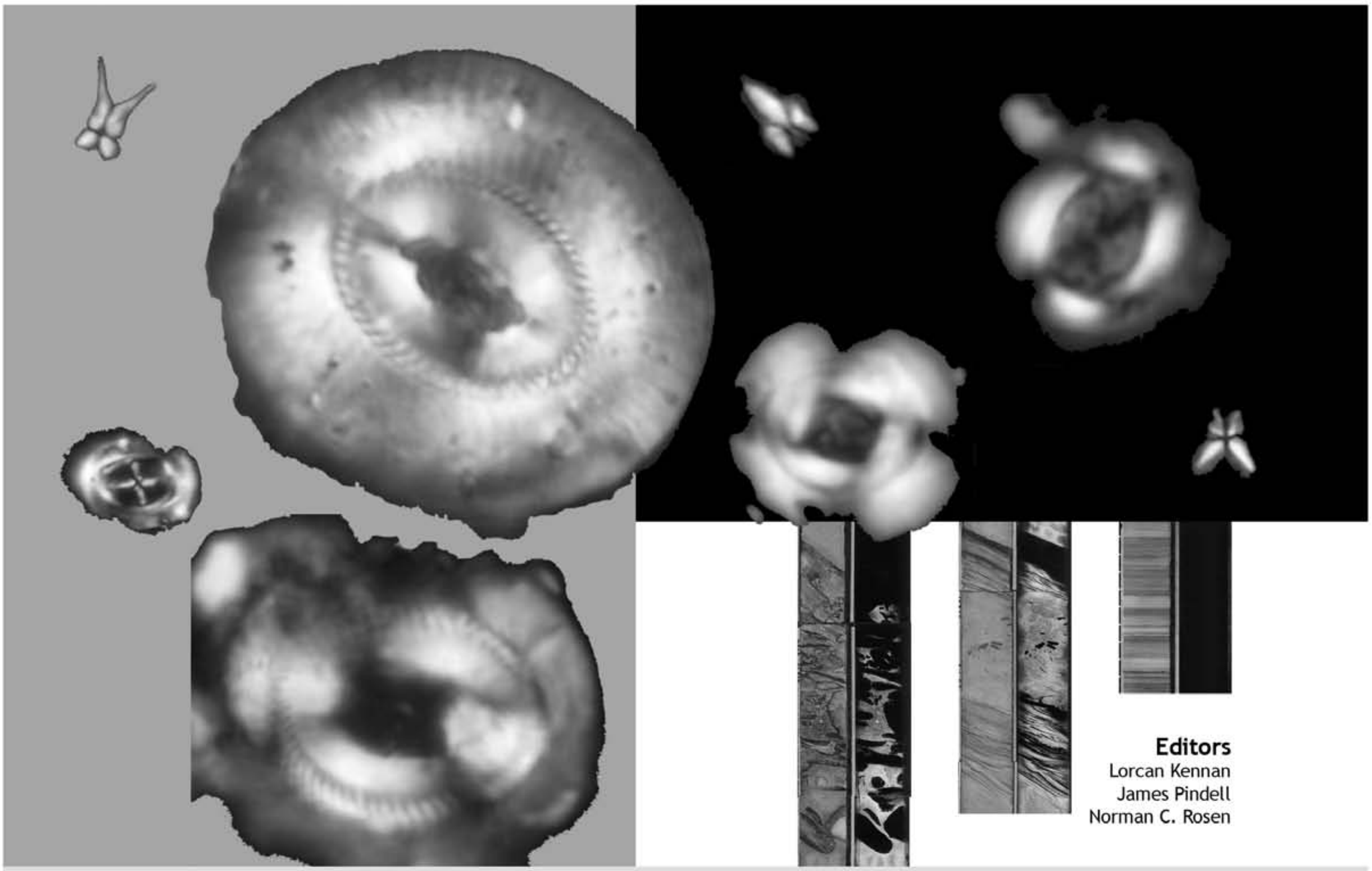
27th Annual GCSSEPM Foundation Bob F. Perkins Research Conference

December 2-5, 2007, Houston, Texas



Editors
Lorcan Kennan
James Pindell
Norman C. Rosen

The Paleogene of the Gulf of Mexico and Caribbean Basins:
Processes, Events, and Petroleum Systems

Program and Abstracts

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2007

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Houston Marriott Westchase,
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Edited by

Lorcan Kennan
James Pindell
Norman C. Rosen

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Preface

This year's theme for the 27th Annual Bob F. Perkins Research Symposium was to examine a distinctive time period within the greater evolutionary history of the Gulf of Mexico, Caribbean, and northern South America; the Paleogene. Within the longer-term Jurassic-Recent histories of these regions, some of the most enigmatic yet crucial aspects of the petroleum systems pertain to the Paleogene. In the Paleogene of the Gulf of Mexico, we have Chicxulub and its "ejecta reservoirs," the Laramide Orogeny as a proximal source of clastic sediment, strong climate changes and re-initiation of glacio-eustatic sea level changes, deep-water Wilcox sand and its age and correlation issues, deep water structures and their genesis, Paleogene canyons and their causal mechanisms, Paleogene marginal failure and re-grading of the slope, and possible isolation from the world's seas and water level draw down, to name a few. The talks, papers, and discussions given at this year's conference provided one of most comprehensive examinations of these issues made to date, thereby helping the exploration community move ahead on Paleogene leads with a shared sense of enthusiasm and risk.

Papers on the Gulf of Mexico ranged from formal USGS estimates of reserves in the Gulf's Cenozoic (Warwick *et al.*; Swanson *et al.*); stratigraphy, sedimentology, and petrophysics of the "whopper" and other sands of the deep water Wilcox system (Zarra; Winker; Fiduk; Fillon; Matava *et al.*); delivery systems of these sands to the toe of the former slope (Pindell and Kennan); discussions of the age, form, and origin of the Paleogene paleo-canyons along the Gulf's rims (Galloway; Cossey); an update on the hypothesis of Paleogene water level draw down in the Gulf as a result of the Cuban collision with the Bahamas (Berman and Rosenfeld); Paleogene bio- and other chrono-stratigraphies (Rosen; Denne; Ellwood *et al.*); structure of the Paleogene, both of Paleogene age as well as younger structuring *of* the Paleogene strata (Mount *et al.*; Seitchik *et al.*; Radovich *et al.*); an analysis of K-T impact generated sediments in Mexico (Grajales); exploration and appraisal challenges of the deep water Paleogene (Stokes *et al.*; Lewis *et al.*); and the link to Laramide deformations in the supply of sediment to the Gulf (Eguiluz); and thermal modelling at the Wilcox level of the Gulf's petroleum systems (Rowan *et al.*).

Turning to the Paleogene of northern South America, reconstructing Paleogene sandstone fairways, great rivers, and the processes that controlled them are top of the exploration checklist. Here, as with the Gulf of Mexico, the progressive release of seismic, well, and core information is allowing a consensus to form regarding tectonic evolution in the complex Caribbean plate boundary zone, upon which exploration strategies may now be based more firmly. Themes included tectonostratigraphic evolution and basin genesis (Pindell and Kennan; Gomez *et al.*); clastic sediment distribution systems (Vincent and Wach); analyses of exploration strategy and risk reduction (Villamil; Kean *et al.*); and review of criteria from the northern Andes requiring that the Caribbean Plate is of Pacific origin (Kennan and Pindell).

In both the Gulf of Mexico and northern South America, these papers looked back through the veil of Neogene evolution and examined the interrelated elements of the region's Paleogene geology. In so doing, we broadened our appreciation for what it was about the Paleogene that made it so unique, as well as so crucial to ongoing exploration efforts.

As usual, the GCSSEPM Section and Foundation and this year's technical committee are deeply grateful and indebted to all the technical contributors who have donated their time, data, and effort to give talks at the conference and papers for these transactions. This year in particular seems to have been worse than most years regarding time, given the occurrence and elevated stakes of the various license rounds. Without these valiant efforts by the entire cast of speakers, which I personally am aware involved much weekend time, we would lose one of the most important events of the year on the Houston calendar.

In addition, I personally would like to thank a number of people who played key roles in this year's meeting and transactions. Dr. Lorcan Kennan took on most of the daunting task of processing the manuscripts from initial receipt to final submission. Lorcan did a terrific job and I hope neither he nor I caused any offence to anyone in our efforts to get the papers submitted "in time," if not always "on time." "Final submissions" then went on to Norman Rosen, who personally read and standardized every paper and ensured a certain level of English comprehension across the board. The next step was for the papers to go on to Gail Bergan, who organized them all interactively onto this year's CD ROM. I would also like to thank those on the technical committee for helping to fill out the top notch technical agenda that was this year's meeting; Josh Rosenfeld, Jon Blickwede, Stuart Lake, Tomas Villamil, Larry Zarra, and Dick Fillon.

And then there are the conference sponsors, who are listed elsewhere on the CD. We are most appreciative of the corporate support that we have

received for this conference; these meetings would not be possible without it.

Finally, let us not forget that the entire Gulf of Mexico exploration community owes a huge and gracious thanks to Dr. Norman Rosen and the trustees, who share and believe in the original vision and wisdom of Bob F. Perkins and keep this fabulous annual meeting running.

James Pindell
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October, 2007

The Paleogene of the Gulf of Mexico and Caribbean Basins:
Processes, Events, and Petroleum Systems

27th Annual Gulf Coast Section SEPM Foundation
Bob F. Perkins Research Conference

Houston Marriott Westchase
Houston, Texas
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Program

Sunday, December 2

4:00–6:00 p.m. **Registration (Grand Foyer) and Poster Setup (Grand Pavilion)**
6:00–8:00 p.m. **Welcome Reception and Poster Preview (Grand Pavilion)**

Monday, December 3

7:00 a.m. **Continuous Registration (Grand Foyer)**
8:00 **Welcome, Rashel Rosen (Chair of the Board of Trustees, GCSSEPM Foundation) (Grand Pavilion)**

Session I—Monday morning:
Setting and Hydrocarbon Potential of Paleogene Sands, Gulf of Mexico
Co-Chairmen: Josh Rosenfeld and Lorcan Kennan

Session I Cont.—Monday morning:
Setting and Hydrocarbon Potential of Paleogene Sands, Gulf of Mexico

Co-Chairmen: Lorcan Kennan and Josh Rosenfeld

Keynote Address:

10:30 **Zarra, Larry**
Chronostratigraphic Framework for the Wilcox Formation (Upper Paleocene–Lower Eocene) in the Deep-Water Gulf of Mexico: Biostratigraphy, Sequences, and Depositional Systems *5*

11:15 **Pindell, James and Kennan, Lorcan**
Rift Models and the Salt-Cored Marginal Wedge in the Northern Gulf of Mexico: Implications for Deep-Water Paleogene Wilcox Deposition and Basinwide Maturation *6*

12:00–1:15 Lunch (provided)

Session II—Monday afternoon:
Paleogene Biostratigraphy and Geochronology, Gulf of Mexico

Co-Chairmen: James Pindell and Art Berman

1:30 p.m. **Rosen, Rashel N.**
Lower Paleogene Chronostratigraphy: A Review *7*

2:00 **Denne, Richard A.**
Paleogene Calcareous Nannofossil Bioevents from the Fold Belts of the Deep-Water Central Gulf of Mexico *8*

2:30 **Ellwood, Brooks B.; Fillon, Richard H.; Waterman, Arthur S.; and Kassab, Ahmed**
High Resolution Correlations: Projecting Global Data Sets into Gulf Coast Sedimentary Sequences Using Biostratigraphy and Magnetic Susceptibility *9*

3:00 Coffee

Session III—Monday afternoon:
Paleogene Canyons and Wilcox Sands: Pros and Cons of the Gulf of Mexico Draw-Down Hypothesis

Co-Chairmen: James Pindell and Josh Rosenfeld

Keynote Address:

3:30 **Galloway, William E.**
Wilcox Submarine Canyons: Distribution, Attributes, Origins, and Relationship to Basinal Sands *10*

4:15 **Cossey, Stephen P.J.**
Recent Geological Understanding of the Chicontepec Erosional "Paleocanyon," Tampico-Misantla Basin, Mexico *12*

4:45 **Berman, Arthur E. and Rosenfeld, Joshua H.**
A New Depositional Model for the Deep-Water Gulf of Mexico Wilcox Equivalent Whopper Sand—Changing the Paradigm *13*

5:20 Open discussion on the drawdown hypothesis (Grand Pavilion)

6:30–8:30 Buffet supper (provided) and open poster sessions

Tuesday, December 4

2:30 **Fillon, Richard H.**
Wilcox Depositional Architecture in the Gulf of Mexico Basin: A Framework for Improving Deep Water Exploration and Reservoir Risk 22

3:00 Coffee

Session VII—Tuesday afternoon:
Paleogene Tectonics and Stratigraphy, Northeast South America
Co-Chairmen: Tomas Villamil and Stuart Lake

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Cenozoic Kinematics and Dynamics of Oblique Collision Between two Convergent Plate Margins: The Caribbean-South America Collision in Eastern Venezuela, Trinidad and Barbados 23

4:15 **Vincent, Hasley and Wach, Grant**
Paleogene Slope Deposits; Examples from the Chaudiere, Pointe-a-Pierre and San Fernando Formations, Central Range, Trinidad 24

4:45 **Kean, Allan; Brisson, Ignacio; Preston, Chuck; Colmenares, Julio; Connolly, David; Sikora, Paul; Legarretti, Leonardo; Duddy, Ian; Pindell, James; Kennan, Lorcan; Odegard, Mark; Hossein, Hank; and Armentrout, John**
Reducing Geologic Risk in Frontier Deep Water Exploration of the Paleogene, Suriname, South America 25

5:15 Adjourn

5:30 Beer, wine, snacks, and poster sessions

8:00 Authors will remove posters; contractor will start removing display boards at 8:15 p.m.

Wednesday, December 5

Session VII Cont.—Wednesday morning:
Paleogene Tectonics and Stratigraphy, Northwest South America
Co-Chairmen: James Pindell and Tomas Villamil

8:20 a.m. **Introductory remarks, Jim Pindell**

8:30 **Gomez, Elías; Butcher, Geoff; and Stewart, Dave**
Development of the Colombian Andes and Caribbean Regions at the Interface between the South American, Caribbean, and Nazca Plates 26

9:00 **Villamil, Tomas; Vásquez, César; and Bolaños, Alix**
Differing Structural Trends of Oligocene and Miocene Tectonic Events, Northern Putumayo Basin, Colombia: Implications for Petroleum Exploration 27

9:30 **Kennan, Lorcan and Pindell, James**
Dextral Shear, Terrane Accretion and Basin Formation in the Northern Andes: Explained only by Interaction with a Pacific-Derived Caribbean Plate 28

10:00 Coffee

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Cover Image

The cover images chosen for this year's conference are from Denne: "Paleogene Calcareous Nannofossil Bioevents from the Fold Belts of the Deep-Water Central Gulf of Mexico" (nannofossils, Plate 1) and Zarra: "Chronostratigraphic Framework for the Wilcox Formation (Upper Paleocene–Lower Eocene) in the Deep-Water Gulf of Mexico: Biostratigraphy, Sequences, and Depositional Systems" (core photos, Fig. 23).

USGS Assessment of Undiscovered Oil and Gas Resources in Paleogene Strata of the U.S. Gulf of Mexico Coastal Plain and State Waters

Warwick, Peter D.
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Abstract

This report presents a review of the U.S. Geological Survey (**USGS**) 2007 assessment of the undiscovered oil and gas resources in Paleogene strata underlying the U.S. Gulf of Mexico Coastal Plain and state waters. Geochemical, geologic, geophysical, thermal maturation, burial history, and paleontologic studies have been combined with regional cross sections and data from previous USGS petroleum assessments have helped to define the major petroleum systems and assessment units. Accumulations of both conventional oil and gas and continuous coal-bed gas within these petroleum systems have been digitally mapped and evaluated, and undiscovered resources have been assessed following USGS methodology.

The primary source intervals for oil and gas in Paleogene (and Cenozoic) reservoirs are coal and shale rich in organic matter within the Wilcox Group (Paleocene-Eocene) and Sparta Formation of the Claiborne Group (Eocene); in addition, Cretaceous and Jurassic source rocks probably have contributed substantial petroleum to Paleogene (and Cenozoic) reservoirs.

For the purposes of the assessment, Paleogene strata have divided into the following four stratigraphic study intervals: (1) Wilcox Group (including the Midway Group and the basal Carrizo Sand of the Claiborne Group; Paleocene-Eocene); (2) Claiborne Group (Eocene); (3) Jackson and Vicksburg Groups (Eocene-Oligocene); and (4) the Frio-Anahuac Formations (Oligocene). Recent discoveries of coal-bed gas in Paleocene strata confirm a new petroleum system that was not recognized in previous USGS assessments. In total, 26 conventional Paleogene assessment units are defined. In addition, four Cretaceous-Paleogene continuous (coal-bed gas) assessment units are included in this report. Initial results of the assessment will be released as USGS Fact Sheets (not available at the time of this writing).

Comprehensive reports for each assessment unit are planned to be released via the internet and distributed on CD-ROMs within the next year.

Deep-Water Depositional Trends of Mesozoic and Paleogene Strata in the Central Northern Gulf of Mexico

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Abstract

Seismic reflections interpreted to be top Oligocene, top Wilcox (approximately base middle Eocene), top Cretaceous, top Jurassic, and basement were mapped across portions of the Green Canyon, Keathley Canyon, Walker Ridge, Lund, Sigsbee Escarpment, Amery Terrace, and Lund South OCS areas of the central northern Gulf of Mexico (Fig. 1). 3D Pre-stack depth migrated data were used for mapping the areas covered by allochthonous salt. 2D Pre-stack time migrated data were used for mapping the area on the abyssal plain beyond the Sigsbee Escarpment. These data cover approximately 50,000 km^2 (19,500 miles^2). Well control was obtained from data available through the Minerals Management Service.

Structure maps on the top Oligocene, top Wilcox, top Cretaceous, and basement formed the regional surfaces between which isopach/isochron maps were created to analyze depositional patterns. As might be expected, basement structure displayed the greatest relief and complexity. Outboard from the allochthonous salt of the Sigsbee Escarpment, half-graben structures indicative of rift basin topography were clearly imaged (Fig. 2). Elsewhere on the abyssal plain isolated, sharp-peaked, elevated basement features were observed between more numerous gently sloped highs. These basement structures typically had reflection terminations against their margins or flanks and continuous reflections draping them.

The top Cretaceous and top Wilcox surfaces show broad regional similarities and show less structural complexity than the basement. Outboard of the Sigsbee Escarpment, both surfaces are broadly lobate and have relatively gentle inclinations which rise to the east. The main observable differences between the two are: (**A**) the Cretaceous surface has several isolated high points reflecting underlying basement structures and (**B**) the Wilcox surface has a more lobate/interdigitate contour character. The top Oligocene surface is less lobate in appearance than either the Cretaceous or Wilcox surface and rises to the southeast (Fig. 3).

Isochron maps between the four structural surfaces reflect the underlying structure and depositional trends of the interval. Thus the basement to Cretaceous isochron shows thick Jurassic infill, Cretaceous drape in the grabens (Fig. 2), and thin to no cover over highs in the rifted basement topography. The Cretaceous to Wilcox isochron has a broad lobate form that thins gently from west to east. A very subtle down-lapping pattern is visible within the Wilcox interval on Figure 2. Deviations from this pattern occur primarily where basement structures produce isolated thins. The Wilcox to Oligocene interval shows a regional gradient of north to south thickening and only a slight influence from deeper structure. Down-lapping and thinning to the north strongly suggest a southerly source for the Oligocene interval.

Beneath the allochthonous salt of the Sigsbee Escarpment, all surfaces deepen northward and show much greater local variability. Basement is only occasionally visible as it generally lies below the fifteen kilometer limit of the available **PSDM** data. The deepest area mapped is in Green Canyon where the top Oligocene approaches twelve kilometers depth, the top Wilcox approaches thirteen kilometers, and the top Cretaceous almost fourteen and one half kilometers. These surfaces shallow to less than eight kilometers deep on the abyssal plain. Three coincident lows roughly oriented north-south suggest preferred sedi-

ment pathways and possibly areas of thicker original autothonous salt. A change on the structure and isopach maps from smooth broadly spaced contours on the abyssal plain to highly variable tightly spaced contours suggests the location for the original limits of salt deposition in this area. This location often lies close to but not exactly in line with the present day Sigsbee Escarpment (Fig. 1).

Of key interest to hydrocarbon explorationists are any factors that would effect Wilcox deposition. We have observed three factors that influence the deposition and thickness of Wilcox age strata in this area:

1. Pre-existing basement highs have caused the Wilcox to be thin or absent around those structures. Although basement topography is mostly smoothed over by the end of the Cretaceous, a few large structures still influenced deposition in the Wilcox on the abyssal plain beyond the Sigsbee Escarpment.

2. Salt nappes and salt pillows have caused thinning of Wilcox strata over those structures. Our interpretation indicates multiple kilometer thick salt nappes extruded beyond the limits of the original salt basin during the Cretaceous (Figs. 4 and 5). Inflated salt pillows associated with the nappes lay along the boundary of the salt basin. Though now deflated, the presence of these salt pillows and other salt pillows updip are recorded by the depositional thinning of Wilcox strata above them. These allochthonous bodies provided the core structure over which Wilcox and Miocene reservoirs are folded or draped at Chinook, Atlantis, Das Bump, and other important deepwater discoveries. The location of allochthonous salt at the onset of Wilcox deposition is apparently coincident with the pronounced increase in northerly dips of the Mesozoic and Paleogene strata. This relationship is consistent with originally thick autochthonous salt above the deepest mapped basement.

3. Sites of continued salt withdrawal from the autochthonous level into growing salt structures directly affected Wilcox sediment thickness. Such sites would have been primary candidates for the location of Wilcox sediment fairways. Identification and elimination of salt feeders would help in refining/defining these pathways.

Deposition of the Wilcox strata can be broadly divided into two paleogeographic domains: (**A**) a relatively complex north-westerly region characterized by pre-existing, elevated sea-floor, salt-cored structures and sites of contemporaneous salt evacuation, and (**B**) a relatively simple south-easterly region characterized by a near flat and smooth sea-floor rarely punctuated by unburied basement structures. The transition between these two regions should mark changes in Wilcox depositional styles.

In the more complex topographic region, Wilcox depositional events were forced to interact with relatively rapid changing sea-floor dips. Whereas in the more simple region to the southeast, a much more unconfined sea-floor presented limited impediment to widespread expansion of depositional events exiting the more complex region to the north-west.

Drilling of Wilcox strata to-date has been mainly in the simpler south-easterly region and in the transition zone to the more complex Wilcox geometries towards the north-west.

Figure 4 shows an example of one salt nappe and its contractional deformation front that lies in close proximity but basinward of the Sigsbee Escarpment. Thrust relationships suggest that the nappe continued to move/inflate until the end of the Cretaceous. An inflated salt pillow associated with the nappe is present through the Oligocene but then deflates during the Miocene. This interpretation is supported by the thin but depressed Wilcox and Oligocene section behind the nappe today. We predict that the edge of the salt basin lies behind the nappe, below where the Wilcox and Oligocene intervals begin dipping to the north.

Figure 5 shows another example of a salt nappe that lies in about thirty kilometers inside of the Sigsbee Escarpment. This nappe does not have a deformational front associated with it. But an inflated salt pillow is associated with this nappe as in Figure 4. Similar to Figure 4, the interpretation is supported by a thin but depressed Wilcox section behind the nappe. In contrast, evacuation of the pillow begins in the Oligocene, as evidenced by the Oligocene age turtle structure. Evacuation continues into the Miocene until the pillow is completely deflated. The nappe remnant is all that remains of this salt body. Unique to these two examples, but possibly typical of most salt pillows around the edge of the salt basin, loading has forced salt backwards (updip) into the salt basin. In Figure 4, the reversal of salt movement is about ten kilometers. In Figure 5, the reversal of salt movement may be twenty to twenty-five kilometers.

Structural Style and Evolution of Traps in the Paleogene Play, Deepwater Gulf of Mexico

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Abstract

A basic understanding of the structural evolution and timing of trap development in the deep water Paleogene play is critical in prospect risk assessment. In this paper, regional and prospect scale interpretations and restorations are used to illustrate structural styles and evolution of common traps associated with the Paleogene play in the north-central and northwest deep water Gulf of Mexico. In this area, the interplay between salt tectonics and depositional systems throughout Late Mesozoic and Tertiary time has resulted in complex scenarios of structural trap development—which can be quite variable in style and timing. Processes typically involved in the formation of these traps are discussed, including: (A) subsidence of sedimentary depocenters into an autochthonous salt layer and synchronous salt canopy emplacement via a salt stock feeder network that borders the depocenters; (B) a component of regional, downdip contraction above the autochthonous salt layer (the magnitude of which is variable, often relatively small—but large enough to squeeze the salt stock feeder system, and generate frontal fold structures at the downdip limit of the salt basin), and (C) weld development through displacement of salt within large salt features (salt features that are part of the canopy system, or large salt features that are rooted to the autochthonous salt layer) by relatively late deposition. Several structural case studies of common trap styles (generated by the processes listed above) are used to illustrate the complexity and dynamic history of trap formation. Examples of Paleogene play trap types discussed include: (1) three-way dip closed structures bounded by salt stocks, squeezed salt stocks, or salt welds, and (2) four-way dip closed anticlinal structures, which are formed either in response to contraction or subsidence of a sedimentary depocenter onto a base of autochthonous salt surface.

Chronostratigraphic Framework for the Wilcox Formation (Upper Paleocene–Lower Eocene) in the Deep-Water Gulf of Mexico: Biostratigraphy, Sequences, and Depositional Systems

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Abstract

The Wilcox Formation (upper Paleocene–lower Eocene) is a world-class hydrocarbon resource in the Gulf of Mexico. Since the late 1920's, the onshore Wilcox trend has produced primarily gas from fluvial, deltaic, and shallow marine sandstone reservoirs from southwest Louisiana to south Texas and northeast Mexico. Total estimated ultimate recoverable reserves (**EUR**) from the onshore trend exceed 30 trillion cubic feet (**TCF**) of natural gas, or 5 billion barrels of oil equivalent (**BBOE**), most of which has already been produced. Recent exploration in the offshore Gulf of Mexico has documented a deep-water Wilcox turbidite trend containing significant hydrocarbon resources. Since 2001, exploration and appraisal drilling has discovered nearly 2.5 billion barrels of potentially producible oil reserves in the deep-water Wilcox trend.

Chronostratigraphic analysis is the key to correlating accurately the established onshore Wilcox trend to the new deep-water Wilcox trend. Stratigraphy for the onshore Wilcox is documented in numerous publications, but there are differences in ages assigned to various lithostratigraphic components of the section. A new onshore chronostratigraphic model based on integrated paleontologic data from downdip wells is presented to clarify the ages of Wilcox sequences in the Texas subsurface. This onshore model is consistent with the new chronostratigraphic framework developed for the deep-water Wilcox.

The primary focus of this paper is a detailed description of a new deep-water Wilcox chronostratigraphic framework. Five chronostratigraphic units are recognized. In ascending order, they are; Wilcox 4, Wilcox 3, Wilcox 2, Wilcox 1B, and Wilcox 1A. These units represent early lowstand turbidite deposits of single third-order sequences or groups of third-order sequences. Each unit is defined by relevant biostratigraphic control, sequences and systems tracts, depositional systems, and sedimentary processes.

On the basin floor, early lowstand sandy turbidite sequences are characterized as channelized fan systems or distributary fan systems. Sand-poor intervals on the basin floor are in bypass zones or are condensed. The lower slope is mudstone dominated by turbidite channels and discrete ponded fans. Sedimentary processes are interpreted from approximately 3,000 feet of conventional core, which is used to calibrate interpretation of depositional systems.

Since the initial deep-water Wilcox well at Baha prospect in 2001, more than 20 wildcat wells have penetrated Wilcox turbidites, resulting in a 65 to70 percent discovery rate. With continued exploration and appraisal success in the last six years, the Wilcox has become an increasingly important trend in the deep-water Gulf of Mexico.

Rift Models and the Salt-Cored Marginal Wedge in the Northern Gulf of Mexico: Implications for Deep-Water Paleogene Wilcox Deposition and Basinwide Maturation

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Abstract

Two primary issues continue to plague geological assessments of the Gulf of Mexico. The first is the common view of "mother salt," with terms such as "basinward depositional limit" or "onlap limit" of salt being used in reference to the deep Gulf basin without apparent concern for whether or not this limit is depositional. Backstripping techniques clearly show that the crust in the deep Gulf is typical oceanic crust, accreted (crystallized) at about 2.7 km paleo-water-depth, such that this contact cannot be a depositional one if the salt was deposited in shallow water in a basin more or less full to sea level. We argue that the seaward salt limit, even where not reactivated in the Tertiary, is a structural contact formed by salt flow onto oceanic crust. The second is the portrayal of the abyssal plain continuing well north of today's continental slope prior to the Miocene, and approaching the Sligo-Stuart City carbonate shelf edge (to beneath present-day onshore areas) in the Late Cretaceous. These portrayals appear to presume that the Louann Salt was conveniently "stored" beneath the northernmost abyssal plain (*i.e.*, without bathymetric expression) until the Cenozoic. This paper sets out to revise these long-held concepts, and to replace them with alternatives that explain primary observations in the Gulf much better. We start by assessing the Jurassic rift configuration and its impact on subsequent basin development, which in our view was very different to traditional models. We propose that a "salt-cored marginal sediment wedge" existed between the Sligo-Stuart City carbonate shelf edge and the deep water Wilcox trend which provided a continuous (but perhaps stepped) continental slope, down which Wilcox clastic sediments were free to flow from source to sink without first having to cross hundreds of kilometers of flat abyssal plain to reach their final position. In addition, the analysis hints at a mechanism for the incision of deep canyons (*e.g.*, Yoakum) along the northern and western Gulf shelf margins and leads us to propose a new maturation mechanism in the northern Gulf margin.

Lower Paleogene Chronostratigraphy: A Review

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Abstract

Although some unpublished planktonic foraminiferal zonations were being used for onshore subsurface Wilcox correlation prior to 1994, Rosen *et al*. (1994) was one of the first publications suggesting a tested zonation and relating it to relative changes of coastal onlap. Since 1994, hundreds of additional wells have been analyzed, resulting in the refinement of the zonation and a better understanding of the depositional environment.

A refined early Eocene to basal Paleocene zonation for subsurface Reklaw–Wilcox–Midway formations, based on 21 planktonic and 24 benthonic foraminiferal datum markers, has been established. Their correlation to global planktonic **P**-Zones as well as the local benthonic foraminiferal zones is given. The environment in which they were deposited and their relation to 13 condensed sections, as related to maximum flooding surfaces and system tract boundaries in subsurface Texas and Louisiana, are discussed. Their similarities and differences with the recent ultra-deep water Wilcox discoveries are compared.

This zonation is based on analysis of more than 600 wells, construction of several regional environmental maps, and integration with electric logs and 2,500 miles of high-resolution seismic data, in the Wilcox trend, south Texas to central Louisiana.

Paleogene Calcareous Nannofossil Bioevents from the Fold Belts of the Deep-Water Central Gulf of Mexico

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Abstract

Although the Oligocene to middle Eocene sediments of the fold belts of the deep-water central Gulf of Mexico are generally condensed and fossiliferous, many open-ocean and nearshore calcareous nannofossil markers are very rare or non-existent, necessitating the use of non-standard markers and assemblage changes (bioevents). These bioevents are based on species' highest occurrences, consistent last occurrences, downhole abundance increases, morphometric changes, and acmes. Forty-five bioevents have been identified in the Oligocene to Middle Eocene of the northern Gulf Basin (onshore and offshore) utilizing 52 calcareous nannofossil species. As 10 of these horizons are based on nearshore forms and not recognized in the deep-water, 35 bioevents have been found in the deep-water Gulf of Mexico. This compares to the 14 zones and subzones of the standard nannofossil zonation schemes. Twenty-six additional species have been determined to be useful as zonal "flags."

The lower Eocene and upper Paleocene sediments are expanded and contain few nannofossils. Seventeen bioevents have been identified in the northern Gulf Basin utilizing 25 calcareous nannofossil species. Due to the low fossil abundances and possible unconformities, only 10 of these bioevents have been found in the deep-water Gulf of Mexico. There are 12 standard zones and subzones within this interval, but 10 of the zonal boundaries are defined by species' bases, and therefore not reliable in a petroleum industry context. Thirty-three additional species are useful as zonal "flags". The lower Paleocene section is generally either very condensed or missing, with the exception of the K/T boundary debrite.

High Resolution Correlations: Projecting Global Data Sets into Gulf Coast Sedimentary Sequences Using Biostratigraphy and Magnetic Susceptibility

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Abstract

High resolution stratigraphy is important in understanding sedimentary systems in the Gulf of Mexico basin. We have been using magnetic susceptibility measurements, a relatively new, abiotic method, to characterize global stratotype sections defined for the Paleogene and projecting that work into the Gulf Coast. When magnetic susceptibility is combined with chronostratigraphically calibrated biostratigraphic data, such as that provided by our ongoing multi-well Gulf of Mexico basin-wide graphic correlation project, very high resolution is possible. Here we show preliminary data for the Paleocene, including the Paleocene-Eocene boundary stratotype in Egypt, and use characteristic in that data to identify the boundary location in the Gulf Coast. The MGS-1 Harrell core (southeastern Mississippi) and the OSM-2 Wahalak core (southwestern Alabama) penetrate Wilcox "type" section, sampling member beds of the Clayton, Porters Creek, Naheola, Nanafalaya, Tuscahoma, and Hatchetigbee formations. Results of this investigation illustrate the potential utility of the methods for detailed stratigraphic studies in the Gulf Basin. We plan to extend our Gulf Basin magnetic susceptibility chronology through the Eocene in an effort to clarify unresolved stratigraphic problems in ultra deep-water Gulf of Mexico sediments of Paleocene and Eocene age that are important targets of the petroleum exploration industry. Of particular interest will be examination of the age and duration of the Eocene foraminiferal and calcareous nannofossil "barren interval" and the radiolarian zones identified within it.

Wilcox Submarine Canyons: Distribution, Attributes, Origins, and Relationship to Basinal Sands

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Abstract

The Wilcox Group contains most of the documented large submarine canyons and slump scars within the northern Gulf of Mexico Paleogene section. Indeed, comparable abundance and scale of canyons is not seen again in the Gulf until the late Neogene. Four styles of shelf margin excavation morphologies can be differentiated based on published examples:

1. Simple slump scars.
2. Submarine canyons created by retrogradational slumping.
3. Graded, mature submarine canyons.
4. Valley-form cross-shelf gorges.

These styles appear to be part of a continuum; many examples share elements of two or more types. However, most canyons have been mapped using limited well control, and their illustrated morphology may largely reflect the interpreter's use of fluvial morphologic analogues as much as data constraints.

Wilcox canyons typically occur in geographically localized clusters, which are centered beneath the central and upper Texas coastal plain and the central Louisiana coastal plain. Two of the clusters occur on the flanks of the lower–middle Wilcox Houston delta system; the third lies on the progradational front of the lower Wilcox Holly Springs delta system. Canyon clusters appear to occur at or near major tectonic-stratigraphic domain boundaries of one or more Wilcox deposodes. Several of the largest canyons, including the Yoakum canyon, correlate with two thin, regional marine flooding units, the Yoakum and Big shales. However, known canyons also occur at several additional stratigraphic positions at the base of and within the Paleocene lower Wilcox genetic sequence. Recurrent shelf margin mass wasting events could have been triggered by seismic shocks initiated along the Laramide tectonic front, which lay along the west and northwest margin of the Gulf basin.

Detailed analyses of the Yoakum and Lavaca canyons showed that they were excavated (at least in their late stage of development) across the Wilcox shelf and deltaic platform during times of local to regional transgression by processes of headward slumping and erosion by submarine currents. Canyon cutting and filling occurred sufficiently rapidly that steep (up to thirty degree) unstable canyon walls consisting of unconsolidated slope and prodelta muds were buried and preserved. Infilling occurred during subsequent progradational advance of the shore line. The obvious canyons were largely mud filled. However, sand bodies were present within the fill of both the Yoakum and Lavaca canyons. Fill of the Lavaca canyon was extensively cored and consists of turbidite channel and levee facies suspended within volumetrically dominant, muddy debris flow deposits. Intact slump blocks of canyon-bounding delta front successions were also found. Updip reaches of canyons typically included a lower onlap fill and a superimposed, mud-dominated progradational fill.

The presence of clusters of canyons along the updip Paleocene continental margin suggests a genetic relationship to turbidite channel and lobe sand bodies that constitute the reservoirs for the recent deep-water Paleogene discoveries. Successive canyons would have served to collect and focus sediment transport across the shelf and down the nascent Cenozoic continental slope, creating a submarine canyon—fan couple. Such highly evolved sediment transport systems would allow efficient separation of bed load (sand) from suspended load (silt/clay) as sediment gravity flows traveled from the shelf margin and upper slope, through mature canyons, and onto large, abyssal plain fan systems with well segregated upper, middle, and lower fan provinces. The high net/gross sections of channeled turbidite lobe sand bodies penetrated in the Mississippi

Fan and Perdido fold-belt fairways likely have accumulated in the sand-rich middle fan. Paleogeographic reconstruction places the sand-rich middle fans more than 200 km basinward from the slope toe. Although impressive, such dimensions are typical of many sandy Quaternary abyssal fan systems.

Recent Geological Understanding of the Chicontepec Erosional "Paleocanyon," Tampico-Misantla Basin, Mexico

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Abstract

The Chicontepec Formation in eastern central Mexico has long been explored for its oil accumulations and contains several large unconformities, which in the past seem to have been miscorrelated across the Tampico-Misantla Basin. The formation is of current interest because it may help us to understand the mechanisms of delivery of the Wilcox sands in the deep Gulf of Mexico. In the northern part of the Chicontepec play, outcrop data indicate that a major unconformity occurs at about 55 Ma *(i.e.*, the Paleocene/Eocene boundary). Outcrops overlying this unconformity show a "classic" section about 150 meters thick; mass transport complexes on top of the unconformity are in turn overlain by sheet sandstones, channels, and channel levee complexes.

In the central part of the play, there is a major unconformity in the Eocene, between 47 and 53 Ma (probably late early Eocene). In the southern part of the play (in the Agua Fria Field area) the first major erosional unconformity is between 43.6 and 50.4 Ma. In the extreme southern part of the play, in the Presidente Alemán area, the oldest unconformity is at approximately 40 Ma. The unconformities all have been generated in submarine environments. Without the benefit of seismic and high-resolution biostratigraphic data, earlier workers miscorrelated these unconformities and assumed that they were one large unconformity, forming the Chicontepec "paleocanyon." All the unconformities are regional events and occur throughout the basin.

The 43.6 to 50.4 Ma erosional event (unconformity **A**) is a correlatable seismic event across a large proportion of the Tampico-Misantla Basin. This event has been cored in at least two wells. In the closest well to the canyon, a 110 meter thick mass transport deposit immediately overlies the unconformity. The mass transport deposit consists of a basal 30-meter pebbly mudstone debrite, overlain by an 80 meter thick slump. Recent interpretation in the Agua Fria, Tajin and Coapechaca (**ATC**) fields, west of Poza Rica, Veracruz, has allowed more detailed mapping of the erosional unconformities and a better estimate of the volume of material removed at unconformity **A**. In this area, the feature is up to 6 km wide and, in some places more than 600 meters of consolidated Paleocene and Cretaceous strata have been removed. Production from the **ATC** fields west of Poza Rica, is from the infill of the "paleocanyon" (canyon-fill trap) and the pre-erosion strata (canyon truncation trap), and the trapping mechanism is both stratigraphic and diagenetic in nature.

A New Depositional Model for the Deep-Water Gulf of Mexico Wilcox Equivalent Whopper Sand—Changing the Paradigm

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Introduction

The lower Tertiary (Paleogene) of the offshore Gulf of Mexico has emerged as an important frontier oil and gas play as there are a series of major discoveries in the deepest parts of the Alaminos Canyon, Keathley Canyon and Walker Ridge **OCS** protraction areas. Reservoirs consist of thin, channelized Eocene to Oligocene distal turbidite sands and thick Paleocene-Eocene amalgamated sheet sands. The latter are collectively named the "Whopper sand." The pre-Oligocene portion of this sequence correlates with the onshore Wilcox Group. The unique character of the Whopper is its generally high sand content (~70%) and great thickness (>1,000 feet), although deposited hundreds of miles seaward of the Wilcox shelf margin and slope. The presence of this voluminous sand, reported to contain substantial amounts of coarse-grained sand, so far beyond the contemporaneous shallow marine depocenters, challenges explorers to consider alternate scenarios to earlier Wilcox depositional models.

A Paleocene sea-level drop in the Gulf of Mexico by as much as several thousand feet was discussed by Rosenfeld and Pindell (2002, 2003) who proposed that tectonic closure of the Florida-Yucatan Straits isolated the Gulf of Mexico from the world ocean, causing rapid evaporative drawdown. This hypothesis was proposed to explain massive sandstone reservoirs that had just been discovered in the deep-water Perdido Fold Belt (Alaminos Canyon) of the western Gulf of Mexico. By 2007, at least 19 exploratory wells penetrated the Whopper sand across a 300 mile-wide swath of the deep Gulf of Mexico. Twelve of these wells have found oil and gas (Fig. 1 and Table 1). Reserve estimates for the deep-water lower Tertiary reservoirs currently range from 3 to 15 billion barrels of oil equivalent, and first production is scheduled for 2009-2010.

Published interpretations (*e.g.*, Meyer *et al.*, 2005; Seitchik and Powell, 2006) interpret the Whopper sand to be a distal submarine basin floor fan deposit within an uninterrupted shallow to deep-water facies succession from the Wilcox shelf margin to the Walker Ridge **OCS** protraction area. This creates serious problems of scale as no other Cenozoic depositional system has delivered sand so far from the shelf margin, much less a high net-to-gross sand sequence over 1000 feet thick more than 225 miles from the base of the coeval continental slope that would have required sand-dominated, gravity-driven density flows to travel hundreds of miles across a virtually flat basin floor.

Defenders of the distal submarine paradigm might claim that modern deep-water systems are capable of transporting sand onto the basin floor hundreds of miles from the base of the slope as, for example, in the Pleistocene Gulf of Mexico. Pleistocene basinal sand bodies, however, are confined to the main channels in shale and silt dominated fans. In fact, turbidite depositional currents require high clay content in order to prevent drop-out of suspended sand near the base of the continental slope. Corresponding shale volumes have not been found in association with the Whopper.

Rosenfeld and Pindell (*op. cit.*) proposed that the most reasonable explanation for the observed facies and thickness of the Whopper sand was a brief, though extreme, intra-Wilcox Gulf of Mexico sea-level drop approximately 55 million years ago (Ma) around the Paleocene-Eocene boundary. This sea-level fall can only be explained by evaporation following the tectonic isolation of the Gulf of Mexico due to the collision of the Cuban Arc with the Florida-Bahamas and Yucatan platforms. The Gulf dropped about 6000 feet below world sea level (Fig. 2) leading to the rapid progradation of sand-rich fan deltas, and slope and basin floor fans. Sand reached the deep basin during this forced regression by continual recycling ("cannibalization") of previously deposited material.

The presence of thick, widely distributed Wilcox sandstones in the deep-water Gulf of Mexico is an unprecedented anomaly in the Gulf Basin that cannot be adequately explained by existing deep-water models from either the modern or the ancient. Although difficult to visualize, there are several additional lines of evidence that support the drawdown hypothesis. Quoting Conan Doyle's Sherlock Holmes, "When you have eliminated all which is impossible, then whatever remains, however improbable, must be the truth."

Wilcox Structural Variations in Walker Ridge and Central Keathley Canyon

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Abstract

Detailed study of exploration wells penetrating the Wilcox interval in the Walker Ridge and Keathley Canyon protraction areas, Gulf of Mexico, support the presence of an extensive, correlative, Wilcox depositional system. They also reveal differences in structural styles and timing of formation. While mobilization of the Jurassic autochthonous salt layer results in many deep structures, their evolution and style varies across the region. South of Green Knoll in Walker Ridge, the structural style exhibits characteristics of compression and inflation, and greatest growth is in the middle to late Miocene. This style transitions into structures along remnant polygonal salt ridges resulting from evacuation of the autochthonous salt layer into the allochthonous salt canopy during the middle to late Miocene. Farther west into Keathley Canyon, earlier salt movement, possibly generated by up-dip Oligocene extension, creates structures along remnant salt ridges associated with salt evacuation and inflation.

Deep Imaging of the Paleogene, Miocene Structure and Stratigraphy of the Western Gulf of Mexico using 2D Pre-Stack Depth Migration of Mega-Regional Onshore to Deep Water, Long-Offset Seismic Data

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Abstract

The northwestern Gulf of Mexico basin has emerged as an archetype example of a robust, progradational passive margin system that induces substantial translation over underlying detachments due to gravitational loading. Despite this recognition, the difficulties in deep imaging of seismic data have continued to obscure key features of this deformation. Mega-regional, 2D, long-offset **PSDM** data help advance the interpretation of the Paleogene and Miocene of the Gulf of Mexico. We present results from new seismic line composites made up of reprocessed **PSDM** legacy onshore data (sourced from **SEI** and **GPI**), and newly acquired ocean bottom cable data and marine streamer data acquired and processed by GX Technology. Key lines from this dataset link robust, onshore shelf lowstand wedges to deep-water sediments and more clearly image deep structural styles and salt remobilization events. The lines span approximately 300 miles (500 km) from onshore Texas to the ultra-deep water and finally show the full size of geologic features, including a regional salt weld that starts onshore at the top Eocene and extends for over 100 km, ramping up to Oligocene. The interpretation highlights the effects of gravitational forces on the stratigraphic section and delineates prominent extensional faults that sole-out at major detachment levels and are linked to a newly recognized Paleogene thrust belt, as well as to previously documented Oligo-Miocene contractional belts. Significant lateral translation occurs along these detachments. The data image a key fault connection from Oligo-Miocene extensional faults down to the Louann detachment surface, and the interpretations provide viable scenarios for Oligo-Miocene expansion to drive the Perdido fold belt along the Louann detachment.

Source Rock and Reservoir Controls on Deepwater Prospectivity in the Gulf of Mexico Paleogene Play

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Abstract

Onshore at the rim of the Gulf of Mexico basin near Dallas, Texas, deposition in the Fort Worth basin during the Cretaceous and early Tertiary is the primary factor controlling maturation of the Mississippian age Barnett Shale source rock. During Laramide time, uplift of up to 2 km in the Fort Worth basin ends the generation of hydrocarbons from the Barnett Shale and the eroded sediments constitute a significant source of sediment for the Gulf of Mexico Basin. Although the Fort Worth basin is only one of many sources of sediment to the Gulf of Mexico, it is the accumulation of material from these ages that affects reservoir properties of the Paleogene age sediments in the deep water Gulf of Mexico. The emerging deep water Paleogene play in the Gulf of Mexico has seen several large discoveries in recent years in water depths greater than 2 km. Discovered hydrocarbons have gas-oil-ratios (**GOR**) significantly less than bubble point pressures suggesting early source rock maturity and late migration of hydrocarbons into traps. Paleogene reservoirs are typically encountered at depths greater than 5 km below mud line, and reservoir temperatures are greater than those encountered in lower Miocene reservoirs in the Green Canyon and Mississippi Canyon areas. These reservoir temperatures suggest quartz diagenesis may be a significant factor affecting the flow rates in individual wells in the play. This paper links together the history of Paleozoic onshore Fort Worth basin in the upper Gulf Coast and the Paleogene section in the deep water Gulf of Mexico utilizing long, regional 2D seismic lines extending from the rim of the Gulf of Mexico Basin to the current abyssal plain. Results from the two dimensional, integrated basin model developed from this present day section allow pressure, temperature, and effective stress histories to be developed over the Gulf of Mexico Basin. This study is the beginning of a more integrated physical understanding of these two diverse but related plays.

USGS Assessment of Undiscovered Oil and Gas Resources for the Oligocene Frio and Anahuac Formations, U. S. Gulf of Mexico Coastal Plain and State Waters: Review of Assessment Units

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Abstract

The Oligocene Frio and Anahuac formations were examined by the U.S. Geological Survey (**USGS**) as part of an assessment of technically recoverable undiscovered conventional and unconventional hydrocarbon resources in Paleogene and Neogene strata underlying the U.S. Gulf of Mexico Coastal Plain and state waters. Work included the identification of structural, stratigraphic, and tectonic relations between petroleum source rocks and migration pathways to Frio and Anahuac reservoirs; preliminary evaluation of the potential for shallow (less than 3,000 ft) biogenic gas accumulations; and evaluation of the potential for deep, undiscovered gas and oil accumulations in slope and basin floor areas. All assessments were conducted using USGS methodology (http://energy.cr.usgs.gov/oilgas/noga/methodology.html). Final products from the USGS assessment of the Paleogene and Neogene were reported in USGS fact sheets (Dubiel *et al*., 2007; Warwick *et al*., 2007).

Five assessment units for the Frio Formation were defined, and three of these were based on the character of the reservoirs in relation to growth faults and other related factors: (1) the Frio stable shelf oil and gas assessment unit, which contains thin (average thickness of 34 ft) and shallow reservoirs (average depth of 4,834 ft); (2) the Frio expanded fault zone oil and gas assessment unit, which contains thick (average thickness of 56 ft) and deep reservoirs (average depth of 9,050 ft) in over-pressured intervals; and (3) the Frio slope and basin floor gas assessment unit, which has potential for deep gas (greater than 15,000 ft) and extends from the downdip boundary of the expanded fault zone to the offshore State/Federal water boundary. The fourth Frio assessment unit is the Hackberry oil and gas assessment unit. The Hackberry embayment of southeast Texas and southwest Louisiana consists of a slope facies in the middle part of the Frio Formation. The fifth unit, the Frio basin margin assessment unit, extends from the updip boundary of the Frio stable shelf oil and gas assessment unit to the outcrop of the Frio. Because the basin margin unit has no production data and little potential for biogenic gas, it was not assessed; however, a description of this unit will be included in the final assessment report. An assessment unit also was defined for the Anahuac Formation, a major transgressive unit overlying the Frio.

Paleogene Stratigraphic Revision and Tectonic Implications, Gulf of Mexico Abyssal Plain

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Abstract

Paleogene stratigraphy of the northern Gulf of Mexico abyssal plain was revised using baselap surfaces that define major depocenter shifts. Age and lithologic control was provided by ties to wells in the Perdido fold belt. The three major Paleogene units, named for coeval units in Texas and Louisiana, are Wilcox-Midway (**WM**), Vicksburg-Jackson-Claiborne (**VJC**), and basal Miocene-Anahuac-Frio (**BMAF**). Late Laramide (Paleogene-lower Eocene) Wilcox submarine fans were sourced from the north, west, and northwest; each of three subunits has a different depocenter. The **VJC** submarine fan depocenter (middle Eocene to lower Oligocene) reflected sediment influx from post-Laramide uplift in Mexico and simultaneous sediment starvation from Texas and Louisiana. **BMAF** depocenters (middle Oligocene to lowermost Miocene) indicated a return to sediment input from the north and northwest. Deformation of the Perdido foldbelt began during **BMAF** time, following deposition of the Frio fan.

Exploration and Appraisal Challenges in the Gulf of Mexico Deep-Water Wilcox: Part 1—Exploration Overview, Reservoir Quality, and Seismic Imaging

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Abstract

The deep-water Wilcox trend covers more than 34,000 mi^2, extending across the Alaminos Canyon, Keathley Canyon, and Walker Ridge protraction areas, plus parts of adjacent protraction areas and Mexican territorial waters. Discoveries are in turbidite sands that have been deposited in lower slope channels and ponded fans to regionally extensive basin floor fan systems. Primary trap styles are compressional Louann salt-cored symmetrical box folds, symmetrical salt pillows, and asymmetrical salt cored thrust anticlines. More than 20 wildcat wells have been drilled in the Wilcox Trend. Recoverable reserves for each of the 12 announced discoveries range from 40 to 500 million barrels of oil (**MMBO**). Ultimately, the Wilcox trend has the potential for recovering 3 to 15 billion barrels of oil reserves (**BBO**) from these discoveries and additional untested structures. Many technical issues need to be resolved to move the billions of barrels of resources trapped in deep-water Wilcox structures to recoverable economic reserves. Exploration challenges include well depths up to 35,000 feet subsea, water depths ranging from 4,000 to 10,000 feet, and salt canopies from 7,000 to more than 20,000 feet thick. Allochthonous salt covers 90% of the trend, complicating regional reconstructions and resolution of individual structures. Appraisal challenges include: delineating and modeling reservoir quality, sand distribution, and flow capability; improving complex subsalt images; and developing cost effective drilling, completion, facility, and infrastructure designs.

Exploration and Appraisal Challenges in the Gulf of Mexico Deep-Water Wilcox: Part 2—Porosity, Permeability, and Producibility

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Introduction

Conventional deep-water Gulf of Mexico appraisal projects have typically focused on characterizing original oil in place (**OOIP**) by gathering data on reservoir distribution and defining an oil/water contact. Earlier deep-water Gulf of Mexico appraisal projects involved drilling numerous wells to determine reservoir distribution in complex depositional settings. Industry is currently experiencing a drive to accelerate deep-water appraisal projects, largely due to rig shortages, increasing well costs, and a significant turnover in deep-water leases. Appraisal projects need to understand and reduce subsurface uncertainty, despite limited well control. The challenge to accelerate appraisal and determine economic viability is particularly difficult in the deep-water Wilcox trend, where there are significant uncertainties concerning permeability distribution.

A key issue in appraising deep-water lower Tertiary Wilcox discoveries is the prediction of permeability. Wilcox permeability values are more than an order of magnitude lower than values typical of conventional upper Tertiary deep-water plays in the Gulf of Mexico. In typical upper Tertiary plays, reservoir quality is easily evaluated with conventional wireline log suites, but in much of the deep-water Wilcox trend, permeability and producibility are more difficult to estimate using wireline logs alone. Calibration of log data to whole core, supplemented with rotary side wall cores, has improved the estimation of permeability, and has also confirmed a long hydrocarbon column. Additionally, extended production tests of Wilcox reservoirs are justified in order to calibrate the permeability-thickness (**KH**) with logs. Despite intensive data collection and analysis, uncertainties in prediction of porosity and permeability remain, resulting in wide ranges of recoverable reserve estimates for discoveries in the deep-water Wilcox trend.

The current deep-water Wilcox appraisal approach within Chevron involves co-location of specialists in petrology, formation evaluation, static modeling, dynamic modeling, completions, and artificial lift. Decision analysis occurs at a higher but interactive level in order to aid the team in efficiently characterizing uncertainties. Integration of these disciplines and co-location of experts from various parts of Chevron have resulted in a high performance dynamic team that is better able to tackle the challenges of the deep-water Wilcox play.

Wilcox Depositional Architecture in the Gulf of Mexico Basin: A Framework for Improving Deep Water Exploration and Reservoir Risk

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Abstract

This study presents a revised Gulf of Mexico Basin chronology for the Paleogene based on depth vs. age graphic correlation of biostratigraphic event data from over 200,000 wells using a new Paleogene standard timescale. This places Gulf of Mexico Wilcox strata in the interval between 61.4 Ma and 51.0 Ma relative to the new time scale and provides high resolution regional stratigraphic control necessary for investigating the causes of apparent heterogeneity in deep water Wilcox age reservoirs. It brings turbidite section recorded at the deep water Baha boreholes located in the southeastern Alaminos Canyon protraction area into close agreement with important features of basin margin Wilcox stratigraphy. Lower Wilcox seafloor drainage axes are identified using GIS-based geomorphic analysis of a chronostratigraphically defined, isostatically restored basin surface. The identification of basin drainage systems reveals links between potential sediment sources in ancestral river drainages tributary to the Gulf of Mexico and deep basin fan systems. This allows assessment of relative detrital contributions from different source areas for any location in the basin. Surface gradients on the restored lower Wilcox seafloor may reflect the syndepositional distribution of energy at the seabed, related to bedforms, grain size and sorting, and may provide clues to the variable results of deep water Paleogene discoveries.

Cenozoic Kinematics and Dynamics of Oblique Collision Between two Convergent Plate Margins: The Caribbean-South America Collision in Eastern Venezuela, Trinidad and Barbados

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Abstract

Numerous structural, tectonic, and geometric aspects of the eastern South Caribbean plate boundary zone are assessed or reassessed in the light of seismic reflection data, field studies from 2000-2007, heavy mineral analysis, updated interpretation of seismic tomography, seismicity, **GPS** data, and refined plate kinematic constraints for the Cenozoic. We show that the Cretaceous passive margin of northern South America was transformed to a north-facing, slowly convergent margin in the late Maastrichtian, and that the collision between the Caribbean and South America was a collision of two convergent margins above an intervening, "doubly subducting" proto-Caribbean oceanic lithosphere. The new assessments are iteratively integrated to create semi-quantitative palinspastic reconstructions for 5, 10, 25, 31, and 42 Ma, on which paleogeographies are developed. The origin of key sandstone units are considered, due to their importance as major reservoirs, as well as the implications of the kinematic and dynamic modeling for structural timing. The primary collision between the two plates was completed by 10 Ma; subsequent motion was essentially east-west strike slip; and the deformations were driven mainly in a bow-wave model of transcurrent simple shear.

Paleogene Slope Deposits; Examples from the Chaudiere, Pointe-a-Pierre and San Fernando Formations, Central Range, Trinidad

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Abstract

Various interpretations have been proposed for depositional environments in the Trinidad-Eastern Venezuela area during the Paleogene, most without supporting sedimentological evidence. We describe lithofacies in the Chaudiere, Pointe-a-Pierre, and San Fernando formations, which suggest that sediment gravity flows were the primary delivery mechanism for the coarse-grained clastics and carbonates that characterize these formations. Outcrop examples of soft sediment deformation, block slides, and floating boulders attest to sediment instability along over-steepened gradients, consistent with a slope environment. Other common facies characteristics include low and high density turbidites and amalgamated channel fills, but there is no evidence for shallow-water reworking of sediments. The reinterpretation of a late Eocene outcrop highlights the need to resolve depositional processes along with biostratigraphy, as estimates of water depths based solely on paleontology may be underestimated. This has implications for Paleogene paleogeographic reconstructions.

Reducing Geologic Risk in Frontier Deep Water Exploration of the Paleogene, Suriname, South America

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Introduction

Exploration in frontier areas involves making interpretation based on little to no geological and geophysical (**G&G**) data; the enduring lack of data is what defines an area as frontier. The data must be extrapolated a long way to build a prospect, and in order to justify the drilling of a single well with costs that can be in excess of $30 million, it becomes important to address geologic and geophysical risk. This increases the probability of success through the application of science and the integration of different disciplines and technologies and the development of a consistent story for our recommendations. We need to address the geologic and geophysical risks associated with specific areas and prospects to determine where best to spend our time, energy, and resources and to determine what further studies are suited to this risk reduction.

This paper is based on RepsolYPF's efforts to maximize the probability of geological and geophysical (**PG&G**) success for a frontier exploration project in the offshore deepwater area of Suriname, northeastern South America (Fig. 1). The project is ongoing and this is an update of our approach to evaluating an area pre-drill. Pre-drill, one's interpretation is still valid; post-drill is where the real story is revealed.

Development of the Colombian Andes and Caribbean Regions at the Interface between the South American, Caribbean, and Nazca Plates

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Abstract

The north/northeast-striking Central Cordillera of Colombia is a major tectonic element in northwest South America that is flanked by two sedimentary-basin systems. To the east, a back-arc foreland-basin system extends from the Middle Magdalena Valley basin to the Llanos basin across the now uplifted Eastern Cordillera region. The marginal trench along the western side of the Central Cordillera evolved into forearc basins and fringing accretionary fold belts in the Lower Magdalena Valley basin and the Caribbean offshore. In this paper, we integrate recent evaluations from the Andes and Caribbean regions of Colombia and summarize the chronologies of geologic events that led to the formation of this complex convergent-margin geodynamic system. In general, such chronologies fit published models of Late Cretaceous-Cenozoic west-east movement of the Caribbean plate relative to South America, and Neogene west-east subduction of the Nazca plate underneath South America.

Differing Structural Trends of Oligocene and Miocene Tectonic Events, Northern Putumayo Basin, Colombia: Implications for Petroleum Exploration

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Abstract

3D seismic data acquired in 2007 in the northern Putumayo foothills, along the transition zone between the leading edge of the thrust belt and the basin, allows evaluation of the structural configuration and tectonic transport directions of the Oligocene and Miocene deformation events, and of the clear obliquity between them. Oligocene tectonic transport was towards the east, having an azimuth between 90° and 95°, and faults were oriented north-south (0° to 5° azimuth). The Oligocene deformation front was a thrust belt of multiple stacks, faults are relatively high-angle (30°-35° dip), and they involve the basement. The tectonic transport of the Miocene Andean Orogeny in this region was towards the southeast (azimuth of 130° to 140°); faults are of higher angle and may detach deeper within the basement. There was stratigraphic evidence suggesting that some of these faults might be reactivated extensional features. Miocene deformation was characterized by forward-breaking reverse faults and monoclinal tilting of the foredeep as in a triangle zone. The cause of this tilting could not be seen on seismic data but could be related to propagation of the tip of a triangle zone wedging somewhere within the basement. Most Andean Orogeny traps were breached and 1D basin modeling suggested that they were not charged because of timing of migration was younger than timing of Miocene trap formation. Some Oligocene traps were breached by the Miocene orogeny but some were not; these constitute the primary targets for petroleum exploration in the area.

Dextral Shear, Terrane Accretion and Basin Formation in the Northern Andes: Explained only by Interaction with a Pacific-Derived Caribbean Plate

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Abstract

Pacific-origin models for the Caribbean Plate imply strong Cretaceous interaction with the northern Andes, and this is reflected in regional structure, stratigraphy and magmatic history. Intra-American models for the origin of the Caribbean Plate do not imply this interaction and cannot explain the dramatic contrasts in Cretaceous orogenesis and magmatism between the northern Andes (Ecuador, Colombia) and the central Andes (central Peru to Bolivia). In this paper we summarize the contrasts between the Northern and Central Andes, focusing on fault offsets, magmatic history, and dated history of uplift, unroofing and erosion. The Central Andes show persistent large magnitude subduction and more or less continuous arc magmatism. Associated deformation is dominantly compressional or extensional, without significant strike-slip offsets, all related to more or less head-on relatively rapid subduction of the Farallon Plate. The Farallon Plate was also subducted beneath the Panama Arc at the rear of the Caribbean Plate. In contrast, the Northern Andes shows a protracted history of accretion of oceanic plateau basalt and island arc terranes, combined with large magnitude dextral shear, without large magnitude subduction and associated arc magmatism. All the accreted terranes have a distinctive Caribbean Plate geochemical character. Regional plate reconstructions clearly show that the Caribbean Plate originated in the eastern Pacific. A tight fit against northwestern South America and southern Mexico clearly implies that the Northern Andes deformation was caused by northward migration of the Caribbean Plate. The age of associated intense dextral shear is well constrained to the interval 100-40 Ma, and these deformation events are never seen in the Central Andes. As late as Eocene time, the triple junction between South America, the Caribbean, and the Farallon Plate, where the Panama arc joined western South America, was located west of Ecuador, and strike-slip pull-apart basins such as the Talara, Tumbes and Manabi Basins directly relate to the northward migration of the triple junction. Features associated with the subduction of the Nazca Plate only establish themselves in Ecuador, and then Colombia, as the triple junction migrates.

Laramide Deformation in the Burgos Basin, Northeastern Mexico

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Abstract

Laramide deformation is represented in stratigraphic sequences and structures in the Burgos Basin. Paleontological data support the continued eastward migration of siliciclastic facies in space and time from the western central Mexican basin at Zacatecas to the eastern Burgos Basin at Tamaulipas. In the Burgos Basin, Paleocene and Eocene Wilcox deposits are third-order sequences which may be controlled by eustatic sea level changes from 60 Ma to around 49 Ma. Overlying the upper Wilcox and lower Reklaw deposits, a regional deeply erosive surface has a suggested age around 48.5 Ma; above this unconformity a prograding wedge complex having a **TST** (upper Reklaw deposit) is identifiable. The Queen City, Weches-Cook Mountain and lower Yegua (Crockett) deposits are also third-order sequences from 48.5 to around 39.5 Ma, inferred to be controlled by eustasy and synsedimentary growth faults.

A new deeply erosive surface developed around 39.5 Ma. Above this submarine unconformity, the middle and upper Yegua were deposited and represent another prograding wedge complex having a high sedimentary rate (280 m/Ma). In the surface and subsurface of the Burgos Basin, the folded Paleocene-Eocene rocks strike north-northwest/south-southeast as a result of Laramide deformation. Isotopic and structural data in the Sabinas Basin support the idea that both unconformities (at base upper-Reklaw and at base middle-Yegua) are related to uplift and denudation in western continental areas and have been produced mainly by tectonic mechanisms, during progressive pulses of the Laramide uplift of the Sierra Madre Oriental and fold belt of the Sabinas Basin. The younger Frio sequence belongs to another tectonic event, discrete from the Laramide uplift.

Impact-Induced Sediments at the K-T Boundary: Offshore Campeche and Chiapas-Tabasco Region, Southeastern Mexico

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Abstract

An important carbonate breccia interval represents a significant portion of the Cretaceous-Tertiary (K-T) boundary sedimentary succession accumulated under deep-water conditions in the western part of the Yucatan platform, offshore Campeche, during the Chicxulub impact event. The K-T boundary sedimentary succession is located approximately 300 km westward from the center of the Chicxulub structure. This sedimentary succession consists of a single graded deposit subdivided into three main units that from base to top includes: (1) a basal 50 to 300 m-thick, coarse-grained carbonate breccia; (2) a 10 to 20 m-thick, fine-grained carbonate breccia, and; (3) a 25 to 30 m-thick, interval of sand and silt to clay-sized constituents, mostly abundant ejecta material. Additionally, a 10-20 m-thick, fine-grained calcareous breccia is recognized within the ejecta material-rich layer (unit 3) in some wells. The K-T boundary sedimentary succession is bounded at its base by a deep-water, shaly-calcareous facies of Upper Maastrichtian age and at its top by similar rocks of lower Paleocene age. Similar sedimentological characteristics and stratigraphic relationships are observed in analog outcrops in the Sierra de Chiapas (El Guayal, State of Tabasco; and Bochil, Chilil and Soyaló, State of Chiapas). Lithoclasts of the calcareous breccias are derived dominantly from platform-interior and platform-margin environments and only a few from deep-water settings. Ejecta material in unit 3 includes: shocked quartz, quartz with ballen structure, shocked plagioclase, altered melt rock, and rare pelitic schist fragments. Wireline log data, distribution, and stratigraphic relationships indicate a base-of-slope apron geometry for the thick carbonate breccia deposit.

The stratigraphic architecture and distribution of impact material within the K-T boundary sedimentary succession suggest the following sequence of events and products that probably occurred within a very short time span following the Chicxulub impact:

1. Unusually strong seismic shaking induced the collapse of the platform margin, resulting in an enormous debris flow (units 1 and 2),
2. Arrival and deposition of ballistic impact ejecta (unit 3), and
3. Reworking and deposition, possible induced by tsunami currents (carbonate breccia within unit.

Units 1 and 2 represent the most important oil reservoirs at the Campeche Bay oil fields, and unit 3 is the seal layer. Unit 4 is a dark clay bed deposited during a global decrease in ocean productivity following the meteorite impact.

Thermal Maturation History of the Wilcox Group (Paleocene-Eocene), Texas: Results of Regional-Scale Multi-1D Modeling

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Abstract

The thermal maturation history of the Paleocene-Eocene Wilcox Group has been reconstructed based on burial history models of 53 wells in the Texas coastal plain. This modeling study has been conducted in conjunction with a geologically based assessment of the oil and gas resources in Cenozoic strata of the Gulf of Mexico coastal plain and state waters. In the onshore Texas coastal plain, coals and organic-rich shales, predominantly of terrestrial origin, within the Wilcox Group are the primary source of oil (Wenger *et al.*, 1994) as well as a source of gas. The Wilcox, however, is modeled as a single unit, without subdivision into source rock and non-source rock intervals.

Generation of oil from Type III kerogen within the Wilcox Group is modeled using hydrous pyrolysis reaction kinetic parameters (Lewan, M.D., written communication, 2006). Gas generation from Type III kerogen is represented using calculated Ro values. The models are calibrated with bottom hole temperature (**BHT**), and vitrinite reflectance (**Ro %**) data for the Wilcox Group. **Ro** data from near-coastal sites have been selected to minimize the possible effects of uplift and erosion and then composited to give a regional **Ro**-depth trend.

Model calculations for the study area, the onshore Texas coastal plain, indicate that downdip portions of the basal Wilcox had reached sufficient thermal maturity to generate hydrocarbons by early Eocene (~50 Ma). This relatively early maturation is explained by rapid sediment accumulation in the early Tertiary combined with the reaction kinetic parameters used in the models. Thermal maturation increases through time with increasing burial depth and temperature, gradually moving the maturation front updip. At present day, hydrocarbon generation is complete in the downdip Wilcox within the study area but is currently ongoing in the updip portions of the formation.

Margin Tectonics: Passive Continental Margins Migrating Basinward

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Abstract

A review of the basic structure of passive continental margins suggests that their general movement along the margin is down slope and basinward. In the case of the northern Gulf of Mexico, the continental margin extends from the fall line at Little Rock, Arkansas, to the Gulf's abyssal plain. This margin represents an overall dip-oriented lateral distance of some 10 degrees latitude, circa 1200 km. It descends from continental elevations of ca. 500 m to submarine depths of greater than 3 km.

As the rifting basin rapidly evolved during the tectonic subsidence phase, various rifted basement blocks have subsided and rotated basinward and seafloor spreading and plate tectonics have determined subsidence rates. Tectonic motions within the overlying sediment cover are primarily extensional, as shown by listric faulting. Localized compression occurs at the foot of the listric faulting. Dynamic migration of shale or salt serves as a "tectonic escape" moving basinward and down slope. These motions range from margin spanning, to regional, to local, to microscopic; the motions occur on time scales varying from instantaneous to geologically slow.

The second-order sedimentary units, determined from sequence and seismic stratigraphy, record characteristics of the deposition itself. The sediments at present occur at greater depths in the subsurface than their original site of deposition as a result of subsidence and lateral migration.

This paper suggests that "margin tectonics" along passive continental margins cause general down slope movements of debris, due to both subsidence and lateral motion.

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