced far landward of the underlying Sligo shelf edge around much of the northern Gulf (Figure 9).

Shelf drowning was followed by slow reestablishment of regional carbonate platform and barrier reef systems — the Stuart City reef — that are defining features of the Mid-Cretaceous Gulf basin. Reef progradation and aggradation reconstructed the Cretaceous shelf edge into a nearly continuous barrier rim extending from Mexico to south Florida. Rudistids continued as principal bank and reef builders, forming the barrier reef as well as platform patch reef and bank complexes (Bebout and Loucks, 1974; Scott, 1990; Kauffman and Johnson, 1997). Corals, encrusting algae, and stromatoporoids contributed to reef construction. Bathymetric contrast between the shallow carbonate platform and the deep central Gulf likely approached its maximum. Winker and Buffler (1988) calculated probable central Gulf water depths above oceanic crust of between 4.2 and 4.7 km, deeper than the modern Gulf abyssal plain.

Three deepening events and one episode of clastic sediment input punctuated the ca. 12-Ma growth of the Albian rimmed platform, creating three depositional episodes named for the outcropping Glen Rose, Fredericksburg, and Washita groups that compose them (Figure 9). Basal beds of the Glen Rose depositional episode onlap underlying strata (Yurewicz et al., 1993), suggesting a local disconformity. Strata of the Glen Rose episode are characterized by sandy to argillaceous, oolitic and bioclastic lime mudstone, packstone, and grainstone. Contained within the middle of the Glen Rose limestones are evaporites and dolomites of the Ferry Lake Anhydrite, which accumulated in an internal lowland salina behind the barrier reef. Detailed facies analysis of the Glen Rose in the NW Gulf margin indicates an internal flooding surface that might be used to further subdivide it into upper and lower episodes (Kerans and Loucks, 2002).

Terminal deepening followed by an updip unconformity, shoaling, and resurgent clastic influx onto the inner shelf separate the Glen Rose from the overlying Fredericksburg depositional episode. The Fredericksburg genetic sequence consists of three principal lithostratigraphic components. The Paluxy (Texas) and Danzler (Mississippi and Alabama) Formations record depositional progradation of deltas and flanking shore-zone systems onto the inner- to middle shelf of the East Texas basin and northeastern Gulf early in the episode (Figure 16) (Caughey, 1977; McFarlan and Menes, 1991). Shelf limestone and dolomite of the Edwards Group and its equivalents accumulated throughout the episode on the outer shelf and transgressed landward over Paluxy inner-shelf, deltaic, and shore-zone systems late in the episode. As clastic bypass to the slope decreased and carbonate systems dominated shelf margin and slope sedimentation, the declivity and relief of the continental slope increased to angles exceeding 10° (Corso et al., 1989). The resultant high-relief, steeply bounded carbonate margin around the northern Gulf set the stage for later development of the prominent Mid-Cretaceous stratigraphic discontinuity.

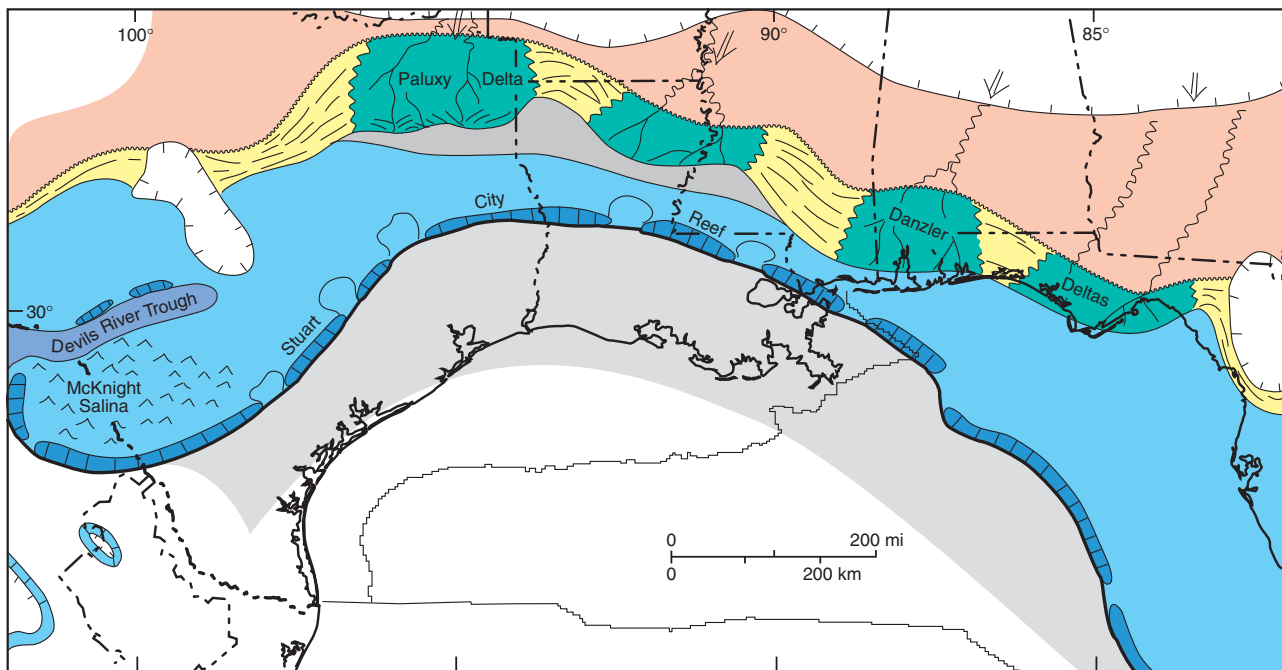


Figure 16 Paleogeography and principal depositional systems of the Lower Cretaceous Fredericksburg depositional episode.

Throughout the episode, low-relief reefs flourished along the shelf margin, forming the widely recognized Stuart City reef (Figure 16) (Bebout and Loucks, 1974; Scott, 1990). Above the San Marcos arch and in the northeast Gulf, the Stuart City aggraded on the foundation of the Sligo shelf-margin reef. The reefal shelf margin prograded across the central Gulf, regaining and aggrading the older Sligo margin, except along the segment lying south of the East Texas basin and Sabine arch where the Stuart City reef remained a few tens of kilometers landward of the underlying Sligo reef. At the Rio Grande embayment, the Stuart City reef axis diverted westward, across the embayment, and then inland around the Maverick Basin (a subsiding intrashelf basin), forming the Devil's River trough (Winker and Buffler, 1988). Here, the reef sufficiently restricted the shelf to form the extensive McKnight salina by Late Fredericksburg deposition (Figure 16). Exact configuration of the Maverick basin changed through the episode, and paleogeographic reconstructions by various authors commonly differ in detail.

Fredericksburg episode deposition terminated with widespread accumulation of dark, calcareous claystone and interbedded lime mudstone of the Kiamichi Formation and its equivalents (Figure 9). The Kiamichi lithologies indicate regional deepening of the northern Gulf shelf. Concomitantly, epeirogenic uplift and tilting of the landward basin margin created a minor unconformity at the base of overlying Washita strata.

During the Middle Albian, global sea-level rise and ongoing subsidence and northwestward expansion of the Gulf of Mexico combined to open a connection to the Western Interior seaway. It is appealing to suggest that this connection reorganized or diverted continental drainage systems, greatly reducing or terminating sand supply to the northwestern Gulf and leading to the widespread expansion of clean Edwards Group carbonate deposition onto the rapidly shrinking Paluxy coastal plain within the Fredericksburg episode. Clastics continued to be derived by basin-margin streams, but local source areas were of limited area and low relief in the northwestern Gulf. However, in the northern Gulf, deltaic and shore-zone systems fed by streams arising in the eastern uplands continued to accumulate sand and mud throughout the Fredericksburg episode.

The Washita depositional episode bridged the Early to Late Cretaceous boundary; however, its depositional style remained that of the Early Cretaceous. The episode was characterized by climax, aggradational growth of the Stuart City reef. On the northern Gulf platform, widespread accumulation of shallow shelf lime mud, bioclastic sand, marl, and calcareous mud-dominated. Although clastic influx in the northwest Gulf was substantial, it was limited to fine, suspended load that was dispersed widely across the shallow marine shelf. Latest deposits of the episode are dominantly marine to restricted marine shale, again recording partial drowning of the carbonate platform and diminished carbonate formation within deeper embayments.

The episode terminated with the formation of one of the major discontinuities in the Mesozoic record of the Gulf, the Mid-Cretaceous unconformity, or MCU, which is widely used as a practical boundary between Early and Late Cretaceous rocks in the basin. The Mid-Cretaceous unconformity records a profound break in the

depositional architecture of the northern Gulf of Mexico (Wu et al., 1990; Buffler, 1991). The broad carbonate-dominated shelf was replaced by alluvial, deltaic, and coastal depositional systems. The reefal Lower Cretaceous shelf margin, which had persisted for nearly 14 Ma, was abandoned and regionally overstepped by clastic progradation. Subsequently, Upper Cretaceous strata blanketed the relict shelf edge, subduing its morphology and creating a ramp-like inflection across the buried reef complex. The depocenter shifted from the shelf margin and basement-controlled basins and embayments to the fore-shelf continental slope. Along the Florida and western Gulf continental slopes, scours and channel cuts record onset of active submarine erosion.

The MCU has been widely attributed to the Mid-Cenomanian sea-level fall of the Haq chart (Buffler, 1991; Yurewicz et al., 1993). However, several attributes of the MCU indicate that global sea-level change was at best a minor factor in its formation. (1) Uplift and tilting of the San Marcos arch, Sabine uplift, and Monroe uplift removed much of the Lower Cretaceous section. Subaerial erosion cut as deeply as the Upper Jurassic Cotton Valley sandstones in northeast Louisiana, indicating uplift of as much as several hundred meters. Angular discordance across the MCU clearly demonstrates the role of tectonic uplift in its origin. Changes in crustal stress regime, likely associated with changing rates of Pacific and North American plate convergence and the Sevier orogeny of the western United States may explain the basin flank deformation (Laubach and Jackson, 1990; Cao et al., 1993). (2) Uplift was coincident with and closely followed by a nearly 8 Ma influx of sandy sediments from fluvial systems draining eastern continental uplands. Clearly uplift and erosion rejuvenated or created new upland sources. Timing and location of post-MCU clastic depocenters is consistent with interpreted uplift of the eastern interior, beneath what is now the Mississippi embayment, which parallels the modern Mississippi Valley, due to passage of the Bermuda hotspot beneath thinned Paleozoic crust (Cox and Van Arsdale, 2002). (3) The MCU can be traced down the bounding continental slopes where it records a variable period of sediment starvation and separates Early Cretaceous basinal carbonates from Late Cretaceous or Cenozoic basinal mudstone (Buffler, 1991). However, its interpreted correlation as a prominent reflection horizon beneath the Gulf floor (Buffler, 1991) has been disproven by recent deep-water drilling (Dohmen, 2002). (4) The stratigraphic context shows that the shallow water carbonate factory was progressively drowned by the shelf deepening, as recorded in the uppermost Washita episode, then poisoned as clastics from rejuvenated fluvial systems poured onto the northern shelf. The MCU is thus an excellent example of a drowning unconformity (Schlager and Camber, 1986; Wu et al., 1990). As regressive clastic systems prograded over the dying Stuart City reef, sedimentary bypass and slumping created onlap relations between the clastic and carbonate slope wedges. Unlike a short-term sea-level fall, differential tectonic uplift of the basin margin, creation of a new upland source area, and tilting subsidence of the outer shelf and shelf margin readily explain concomitant subaerial erosion, long-term rejuvenation of clastic influx, carbonate suppression, and a permanent change in basin-wide depositional style across a composite unconformity surface.

5.3. Late Cretaceous (Cenomanian–Maastrichtian) depositional episodes

The Late Cretaceous, above the MCU, contains at least six depositional episodes (Figure 10) (Winker and Buffler, 1988; Wu et al., 1990; Sohl et al., 1991; Mancini and Puckett, 1995; Goldhammer and Johnson, 2000; Liu, 2004). Additional known deepening or transgressive events might be used to further subdivide the section. However, six bounding transgressions associated with regional flooding surfaces or basin-margin disconformities differentiate six clastic supply episodes.

The Tuscaloosa/Woodbine composite depositional episode consists of the Lower and Upper Tuscaloosa episodes of the Louisiana margin and the Woodbine and Eagle Ford episodes of the Texas margin. It records major progradational deltaic systems that built along the Mississippi embayment and into the East Texas basin (Figure 17). Ongoing uplift of the Sabine arch separated the two clastic depocenters and dispersal systems. The larger of the two fluvial/deltaic axes deposited the Tuscaloosa Formation. The Tuscaloosa fluvial/deltaic system was rapidly forced across the shelf and spilled over the abandoned Stuart City reef, to create a prograding shelf-margin wedge of delta and delta-fed slope apron sandstone and mudstone (Mancini et al., 1987). The prograding deltas constructed a new shelf edge slightly seaward of the foundered reef. Offlap of the clastic wedge, which was more than 1-km thick, onto the steep carbonate slope initiated the first of the many growth-fault families of the northern Gulf (Figure 4). Tuscaloosa regression was interrupted by transgression, creating lower fluvial/deltaic and upper deltaic sandstone units separated by the “marine Tuscaloosa”. Through later Cenomanian, Tuscaloosa deltas backstepped as the thermal uplift began to collapse and sediment supply decreased.

To the west, the Woodbine fluvial/deltaic system remained largely on the shelf (Figure 17). The delta, which was wave-dominated, prograded to the southwest into the East Texas basin (Oliver, 1971; Turner and Conger, 1984). However, distal suspended mud spread across the Cretaceous reef and built a muddy shelf margin that merges with the Tuscaloosa deltaic wedge south of the Sabine arch. The Woodbine sediment dispersal system records a single clastic pulse that was, however, complicated by ongoing uplift and subaerial exposure of the

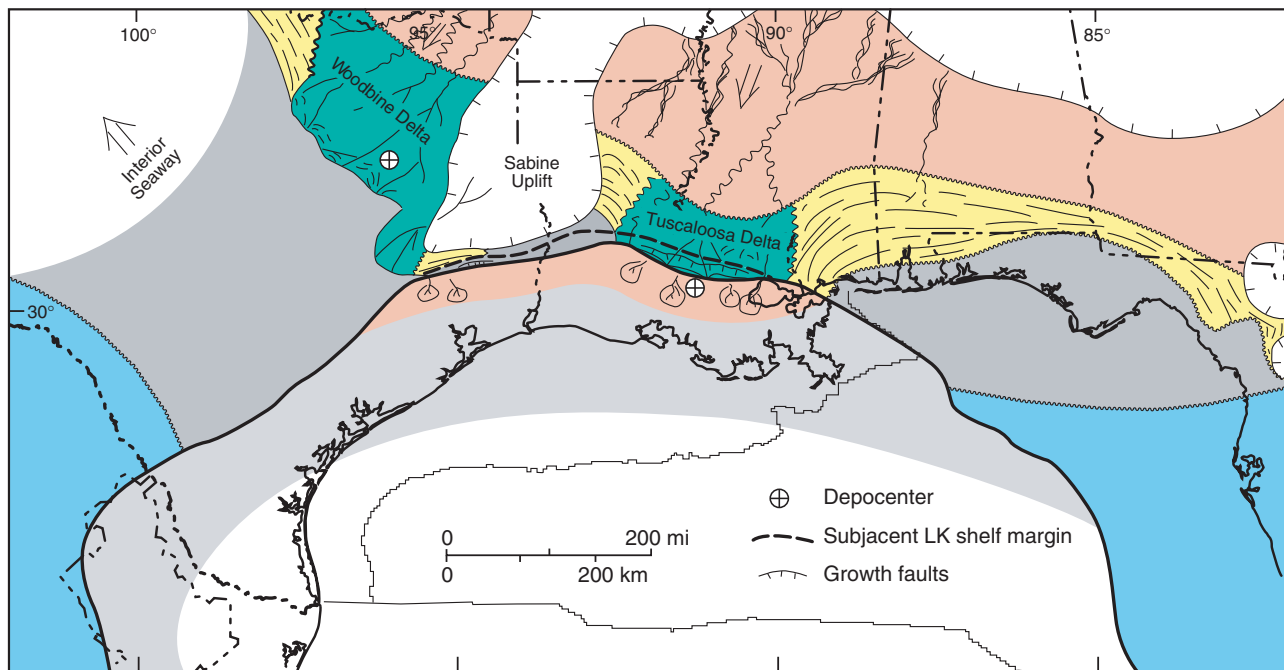


Figure 17 Paleogeography and principal depositional systems of the Upper Cretaceous Tuscaloosa–Woodbine depositional episode.

Sabine arch. Emergence of the uplift first provided a local source area and then culminated in angular truncation of Woodbine strata on the east flank of the East Texas basin, creating the unconformity trap for the giant East Texas oil field. Transgression of the Woodbine fluvio-deltaic plain, which lay more distant from the upland source and inferred hotspot-created uplift, relatively early led to widespread deposition of the Eagle Ford Shale across a broad muddy shelf that was contemporaneous with renewed progradation of the Upper Tuscaloosa (Figure 10). The northwest Gulf remained fully open to the Cretaceous Interior seaway, and only thin shelf deposits accumulated there.

The episode terminated with regional flooding and development of a Late Turonian condensed, maximum flooding horizon across the northern Gulf shelf, recording waning sediment supply and renewed subsidence (Figure 10). Condensation and/or erosion is also suggested by contact relationships with the overlying Coniacian strata from south Texas to north Louisiana (Lundquist, 2000).

The Coniacian through Santonian was a time of global eustatic sea-level highstand. Depositional style changed dramatically in the northern GOM. The Austin depositional episode (Figure 10) is defined and named for the blanket of chalk that covered the northern Gulf (Lundquist, 2000). The northern Gulf was dominated by extensive deep carbonate shelves (Figure 18) that extended to and beyond present outcrop. Austin deposits are characterized by the chalks created from deposition of organic-rich globigerinid and coccolith oozes on a deep, clastic-starved shelf. Pelecypod and echinoderm-rich grainstones, mudstones, marls, and calcareous shales are also widespread.

The northwest Gulf remained an open platform connecting to the Cretaceous Interior seaway (Figure 18). Currents flowing across the connection between the two large oceanic basins may have played a role in creation of the distinctive intraformational scours and hard grounds that typify the Austin chalk in northeast Texas (Hovorka and Nance, 1994). Interchange of the Boreal water mass of the Interior Seaway with Tethyan water mass of the Gulf is recorded by presence of mixed faunas in central Texas (Lundquist, 2000).

A minor pulse of clastic sediment supply rebuilt local coastal deposits (Eutaw Formation) across the innermost northwestern and central shelf, but these were a faint ghost of the earlier Woodbine and Tuscaloosa fluvial/deltaic systems. Most of the clastics contain abundant glauconite and carbonate grains, reflecting extensive reworking in shore-zone and shallow-shelf environments associated with ongoing transgressive flooding of older coastal plain deposits during the Austin episode. Mud cracks and intertidal features indicate local carbonate shore-zone deposition above the San Marcos arch (Figure 18). The Cretaceous shelf margin-faulted and was blanketed by a ramp-like wedge of fine carbonate sediments. In contrast to the hundreds of meters of Austin strata found on the northern shelf, the deep, central Gulf was largely sediment-starved during this interval of regional highstand.

Across the north-central shelf, from the East Texas basin to the Monroe uplift, tuffs and bentonites record extrusive volcanism from several vents located in southern Arkansas and on the Monroe uplift (Byerly, 1991).

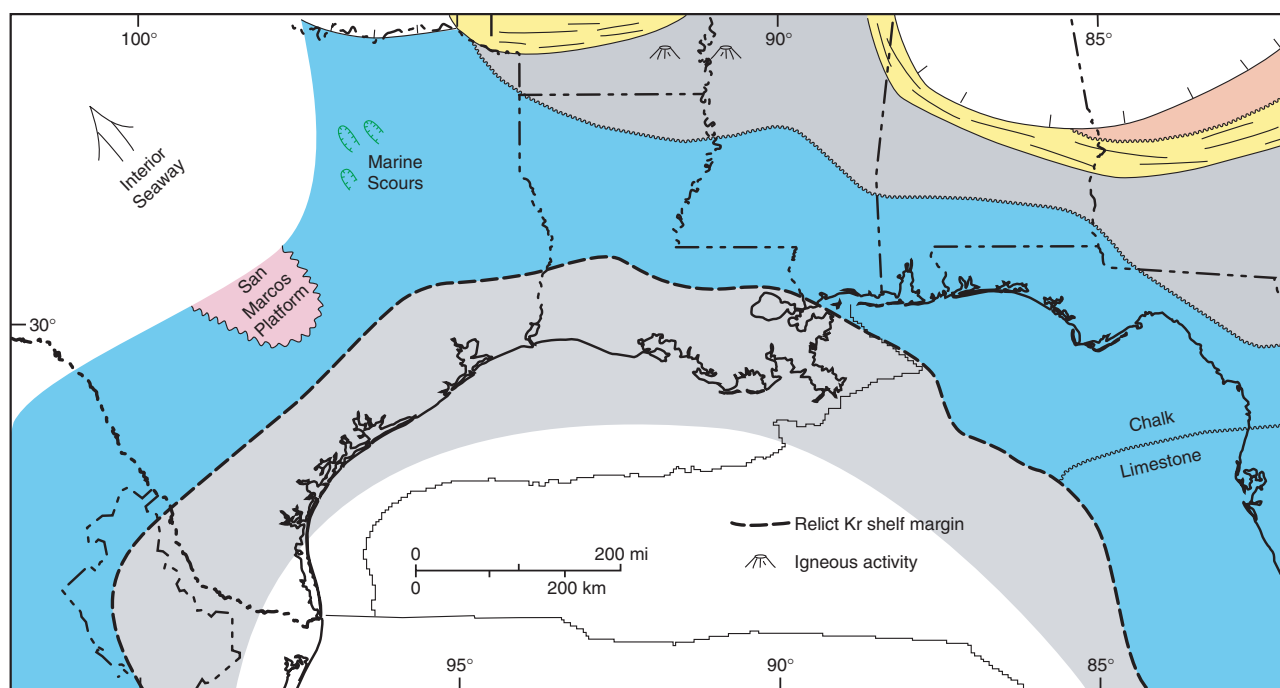


Figure 18 Paleogeography and principal depositional systems of the Upper Cretaceous Austin depositional episode.

This volcanic activity, which continued through the Late Cretaceous, may be a residual effect of mantle plume activity (Cox and Van Arsdale, 2002).

The Austin depositional episode, although characterized by accumulation of open-shelf carbonates across the northwestern Gulf, nonetheless records a shoaling cycle bounded by periods of relatively deep water (Lundquist, 2000). The boundary between the Austin and overlying Campanian Taylor episode is regionally disconformable. Updip basal Taylor strata in Arkansas contain abundant glauconite, phosphorite, shark teeth, and shells, typical of marine condensed and shelf deflation horizons. A deepening event separates mud- and limestone-dominated Lower Taylor from sandy Upper Taylor episode strata.

Upper Taylor episode deposition (Figure 10) was characterized by renewed sandy terrigenous sediment influx to the Gulf margin, this time to depocenters in the northwestern part (Weise, 1980; Tyler and Ambrose, 1986; Sohl et al., 1991). Initially, muddy, sediment-laden plumes from southern Rocky Mountain-sourced delta and coastal systems of the southern Interior Seaway spread into the northwestern Gulf. By Late Campanian, the southern seaway had filled, and the wave-dominated San Miguel (Figure 9) delta system spilled across the remnant foreland basin into the Rio Grande embayment. This overflow of Laramide-sourced clastics created a depocenter that dominates the otherwise thin Campanian sequence of the Gulf. The mixing of Tethyan and Boreal water masses ceased, as the western Gulf again became an enclosed ocean basin. Additional siliciclastic material was locally provided by numerous volcanic cones that rose across the Rio Grande embayment and San Marcos arch, in South Texas, and over the Jackson dome (Byerly, 1991). Extrusion, intrusion, and crustal heating elevated the south Texas shelf, creating bioclastic grain shoals that constitute the Anacacho Limestone (Luttrell, 1977).

Regionally across the central and northeastern Gulf, relative sea level remained high, submerging the basin margin throughout most of the Taylor depositional episode. Deposition occurred dominantly in shallow- to deep shelf systems. Even the fringing terrigenous deposits, found along the present outcrop belt, largely record shallow shelf, shoreface, and transgressive marine settings. Thus the genetic sequence consists of a mosaic of marine sediments including calcareous claystone, fossiliferous mudstone, glauconitic and fossiliferous sand, marl, chalk, and impure limestone.

The terminal, Maastrichtian stage, depositional episode of the Cretaceous Gulf of Mexico is recorded by the Navarro Group (Figure 10). It too created a succession of strata that record a phase of siliciclastic-dominated progradation and shoaling bounded above and below by intervals of erosion, marine transgression, shelf starvation, and prominent flooding surfaces (Mancini and Puckett, 1995, 2005). In the northeast Gulf, shallow shelf sands, chalks, and marls bracket a Lower to Middle Maastrichtian shore-zone sand containing one or more inner-shelf disconformities (Skotnicki and King, 1989; Mancini and Puckett, 1995). Abundant lags of phosphorite, bored phosphatized mud clasts and fossil casts, turtle, shark, fish, and mosasaur teeth and bone fragments, and durable shell debris indicate nearshore to inner-shelf current erosion formed the disconformities,

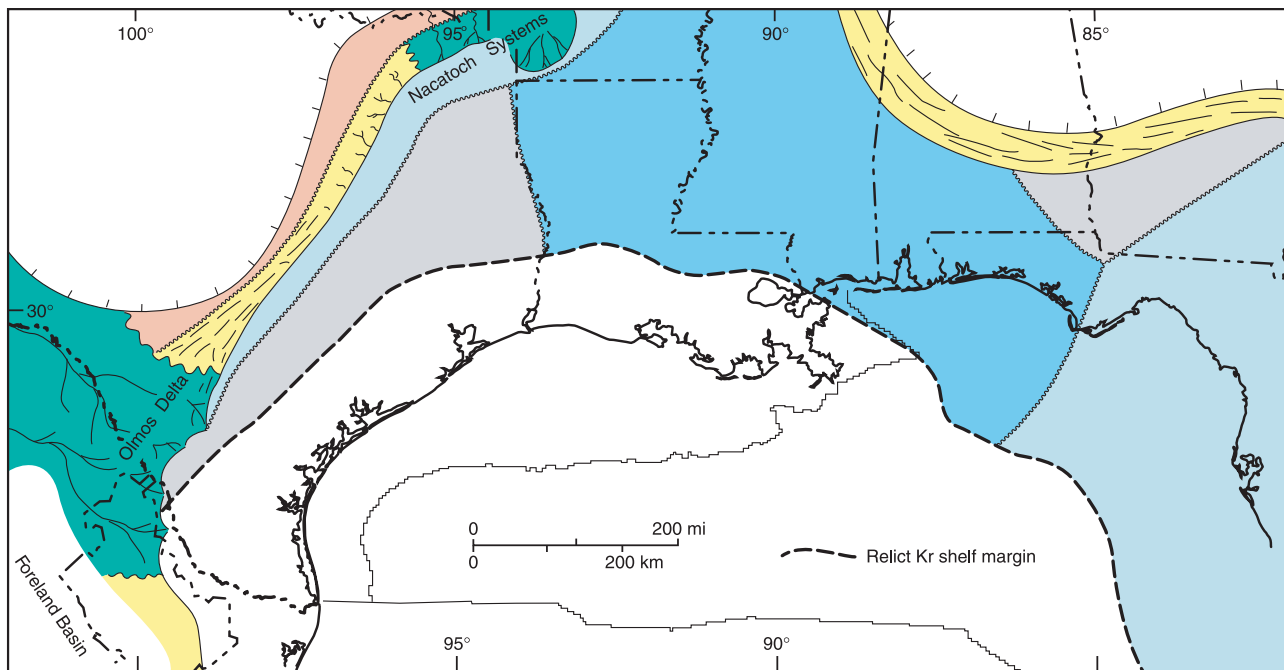


Figure 19 Paleogeography and principal depositional systems of the Upper Cretaceous Navarro depositional episode.

likely in response to relative sea-level fall. Collapse of the Mississippi embayment as cooling subsidence followed upon Late Cretaceous migration of the Bermuda hotspot eastward, had, by this time, created a marine reentrant that extended northward along the modern Mississippi Valley (Figure 19).

In the east-central Gulf margin, progradation of the Nacatoch delta and shore-zone systems (Figure 19) records a significant clastic pulse (McGowen and Lopez, 1983). The Olmos delta system, the largest Navarro episode delta, prograded across the Rio Grande embayment from Laramide uplands in northern Mexico (Tyler and Ambrose, 1986).

Several unconformities within and at the base and top of the Navarro Group record continued influence of Laramide crustal stresses on local uplift and subsidence across the northern Gulf basin (Tyler and Ambrose, 1986; Sohl et al., 1991). In general, maximum deltaic and shore-zone progradation occurred by late Middle Maestrichtian. Subsequent transgression of the northern Gulf margin formed an extensive flooding surface; however, local tectonics and sediment supply pulses created an extended period of latest Cretaceous retrogradational and highstand deposition that is here included in the 6 Ma Navarro depositional episode.

The Cretaceous–Tertiary boundary strata of the Gulf of Mexico constitute a condensed horizon, recording widespread sediment starvation throughout the area of preserved Cenozoic strata. They also record a cataclysm of global proportions, the Chicxulub meteorite impact event (Hildebrand et al., 1991). The Chicxulub crater is located beneath the Yucatan Platform, in the southern Gulf. The impact crater forms an oval feature that is 90 by 120 miles (140 by 190 km) in diameter. The consequent seismic shock triggered submarine slides and mass flows (Bralower et al., 1998). An impact tsunami created a distinct event bed widely noted around the northern Gulf margin (Schulte et al., 2006).

5.4. Cenozoic depositional episodes

The Cenozoic depositional history of the northern Gulf basin has been synthesized by Galloway et al. (1991a, 2000). Galloway et al. (2000) differentiated 18 northern GOM depositional episodes. Here, I have grouped these into 13 episodes (Figure 7) by combining some minor episodes and emphasizing only the first-order changes in supply history and paleogeography. These episodes can be further grouped into four families that record major evolutionary phases in the adjacent North American drainage basins. (1) Paleocene–Middle Eocene Laramide compression-related episodes. (2) Late Eocene–Oligocene episodes initiated by crustal heating, uplift, and volcanism in the southwestern United States and Mexico. (3) Miocene episodes that record erosional rejuvenation of eastern North American uplands. (4) Early Pliocene–Quaternary episodes that record rejuvenation of western interior drainage basins due to uplift, climate deterioration, and high-amplitude, high-frequency glacioeustatic sea-level change.

Deposits of each episode are separated by regional transgressive marine shale tongues that contain at or near their base, a maximum flooding surface. These Cenozoic depositional episodes create the archetypal genetic stratigraphic sequences (Galloway, 1989b).

5.5. Laramide depositional episodes

Regional flooding of the Gulf margin to and beyond present outcrop that terminated the Cretaceous persisted for the first few million years ago of the Paleocene. Widespread shelf mudrocks and marls of the Midway and Porters Creek Formations blanketed the northern Gulf margin. However, beginning in the Late Paleocene and Early Eocene, depositional outbuilding of the coastal plain, spearheaded by large delta systems centered in the Houston, Mississippi, and Rio Grande embayments, heralded the onset of successive waves of Cenozoic clastic influx (Galloway et al., 2000).

Four principal depositional episodes punctuate Paleocene through Early Eocene history throughout the northern Gulf of Mexico (Figures 11 and 12). They record surges of clastic supply, modulated the progressive advance of Laramide uplift that began in the Central and Southern Rocky Mountains of the United States and spread progressively south to the Sierra Madre Oriental of northern Mexico (Winker, 1982; Galloway, 2005b). Laramide compressional crustal stress extended eastward into the Gulf basin, as reflected by broad folding in the Rio Grande embayment, rejuvenation of the Sabine and Monroe uplifts, and accentuated subsidence of the western Gulf abyssal plain (Laubach and Jackson, 1990; Cao et al., 1993; Feng et al., 1994). The Late Paleocene and Early Eocene Wilcox episodes significantly prograded the northern Gulf shelf margin and continental slope from its Cretaceous position (Figure 6B).

The Lower Wilcox depositional episode records the first major Cenozoic influx of sediment onto the northern Gulf continental margin. A broad fluvial-dominated delta system prograded across the Houston embayment and onto the relict Cretaceous slope (Figure 6B). A second, smaller fluvial-dominated delta built across the Mississippi salt basin. Both form primary Late Paleocene depocenters. An extensive wave-built shore-zone system extended across the San Marcos arch into northern Mexico.

Rapid sediment loading mobilized the deep-water muds and Louann salt, initiating numerous extensional growth faults along the paleo-shelf margin. These growth faults form the inboard elements of the Wilcox fault zone, which extends from northern Mexico to central Louisiana (Figure 4). Loading also initiated the first of successive Cenozoic phases of salt mobilization and expulsion from beneath the basin-margin depocenters toward the paleo-continental slope, where salt canopies were initiated. In the northwestern Gulf, contemporaneous Laramide compression uplifted and tilted the underlying Cretaceous shelf deposits, which formed the foundation beneath Early Paleocene strata. Tilting triggered the Lobo megaslide, centered above the Rio Grande embayment, which affected more than 5,000 km² of the Gulf margin. Burial of the megaslide created the third of the Lower Wilcox depocenters. Ongoing seismicity associated with foreland deformation of the West Gulf margin triggered frequent smaller slumps and slides along the prograding clastic shelf margin from south Texas to central Louisiana. Several of these slumps nucleated submarine canyons that excavated up to several hundreds of meters of older Wilcox strata (Galloway et al., 1991b).

The Lower Wilcox depositional episode terminated with backstepping of delta and shore-zone facies. The Middle Wilcox, which was differentiated as a minor episode bracketed by two widely correlated, thin, marine shale horizons by Galloway et al. (2000), is here grouped with the Lower Wilcox. The transgressions, recorded by the regional Yoakum Shale and Big Shale markers, that punctuated the Paleocene-to-Eocene transition are associated with large submarine canyons. The best known canyon, the Yoakum, is located above the San Marcos arch in the central Texas coastal plain, cut across the transgressive shelf more than 150 km landward from the shelf edge, and excavated as much as 1.5 km of underlying Lower Wilcox deltaic deposits (Galloway et al., 1991b). A canyon of this size was not seen again on the northern Gulf margin until the Pleistocene (Galloway, 2005a).

Following the Middle Wilcox “breather” in clastic supply and consequent transgression, which is reflected by the fossiliferous, glauconitic Sabinetown Formation in Texas outcrops and the Yoakum Shale in the subsurface, rejuvenated and reorganized Early Eocene bedload-dominated fluvial systems spilled across the San Marcos arch (Figure 20). The fluvial systems deposited an amalgamated network of coarse, sandy channel fills across the middle and south Texas coastal plain, creating the Carrizo aquifer, one of the major aquifer systems of the Gulf basin (Hamlin, 1988). Basinward, these fluvial systems supported a family of wave-dominated deltas that prograded rapidly to and over the shelf margin (Edwards, 1981). Here, basinward rafting of the underlying Mesozoic section opened an arcuate, growth-fault-bounded “depotrough” that collected highly expanded successions of delta front and slope apron sediment (Fiduk et al., 2004). Initial progradation into the head of the Yoakum canyon likely led to sediment bypass down the canyon and speculative formation of a submarine fan system at the base of the central Texas continental slope (Figure 20).

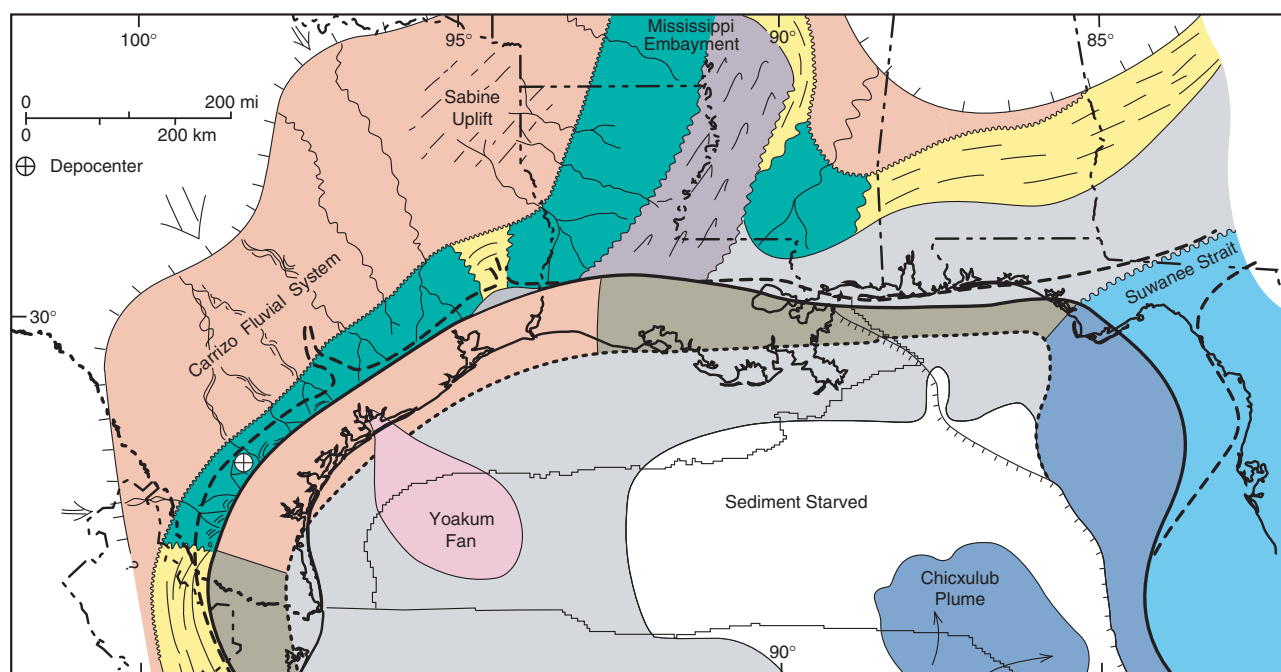


Figure 20 Paleogeography and principal depositional systems of the Eocene Upper Wilcox depositional episode.

Tectonic realignment of continental drainage systems diverted supply from the east-flowing tributaries that drained into the central Gulf during the Lower Wilcox episode. There, limited sediment supply and extensive marine reworking created broad, sandy shore-zone and shelf systems that trend northward along the flank of the deltaic coastal plain, which extended as far as east-central Louisiana, and into the Mississippi embayment (Figure 20). The Sabine uplift provided a low-relief upland drained by minor fluvial tributaries. The eastern Gulf of Mexico was largely a shallow shelf that, along with the basin floor, remained sediment-starved. Carbonate sediment accumulated throughout the length of the Florida platform. Beginning in the Paleocene, and continuing into the Eocene, the broad, moderately deep Suwannee strait (Figure 20) connected the northeast corner of the Gulf with the Atlantic Ocean. Strong marine currents were funneled through this strait, which separated siliciclastic and carbonate shelf provinces. By Upper Wilcox deposition, the northeast Gulf shelf had evolved the compound dip profile that is still reflected in the West Florida terrace and Florida escarpment (Figure 1). A shallow, perched, prograding shelf break, located near the present Florida coast line, separated the shallow clastic and carbonate shelf systems from a broad submarine ramp, which in turn was perched atop the foundered, relict Cretaceous deep shelf and fore-reef slope.

The regional Recklaw transgression terminated the Wilcox depositional episode at about 49 Ma. Meanwhile, erosion and burial of Laramide southern Rocky Mountain uplands, which provided the principal source of sediment to the Gulf, resulted in diminishing sediment supply (Galloway and Williams, 1991). The Middle Eocene Queen City and Sparta episodes deposited sediment primarily on the Wilcox depositional platform (Figures 11 and 12). The continental slope and abyssal plain remained sediment-starved in the northern and eastern Gulf.

The Queen City episode paleogeography resembled that of the Upper Wilcox. Deposition of wave-dominated deltas and thick barrier and strandplain systems was centered in the northwestern Gulf, and an embayed, marine shelf extended across Louisiana and Mississippi and northward into the Mississippi embayment. The very broad, funnel-shaped embayment amplified the normally low tidal range of the Gulf and created, in Queen City deposits, a unique assemblage of tide-dominated shore-zone and shelf facies in the East Texas basin (Ramos and Galloway, 1990).

Following the Weches transgression, the Sparta depositional episode records a shift of continental fluvial drainage axes back into the central Gulf, filling the Mississippi embayment with deposits of a fluvial-dominated delta system. The overall low rate of sediment supply and extensive but shallow marine flooding of the northern Gulf margin created widespread fossiliferous marine shale and glauconite beds that extend to outcrop and record long periods of very slow sediment accumulation. The Weches Formation (ca. 45 Ma), which separates deposits of the Queen City and Sparta episodes, is a muddy, fossiliferous glauconite sand that can be traced from northern Mexico to Mississippi, and records as much as 1 Myr of time in its few meters of sediment. The Cook Mountain transgression, which terminated the Sparta episode, also records about 2 Ma of northern Gulf coast inundation.

5.6. Middle Cenozoic volcanism and related depositional episodes

The latest Middle Eocene saw a modest rejuvenation of sediment influx onto the northwestern and central Gulf margin. Deposits of this episode, named the Yegua Group in Texas and Cockfield Formation in Louisiana, are also distinguished by a new appearance of volcanic ash beds. Initially, Yegua and Cockfield fluvial-dominated deltas prograded across the shallow transgressive shelf that had submerged Sparta delta and shore-zone systems in the Houston embayment and Mississippi salt basin. As the largest and most actively prograding Yegua deltas of the Houston embayment approached the shelf margin, they first built across the perched Sparta and Queen City delta platform margins, which formed a mid-shelf platform break. Progradation was then onto the much deeper, mud-blanketed, distally steepened ramp that had evolved during more than 10 Myr of subsidence and tilting of the continental margin created by Upper Wilcox offlap. The combination of rapid sediment influx and renewed loading of the old, muddy continental margin triggered a succession of submarine slumps and growth faults that coalesced along the Yegua delta front to form a compound intraformational mass wasting surface that soles out within underlying muddy Eocene strata (Edwards, 1991). Slide scars extended as much as 20 km inland from the margin, creating steep slopes and local depocenters that both initiated and collected further mass flows and turbidity currents (Figure 21). Following this retrogradational phase, shelf-margin deltas built across the slump complex, healing the embayed margin and prograding the shelf edge. Sediment remobilized from the unstable shelf-margin delta front and prodelta formed a heterolithic slope apron.

Yegua strata are well known for their excellent development of incised channels or valleys that extend many kilometers from platform delta lobes across a muddy outer shelf and terminate in small, low-stand, shelf-margin delta lobes. A series of transgressions and forced regressions created 5–10 (depending on location and author) significant progradational pulses during the 2.5 Ma Yegua episode (Edwards, 1991; Meckel and Galloway, 1996). High-effort micropaleontological analysis (Fang, 2000) of mid- and down-dip Yegua strata confirm that maximum flooding surfaces found within the bounding transgressive marine shelf mudstones are disconformities. In contrast, despite clear forced regression and channel cutting across shelf mudstones, no measurable hiatus could be documented across these surfaces within the Yegua genetic sequence.

Additional delta systems prograded into the Rio Grande embayment and North Louisiana and Mississippi salt basins (Figure 21). Much delta sediment was reworked along strike to build thick, progradational, barrier and strandplain systems, particularly in the NW Gulf. The Suwannee strait was in the last stages of filling, but continued to separate the carbonate-dominated shelf of the Florida platform from the siliciclastic shelf and shore-zone systems of Mississippi and Alabama.

Eocene deposition terminated with the minor, but economically significant Jackson depositional episode (Figure 12). Following the tentative Yegua probe to the continental margin, which terminated with the regional Moodys Branch transgression of the northern Gulf, deposition during the next 2 Ma remained firmly on the

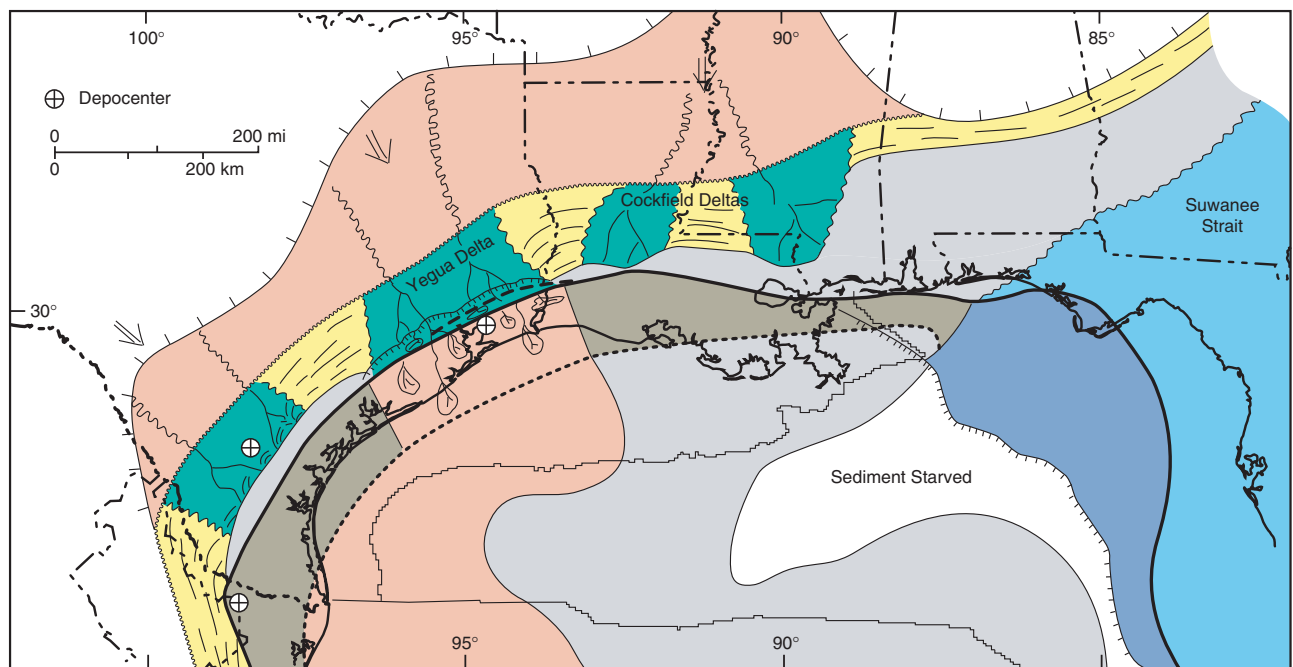


Figure 21 Paleogeography and principal depositional systems of the Eocene Yegua depositional episode.

up- to mid-dip platform (Figure 13) and sandy deltaic and shore-zone systems were restricted to the NW Gulf margin (Galloway et al., 1991a). Delta systems prograded only into the Houston embayment. Extensive barrier island and strandplain systems extended across the central and south Texas coast. For the last time, the Mississippi embayment suffered marine inundation as all of the central and NE Gulf margin reverted to an extensive muddy shelf. Jackson strata in Texas contain common bentonite and vitric ash beds, presaging the impending Oligocene climax of crustal heating and continental uplift.

The Oligocene was a time of massive sediment influx to the Gulf (Galloway and Williams, 1991). The epoch began with extensive crustal heating, uplift, and volcanism of source areas in northern Mexico and the southwestern United States. Uplift impinged directly on the western margin of the Gulf Basin. Cretaceous and Early Cenozoic foreland basin fill was elevated more than 3 km in the Late Eocene through Early Oligocene along the SW Gulf margin (Gray et al., 2001). The NW margin, now the western edge of the Burgos basin, was similarly elevated in the Middle Oligocene. Further west, explosive volcanism and caldera collapse combined with the uplift to create a long-lived outpouring of recycled sedimentary rocks, volcanoclastics, and reworked, devitrified ash that peaked by the Mid-Oligocene and continued into the Early Miocene. The response in the Gulf was the sediment-supply dominated Frio depositional episode, which lasted for more than 8 Ma (Figure 12).

Stratigraphic and structural architecture of the basal strata of the Frio episode, the Vicksburg Group, is complex. Uplift and volcanism directly affected the northwestern Gulf margin and indirectly affected the north-central margin by rejuvenation of several drainage basin hinterlands and pervasive deposition of easily reworked ash. The preceding transgression of the Jackson coastal deposits was brief and most clearly recognizable in the shallow subsurface to mid-dip central Texas coastal plain (Galloway et al., 1994). At outcrop along the northwest Gulf margin, the boundary is variously manifested by the abrupt superposition of alluvial plain deposits on coastal Jackson facies, prominent mature paleosoils, locally inset basal Vicksburg alluvial channel and valley fill successions, and low-angle discordance between Jackson and basal Oligocene deposits (Galloway, 1977; Galloway et al., 1979; Combes, 1993). This assemblage of features shows that relative base level rise and transgression of the mid-dip Jackson fluvial and shore-zone systems were contemporaneous with mild tilting and relative uplift along the updip margin of the basin. Indeed, the beginning of the Oligocene marks a change in the style of tectonic subsidence along the Gulf margin (see Galloway et al., 1991a, Figure 3). Paleocene-Eocene subsidence involved minimal basinward tilting; sequences thicken only gradually until they reach the paleo-shelf margin. In contrast, Oligocene and all younger sequences thin rapidly as they approach their outcrop, indicating that tilting subsidence along a basinward progressing hinge has characterized the Late Cenozoic.

The combined influences of continental uplift and concomitant deposition of massive amounts of air-fall ash in the various fluvial drainage basins is reflected in the total load, sediment composition and texture, and the progressive growth of the four delta systems that were active during Frio deposition (Galloway, 1977; Galloway et al., 1982b) (Figure 22). The primary Oligocene depocenter lies in the Rio Grande embayment and consists of up to 5 km of deposits of the Norias wave-dominated delta system and its associated fluvial and delta-fed apron systems (Galloway et al., 1982b). Norias deposition began with rapid progradation of the Vicksburg phase deltas onto a thick foundation of muddy Eocene shelf and slope deposits. The shelf margin was further destabilized by seismicity and uplift and tilting of the western Gulf margin. The immediate consequence was development of the Vicksburg detachment (Figure 5), a shale-based detachment system that extends more than 500 km along strike from the Burgos basin in northern Mexico (Diegel et al., 1995). This detachment created the Vicksburg growth-fault zone, which forms the updip boundary of the much broader Frio fault zone (Figure 4). The shallow detachment within Upper Eocene mudstone resulted in horizontal displacement of Vicksburg delta front and upper slope deposits of as much as 16 km horizontally (Diegel et al., 1995). Following stabilization of this detachment, further Frio progradation built the continental margin 90–145 km beyond its Eocene position. Progradational loading of the continental slope initiated basinward advancing lines of growth faults that form the updip part of the northwest Gulf Oligo-Miocene detachment province (Figures 4 and 5). Basinward, extension was compensated by compressional faulting and folding in the Port Isabel fold belt, which lay at the base of the Oligocene continental slope (Figure 4).

To the south, the Norma delta rapidly prograded into the Burgos Basin. Here, however, most tilting and uplift followed Early Oligocene progradation. A prominent, angular unconformity separates the Norma Conglomerate and equivalent “Non-marine Frio” from underlying Vicksburg and “Marine Frio”. As uplift of the Sierra Madre Oriental migrated eastward, older Cenozoic strata were elevated and recycled.

The third principal delta system, the Houston delta, is centered beneath the southeast Texas coastal plain (Figure 22). Initial Vicksburg delta lobes are thin, and largely remained on the Eocene shelf platform; growth faulting effected only their distal fringes. However, relative base-level fall along the inboard basin margin is indicated by incision of valley systems that extend from outcrop into the shallow subsurface (Galloway, 1977; Combes, 1993). As Frio deltas prograded into and across the Houston salt basin, loading of subjacent Louann salt fostered a phase of active salt diapir growth and minibasin development (Diegel et al., 1995). A fourth delta

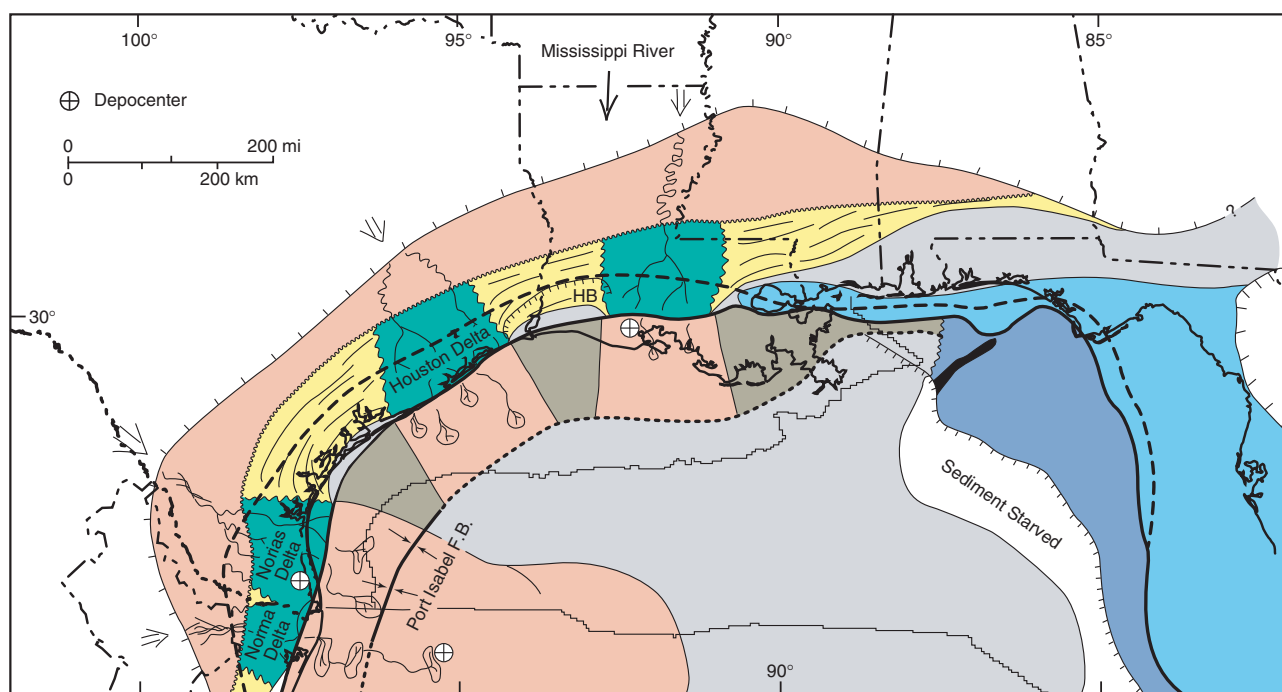


Figure 22 Paleogeography and principal depositional systems of the Oligocene Frio depositional episode. HB, Hackberry embayment.

system, which was fed by a large, suspended load-rich fluvial system flowing south along the Mississippi embayment axis, prograded across the Louisiana salt basin (Figure 22). Here, large-scale salt evacuation from beneath the delta and continental slope depocenter accommodated as much as 4 km of Oligocene strata (Figure 6B). However, arrival of sediment to the central Gulf was delayed. Early Eocene Vicksburg strata of Louisiana consist of shelf mud and marl. The paleo-Mississippi fluvial system, unlike its sister systems of the northwestern and western Gulf, was not directly effected by uplift of its tributary drainage basin. Rather, sediment influx was accelerated by the rapid recycling of largely altered volcanic ash, in the form of suspended mud, through this mid-continental drainage system. Thus, the resultant delta system was large, but mud-dominated and slow to develop.

Between the delta systems, the Frio sequence contains comparably thick successions of strandplain and barrier/lagoon complexes (Figure 22). These wave-dominated shore-zone systems were nourished by longshore reworking of sediment from the deltaic headlands. The central Texas barrier/lagoon complex contains as much as 1.5 km of stacked, amalgamated barrier, beach ridge, and shoreface sand (Galloway et al., 1982b). Together, the thick, prograding delta, shore-zone, and slope apron systems initiated and perpetuated a succession of growth faults that extend from northern Mexico to eastern Louisiana (Figure 4). Between the SE Texas and Louisiana delta systems, particularly rapid Mid-Oligocene salt withdrawal from beneath the shore-zone, shelf, and upper slope systems triggered a brief phase of tilting, collapse, and submarine erosion that interrupted margin progradation. The resultant Hackberry embayment is one of the best-described examples of many such destructional slope systems within the Gulf Cenozoic section (Cossey and Jacobs, 1992; Galloway, 1998a).

The eastern Gulf basin remained clastic sediment starved. By Early Oligocene, the Suwanee strait had filled in, merging the Florida platform with the northeast shelf. Carbonate deposition on the outer shelf expanded westward as far as Louisiana. Local Late Oligocene patch reefs, known as the *Heterostegina* Limestone, developed over active salt domes in the Houston salt basin, the westernmost expansion of carbonate systems during the Cenozoic.

Decreasing rate of sediment supply and accumulation in the Late Oligocene (Galloway and Williams, 1991) terminated the Frio depositional episode. Long-term backstepping of delta and shore-zone systems culminated in regional transgressive flooding and deposition of the Anahuac shale across the breadth of the Gulf margin.

5.7. Miocene depositional episodes

Miocene basin fill reflects three multi-million-year depositional episodes that record the progressive shift of the locus of deposition in the Gulf of Mexico from the northwestern to the eastern margins. This shift reflects the

concurrent reduction of the volcanic uplands, which sourced fluvial systems draining across northern Mexico and Texas, and the rejuvenation of the Appalachian and Cumberland Plateau uplands, which supplied rivers emptying into the central and east-central Gulf. Also during the Miocene, effects of Basin-and-Range tectonism extended to the western margin of the Gulf with activation of the Balcones fault system, uplift to the Edwards plateau, and development of the Rio Grande rift, which disrupted drainage into the Gulf from the southwestern United States. Consequent long-term changes in the rate and location of sediment supply largely defined three episodes that are approximately coincident with the Early, Middle, and Late Miocene (Figure 12). Concurrently, global climate was evolving toward the ice house world of the Late Cenozoic. Increasing amplitude and frequency of glacioeustatic sea-level fluctuations impacted stratigraphic and facies architecture, especially within deposits of Miocene shore-zone systems (Galloway, 1998b, 2002).

The Gulf Miocene stratigraphy is characterized by extensive continental margin progradation (Figure 6B). By the Middle Miocene depositional episode, the dominant extrabasinal fluvial systems were established in positions that closely approximate Quaternary counterparts (Galloway et al., 2000; Galloway, 2005b).

The Lower Miocene succession consists of an 8 Ma depositional episode that closely resembled major Paleogene episodes in its development (Galloway et al., 1986). An extended phase of high rates of sediment supply and continental margin outbuilding followed upon the Anahuac transgression. Following a transgressive interruption at about 18 Ma (used by Galloway et al. (2000) to differentiate two Lower Miocene sequences) that is best developed in the northwest Gulf, a 2 Ma phase of retrogradation and transgression terminated the episode. The widespread *Amphistegina* shale and its contained maximum flooding surface, which is named for the diagnostic *Amphistegina* B faunal top, caps the Lower Miocene genetic sequence (Figure 11).

Following the Anahuac transgression, the bedload-dominated Rio Grande and Norma fluvial axes continued to decrease in relative importance, although they remained a major depocenter. Wave reworking and long-shore transport dominated the delta system, shifting the depocenter northeast to the laterally adjacent central Texas barrier-strandplain system. In the central Gulf, the paleo-Mississippi continued to increase in relative importance. A new fluvial axis, coincident with the modern Trinity/Sabine rivers, but with a drainage basin and size more commensurate with those of the modern Red River, entered the Gulf near the Texas/Louisiana border. Together, these two fluvial-dominated deltas prograded the continental margin 65–80 km basinward. At the onset of deposition, the Red and Mississippi deltas and slope aprons experienced a second episode of Hackberry-like hyper-subsidence and continental margin collapse and mass wasting. Numerous slump scars, fault-expanded shelf-margin deltas, and submarine canyon fills reflect the interplay of margin collapse, submarine erosion, and rapid deposition. The collapse of this “*Planulina* embayment” and concomitant development of the *Planulina* fault zone (Figure 4) was a consequence of large-scale salt withdrawal from beneath coastal Louisiana in response to the eastward migration of depositional loading. Combined deflation of the shallow, underlying Oligocene canopy and extension along the Oligocene and Louann detachment zones (Figure 8, panel C) (Diegel et al., 1995; Peel et al., 1995) accommodated nearly 7 km of Lower Miocene sediment in the central Gulf depocenter. Thick, sandy turbidite successions began to spill down the continental slope in the east-central and NE Gulf.

Despite the proximity of the paleo-Mississippi delta system, the northeast Gulf margin initially remained a carbonate province. Much of the Alabama and Mississippi shelf was sediment-starved, creating a prominent nonconformity. Later in the episode, the delta-fed, muddy shelf encroached eastward, terminating reef growth and restricting carbonate platform deposition to the Florida shelf.

Depositional loading beneath the deltas and well-nourished interdeltaic shore zones, and offlap of thick, sandy slope apron systems created prominent structural features, including the Lunker and *Planulina* fault zones (Figure 4). Compression continued along both the Port Isabel fold belt and initiated the Perdido fold belt, which lies along the basinward margin of the Louann salt. Salt extruded from beneath the prograding margin spread southward, nucleating new canopy complexes beneath the lower paleo-slope and adjacent abyssal plain. Inland along present outcrop belts in Texas, low-angle unconformities locally separate basal Miocene (Oakville Fm.) strata from underlying Oligocene (Catahoula Fm.) strata, and basal Middle Miocene (Goliad Fm.) strata from underlying Lower Miocene (Fleming Fm.) strata (Figure 12) (Galloway et al., 1982a, 1986). These discordances record intermittent tilting subsidence generated by successive episodes of sediment supply and crustal loading.

The Middle Miocene sequence records a relatively brief (ca. 3 Ma) episode that was terminated by regional, but short-lived Gulf margin transgression associated with the *Textularia stapperi* faunal top. The paleogeography of the episode clearly documents the effects of Early Neogene continental tectonics and source area rejuvenation (Figure 23) (Galloway et al., 2000; Combellas-Bigott and Galloway, 2006). A new fluvial system, named for the Tennessee River, which currently occupies the comparable drainage basin, made its appearance. The system drained uplands characterized by Paleozoic outcrops and, consequently, transported sandy, mineralogically mature sediment to the Gulf. Together the paleo-Mississippi and paleo-Tennessee created the dominant Mid-Miocene

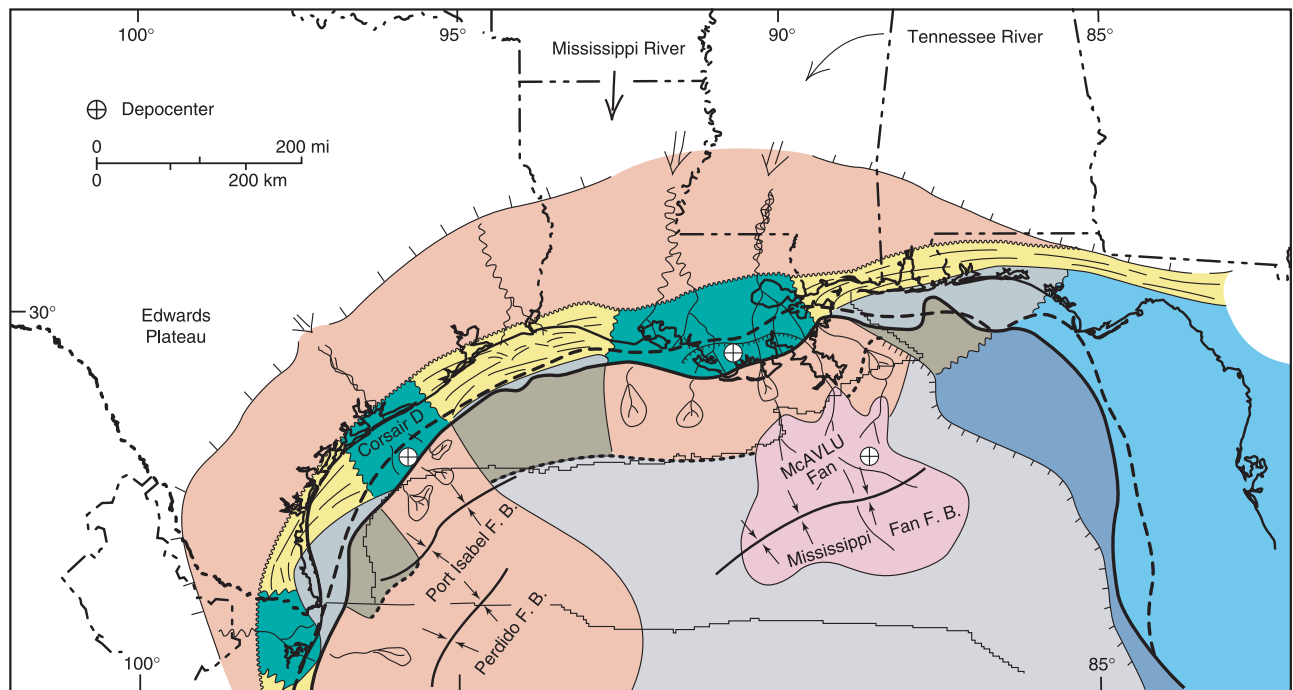


Figure 23 Paleogeography and principal depositional systems of the Middle Miocene depositional episode.

depocenter and prograded the continental margin as much as 70 km. Initial margin progradation was interrupted, however, by a third pulse of salt evacuation and hyper-subsidence, located beneath the southeast Louisiana coastal plain (Combellas-Bigott and Galloway, 2006). This “Harang embayment” and bounding fault zone (Figure 4) is the culmination of an Oligocene (Hackberry) to Miocene west-to-east wave of salt evacuation from beneath the prograding margin. Beneath the central Texas shelf, a second newly consolidated Corsair fluvial-deltaic system, prograded onto the continental slope (Morton et al., 1988; Galloway et al., 2000). Here, salt withdrawal and prolonged growth of the Corsair fault zone created a depocenter that was filled by wave-dominated delta and delta-fed apron deposits (Figure 23). Between deltaic headlands, extensive wave-dominated shore-zone systems were fronted by narrow, muddy to sandy shelves and prograding, muddy, shelf-fed slope aprons.

In the northeast, combined margin collapse, slope bypass, and alignment of a series of dip-elongate slope minibasins created a relatively focused submarine transport pathway that diverted a large quantity of sediment from the paleo-Tennessee delta front to the adjacent slope toe and abyssal plain (Figure 23) (Combellas-Bigott and Galloway, 2006). The McAVLU submarine fan system (named for the three U.S. Minerals Management Service (MMS) protraction areas beneath which it lies) was born. It would persist as a major depositional feature of the eastern Gulf basin floor until the end of the Miocene. This and subsequent Neogene fan systems are distinguished from slope aprons by (1) location of a depocenter at the base of the contemporaneous continental slope, on the abyssal plain, (2) aggradational, rather than offlap, stratigraphic architecture, and (3) development of a radial sediment dispersal pattern indicating focused down-slope transport as a point source rather than a line source. By these criteria, fan systems are unusual features of the Gulf deep water; slope aprons are much more common and volumetrically important.

Combined depositional loading and extension along the Gulf shelf margin caused continued compression along the Port Isabel and Perdido fold belts, triggered further shallow salt canopy inflation beneath the paleo-continental slope of Louisiana, and initiated the Mississippi fan fold belt on the northeast Gulf abyssal plain (Figure 23). Like the Perdido fold belt, compression along the Mississippi fan system was localized along the basinward pinchout of deep Jurassic salt.

The Upper Miocene depositional episode records a long period (6 Ma) of relative paleogeographic stability and high sediment supply (Morton et al., 1988; Galloway et al., 2000; Wu and Galloway, 2002). Sediment input was dominated by the paleo-Mississippi and paleo-Tennessee systems. A large, compound fluvial-dominated delta system prograded onto the slope. Continental margin offlap occurred dominantly in the central Gulf, where the shelf edge advanced 40–90 km. The McAVLU fan continued to expand and evolve until late in the episode. However, to the west, the Corsair delta and surrounding shore-zone systems decreased in importance as sediment repositories. Wave reworking created an extensive strandplain, interrupted by several small wave-dominated deltas, from northern Mexico to eastern Louisiana.

Depositional loading of the basin margin in the east-central Gulf by up to 5 km of Upper Miocene sediment continued to drive wholesale basinward salt displacement beneath the paleo-continental slope and abyssal plain and compression along the Mississippi fan fold belt. Along the curvilinear, wave-dominated northwest Gulf margin, continental margin progradation onto muddy slope aprons built the shelf edge to or near its present position. Here, loading created a linear belt of growth faults known as the Wanda fault zone (Figure 4). Compensatory contraction was focused along the northeastern segment of the Miocene compression domain (Figure 7B).

The Upper Miocene episode terminated with regional marine flooding associated with the last occurrence of benthic foraminifer *Robulus* E and/or *Bigenerina* A. The subsequent 2 Ma depositional episode, which is named for the contained *Buliminella* 1 fauna, bridges the latest Miocene to Early Pliocene (Figure 12). Although sediment supply rates remained high and clastic input continued to be focused through the paleo-Mississippi and -Tennessee rivers, accumulation shifted back onto the continental shelf and margin (Galloway et al., 2000). Thickest deposits occur within a combined fluvial-dominated delta system and upper slope delta-fed apron on the central Gulf margin. Upper slope minibasins captured the bulk of the sediment that spilled over the shelf edge. Continued remobilization of the subjacent salt canopy is recorded in the South Timbalier Ship Shoal fault family, which is part of a larger roho domain (Figures 4 and 5) (Schuster, 1995). The middle and deep slope was under-girded by the extensive Miocene salt canopy complex. The McAVLU fan system was completely abandoned.

5.8. Early Pliocene–Quaternary depositional episodes

Sediment influx and depositional patterns record the combined effect of further intracratonic tectonism, pronounced global and North American climate change, and high-frequency and amplitude glacioeustasy. As in the earlier Cenozoic, accumulation was concentrated along the continental margin and slope where depositional loading and salt migration produced the mosaic of minibasins and salt-cored highs. These minibasins have progressively been filled by advancing delta-fed aprons (Prather et al., 1998). Rapid, high-amplitude glacioeustatic sea-level changes are manifested in the Gulf stratigraphic record by development of multiple sequences of one to several hundred thousand years ago duration with well-defined subaerial exposure and flooding surfaces (Lawless et al., 1997; Weimer et al., 1998). Depositional paleogeography (Figures 24 and 25) and supply rate suggest these can be grouped into two low-order genetic sequences of about 2 Ma duration (Figures 11 and 12).

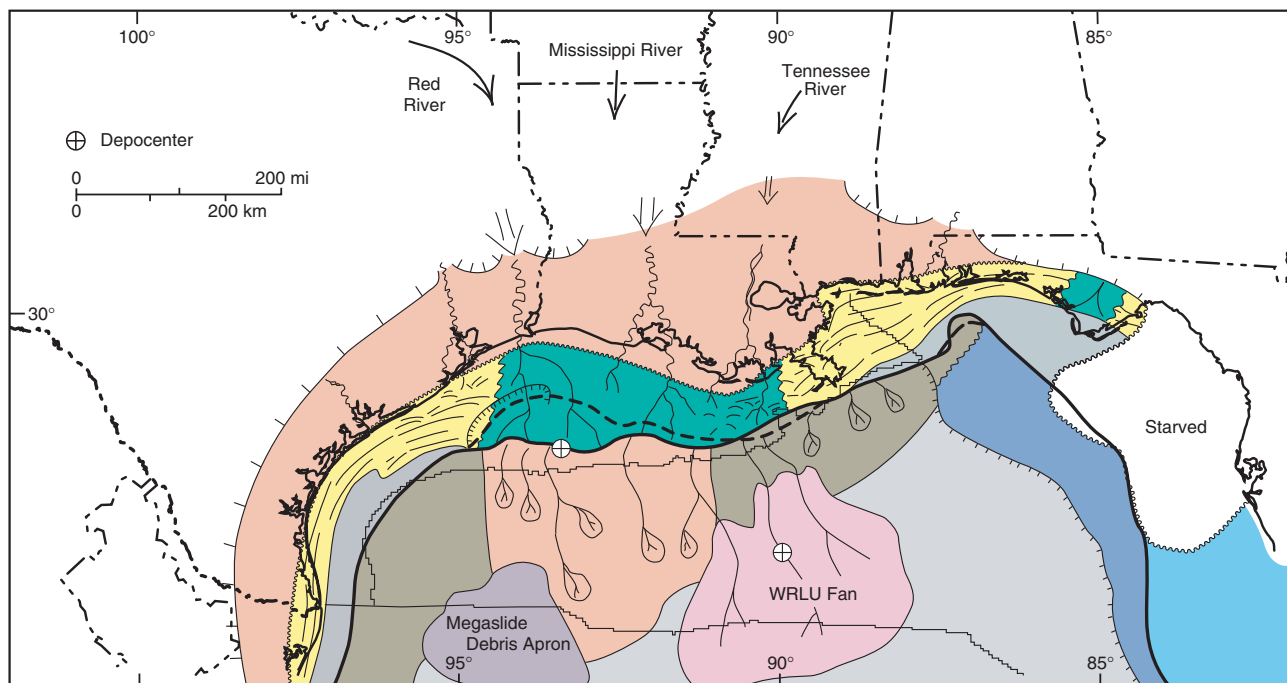


Figure 24 Paleogeography and principal depositional systems of the Pliocene (*Globotruncana altispina* interval) depositional episode.

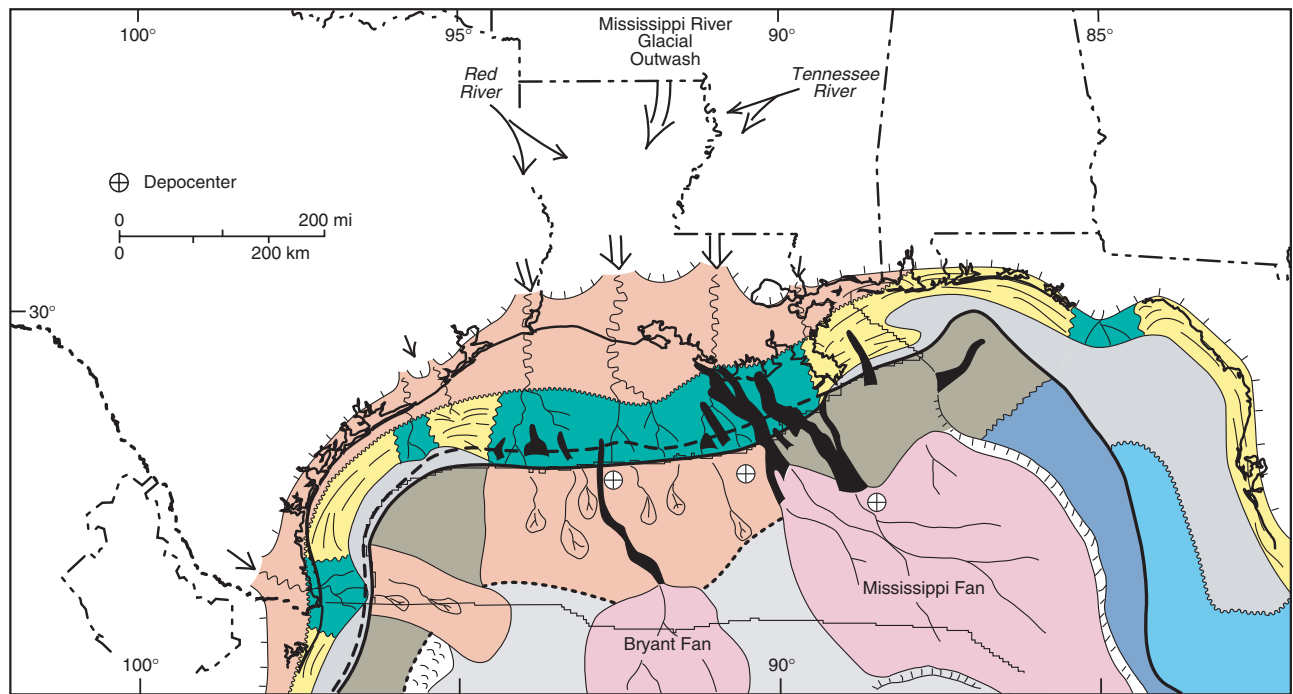


Figure 25 Paleogeography and principal depositional systems of the Pleistocene (*Trimosina A* interval) depositional episode.

Following the brief, post-*Buliminella* 1 transgression, the pattern of deposition changed in several ways (Galloway et al., 2000; Galloway, 2005b):

1. The paleo Red River fluvial axis was rejuvenated. This reflects a response of its drainage basin to epeirogenic uplift and eastward tilting of the western High Plains and Rocky Mountains.
2. Sediment supply through the paleo-Tennessee continued to decline. As a consequence depocenters shifted to the northwestern Gulf margin, and the northeastern Gulf continental slope again became relatively sediment-starved. There, Pliocene strata are thin, but sandy.
3. Shelf margin progradation occurred primarily along the west-central Gulf margin.
4. The northeastern upper slope and shelf edge locally retreated by combined subsidence and mass wasting, particularly in the Mid-Pliocene. Further evidence of slope instability is reflected in the development of a megaslide scar along the west flank of the delta system and correlative debris apron on the west Gulf abyssal plain (Figure 24).
5. Along the relatively steep northeast margin, turbidite channel complexes extended to the slope toe, initiating a new submarine fan system. This fan has been informally called the WRLU fan for its location beneath Walker Ridge and Lund MMS areas (Figure 24). Deposition in this fan system continued for much of the remaining Pliocene.
6. Across most of the slope, depositional loading of the shallow salt canopy began a process of molding the minibasin province that is reflected in the slope structure and topography of today (Figures 1 and 6). Beneath the outer shelf, salt withdrawal caused active growth of the South Cameron fault family (Figure 4).

Oxygen isotopic data indicate inflow of glacial meltwater into the Gulf by latest Pliocene (Joyce et al., 1993). Development of the North American ice sheet profoundly altered drainage systems flowing into the Gulf. The paleo-Mississippi drainage basin was integrated as north-flowing streams were dammed and diverted south. Recurrent climate changes and consequent meltwater pulses began the process of excavation of the Mississippi Valley (Saucier, 1994) (Figure 1). As the valley was cut and back filled by glacial outwash, the Red and Tennessee Rivers were intermittently and then permanently trapped. The single Mississippi “Father of Waters” that now drains the middle of the United States was established by Late Pleistocene.

Development of a singularly large river draining into the central Gulf of Mexico created an extensive fluvial-dominated delta and subjacent slope apron system (Figure 25). At the same time, the high-amplitude, high-frequency glacioeustatic sea-level changes of the Pleistocene punctuated Pleistocene stratigraphy. Rapid transgressions forced shorelines temporarily landward 150–250 km, creating broad shelves. Subsequent sea-level draw downs carved deep valleys across the shelves and, together with the high rates of sediment supply, forced delta lobes to the shelf edge. Instabilities associated with rapid shelf edge deposition, pulses of glacial outwash and

frequent sea-level changes triggered a phase of mass wasting and submarine canyon erosion and filling unlike any previously seen in the basin (Figure 25). Canyon excavation was most active on the east flank of the delta system. The Quaternary Mississippi fan system, the third in the succession of Neogene abyssal fan systems, has been fed through these canyons. Smaller, relatively short-lived canyons have created smaller fans, such as the Bryant fan.

Beneath the prograding slope apron, minibasins continued to subside and fill as many delta-fed turbidite channel/lobe complexes and debris flows spilled down slope from prograding shelf-margin deltas. Salt mobilization and loading beneath the outer shelf is recorded by growth of the south Cameron and South Eugene Island fault families (Figure 4).

The modern Gulf margin reflects, in sediment distribution and morphology, the latest Pleistocene Wisconsin lowstand and subsequent Holocene transgression. Much of the modern shoreline is relatively stable, lying at or near shoreline positions of the previous interglacial highstands. However, the Louisiana coastal zone is a product of the extensive Holocene progradation and abandonment of a succession of Mississippi delta lobes. Ongoing subsidence and wetland loss largely reflects the natural instabilities of such a young deltaic coast line.

6. PATTERNS AND GENERALIZATIONS IN GULF DEPOSITIONAL HISTORY

The northern Gulf of Mexico history is long and complex. However, some common themes emerge. In addition, the high rate of sediment supply and accumulation creates an unusually complete record of nearly 160 Ma of North American geologic history.

6.1. Sediment supply: Sources and drainage history

Siliciclastic depocenters and reconstructed paleogeographies of the northern Gulf margin reflect and amplify the story of tectonism within the North American continent. Mesozoic drainage axes primarily focused into the Maverick basin, East Texas basin, Mississippi salt basin, and Apalachicola embayment (Figure 26). They record five principal phases of continental drainage basin integration or reorganization:

1. Initially, syn-drift Jurassic fluvial systems arose in the remnant uplands of the southern Appalachian Mountains, and entered the northeast Gulf along the adjacent crustal sags (Figure 14).
2. By the Late Jurassic Cotton Valley episode, a southeastward-flowing fluvial system, arising from tributaries draining uplands in Colorado and New Mexico, created a new clastic depocenter within the East Texas basin (Figure 26, ETW axis).
3. High rates of clastic influx from multiple peripheral source areas were further augmented by Early Cretaceous intracontinental and basin-margin uplift at the termination of sea-floor spreading (creating the break-up unconformity and superjacent Hosston clastic episode).
4. Cenomanian thermal uplift of the Mississippi embayment, augmented by Laramide elevation of the Sabine and Monroe uplifts, rejuvenated fluvial systems of the Woodbine/Tuscaloosa episode (Figure 26, ETE axis). Principal rivers flowed into the East Texas and Mississippi salt basins.
5. Southward migration of Laramide uplift filled the southern remnant of the Cretaceous foreland basin, and clastics began to spill over into the Maverick Basin by the Late Campanian.

During the Cenozoic era, five principal and three secondary, long-lived, extrabasinal fluvial/deltaic axes provided the bulk of the sediment that infilled the northern Gulf basin (Figure 27). Four major phases of continental uplift and erosion are recorded in the shifting patterns and rates of supply (Galloway, 2005b):

1. Palaeocene through Middle Eocene pulses of Laramide uplift along the Central and Southern Rockies and Sierra Madre Oriental supported the Early Cenozoic depositional episodes. Drainages focused through the cz, HN, and MS axes (Figure 27).
2. Late Eocene through Early Oligocene crustal heating, volcanism, and consequent uplift and erosion of much of central Mexico and the southwestern United States nourished major Oligocene through Early Miocene depositional episodes. The no, RG, HN, and MS axes (Figure 27) dominated input.
3. Initiation of erosion during the Early to Middle Miocene of the Cumberland Plateau and Appalachians invigorated supply to the east-central Gulf basin. At the same time, the high-standing Rocky Mountain uplands experienced continued regional exhumation. Whether climate change or uplift triggered this Miocene phase of erosion remains controversial; current literature favours climatic causes. In either case, sediment supply was concentrated in the cr, MS, and TN axes (Figure 27).

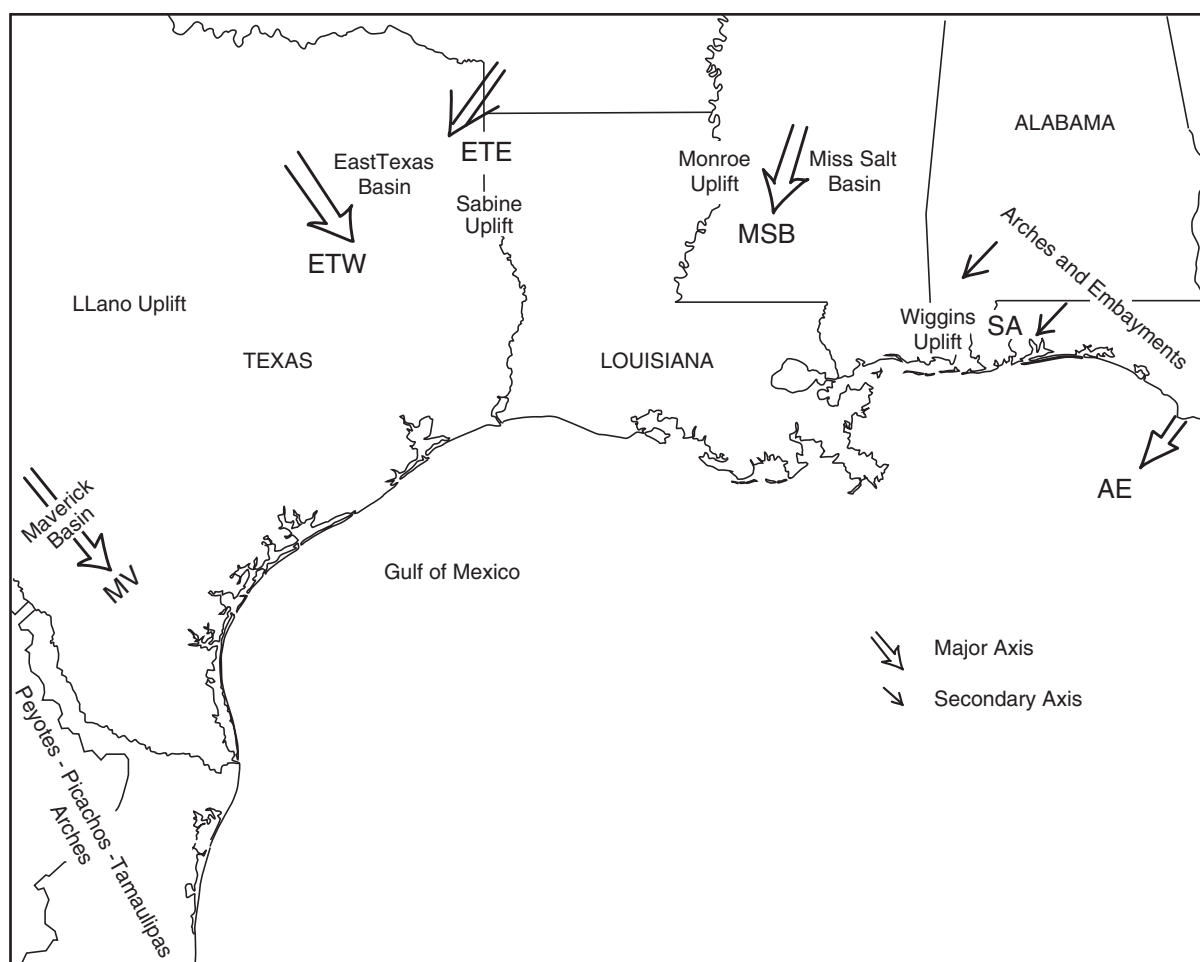


Figure 26 Principal input axes of continental fluvial systems providing sediment to the northern Gulf of Mexico basin during Mesozoic time. MV, Maverick basin axis; ETW, western East Texas basin axis; ETE, eastern East Texas basin axis; MSB, Mississippi salt basin axis; SA, sags and arches axes; AE, Apalachicola embayment axis.

Pliocene uplift of the western High Plains further rejuvenated northwestern sources and created a broad eastward slope that converged with the west-sloping alluvial apron of the eastern interior. Converging streams were variously combined and directed southward, forming the distinct Red, Mississippi, and Tennessee fluvial axes that dominated Middle Pliocene through Holocene sedimentation.

High rates of Pleistocene sediment accumulation reflect rapid Quaternary climate cycling, and glacial erosion and runoff directly into the principal sediment transport systems. Only in the Late Pleistocene was the Mississippi valley sufficiently incised that the Tennessee and Red Rivers became permanently trapped within it (Saucier, 1994).

6.2. Climate and oceanography

Climate setting of the Gulf basin has remained relatively constant throughout its history. The Gulf has generally lain within warm, subtropical climate zones. The Jurassic aridity of south-central North America is reflected in the widespread occurrence of evaporite, eolian, and sabkha deposits in the Louann and Smackover episodes. Evaporite deposits occur in Lower Cretaceous strata from northern Mexico to the Florida platform, suggesting continued hot, dry conditions. Late Cretaceous continental flooding likely led to a more equitable climate across the northern Gulf; however, limited preservation of terrestrial strata may also bias the preserved record of continental climate indicators.

By Early Cenozoic, the climate of the northern Gulf margin was uniformly wet and tropical. Lignite deposits occur widely within Paleocene and Eocene fluvial, deltaic, and shore-zone systems. A dramatic climate change occurred at the beginning of the Oligocene Frio episode. Lignite deposition ceased. Carbonate-bearing paleosoils across the Texas coastal plain indicate rapid development of a strong east-west climatic gradient from wet subtropical in Florida to arid in northern Mexico (Galloway, 1977). This strong zonal pattern persists today.

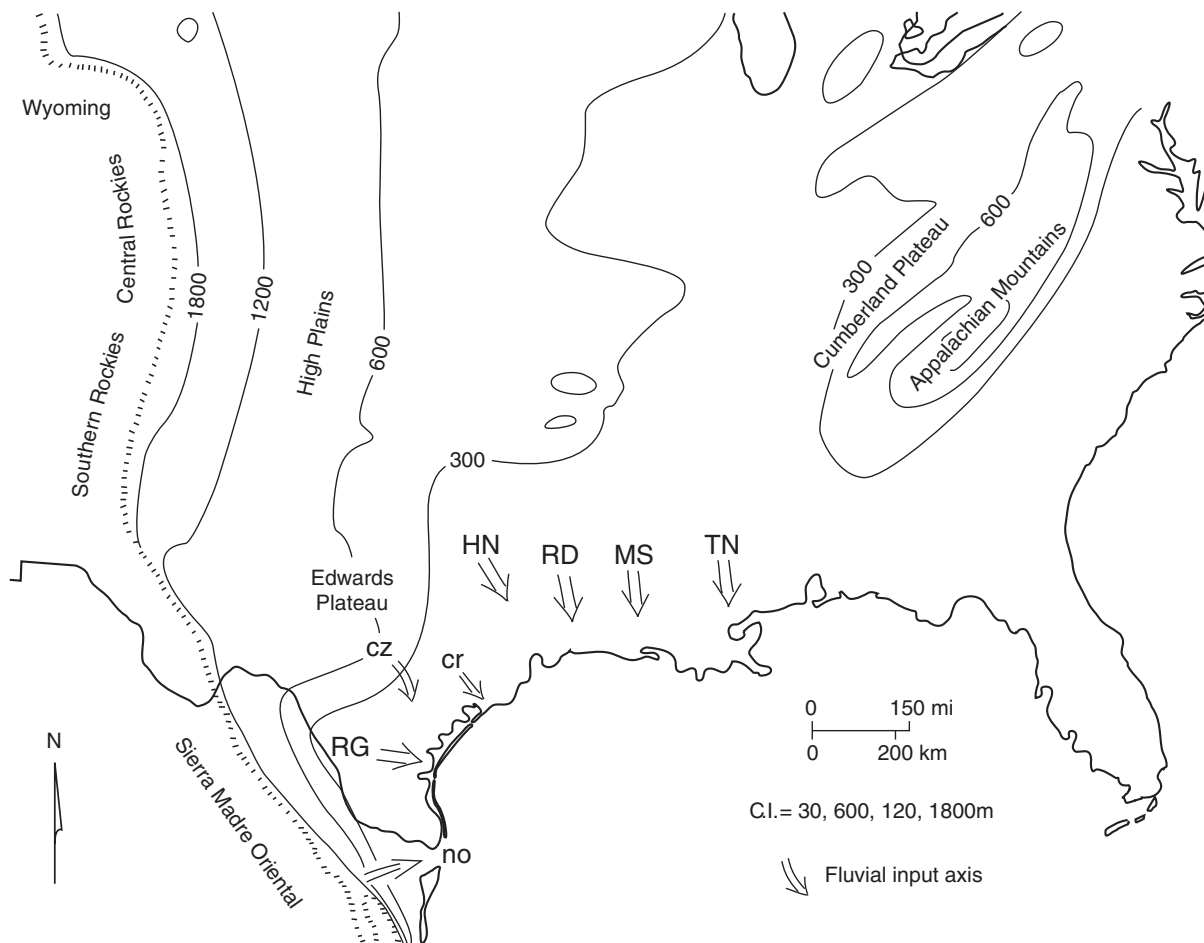


Figure 27 Principal input axes of continental fluvial systems providing sediment to the northern Gulf of Mexico basin during Cenozoic time. Principal elevated source areas, as currently distributed are also shown. From Galloway (2005b). no, Norma axis; RG, Rio Grande axis; cz, Carrizo axis; cr, Corsair axis; HN, Houston axis; RD, Red River axis; MS, Mississippi axis; TN, Tennessee axis.

Deep Gulf oceanography experienced several major evolutionary milestones. The earliest (Middle Jurassic) opening was to the Pacific Ocean across Mexico (Salvador, 1991a). By onset of the Smackover episode, the Gulf had opened to the Atlantic. Through Late Jurassic deposition, the basin evolved into a small, east-west-elongate ocean basin open to the Atlantic through broad straits between the Yucatan and Florida platforms (Marton and Buffler, 1999). During the Albian, transgression and continental flooding established a shallow connection across northwest Texas with the southern end of the Cretaceous Interior seaway. The connection persisted until the Campanian. Strong marine currents periodically flowed through this broad strait (Figure 18). The connection also allowed mixing of equatorial Tethyan faunas with cool-water faunas of the Boreal Cretaceous seaway (Lundquist, 2000).

Following the re-emergence of the basin margin following the Late Cretaceous flooding, a new pathway to the Atlantic, the Suwannee strait (also known as the Gulf trough) extended from the northeast Gulf across Georgia to the Atlantic (Popenoe et al., 1987). Initially, this strait formed a relatively deep trough that limited southward diffusion of terrigenous clastic sediment southward onto the Florida platform (Figure 20). Large erosional scours along the southeast Atlantic coastal plain indicate strong currents flowed through the trough. As Eocene deposition progressed, the strait shoaled and filled. Bridging of the strait is recorded in the appearance of siliciclastic beds within the previously pure carbonate platform facies of south Florida (Missimer and Ginsburg, 1998; Guertin et al., 2000). In the Middle Miocene, the first appearance of strong, deep-marine currents flowing through the Florida and Yucatan straits is recorded by erosion on the Florida escarpment and outer platform (Mullins et al., 1988; Guertin et al., 2000) and the first appearance of contourite drift deposits in the western Gulf abyssal plain (Galloway et al., 2000). This current system persists today as the Loop current and related systems. Glacial outflow from the North American Laurentide ice sheet first entered the Gulf in the Late Pliocene. The Pleistocene depositional episode as defined here extends to about 2.2Ma to incorporate this milestone in northern Gulf margin deposition.

The broad east-west fetch and prevailing west-to-east winds over the Gulf, at least through the Cenozoic, is reflected by the dominance of strandplain, barrier island, and wave-dominated delta systems along the north-west Gulf margin (Figures 20–25) (Galloway et al., 2000). However, the volume of sediment actually preserved in shore-zone systems relative to delta systems shows a pronounced and inexorable decrease beginning in the Middle to Late Miocene, coincident with increasing frequency and amplitude of glacioeustasy (Galloway, 2002). Development of the strong east-west climate gradient in the Oligocene is coincident with a period, extending from latest Eocene through Middle Miocene, which shows greatest development of shore-zone systems.

Tidal modification of northern Gulf of Mexico coastlines has remained minimal. Tidal facies formed in local environments, such as barrier inlets and bays, that enhanced the typically microtidal range. Only at a few times and locations did an ideal combination of shelf width and embayed coastal geography lead to development of regionally tide-dominated coasts (e.g., Queen City episode; Ramos and Galloway, 1990).

6.3. Continental margin evolution

The continental margin of the northern Gulf of Mexico experienced five general phases in its development (Figure 28A) (Winker and Buffler, 1988).

1. Evolution from ramp to defined, prograding clastic shelf-slope break during the Smackover through Hosston depositional episodes.
2. Stabilization of a rimmed carbonate platform and accentuation of slope-to-basin relief during the Early Cretaceous Sligo through Washita episodes.
3. Brief progradation of perched shelf-margin deltas and slope apron during the Woodbine/Tuscaloosa episode.
4. Drowning and blanketing by deep shelf and ramp deposits of the Late Cretaceous episodes.
5. Cenozoic offlap.

Continental margin outbuilding has primarily been accomplished during clastic-dominated episodes by progradation of large delta systems and, as a well-developed slope developed, of their subjacent, sandy slope aprons (Prather, 2000; Winker and Booth, 2000; Galloway, 2005a) (Figure 28B). Between deltaic headlands, along-strike reworked sediment of shore-zone and shelf systems also spilled over the shelf edge, creating subordinate, but also extensive shelf-fed aprons, which consist largely of muddy sediment. In the northeastern Gulf, Cretaceous shelf margins retreated up to several hundred kilometers landward in response to subsidence and long-term sea-level rise. Subsequent Cenozoic margins have advanced through a combination of deposition and global sea-level fall.

Although dominantly depositional in origin, and reflecting the long-term domination of sediment supply over subsidence, the Cenozoic continental margins of the northern Gulf record numerous phases of shelf edge and slope retreat and erosion (Edwards, 2000; Galloway et al., 2000) (Figure 28C). Such margins can be considered as destructional (Galloway, 1998a), in comparison to the offlapping, constructional continental margins that dominated Gulf deposition. Gulf destructional margins form three general groups, depending on their morphology and origin.

1. Submarine canyons are dip-elongate, erosional troughs that are hundreds of meters deep. Canyons generally occur in middle- to upper slope strata, but may extend onto the shelf as much as several tens of kilometers. They were excavated by combined processes of submarine mass wasting and turbidity current flow. Large submarine canyons cluster along margins constructed by the Paleocene–Early Eocene Wilcox depositional episodes (Figure 28C, features 4–7) and in the Late Pliocene Pleistocene margins (Figure 28C, features 18–21).
2. Megaslides are laterally extensive features that include extensive slump or slide deposits and an embayment within the upper slope and shelf edge bounded by a prominent slump scar and glide plane faults. Examples include features 2, 3, 15, and 17 (Figure 28C). They record brief, catastrophic failures of the continental margin due to tectonic tilting, salt withdrawal, or sedimentary loading. The latest Cretaceous slide (feature 2) is the most exotic if it was, in fact, triggered by the Chicxulub meteorite impact event.
3. Retrogradational slopes are the largest, longest lived, and most complex destructional slope type. Examples occur along the Yegua (feature 10), Frio (feature 12), Lower Miocene (feature 13), Middle Miocene (feature 14), and Pliocene (feature 16) margins. Such slopes exhibit complex mixtures of slump scars, canyons and erosional channels, growth faults, and thick sections of mixed shelf-margin delta, turbidite and debris flow facies. Most are distinguished by a muddy sediment wedge containing deep-water faunas and by concave reentrants in the shelf margin. Most appear to be related to pulses of evacuation of subjacent thick primary salt or salt canopies, causing subsidence and tilting and destabilization of a segment of the slope and outer shelf. Tilting led to oversteepening and slope failure. Forming and filling of the embayments commonly required more than a million years.

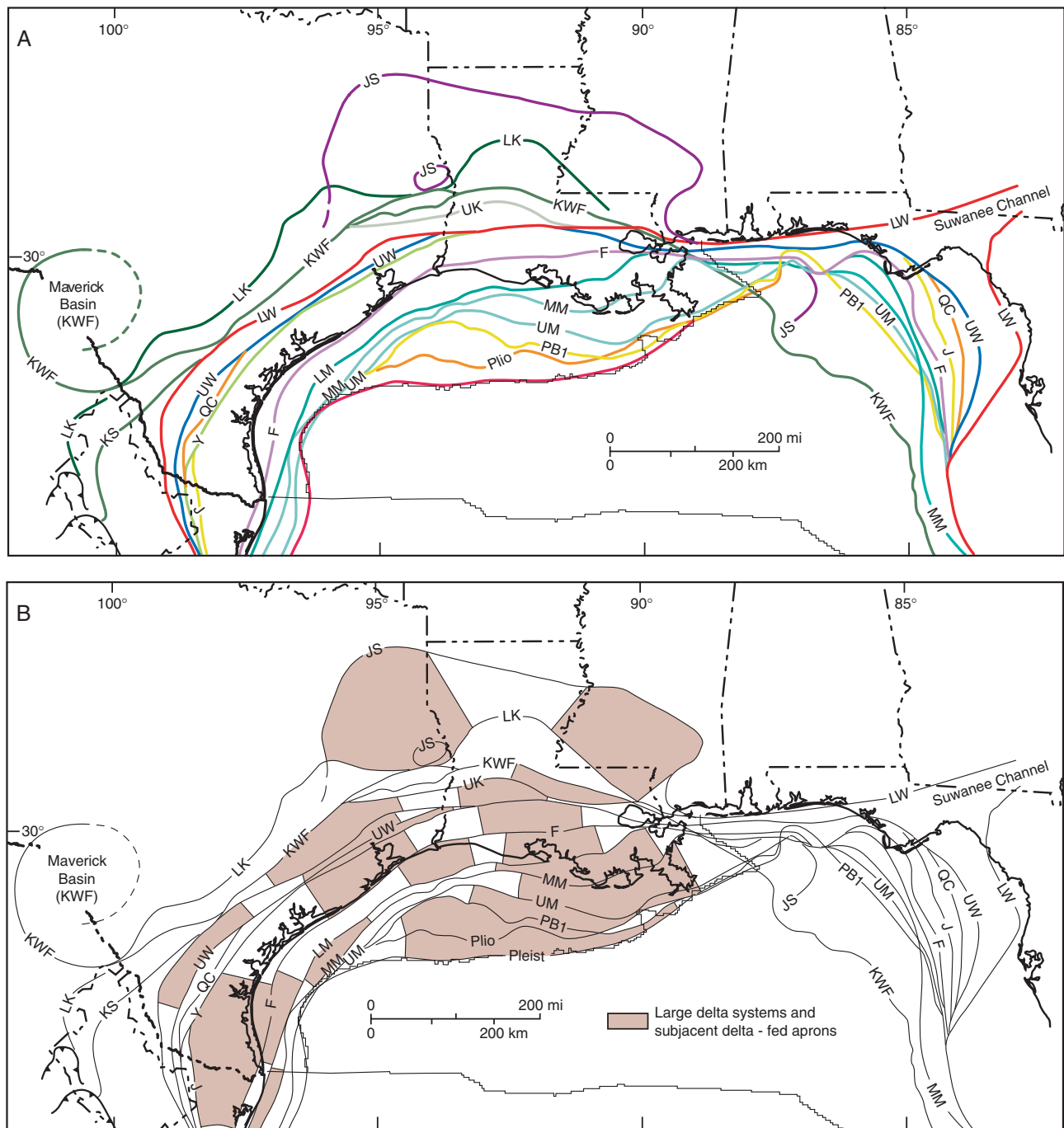


Figure 28 Mesozoic and Cenozoic shelf margins and related features of the Northern Gulf Basin. Mesozoic: JS, Smackover, LK, Hosston; KS, Sligo; KWF, Washita-Fredericksburg (Stuart City reef); UK, Upper Cretaceous (Tuscaloosa/Woodbine); LW, Lower Wilcox; UW, Upper Wilcox; QC, Queen City; Y, Yegua; JS, Jackson; F, Frio; LM, Lower Miocene; MM, Middle Miocene; UM, Upper Miocene; PB1, *Buliminella* 1; Plio, Pliocene; Pleist, Pleistocene. (A) Shelf margins at maximum offlap of principal depositional episodes. Modified from Galloway (2005a). (B) Relationship between shelf margin advance and location of major shelf-margin deltaic depocenters. (C) Location of principal submarine canyons, slides, slump scars, and compound retrogradational slope complexes. 1, Cretaceous canyon; 2, Top Cretaceous megaslide; 3, Lobo megaslide; 4, Lavaca/Smothers canyons; 5, Yoakum canyon; 6, Hardin canyon; 7, St. Landry canyon; 8, Upper Wilcox slumps; 9, Queen City slumps; 10, Lower Yegua retrogradational slope; 11, Lower to Middle Frio canyon; 12, Hackberry embayment/retrogradational slope; 13, Planulina embayment/retrogradational slope; 14, Harang embayment/retrogradational slope; 15, Middle Miocene megaslide; 16, *Globoquadrina altispira* (Middle Pliocene) retrogradational slope; 17, *Globoquadrina altispira* (Middle Pliocene) megaslide; 18, Late Pliocene slump and canyon cluster; 19, Early Pleistocene canyon cluster; 20, Late Pleistocene canyon cluster; 21, Bryant canyon; 22, DeSoto canyon; 23, Alabama scour trough.

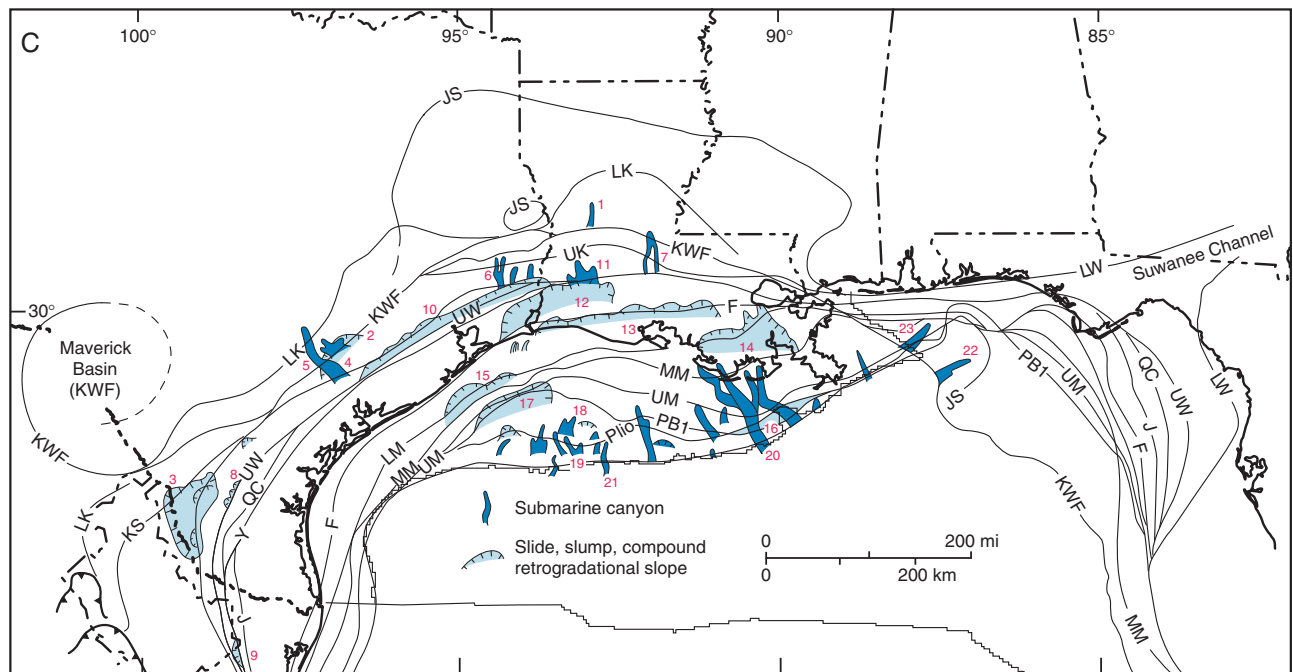


Figure 28 (Continued).

Gulf submarine canyons, slides, and retrogradational embayments in the Gulf, as in many basins, have popularly been related to eustatic sea-level fall. Such an explanation does not explain their localization along otherwise normally prograding margins, their diversity, nor their common paleogeographic location on the margins of major deltaic depocenters. On the other hand, correlations with structural elements and events are clear for many of the Gulf features.

7. ENERGY RESOURCES

The Gulf of Mexico basin is a world class repository of hydrocarbons, and has produced significant lignite and sedimentary uranium (Nehring, 1991; Riggs et al., 1991). It has been actively explored for nearly 100 years, creating a three-dimensional well and reflection seismic data base of unique abundance, extent, and diversity. Hydrocarbon exploration and development moved off-shore in mid-century, and has progressed to the slope, and now onto the abyssal plain (Crawford et al., 2003). As stated by Nehring (1991), “No other basin worldwide has even come close to producing so many discoveries for such a long period”. Because of this history, the northern Gulf has served, for more than 50 years, as a natural laboratory for understanding the sedimentary processes, facies, stratigraphy, and gravity tectonics of prograding continental margins.

Unlike many basins, where a limited volume of the stratigraphic section produces the bulk of reserves, major hydrocarbon plays are found throughout the basin fill in reservoirs nearly every depositional episode. In descending volumetric rank, hydrocarbons occur in Miocene, Oligocene, Paleocene–Eocene, Plio–Pleistocene, Upper Cretaceous, Lower Cretaceous, and Jurassic strata. Total produced and known reserves of the U. S. part of the Gulf of Mexico basin exceed 150 BBOE (billion barrels of oil equivalent) (Nehring, 1991; Crawford et al., 2003). Of this total oil and condensate aggregate about 70 Bbl; natural gas volumes are about 500 Tcf. Ongoing exploration had discovered very large reserves of oil within Paleogene and Miocene reservoirs beneath the continental slope and in tight sand and shale gas reservoir systems within Jurassic and Early Cretaceous units (Cotton Valley, Bossier, Hosston) of the north-central Gulf margin. These will substantially increase ultimate recoverable recovery in the basin, and continue to make the Gulf basin one of the most active exploration theatres in the world.

Thermally mature petroleum source rock strata occur in Jurassic, Cretaceous, and Early Cenozoic basal marls and shales, principally deposited during Eocene, Turonian, and Tithonian–Oxfordian depositional episodes (Hood et al., 2002). Generation phases have extended over several tens of millions of years, depending on source level, burial history, and ambient heat flow. A hallmark of Gulf petroleum systems is large-scale vertical migration from Mesozoic source rocks into Cenozoic reservoirs.

The long and varied history of deposition and immense volume of porous rock, combined with the equally long and complex history of gravity deformation and salt migration have created a diversity of reservoir and trap combinations rarely matched in global petroleum mega-provinces. Stratigraphic, structural, and combined trap types abound. The array of structures created by salt deformation and migration have played a particularly important role in trap development.

In addition to its hydrocarbon wealth, the Gulf of Mexico basin contains large reserves of bituminous coal and lignite (Riggs et al., 1991). Lignite is extracted from Lower Wilcox, Yegua, and Jackson strata in Texas and Louisiana. Bituminous coal occurs in Upper Cretaceous strata of northern Mexico and along the Rio Grande River.

Sedimentary uranium deposits occur along the South Texas coastal plain in strata of the Upper Wilcox (Carrizo Sandstone), Jackson (Whitsett Sandstone), Frio/Vicksburg (Catahoula Formation), Lower Miocene (Oakville Sandstone), and Middle Miocene (Goliad Sand) depositional episodes (Riggs et al., 1991). Uranium ore occurs along the irregular boundaries between reduced and oxidized parts of aquifer sand bodies known as roll fronts because of their "C"-shaped cross-section. Uranium was leached from reworked air-fall ash associated with the Middle Cenozoic volcanogenic phase (principally within the Oligocene episode), transported by groundwater into the shallow fluvial and coastal sand aquifers, and trapped by reduction by detrital organic matter and/or epigenetic sulfide minerals. Ore has been mined both by open pit and in-situ solution methods.

ACKNOWLEDGMENTS

Jeffrey Horowitz drafted the figures. Co-workers Patricia Ganey-Curry, Timothy Whiteaker, and Lisa Bingham aided in preparation of selected figures. Comments of reviewers Jim Dixon and Andrew Miall significantly improved the clarity and content. Angela McDonnell reviewed the final draft with care and efficacy.

REFERENCES

- Ambrose, W. A., Wawrzyniec, T. F., Fouad, K., Sakurai, S., Jenette, D. C., Brown, L. F., Jr., Guevara, E. H., Dunlap, D. B., Talukdar, S. C., Garcia, M. A., Romano, U. H., Vegta, J. A., Zamora, E. M., Ruiz, H. R., and Hernandez, R. C., 2005, Neogene tectonic, stratigraphic, and play framework of the southern Laguna Madre-Tuxpan continental shelf, Gulf of Mexico. *AAPG Bulletin*, v. 89, pp. 725–751.
- Badali, M., 2002, Sequence stratigraphy and seismic stratigraphy of the Lower Cretaceous section in the northeastern Gulf of Mexico. *Gulf Coast Association of Geological Societies Transactions*, v. 52, pp. 13–24.
- Bebout, D. G., 1977, Sligo and Hosston depositional patterns, subsurface of South Texas, in Bebout, D. G. and Loucks, R. G. eds., *Cretaceous carbonates of Texas and Mexico: applications to subsurface exploration*, University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 89, Austin, TX, pp. 79–96.
- Bebout, D. G., and Loucks, R. G., 1974, Stuart City trend, Lower Cretaceous, South Texas, The University of Texas at Austin, Bureau of Economic Geology Report of Investigations 78.
- Bebout, D. G., Budd, D. A., and Schatzinger, R. A., 1981, Depositional and diagenetic history of the Sligo and Hosston Formations (Lower Cretaceous) in South Texas, University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 109, Austin, TX.
- Berggren, W. A., Kent, D. V., Swisher, C. C., III, and Aubry, M.-P., 1995, A revised Cenozoic geochronology and chronostratigraphy, in Berggren, W. A., Kent, D. V., Aubry, M. P., Hardenbol, J. eds., *Geochronology, time scales and global stratigraphic correlation*. (Special Publication No. 54), Society for Sedimentary Geology, Tulsa, OK, pp. 129–212.
- Bird, D. E., Burke, K., Hall, S. A., and Casey, J. F., 2005, Gulf of Mexico tectonic history: hotspot tracks, crustal boundaries, and early salt distribution. *AAPG Bulletin*, v. 89, pp. 311–328.
- Bralower, T. J., Paull, C. K., and Leckie, R. M., 1998, The Cretaceous-Tertiary boundary cocktail: chicxulub impact triggers margin collapse and extensive sediment gravity flows. *Geology*, v. 26, pp. 331–334.
- Bryant, W. R., Lugo, J., Cordova, C., and Salvador, A., 1991, Physiography and bathymetry, in Salvador, A. ed., *The Gulf of Mexico Basin, The Geology of North America*, v. J. Geological Society of America, Boulder, CO, pp. 13–30.
- Budd, D. A., and Loucks, R. G., 1981, Smackover and Lower Buckner formations, South Texas: depositional systems on a Jurassic carbonate ramp, University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 112, Austin, TX.
- Buffler, R. T., 1991, Seismic stratigraphy of the deep Gulf of Mexico basin and adjacent margins, in Salvador, A. ed., *The Gulf of Mexico Basin, The Geology of North America*, Geological Society of America, Boulder, CO, v. J, pp. 353–388.
- Buffler, R. T., and Thomas, W. A., 1994, Crustal structure and evolution of the southeastern margin of North America and the Gulf of Mexico basin, in Speed, R. C. ed., *Phanerozoic evolution of North American continent-ocean transitions*, Geological Society of America, Boulder, CO, pp. 219–264.
- Byerly, G. R., 1991, Igneous activity, in Salvador, A. ed., *The Gulf of Mexico Basin, The Geology of North America*, Geological Society of America, Boulder, CO, v. J, pp. 91–108.
- Cao, S., Petersen, K., Lerche, I., Lowrie, A., and Sullivan, N., 1993, Cretaceous and tertiary structural history in north Louisiana, in Gulf Coast Section SEPM 13th Annual Research Conference, pp. 77–86.
- Caughey, C. A., 1977, Depositional systems of the paluxy formation, The University of Texas at Austin, Bureau of Economic Geology Geological Circular 77–8.

- Combellas-Bigott, R. I., and Galloway, W. E., 2006, Depositional and structural evolution of the Middle Miocene depositional episode, east-central Gulf of Mexico. *AAPG Bulletin*, v. 90, pp. 335–362.
- Combes, J. M., 1993, The Vicksburg formation of Texas, depositional systems distribution, sequence stratigraphy, and petroleum geology. *AAPG Bulletin*, v. 77, pp. 1942–1970.
- Corso, W., Austin, J. A., Jr., and Buffler, R. T., 1989, The Early Cretaceous platform off northwest Florida: controls on morphologic development of carbonate margins. *Marine Geology*, v. 86, pp. 1–14.
- Cossey, S., and Jacobs, R., 1992, Oligocene Hackberry formation of Southwest Louisiana: sequence stratigraphy, sedimentology, and hydrocarbon potential. *AAPG Bulletin*, v. 76, pp. 589–606.
- Cox, R. T., and Van Arsdale, R. B., 2002, The Mississippi embayment, North America: a first order continental structure generated by the Cretaceous superplume mantle event. *Journal of Geodynamics*, v. 34, pp. 163–176.
- Crawford, T. G., Burgess, G. L., Kinler, C. J., Pendergast, M. T., and Ross, K. M., 2003, Estimated oil and gas reserves, Gulf of Mexico, December 31, 2000, U.S. Department of Interior Minerals Management Service OCS Report MMS 2003-050.
- Diegel, F. A., Karlo, J. F., Schuster, D. C., Shoup, R. C., and Tauvers, P. R., 1995, Cenozoic structural evolution and tectono-stratigraphic framework of the northern Gulf coast continental margin, in Jackson, M. P. A., Roberts, D. G., and Snelson, S. eds., *Salt tectonics. A global perspective*, American Association of Petroleum Geologists, Tulsa, OK, pp. 109–152.
- Dobson, L. M., and Buffler, R. T., 1997, Seismic stratigraphy and geologic history of Jurassic rocks, northeastern Gulf of Mexico. *AAPG Bulletin*, v. 81, pp. 100–120.
- Dohmen, T. E., 2002, Age dating of expected MCSB seismic event suggests that it is the K/T Boundary. *Gulf Coast Association of Geological Societies Transactions*, v. 52, pp. 177–180.
- Dutton, S. P., 1987, Diagenesis and burial history of the Lower Cretaceous Travis Peak Formation, East Texas, The University of Texas at Austin, Bureau of Economic Geology Report of Investigations 164.
- Edwards, M. B., 1981, The live Oak delta complex: an unstable, shelf/edge delta in the deep Wilcox trend of South Texas. *AAPG Bulletin*, v. 65, pp. 54–73.
- Edwards, M. B., 1991, Control of depositional environments, eustasy, gravity, and salt tectonics on sandstone distribution in an unstable shelf edge delta, eocene Yegua formation, Texas and Louisiana. *Gulf Coast Association of Geological Societies Transactions*, v. 41, pp. 237–252.
- Edwards, M. B., 2000, Origin and significance of retrograde failed shelf margins; tertiary northern Gulf coast basin. *Gulf Coast Association of Geological Societies Transactions*, v. 50, pp. 81–896.
- Ewing, T. E., 1991, Structural framework, in Salvador, A. ed., *The Gulf of Mexico Basin*, The Geology of North America, Geological Society of America, Boulder, CO, v. J, pp. 31–52.
- Fang, Q., 2000, Biostratigraphic and sequence stratigraphic analysis of the yegua formation, Houston salt embayment, northern Gulf of Mexico, Ph.D. Dissertation, University of Texas at Austin.
- Feng, J., Buffler, R. T., and Kominz, M. A., 1994, Laramide orogenic influence on Late Mesozoic—Cenozoic subsidence history, western deep Gulf of Mexico basin. *Geology*, v. 22, pp. 359–362.
- Fiduk, J. C., Anderson, L. E., and Rowan, M. G., 2004, Extensional rafting: a new idea for structural control of shelf margin and slope facies deposition in Upper Wilcox strata of South Texas, northwestern onshore Gulf of Mexico. *Gulf Coast Association of Geological Societies Transactions*, v. 54, pp. 185–194.
- Fiduk, J. C., McBride, B. C., Weimer, P., Rowan, M. G., and Trudgill, B. D., 1995, Defining the basinward limits of salt deposition, northern Gulf of Mexico, in *Gulf Coast Section SEPM 16th Annual Research Conference*, pp. 53–64.
- Fletcher, R. C., Hudec, M. R., and Watson, I. A., 1995, Salt glacier and composite sediment-salt glacier models for the emplacement and early burial of allochthonous salt sheets, in Jackson, M. P. A., Roberts, D. G., and Snelson, S. eds., *Salt tectonics: a global perspective*, American Association of Petroleum Geologists, Tulsa, OK, pp. 77–108.
- Frazier, D. E., 1974, Depositional episodes: their relationship to the quaternary stratigraphic framework in the northwestern portion of the Gulf Basin, The University of Texas at Austin, Bureau of Economic Geology Geological Circular 71–1.
- Galloway, W. E., 1977, Catahoula formation of the Texas coastal plain: depositional systems, composition, structural development, ground-water flow history, and uranium distribution, The University of Texas at Austin, Bureau of Economic Geology Report of Investigations 87.
- Galloway, W. E., 1989a, Genetic stratigraphic sequences in basin analysis I: architecture and genesis of flooding-surface bounded depositional units. *AAPG Bulletin*, v. 73, pp. 125–142.
- Galloway, W. E., 1989b, Genetic stratigraphic sequences in basin analysis II: application to northwest Gulf of Mexico Cenozoic basin. *AAPG Bulletin*, v. 73, pp. 143–154.
- Galloway, W. E., 1998a, Siliciclastic slope and base-of-slope depositional systems: component facies, stratigraphic architecture, and classification. *AAPG Bulletin*, v. 82, pp. 569–595.
- Galloway, W. E., 1998b, Depositional processes, regime variables, and development of siliciclastic stratigraphic sequences, in Gradstein, F. M., Sandvik, K. O., and Milton, N. J. eds., *Sequence stratigraphy—concepts and applications*, Elsevier Science B.V., Amsterdam, pp. 117–140.
- Galloway, W. E., 2002, Cenozoic evolution of sediment accumulation in deltaic and shore-zone depositional systems, Northern Gulf of Mexico basin. *Marine and Petroleum Geology*, v. 18, pp. 1031–1040.
- Galloway, W. E., 2005a, Cenozoic evolution of the northern Gulf of Mexico continental margin, in *Gulf Coast Section SEPM 25th Annual Research Conference*, pp. 1–15.
- Galloway, W. E., 2005b, Gulf of Mexico basin depositional record of Cenozoic drainage basin evolution. *Fluvial Sedimentology VII*, International Association of Sedimentologists (Special Publication 35), pp. 409–423.
- Galloway, W. E., Bebout, D. G., Fisher, W. L., Cabrera-Castro, R., Lugo-Rivera, J. M., and Scott, T. M., 1991a, Cenozoic, in Salvador, A. ed., *The geology of North America: the Gulf of Mexico Basin*, Geological Society of America, Boulder, CO, v. J, pp. 245–324.
- Galloway, W. E., Dingus, W. F., and Paige, R. E., 1991b, Seismic and depositional facies of Paleocene-Eocene Wilcox Group submarine canyon fills, northwest Gulf Coast, U.S.A., in Weimer, P. and Link, M. H. eds., *Seismic facies and sedimentary processes of submarine fans and turbidite systems*, Springer-Verlag, New York, pp. 247–271.

- Galloway, W. E., Finley, R. J., and Henry, C. D., 1979, South Texas uranium province. The University of Texas at Austin, Bureau of Economic Geology Guidebook 18.
- Galloway, W. E., Ganey-Curry, P. E., Li, X., and Buffler, R. T., 2000, Cenozoic depositional history of the Gulf of Mexico basin. AAPG Bulletin, v. 84, pp. 1743–1774.
- Galloway, W. E., Henry, C. D., and Smith, G. E., 1982a, Depositional framework, hydrostratigraphy, and uranium mineralization of the Oakville Sandstone (Miocene), Texas coastal plain, The University of Texas at Austin, Bureau of Economic Geology Report of Investigations 113.
- Galloway, W. E., Hobday, D. K., and Magara, K., 1982b, Frio formation of the Texas Gulf coastal plain—depositional systems, structural framework, and hydrocarbon origin, migration, distribution, and exploration potential, The University of Texas at Austin, Bureau of Economic Geology Report of Investigations 122.
- Galloway, W. E., and Hobday, D. K., 1996, Terrigenous clastic depositional systems: applications to fossil fuel and groundwater resources, New York, Springer-Verlag.
- Galloway, W. E., Jirik, L. A., Morton, R. A., and DuBar, J. R., 1986, Lower miocene (Fleming) depositional episode of the Texas coastal plain and continental shelf: structural framework, facies, and hydrocarbon resources, The University of Texas at Austin, Bureau of Economic Geology Report of Investigations 150.
- Galloway, W. E., Liu, X., Travis-Neuberger, D., and Xue, L., 1994, Reference high-resolution correlation cross s, Paleogene section, Texas coastal plain. The University of Texas at Austin, Bureau of Economic Geology Cross Sections.
- Galloway, W. E., and Williams, T. A., 1991, Sediment accumulation rates in time and space: paleogene genetic stratigraphic sequences of the northwestern Gulf of Mexico basin. *Geology*, v. 19, pp. 986–989.
- Goldhammer, R. K., and Johnson, C. A., 2000, Middle Jurassic—Upper Cretaceous paleogeographic evolution and sequence-stratigraphic framework of the northwest Gulf of Mexico rim, in Bartolini, C., Buffler, R. T., and Cantu-Chapa, A. eds., *The Western Gulf of Mexico Basin: Tectonics, Sedimentary Basins, and Petroleum Systems*, AAPG Memoir 75, Tulsa, OK, pp. 45–81.
- Gradstein, F. M., Agterberg, F. P., Ogg, J. G., Hardenbol, J., van Veen, P., Thierry, J., and Huang, Z., 1995, A Triassic, Jurassic and Cretaceous time scale, in Berggren, W. A., Kent, D. V., Aubry, M. P., and Hardenbol, J. eds., *Geochronology, time scales and global stratigraphic correlation*, Society for Sedimentary Geology, Tulsa, OK (Special Publication No. 54), pp. 95–126.
- Gray, G. G., Pottorf, R. J., Yurewicz, D. A., Mahon, K. I., Pevear, D. R., and Chuchla, R. J., 2001, Thermal and chronological record of syn-to post-Laramide burial and exhumation, Sierra Madre Oriental, Mexico, in Bartolini, C., Buffler, R. T., and Cantu-Chapa, A. eds., *The Western Gulf of Mexico Basin: Tectonics, Sedimentary Basins, and Petroleum Systems*, AAPG Memoir 75, Tulsa, OK, pp. 159–181.
- Guertin, L. A., Missimer, T. M., and McNeill, D. F., 2000, Hiatal duration of correlative sequence boundaries from Oligocene-Pliocene mixed carbonate/siliciclastic sediments of the south florida platform. *Sedimentary Geology*, v. 134, pp. 1–26.
- Hall, D. J., Murray, S. M., and Mohm, K. W., 1998, Deep structure and evolution of the Gulf of Mexico basin, based in 15-second record seismic with 2-D pre-stack depth migration, and risking a frontier hydrocarbon play in the sub-salt foldbelts, in *Proceedings, AAPG Hedberg Research Conference “Integration of Geologic Models for Understanding Risk in the Gulf of Mexico”*, Tulsa, OK.
- Hamlin, H. S., 1988, Depositional and ground-water flow systems of the Carrizo-Upper Wilcox, South Texas, The University of Texas at Austin, Bureau of Economic Geology Report of Investigations 175.
- Handford, C. R., and Loucks, R. G., 1993, Carbonate depositional sequences and systems tracts—responses of carbonate platforms to relative sea-level changes, in Loucks, R. G. and Sarg, J. F. eds., *Carbonate sequence stratigraphy*, AAPG Memoir 57, Tulsa, OK, pp. 3–42.
- Harry, D. L., and Londono, J., 2004, Structure and evolution of the central Gulf of Mexico continental margin and coastal plain, southeast United States. *Geological Society of America Bulletin*, v. 116, pp. 188–199.
- Hildebrand, A. R., Penfield, G. T., Kring, G. T., Pilkington, D. A., Camargo, A., Jacobsen, S. B., and Boynton, W. V., 1991, Chicxulub crater: a possible Cretaceous-Tertiary boundary impact crater on the Yucatan Peninsula, Mexico. *Geology*, v. 19, pp. 867–871.
- Hovorka, S. D., and Nance, H. S., 1994, Dynamic depositional and early diagenetic processes in a deep-water shelf setting, Upper Cretaceous Austin Chalk, North Texas. *Gulf Coast Association of Geological Societies Transactions*, v. 44, pp. 269–276.
- Hood, K. C., Wenger, L. M., Gross, O. P., and Harrison, S. C., 2002, Hydrocarbon systems analysis of the northern Gulf of Mexico: delineation of hydrocarbon migration pathways using seeps and seismic imaging, in Schumacher, D. and LeSchack, L. A. eds., *Surface exploration case histories: applications of geochemistry, magnetics, and remote sensing*, AAPG Studies in Geology No. 48 and SEG Geophysical References Series No. 11, Tulsa, OK, pp. 25–40.
- Huh, S., Watkins, J. S., Kadande, R., Fiduk, J. C., Bryand, S., Silver, K. E., Bradshaw, B. E., Xue, F., and Xi, J., 1996, Regional structure and tectonics of the Texas shelf, in Jones, J. O. and Freed, R. L. eds., *Structural framework of the Northern Gulf of Mexico*, Gulf Coast Association of Geological Societies (Special Publication), Austin, TX, pp. 39–52.
- Imbert, P., 2005, The Mesozoic opening of the Gulf of Mexico: Part 1, evidence for oceanic accretion during and after salt deposition, in *Gulf Coast Section SEPM 25th Annual Research Conference*, pp. 1119–1149.
- Jackson, M. P. A., 1995, Retrospective salt tectonics, in Jackson, M. P. A., Roberts, D. G., and Snelson, S. eds., *Salt tectonics: a global perspective*, American Association of Petroleum Geologists, Tulsa, OK, pp. 1–28.
- Jackson, M. P. A. and Cramez, C., 1989, Seismic recognition of salt welds in salt tectonics regimes, in *Gulf Coast Section SEPM 10th Annual Research Conference*, pp. 77–89.
- Jackson, M. P. A., Rowan, M. G., and Trudgill, B. D., 2003, Salt-related fault families and fault welds in the northern Gulf of Mexico, The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 268.
- Jackson, M. P. A., Vendeville, B. C., and Schultz-Ela, D. D., 1994, Structural dynamics of salt systems. *Annual Reviews of Earth and Planetary Science*, v. 22, pp. 93–117.
- Jacques, J. M., and Clegg, H., 2002, Late Jurassic source rock distribution and quality in the Gulf of Mexico: inferences from plate tectonic modeling. *Gulf Coast Association of Geological Societies Transactions*, v. 52, pp. 429–440.
- Karlo, J. F., and Shoup, R. C., 1998, Tectonic provinces of the northern Gulf of Mexico, in *Proceedings, AAPG Hedberg Research Conference “Integration of Geologic Models for Understanding Risk in the Gulf of Mexico”*, Tulsa, OK.
- Joyce, J. E., Tjalsma, L. R. C., and Prutzman, J. M., 1993, North American glacial meltwater history for the past 2.3 m.y.: oxygen isotope evidence from the Gulf of Mexico. *Geology*, v. 21, pp. 483–486.

- Kauffman, E. G., and Johnson, C. C., 1997, Ecological evolution of Jurassic – Cretaceous Caribbean reefs, in Proceedings 8th International Coral Reef Symposium, v. 2, pp. 1669–1676.
- Kerans, C., and Loucks, R. G., 2002, Stratigraphic setting and controls on occurrence of high-energy carbonate beach deposits: Lower Cretaceous of the Gulf of Mexico. *Gulf Coast Association of Geological Societies Transactions*, v. 52, pp. 517–526.
- Klein, G. D., and Chaivre, K. R., 2002, Sequence and seismic stratigraphy of the bossier formation (Tithonian), western east Texas basin. *Gulf Coast Association of Geological Societies Transactions*, v. 50, pp. 551–561.
- Laubach, S. E., and Jackson, M. L. W., 1990, Origin of arches in the northwestern Gulf of Mexico basin. *Geology*, v. 18, pp. 595–598.
- Lawless, P. N., Fillon, R. H., and Lytton, R. G., III, 1997, Gulf of Mexico Cenozoic biostratigraphic, lithostratigraphic, and sequence stratigraphic event chronology. *Gulf Coast Association of Geological Societies Transactions*, v. 47, pp. 275–282.
- Liu, K., 2004, Seismic and sequence stratigraphy of Upper Cretaceous strata, offshore Alabama and Mississippi area. *Gulf Coast Association of Geological Societies Transactions*, v. 54, pp. 347–360.
- Lundquist, J. J., 2000, Foraminiferal biostratigraphic and paleoceanographic analysis of the Eagle Ford, Austin, and Lower Taylor Groups (Middle Cenomanian through Lower Campanian) of central Texas, Ph.D. Dissertation, University of Texas at Austin, Austin, TX.
- Luttrell, P. E., 1977, Carbonate facies distribution and diagenesis associated with volcanic cones—Anacacho Limestone (Upper Cretaceous), Elaine field, Dimmit County, Texas, in Bebout, D. G. and Loucks, R. G. eds., *Cretaceous carbonates of Texas and Mexico: applications to subsurface exploration*, University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 89, Austin, TX, pp. 260–285.
- MacRae, G., and Watkins, J. G., 1996, Desoto canyon salt basin: tectonic evolution and salt structural style, in Jones, J. O. and Freed, R. L. eds., *Structural framework of the Northern Gulf of Mexico*, Gulf Coast Association of Geological Societies (Special Publication), Austin, TX, pp. 53–62.
- Mancini, E. A., and Puckett, T. M., 1995, Upper Cretaceous sequence stratigraphy of the Mississippi-Alabama area. *Gulf Coast Association of Geological Societies Transactions*, v. 45, pp. 377–384.
- Mancini, E. A., and Puckett, T. M., 2005, Jurassic and Cretaceous transgressive-regressive (T-R) cycles, northern Gulf of Mexico, USA. *Stratigraphy*, v. 2, pp. 31–48.
- Mancini, E. A., Mink, R. M., Payton, J. W., and Bearden, B. L., 1987, Environments of deposition and petroleum geology of Tuscaloosa group (Upper Cretaceous), South Carlton and Pollard fields, southwestern Alabama. *AAPG Bulletin*, v. 71, pp. 1128–1142.
- Marton, G., and Buffler, R. T., 1993, Application of simple-shear model to the evolution of passive continental margins of the Gulf of Mexico basin. *Geology*, v. 21, pp. 495–498.
- Marton, G., and Buffler, R. T., 1999, Jurassic—Early Cretaceous tectono-paleogeographic evolution of the southeastern Gulf of Mexico basin, in Mann, P. ed., *Caribbean Basins. Sedimentary basins of the world*, Elsevier Science B.V., Amsterdam, v. 4, pp. 63–91.
- McBride, B. C., 1998, The evolution of allochthonous salt along a megaregional profile across the northern Gulf of Mexico basin. *AAPG Bulletin*, v. 82 part B, pp. 1037–1054.
- McFarlan, E., Jr., and Menes, L. S., 1991, Lower Cretaceous, in Salvador, A. ed., *The Gulf of Mexico Basin, The Geology of North America*, Geological Society of America, Boulder, CO, v. J, pp. 181–204.
- McGowen, M. K., and Harris, D. W., 1984, Cotton valley (Upper Jurassic) and Hosston (Lower Cretaceous) depositional systems and their influence on salt tectonics in the East Texas basin, The University of Texas at Austin, Bureau of Economic Geology Geological Circular 84–5.
- McGowen, M. K., and Lopez, C. M., 1983, Depositional systems in the nacatoch formation (Upper Cretaceous), northeast Texas and southwest Arkansas, The University of Texas at Austin, Bureau of Economic Geology Report of Investigations 137.
- Meckel, L. D., III, and Galloway, W. E., 1996, Formation of high-frequency sequences and their bounding surfaces: case study of the Eocene Yegua formation, Texas Gulf coast, USA. *Sedimentary Geology*, v. 102, pp. 155–186.
- Missimer, T. M., and Ginsburg, R. N., 1998, Homogenized carbonates and siliciclastics in the tertiary of southwest Florida. *Gulf Coast Association of Geological Societies Transactions*, v. 48, pp. 263–274.
- Moore, C. H., 1984, The Upper Smackover of the Gulf rim: depositional systems, diagenesis, porosity evolution, and hydrocarbon production, in Gulf Coast Section SEPM 3rd Annual Research Conference, pp. 283–308.
- Morton, R. A., and Ayers W. B. Jr., 1992, Plio-Pleistocene genetic sequences of the southwestern louisiana continental shelf and slope: geologic framework, sedimentary facies, and hydrocarbon distribution, The University of Texas at Austin, Bureau of Economic Geology Report of Investigations 210.
- Morton, R. A., Jirik, L. A., and Galloway, W. E., 1988, Middle-upper Miocene depositional sequences of the Texas coastal plain and continental shelf: geologic framework, sedimentary facies, and hydrocarbon plays, The University of Texas at Austin, Bureau of Economic Geology Report of Investigations 174.
- Mullins, H. T., Garduski, A. F., Hinchey, E. J., and Hine, A. C., 1988, The modern carbonate ramp slope of central west Florida. *Journal of Sedimentary Petrology*, v. 58, pp. 273–290.
- Murray, G. E., 1961, *Geology of the Atlantic and Gulf coastal province of North America*, New York, Harper and Brothers.
- Nehring, R. N., 1991, Oil and gas resources, in Salvador, A. ed., *The Gulf of Mexico Basin, The Geology of North America*, Geological Society of America, Boulder, CO, v. J, pp. 445–494.
- Nelson, T. H., 1991, Salt tectonics and listric-normal faulting, in Salvador, A. ed., *The Gulf of Mexico Basin, The Geology of North America*, Geological Society of America, Boulder, CO, v. J, pp. 73–89.
- Oliver, W. B., 1971, Depositional systems in the woodbine formation (Upper Cretaceous), northeast Texas, The University of Texas at Austin, Bureau of Economic Geology Report of Investigations 73.
- Peel, F. J., Travis, C. J., and Hossack, J. R., 1995, Genetic structural provinces and salt tectonics of the Cenozoic offshore U.S. Gulf of Mexico, in Jackson, M. P. A., Roberts, D. G., and Snelson, S. eds., *Salt tectonics: a global perspective*, American Association of Petroleum Geologists, Tulsa, OK, pp. 153–176.
- Pindell, J. L., and Kennan, L., 2001, Kinematic evolution of the Gulf of Mexico and Caribbean, in Gulf Coast Section SEPM 21st Annual Research Conference, pp. 193–220.
- Popenoe, P., Henry, V. J., and Idris, F. M., 1987, Gulf trough—the Atlantic connection. *Geology*, v. 15, pp. 327–332.
- Prather, B. E., 1992, Origin of dolostone reservoir rocks, smackover formation (Oxfordian), northeastern Gulf Coast, U.S.A. *AAPG Bulletin*, v. 76, pp. 133–163.

- Prather, B. E., 2000, Calibration and visualization of depositional process models for above-grade slopes: a case study from the Gulf of Mexico. *Marine and Petroleum Geology*, v. 17, pp. 619–638.
- Prather, B. E., Booth, J. R., Steffens, G. S., and Craig, P. A., 1998, Classification, lithologic calibration, and stratigraphic succession of the seismic facies of intraslope basins, deep-water Gulf of Mexico. *AAPG Bulletin*, v. 82, pp. 701–728.
- Ramos, A., and Galloway, W. E., 1990, Facies and sand-body geometry of the queen city (Eocene) tide-dominated delta-margin embayment, northwest Gulf of Mexico basin. *Sedimentology*, v. 37, pp. 1079–1098.
- Riggs, S. R., Ellison, S. P., Jr., Fisher, W. L., Galloway, W. E., Jackson, M. L., and Morton, R. A., 1991, Mineral resources and geopressed energy, in Salvador, A. ed., *The Gulf of Mexico Basin, The Geology of North America*, Geological Society of America, Boulder, CO, v. J, pp. 495–528.
- Roesink, J. G., Weimer, P., and Bouroullec, R., 2004, Sequence stratigraphy of Miocene to Pleistocene sediments of east-central Mississippi canyon, northern Gulf of Mexico. *Gulf Coast Association of Geological Societies Transactions*, v. 54, pp. 587–601.
- Rowan, M. G., 1995, Structural styles and evolution of allochthonous salt, central Louisiana outer shelf and upper slope, in Jackson, M. P. A., Roberts, D. G., and Snelson, S. eds., *Salt tectonics: a global perspective*, American Association of Petroleum Geologists, Tulsa, OK, pp. 199–228.
- Rowan, M. G., and Weimer, P., 1998, Salt-sediment interaction, northern green canyon and Ewing bank (offshore Louisiana), northern Gulf of Mexico. *AAPG Bulletin*, v. 82(5B), pp. 1055–1082.
- Rowan, M. G., Inman, K. E., and Fiduk, J. C., 2005, Oligo-Miocene extension at the Louann level in the northern Gulf of Mexico: kinematic models and examples. *Gulf Coast Association of Geological Societies Transactions*, v. 55, pp. 725–732.
- Salvador, A., 1987, Late Triassic-Jurassic paleogeography and origin of Gulf of Mexico basin. *AAPG Bulletin*, v. 71, pp. 419–451.
- Salvador, A., 1991a, Triassic-Jurassic, in Salvador, A. ed., *The Gulf of Mexico Basin, The Geology of North America*, Geological Society of America, Boulder, CO, v. J, pp. 131–180.
- Salvador, A., 1991b, Origin and development of the Gulf of Mexico basin, in Salvador, A. ed., *The Gulf of Mexico Basin, The Geology of North America*, Geological Society of America, Boulder, CO, v. J, pp. 389–444.
- Saucier, R. T., 1994, Geomorphology and quaternary geologic history of the Lower Mississippi valley, Vicksburg, MS, Mississippi River Commission.
- Sawyer, D. S., Buffler, R. T., and Pilger, R. H., Jr., 1991, The crust under the Gulf of Mexico basin, in Salvador, A. ed., *The Gulf of Mexico Basin, The Geology of North America*, Geological Society of America, Boulder, CO, v. J, pp. 53–72.
- Schlager, W., and Camber, O., 1986, Submarine slopes: angles, drowning unconformities, and self-erosion of limestone escarpments. *Geology*, v. 14, pp. 762–765.
- Schulte, P., Speijer, R., Mai, H., and Kontny, A., 2006, The Cretaceous–Paleogene (K–P) boundary at Brazos, Texas: sequence stratigraphy, depositional events and the Chicxulub impact. *Sedimentary Geology*, v. 184, pp. 77–109.
- Schuster, D. C., 1995, Deformation of allochthonous salt and evolution of related salt-structural systems, eastern Louisiana Gulf coast, in Jackson, M. P. A., Roberts, D. G., and Snelson, S. eds., *Salt tectonics: a global perspective*, American Association of Petroleum Geologists, Tulsa, OK, pp. 177–198.
- Scott, R. W., 1990, Models and stratigraphy of mid-Cretaceous reef communities, Gulf of Mexico, Tulsa, OK, SEPM (Society for Sedimentary Geology) Concepts in Sedimentology and Paleontology, v. 2.
- Scott, R. W., 1993, Cretaceous carbonate platform, U.S. Gulf coast, in Simo, J. A. T., Scott, R. W., and Masse, J.-P. eds., *Cretaceous carbonate platforms*, AAPG Memoir 56, Tulsa, OK, pp. 97–110.
- Seni, S. J., and Jackson, M. P. A., 1984, Sedimentary record of Cretaceous and Tertiary salt movement, East Texas basin, The University of Texas at Austin, Bureau of Economic Geology Report of Investigations 139.
- Skotnicki, M. C., and King, D. T., Jr., 1989, Depositional facies and eustatic effects in the Upper Cretaceous (Maastrichtian) Ripley formation, central and eastern Alabama. *Gulf Coast Association of Geological Societies Transactions*, v. 39, pp. 275–284.
- Sohl, N. F., Martinez R. E., Salmeron-Urena, P., and Soto-Jaramillo, F., 1991, Upper Cretaceous, in Salvador, A. ed., *The Gulf of Mexico Basin, The Geology of North America*, Geological Society of America, Boulder, CO, v. J, pp. 205–244.
- Steffens, G. S., Biegert, E. K., Sumner, H. S., and Bird, D., 2003, Quantitative bathymetric analyses of selected deepwater siliclastic margins: receiving basin configurations for deepwater fan systems. *Marine and Petroleum Geology*, v. 20, pp. 547–561.
- Stephens, B. P., 2001, Basement controls on hydrocarbon systems, depositional pathways, and exploration plays beyond the Sigsbee escarpment in the central Gulf of Mexico, in *Gulf Coast Section SEPM 21st Annual Research Conference*, pp. 129–154.
- Todd, R. G., and Mitchum, R. M., Jr., 1977, Seismic stratigraphy and global changes of sea level, part 8: identification of Upper Triassic, Jurassic, and Lower Cretaceous seismic sequences in Gulf of Mexico and offshore West Africa, in Payton, C. E. ed., *Seismic stratigraphy—applications to hydrocarbon exploration*, AAPG Memoir 26, Tulsa, OK, pp. 145–163.
- Trudgill, B. D., Rowan, M. G., Fiduk, J. C., Weimer, P., Gale, P. E., Korn, B. E., Phair, R. L., Gafford, W. T., Roberts, G. R., and Dobbs, S. W., 1999, The Perdido fold belt, northwestern deep Gulf of Mexico, part 1: structural geometry, evolution and regional implications. *AAPG Bulletin*, v. 83, pp. 88–113.
- Turner, J. R., and Conger, S. J., 1984, Environment of deposition and reservoir properties of the Woodbine Sandstone at Kurten field, Brazos Co., Texas, in Tillman, R. W. and Siemers, C. T. eds., *Siliciclastic Shelf Sediments*. S.E.P.M. (Special Publication No. 34), Tulsa, OK, pp. 215–249.
- Tyler, N., and Ambrose, W. A., 1986, Depositional systems and oil and gas plays in the Cretaceous Olmos Formation, South Texas, The University of Texas at Austin, Bureau of Economic Geology Report of Investigations 152.
- Watkins, J. S., Bradshaw, B. E., Huh, S., Li, R., and Zhang, J., 1996a, Structure and distribution of growth faults in the northern Gulf of Mexico OCS, in Jones, J. O. and Freed, R. L. eds., *Structural framework of the Northern Gulf of Mexico*, Gulf Coast Association of Geological Societies (Special Publication), Austin, TX, pp. 63–78.
- Watkins, J. S., Bryant, W. R., and Buffler, R. T., 1996b, Structural framework map of the northern Gulf of Mexico, in Jones, J. O. and Freed, R. L. eds., *Structural Framework of the Northern Gulf of Mexico*, Gulf Coast Association of Geological Societies (Special Publication), Austin, TX, pp. 95–99.
- Watkins, J. S., MacRae, G., and Simmons, G. R., 1995, Bipolar simple-shear rifting responsible for distribution of mega-salt basins in Gulf of Mexico, in *Gulf Coast Section SEPM 16th Annual Research Conference*, pp. 297–305.
- Weimer, P., and Buffler, R. T., 1992, Structural geology and evolution of the Mississippi fan fold belt, deep Gulf of Mexico. *AAPG Bulletin*, v. 76, pp. 225–251.

- Weimer, P., Varnai, P., Budhijanto, F. M., Acosta, Z. M., Martinez, R. E., Navarro, A. F., Rowan, M. G., McBride, B. C., Villamil, T., Arango, C., Crews, J. R., and Pulham, A. J., 1998, Sequence stratigraphy of Pliocene and Pleistocene turbidite systems, northern Green Canyon and Ewing Bank (offshore Louisiana), northern Gulf of Mexico. *AAPG Bulletin*, v. 82 Part B, pp. 918–960.
- Weise, D. R., 1980, Wave-dominated delta systems of the Upper Cretaceous San Miguel formation, maverick basin, South Texas, University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 107, Austin, TX.
- Winker, C. D., 1982, Cenozoic shelf margins, northwestern Gulf of Mexico. *Gulf Coast Association of Geological Societies Transactions*, v. 32, pp. 427–448.
- Winker, C. D., 1984, Clastic shelf margins of the Post-Comanchean Gulf of Mexico: implications for deep-water sedimentation, in *Gulf Coast Section SEPM 5th Annual Research Conference*, pp. 109–120.
- Winker, C. D., and Booth, J. R., 2000, Sedimentary dynamics of the salt-dominated continental slope, Gulf of Mexico: integration of observations from the seafloor, near-surface, and deep subsurface, in *Gulf Coast Section SEPM 20th Annual Research Conference*, pp. 1059–1086.
- Winker, C. D., and Buffler, R. T., 1988, Paleogeographic evolution of early deep-water Gulf of Mexico and margins, Jurassic to Middle Cretaceous (Comanchean). *AAPG Bulletin*, v. 72, pp. 318–346.
- Worrall, D. M., and Snelson, S., 1989, Evolution of the northern Gulf of Mexico, with emphasis on Cenozoic growth faulting and the role of salt, in Bally, A. W. and Palmer, A. R. eds., *The geology of North America—an overview. The Geology of North America*, Geological Society of America, Boulder, CO, v. J, pp. 97–137.
- Wu, X., and Galloway, W. E., 2002, Upper Miocene depositional history of the central Gulf of Mexico basin. *Gulf Coast Association of Geological Societies Transactions*, v. 50, pp. 1019–1030.
- Wu, S., Vail, P. R., and Cramez, C., 1990, Allochthonous salt, structure and stratigraphy of the north-eastern Gulf of Mexico. Part I: stratigraphy. *Marine and Petroleum Geology*, v. 7, pp. 318–333.
- Yurewicz, D. A., Marler, T. B., Meyerholtz, K. A., and Siroky, F. X., 1993, Early Cretaceous carbonate platform, north rim of the Gulf of Mexico, Mississippi and Louisiana, in Simo, J. A. T., Scott, R. W., and Masse, J.-P. eds., *Cretaceous carbonate Platforms*, AAPG Memoir 56, Tulsa, OK, pp. 81–96.