SUBMITTED ABSTRACTS

The Mesozoic of the Gulf Rim and Beyond: New Progress in Science and Exploration of the Gulf of Mexico Basin

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Deep-seated dynamics including crust and upper mantle impacting hydrocarbon localization within sediment-filled basins

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Hydrocarbons occur within sediments in basins within the uppermost crust. Localization is affected by regional temperature and pressure gradients as well as anomalies in sediment distribution; porosity and permeability; and breakages (faults, joints and fractures) in both soft and hard materials. In our search for these hydrocarbons, we map and record geophysical and geochemical anomalies, generally caused by sediment and crustal tectonics. Many of these in turn appear influenced and guided by lower crust-upper mantle interactions that include, among others, buoyant mantle plumes and lateral plate tectonics. In order to better understand how such a total geologic system operates, it is necessary to think of this entire sediment - basin - crust - upper mantle complex as a single unit. We must seek new and pertinent explanations for hydrocarbon occurrences including these mantle and crust influences as we extend our exploration models into new frontiers.

In summary, the cumulative actions of the entire geologic system including upper mantle to upper crust create forces and dynamics capable of modifying overlying basins and hydrocarbon-bearing sediments recording these underlying forces. We suggest that the whole petroleum system concept needs examination in light of upper mantle and crust dynamics.

With mantle plumes causing the Late Triassic North Atlantic Rifting, the evolutionary scenario here is appropriate explanation for continental rifting followed by basin initiation and subsequent deepening and in-filling and locating hydrocarbons. Plume and crust interactions and derivatives are a constant input impacting hydrocarbon formation.

Provenance of Cenozoic siliciclastic units in the Southern Gulf of Mexico by heavy-mineral determinations and geochemistry, and detrital zircon U-Pb geochronology

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We established provenance of Cenozoic sequences sampled in wells in the southern and southwestern Gulf of Mexico by heavy mineral analysis and LAICPMS detrital zircon U-Pb ages. The age spectra are dominated by Cenozoic ages. Other populations are of Cretaceous,

Late Permian-Early Triassic, and Neo-Mesoproterozoic ages. Minor Jurassic, Devonian, and Ordovician ages are included.

Paleoproterozoic-Archean ages are related to the Amazonian craton. Meso-Neoproterozoic ages (1 Ga) are ubiquitous in Mexico (Oaxaquia terrane) and are related to the Grenville orogen. Neoproterozoic ages (750-550 Ma) were possibly derived from sedimentary rocks on the Panafrican orogen. Cambrian-Ordovician ages (490-450 Ma) might relate to plutons of the Esperanza suite of the Acatlán complex. Carboniferous and Permian ages (350-290 Ma) were possibly derived from the western Gondwanan arc. Permian and Triassic ages (290-250 Ma) may represent the east Mexican arc. Late Triassic and Jurassic ages (210-170 Ma) suggest a derivation from the Nazas arc in north-central Mexico. Late Jurassic ages (160 Ma) may represent the Jurassic magmatism associated with an extensional regime. Cretaceous ages (145 Ma) might be derived from Early Cretaceous arc of Mexico. Cretaceous ages (135-90 Ma) were possibly derived from the Alisitos-Peninsular Ranges arc. Late Cretaceous-Early Palaeogene ages (90-55 Ma) suggest relations with Laramide magmatism and the Late Cretaceous volcanic province in southern Mexico.

Paleogene-Neogene zircons (50 Ma and younger) are likely related to Cenozoic volcanic arcs in Mexico such as the Sierra Madre Occidental. Three earlier recognised ignimbrite flare-ups in the Eocene-Oligocene, early Oligocene, and early Miocene, match our detrital zircon populations. Furthermore, Miocene units contain kyanite-sillimanite possibly related to medium- to high-grade rocks such as the Acatlán complex or the Guatemalan Chuacús complex. We discuss the provenance based on geochemistry of the heavy minerals.

Cenomanian Drainage Area and Sediment Routing to the Gulf of Mexico from Detrital Zircons

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The “Mid-Cretaceous” is an important transition period for Gulf of Mexico sediment-routing systems. In the Cenomanian, for the first time, the Gulf of Mexico witnessed large-scale sediment transfer beyond the extent of earlier Cretaceous reef systems and the formation of major basin-floor fans in deep water.

Detrital zircon data from the Cenomanian outcrop belt differentiates three distinct fluvial systems and elucidates contributing drainage areas for Cenomanian fans. In central Alabama, Cenomanian Tuscaloosa fluvial sandstones are dominated by Appalachian and Grenville grains (ca. 300-500 Ma and (950-1250 Ma, respectively), the archetypal signature for the Appalachian Cordillera, but also contain a distinctive population derived from the peri-Gondwanan Suwannee terrane (ca. 500-750 Ma), which accreted to Laurentia during Appalachian assembly. This

population is found today in the Apalachicola and Alabama rivers, which drain the southeastern edge of the Appalachians. Through the remainder of Alabama and Mississippi, the Tuscaloosa is dominated solely by the Appalachian-Grenville signature, very similar to the modern Tennessee River and indicates drainage of the core Appalachians extending into southwestern Virginia. Through southwestern Arkansas to north-central Texas, Cenomanian Woodbine fluvial sandstones are dominated by the Appalachian-Grenville signature, but the detrital zircon population again displays a Suwanee signature and grains derived from the Wichita Mountains of southern Oklahoma, as well as Mesoproterozoic grains derived from what is now the Midwest and Great Plains (Mid-Continent and Yavapai-Mazatzal source terranes): this assemblage represents small fluvial systems that drained the Ouachitas, deriving sediment from Pennsylvanian strata with the same DZ signature.

These data show the Appalachian-Ouachita orogen represented a continental divide between south-draining rivers that delivered sediment to the Gulf of Mexico and north-draining rivers that delivered sediment to the Western Interior Seaway and/or Boreal Sea. The dominant system was the ancestral Tennessee River, discharging to the east-central Gulf of Mexico. This model is consistent with mapped deep-water systems, in which the largest fan system is derived from rivers that entered the Gulf of Mexico in the Mississippi embayment.

Stratigraphy and Mineralogy of the Oxfordian Lower Smackover Formation in the Eastern Gulf of Mexico

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The Oxfordian Smackover Formation is generally acknowledged to be a hydrocarbon source for numerous reservoirs in the Gulf of Mexico, both onshore and offshore. More than 25 wells in the eastern Gulf of Mexico have penetrated the Smackover since 2003. Offshore, the Smackover consists predominantly of limestone and shale containing thin organic layers. Immediately above the lower Smackover is widespread shale. This thin shale is correlated as the base of the upper Smackover, which consists of interbedded shale and limestone. Within the lower Smackover is a conspicuous zone characterized by iron-bearing minerals having a matrix density commonly in excess of 3.0 g/cm^3 throughout.

This study will demonstrate that the lower Smackover in the eastern Gulf of Mexico (Mississippi Canyon and De Soto Canyon offshore areas) is composed of a series of seven units that occur in the same sequence from top to bottom in virtually every well in which the lower Smackover has been encountered. Although the seven individual units can be resolved readily with the proper wireline suite, each has a sub-seismic thickness.

The overall thickness of the lower Smackover is about 300 +/- 100 feet. Unlike the lower Smackover, the surrounding Mesozoic formations, from Cotton Valley to Norphlet, vary greatly in thickness in the eastern Gulf.

The initial correlations of the units in the lower Smackover were made by comparing the gamma ray, resistivity, and density log patterns with the computed mineralogy of Elemental Capture Spectroscopy (ECS) wireline logs. It was immediately obvious that the same sequence of beds/units was present in the lower Smackover in well after well.

However, X-Ray Diffraction (XRD) data from rotary sidewall cores is necessary to validate the mineralogy. Because the mineralogy of the ECS log is a model-based calculation from the elemental concentrations of iron, calcium, aluminum, etc., rather than a direct measurement, the modeled mineralogy can be inaccurate, as was the case in the bottom two units.

Mineralogy of the seven units has been verified by XRD analyses, albeit from a limited number of rotary sidewall cores obtained in a few wells. The top three units are limestones which vary in carbonate content. The fourth and fifth units contain significant amounts of high density minerals, particularly siderite and pyrite. The sixth layer is dominated by anhydrite. The seventh layer is a shale containing hematite.

Although wireline data is plentiful, analysis of the seven units within the lower Smackover is hampered by a paucity of rock data from sidewall cores and the complete lack of whole core. Many depositional and geochemical questions suggested by the unusual mineralogy and sequence of beds remain unanswered.

The KPg Impact Deposits in the Tampico-Misantla Basin, Eastern Mexico

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The impact of the asteroid (KPg impact event) at Chicxulub is now a well-documented geologic event which took place at the Cretaceous/Paleogene (KPg) boundary (Schulte *et al.*, 2010). However, the effect of this event is relatively unknown in the Tampico-Misantla Basin, which is only about 900 km to the west of the impact site.

In the detailed well reports in the Tampico-Misantla Basin, it was noted that a “brecha” (breccia) is often described at the top of the Cretaceous in many of the wells.. The breccia is described as being gray or white, containing mudstone clasts, having a sandy matrix, recrystallized *Globotruncanas*, and traces of chert, amber, and bentonite (for example, in the Marques-1 well). Early geologists thought the breccia had been deposited in response to the Laramide uplift of the Sierra Madre Oriental. To our knowledge, none of the 100 project wells cored the breccia.

The same KPg breccia outcrops in the southern part of the Tampico-Misantla Basin to the southwest of the town of Martinez de la Torre (Figs. 1 and 2). Here, the breccia is a clast-supported conglomerate consisting of cobbles and boulders of limestone, sandstone (medium to coarse grained), and quartz. The matrix is a medium- to coarse-grained sandstone. The KPg contact has been documented just to the west of this outcrop (Mark Bitter, personal communication). The limestone clasts are thought to have been derived from the Tuxpan

platform to the northeast, and the sandstone clasts are thought to have been derived from the Sierra Madre Oriental to the west by the backwash of the tsunami generated by the impact event.

Figure 1. Outcrop of the KPg breccia in the southern part of the Tampico-Misantla Basin, southwest of Martinez de la Torre. Note poorly-sorted clasts of limestone and sandstone.

Figure 2. Close-up of the outcrop of the K/T breccia in the southern part of the basin, southwest of Martinez de la Torre. Note the poorly-sorted texture and variety of clast types.

In many of the well reports, the wellsite geologists also note that the "Velasco Formation" overlies this breccia. The Velasco Formation is always described as a shale, red, gray, or brown, and compacted. The Velasco Formation has been cored in the Entabladero-101 well from 1140-1149m and is described as a compacted grey/brown shale (Fig. 3). It is devoid of sand.

Figure 3. Photograph of one meter of cored Velasco Formation from the Entabladero-101 well at a depth of 1147-48m. The lithology is described as a compacted grey/brown shale.

In this study, the presence and thickness of both the breccia and the Velasco Formation were noted and mapped from the well reports. The wells were drilled between 1936 and 2010 and the early wellsite geologists were probably not always aware of the detailed stratigraphic sequence and certainly not aware of the relevance of the breccia in the basin. The thicknesses of both the breccias and Velasco Formations were estimated from the cuttings descriptions in the wells.

The breccia is absent in the northern third of the Chicontepec Basin. The thickness of the breccia deposit varies between 4 m and 38 m, and is generally about 10-15 m thick. The deposit is fan-shaped, the source is interpreted to be from the northeast (Tuxpan platform), and it pinches out to the southwest (Fig. 4). The only carbonate source area that is present to the northeast is the Faja de Oro atoll, an Albian age reef complex. Additionally, the distribution of the Velasco Formation seems to mimic the distribution of the breccia, albeit covering a slightly larger area. The Velasco Formation varies in thickness between 16 m and 145 m, but it is generally in the range of 30-40 m thick.

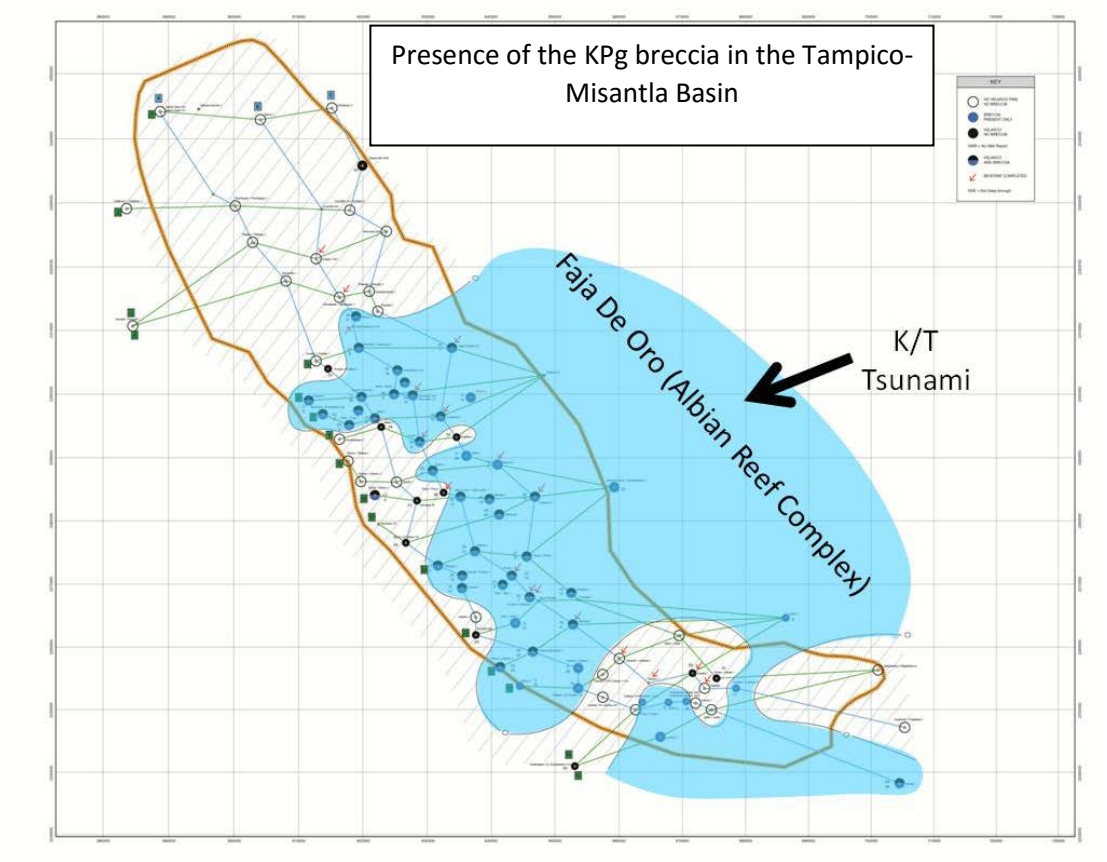

Figure 4. Presence of the K/T breccias in the Tampico-Misantla Basin shown in blue. Dots are well control points The shale-rich Velaso formation is present outside and within the blue outline and overlies the breccia.

It is proposed that the breccia plus the Velasco Formation are actually a megabed created by the huge tsunami (estimated by some authors to be over 300 m high) from the KPg impact event (Fig. 5). Many other megabeds around the world show these same characteristics (Cossey and Ehrlich, 1979). The breccia would represent the basal Bouma "A," or graded division. The Velasco Formation would represent the muddy top, or Bouma "E" division. A good analog for this megabed is from the Jurassic of northern Tunisia (Cossey and Ehrlich, 1979) where a carbonate megabed up to 90 m thick is exposed.

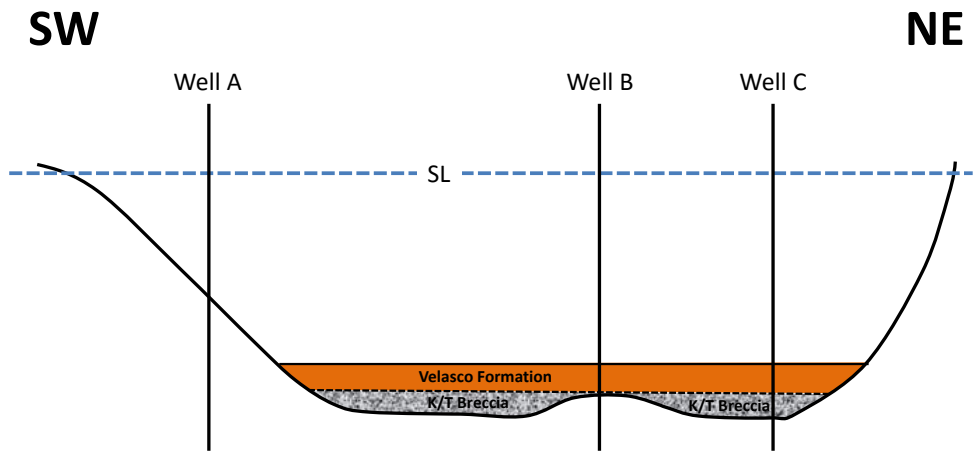

Figure 5. Proposed model for the K/T breccia and the Velasco Formation "megabed." Note that the Velasco Formation (brown) extends to an area slightly larger than the breccia (gray) and that some wells might only penetrate Velasco Formation, depending on basin-floor topography.

Prior to the KPg impact event, the Tampico-Misantla Basin is primarily a site of carbonate deposition throughout the Cretaceous. Afterwards, the Chicontepec Basin forms as a foredeep in front of the rising Sierra Madre Oriental to the west. The overlying Paleocene Chicontepec Formation consists of turbidite sands composed of over 50% carbonate material (Bitter, 1993) derived from the uplift and erosion of the Sierra Madre Oriental.

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Relationship between the depositional episodes of the Woodbine/Eagle Ford of East Texas and the Eagle Ford of South Texas

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The organic-rich shales and marls of the Eagle Ford have played a key role in hydrocarbon production in Texas, acting as the source rock for the Austin Chalk and the prolific sands of the East Texas Woodbine. More recently, the shales and marls are being exploited as an unconventional resource in the Eagle Ford play of South Texas and the "Eaglebine" play of East Texas. Interest in the Eagle Ford and Woodbine extends beyond the petroleum industry.

The depositional systems lie at the juncture between the Western Interior Seaway to the north and the Tethys Sea to the east during the sea-level highstand that culminated with Oceanic Anoxic Event (OAE) 2. Therefore, accurately determining the age of the depositional systems and the stratigraphic relationships between them is crucial to identifying regionally significant events and relating them to corresponding events in the Western Interior Seaway and the global ocean. Prior to this study, the stratigraphic relationships between the Eagle Ford of South Texas and the age equivalent Maness Shale, Woodbine, and Eagle Ford rocks of East Texas were poorly understood. A chronostratigraphic framework has been developed for the subsurface Eagle Ford of South Texas in conjunction with a log-based regional study that was then extended across the San Marcos Arch and into East Texas using biostratigraphic and geochemical data to constrain log correlations of 12 horizons from 1729 wells across 22 counties in South and East Texas.

Seven regional depositional episodes were identified by the study. The clay-rich Maness Shale was deposited during the Early Cenomanian in East Texas and northern South Texas where it correlates to the base of the Lower Eagle Ford. After a relative fall in sea-level, East Texas was dominated by the thick siliciclastics of the Woodbine, whereas in South Texas deposition of organic-rich marls began during the subsequent Lewisville transgression. A shift in depositional style to the limestones and organic-rich shales of the Eagle Ford occurred in East Texas during the Middle Cenomanian produced by the continued rise in sea-level. During the Middle to Late Cenomanian, anoxic to euxinic bottom-water conditions were prevalent throughout the Texas shelf. Erosion along the Sabine Uplift shifted the focus of deposition in East Texas southward to the Harris delta and deposited the “clay wedge” of northern South Texas.

The introduction of an oxygenated bottom-water mass onto the Texas shelf produced the considerable decrease in TOC preservation that marks the lower/upper Eagle Ford contact. This event coincided with the onset of Oceanic Anoxic Event 2 (OAE2) and the Cenomanian-Turonian Boundary sea-level high, which starved much of the Texas shelf of sediment. The only significant source of sediment was from the south; within the study area, the boundary interval is essentially absent north of the San Marcos Arch.

Deposition recommenced on much of the Texas shelf during the Late Turonian with the Sub-Clarksville delta of East Texas and the carbonate-rich Langtry of South Texas and eastern West Texas. Bottom-waters became oxygenated at approximately 90 Ma, initiating the transition from the Eagle Ford to the Austin Chalk.

An Initial Quantitative Attempt to Estimate How Much Louann Evaporite Was Deposited in the Gulf of Mexico Basin

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Published estimates for the original volume of Mid-Jurassic Louann evaporites found throughout the entire Gulf of Mexico Basin vary widely. Volume totals derived from both map data and actual volume numbers, range from about 10,500 km^3 (2,500 mi^3) to 839,000 km^3 (200,000 mi^3), an 80 fold variation. Little new information has been published during the past twenty-five years to address this disparity. But gaining knowledge of the present day volume of salt would be an

important metric if debates concerning the origin of the salt and the nature of the Gulf of Mexico Basin during salt deposition are to be reconciled.

A methodology now exists to estimate more accurately and quantitatively the volume of salt present in a given area. Multiple, recent generations of 3-D seismic depth volumes in the offshore Gulf of Mexico require that salt velocities be inserted. This vital processing step includes a systematic picking and interpretation of the tops and bases of all salt bodies encountered. The resulting models of salt velocity allow salt volume in the 3-D data sets to be calculated. Combining the salt volumes calculated from multiple seismic surveys offers new stratigraphic insights across large portions of the original salt basin.

A comparison of salt volumes derived from seismic data cubes and volumes derived from published maps can now be made. The comparisons should give some suggestion as to the accuracy of the map data. By extrapolation it should also give a more accurate and quantitative estimation of the original salt volume deposited in the Gulf of Mexico basin.

Chronostratigraphic Views of Gulf of Mexico Tectonic and Deposystem Evolution

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A review of 20 Mesozoic chronosequences defined in the greater Gulf of Mexico Basin region based on chronostratigraphic data from over 130,000 well penetrations and pseudo wells extracted from published seismic studies has identified seven super chronosequences reflecting distinct phases of deposystem and basin evolution. The oldest super chronosequence, dubbed ‘MG,’ encompasses ca. 16.45 Ma of Norphlet through lower Cotton Valley (Late Jurassic) deposition. Sediment distribution and accumulation rates within the MG interval clearly define the rectilinear configuration of the earliest Gulf of Mexico Basin. This early basin geometry is consistent with fault controlled attenuation and foundering of North American continental crust, associated flooding, and rapid depositional infill concurrent with the earliest detachment of the Yucatan crustal block from North America.

The next younger super chronosequence, ‘MF,’ contains a ca. 14.47 Ma record of late lower, through middle Cotton Valley (Knowles Limestone.), Early Cretaceous (Berriasian through mid Hauterivian) deposition. The 'MF' interval reflects the same rectilinear outline as the 'MG,' but it is marked by decreased accumulation rates, suggesting that the fault bounded crustal attenuation, rapid sediment infill phase had markedly slowed.

The ca. 9.4 Ma of upper Cotton Valley / Rodessa / James Limestone (Late Hauterivian through Aptian) section contained within the succeeding ‘ME’ super chronosequence records modification of the early rectilinear basin outline by a temporary reactivation of attenuation and foundering in the western portion of the Gulf of Mexico Basin. 'ME' sediment distribution patterns also indicate development of a depositional continental margin reflecting an overall southwesterly tilt to the basin and accumulation of true continental margin deltaic and reef

systems. These observations suggest that ocean crust was beginning to form outboard of the attenuated continental crust.

Sediment distribution and accumulation rates within the ca. 23.47 Ma Mooringsport through Washita, Albian, ‘MD’ super chronosequence reflect a stable phase of relatively low accumulation rates throughout the entire deposystem. The next younger super chronosequence, ‘MC,’ contains a ca. 16.04 Ma record of Lower Eagle Ford / Austin Chalk, late Early Cretaceous through early Late Cretaceous Santonian deposition. During this phase, there is a marked reduction of accumulation rates in the northwestern portion of the basin, attributable perhaps to uplift and erosion along this portion of the old basin margin. Associated small, perhaps tidal delta-like depocenters appear to define a new basin margin presaging the modern curved shape of western Gulf of Mexico so familiar to us today.

At this time, there is the first evidence of abyssal deposition in the deepest portion of the basin underlain by ocean crust. The succeeding ca. 12.82 Ma interval of Campanian (Selma / Taylor) low accumulation rate deposition of chalk and marl contained within the ‘MB’ super chronosequence is evidence of transgressive onlap of 'MC' section during 'MB' time. 'MB' onlap has the effect of temporarily reemphasizing structural trends inherited from crustal attenuation that took place during deposition of the 'ME' super chronosequence.

Finally, the ca. 5.4 Ma long terminal Mesozoic ‘MA’ super chronosequence consists of Maastrichtian, Navarro equivalent, low accumulation rate marls around the basin rim. Characteristically, these low accumulation rate basin rim sediments and similar basin slope sediments are punctuated by restricted high accumulation rate canyon fill and lobe-shaped slope depopods which are probably attributable to sediment reworking, transport and deposition by mega-tsunami backwash flows following the near end Cretaceous Chicxulub impact. Higher accumulation rates in the deeper parts of the basin underlain by ocean crust are also consistent with backwash flows.

Resolving Pre-Salt Sediment Source Terrains and Dispersal Pathways for the Northern Gulf of Mexico Basin

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Delineation and mapping of pre-salt Gulf of Mexico basins has begun in earnest with efforts to focus on sediment routing and distribution from source to sink. The Mesozoic Era has had an extensive history of successful conventional and unconventional reservoir plays in the South-Central US and Gulf of Mexico from the Cotton Valley Formation in Texas/Louisiana to the

Eagle Ford Formation in South Texas to the ultra-deep water targets in the Mississippi and Desoto Canyons. Leveraging expansive interdisciplinary and intercollegiate academic talent with extensive industry experience, we exploit new techniques in detrital zircon geochronology to reconstruct continental scale drainage systems feeding deep Gulf of Mexico Basin play fairways since initial rifting in the late Triassic. By integrating detrital zircon analytical methods with more traditional biostratigraphic, sedimentological, and sequence stratigraphic data from geologic cores and outcrops and geophysical well logs and multichannel seismic data, we delineate crucial sediment provenance and fluvial-deltaic scaling constraints for more accurate, quantitative Mesozoic regional facies model rendering and pre-salt oil and gas reservoir analysis.

Detrital Zircon Evidence for Amazonian Provenance of Upper Jurassic Norphlet Formation in North Central Gulf, Mobile Bay: Implications for Paleo-river Systems in South and Central America

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Detrital zircon from the Upper Jurassic Norphlet Formation in the vicinity of Mobile Bay, AL reflects a Laurentian provenance, with U-Pb age populations including dominant Paleozoic (265-490 Ma), and Grenville (950-1250 Ma) age. Twenty-three zircon grains from a sandstone sample recovered from the upper part of the Norphlet formation shows a population of 850-920 Ma that is not observed in stratigraphically older samples. As there are very few sources for zircon of this age in southeastern US, we interpret derivation from the Goiás magmatic arc of Brazil, conglomeratic sandstone of the eastern Yucatan peninsula, and/or Mixteca terrain of Mexico as probable sources. Previous study of 850-920 Ma zircon grains from the Goiás magmatic arc shows an origin from a depleted mantle without any crustal contamination ($Hf_{(t)}$= +8 to +12); however, the same age zircons in eastern Yucatan and Mixteca terrain indicate crystallization from magmas having strong crustal signatures ($Hf_{(t)}$= -3.2 to -3.8).

Detrital Neoproterozoic zircon grains in the Norphlet Formation show a wide $Hf_{(t)}$ range (-5.1 to +11.9) for the 850-920 Ma zircons, indicating sediments influx to the Gulf of Mexico basin during late Norphlet time was a mix of material from all of these sources during the Norphlet deposition. We propose that sediments from Goiás magmatic arc probably were transported to the Mixteca terrain through a paleo-fluvial system, and given the proximity of Mixteca terrain to southern North America during Late-Early Jurassic, we infer that erosion of Mixteca terrane sedimentary rocks supplied sediment to the Norphlet erg in the Eastern Gulf Of Mexico. Alternately, the Neoproterozoic grains may have been derived directly from the Goiás arc and transported to the Eastern Gulf Of Mexico by a proto-Orinoco river that developed during Jurassic-Early Cretaceous time.

The Siliclastic Upper Cretaceous Play of eastern Mississippi Canyon

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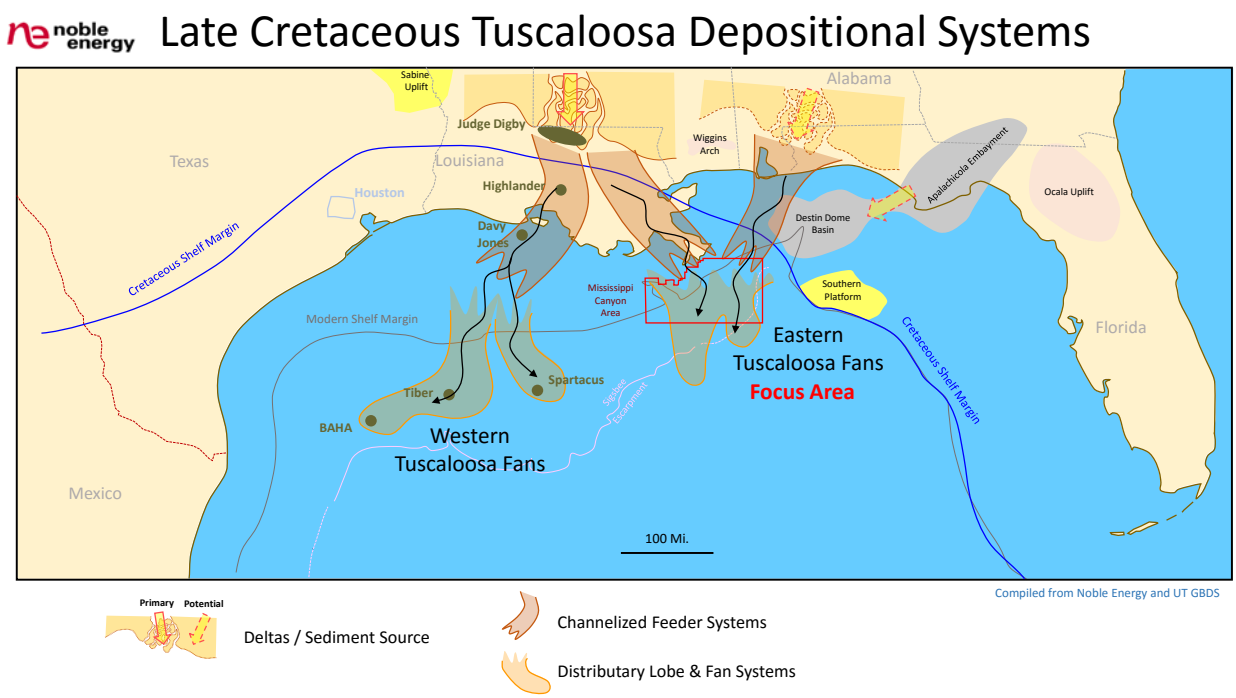
The eastern Mississippi Canyon area has been largely a Miocene oil and gas province and recent discoveries in the Jurassic Norphlet Formation. This paper focuses on a nascent Cretaceous play comprised of large asymmetric structures created by an expulsion-rollover system in the pre-Miocene interval (Fig. 1). The Cretaceous interval is found between 20,000' and 30,000', is up to 10,000' thick, and is underlain by a mature Tithonian source rock. The play extends downdip from the Cretaceous shelf-edge and the reservoir is interpreted to be the equivalent of the Tuscaloosa Formation of onshore South Louisiana.



The interpretation presented is based on Noble Energy's proprietary reprocessing of 4,250+ square miles (474 blocks) of TGS's wide azimuth seismic data. Noble recognizes at least three major Cretaceous depositional fairways within the eastern Mississippi Canyon area. This paper documents and compares the development of the central Cretaceous basin, the western Cretaceous basin, and the eastern Cretaceous basin, which extends farthest to the south in the eastern Mississippi Canyon Cretaceous trend. The development of the fairways and basins is illustrated through a series of structure and isopach maps from the top of autochthonous salt through the upper Jurassic and ending at the upper Cretaceous interval. In the central Cretaceous basin, there is salt withdrawal progressively from north to south, resulting in a series of progradational depositional axes that align with the inferred sediment feeder systems. These

isopach thicks are largely offset from equivalent-aged anticlinal closures. The eastern Cretaceous basin is represented by a variety of styles of three-way combination traps and half turtles. The morphological differences in isopach development and trap styles may be due to systematic differences in accommodation space (as demonstrated by the Jurassic isochore), salt budget and sediment input across the Cretaceous clastic feeder systems.

Wells targeting the Jurassic Norphlet structures in eastern Mississippi Canyon and the western Desoto Canyon areas provide limited control within the objective section. To-date, the Norphlet structures have been drilled on upper Jurassic isopach thicks where the overlying Cretaceous section is significantly thinned and thus not representative of the thicker intervals that developed in areas having greater accommodation space. Within the eastern Mississippi Canyon portion of the deep water Cretaceous play, there are no penetrations that have targeted the thickest intervals and the most prospective parts of the play. Likely clastic objectives within the Cretaceous section are inferred to be the upper Cretaceous Tuscaloosa and Washita-Fredericksburg equivalents. Evidence of these intervals can be found in off-axial penetrations of clastic wedges, such as at the MC 392 Appomattox well.

Lithological and Geochemical Analysis to Reduce Uncertainty in the exploration of Unconventional Gas Deposits in the Burro- Picachos Basin, Northeastern Mexico

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In the search for unconventional reservoirs, one of the geological formations most studied in the United States is the Eagle Ford (Upper Cretaceous), which extends from the state of Texas in United States to the northeastern portion of the Mexican republic. The Eagle Ford Formation consists of argillaceous limestones and calcareous siltstone deposited in a mixed environment. These lithologies have petrophysical and geochemical characteristics sufficient to be considered as producing gas and/or oil, depending on the content of organic matter and the degree of maturity thermal reached.

In the northeast of the State of Coahuila, based on lithology, paleontological content, and TOC, Eagle Ford formation can be divided into three units:

Biozone A: *Heterohelix sigali* and *Helvetoglobotruncana helvética*, dominated by limestone, in platform environments, thicknesses of 16 to 100m, and TOC content of 0.56% to 1.65%.

Biozone B: *Whiteinella archaeocretacea*, limestone and calcareous shales, interbedded lithologies, deposited in slope environment, thickness of 30 to 70m, and TOC content of 0.91% to 2.51%.

Biozone C: *Rotalipora*, black shales deposited in suboxic basin, thicknesses of 60 to 95m, and TOC content of 1.86% to 5.2.

With the thickness distribution of the proposed units, it can be interpreted that the variation in the water depth depends on the topographic relief that prevailed in the Late Cretaceous (Cenomanian - Turonian) in the northeastern portion of Mexico: in a shelf and basin environment, influenced by Maverick Basin. Geochemical data analyzed and the proposed subdivision, indicates that Biozone C drive is the thickest, and has more TOC content in the northeastern part of the Burro-Picachos Basin; the predominant type of kerogen in the area is the type III.

Using the Dykstra-Parson method to determine the homogeneity of the distribution of values of each proposed unit, Biozone A has a higher degree of homogeneity than Biozone C. However, based on TOC and degree of homogeneity, Biozone B has a lower degree of exploration

A Petroleum Systems Perspective on the Siliclastic Cretaceous Play of the Eastern Mississippi Canyon, Gulf of Mexico

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The eastern Mississippi Canyon area has long been known as a prolific Miocene oil and gas province. Organic rich shales and marls of Tithonian and Oxfordian age strata are considered the major source rocks in the region. Recently however, attention has been directed towards the intervening siliciclastic Cretaceous strata as an enticing exploration target.

This presentation focuses on the duality of the Cretaceous section as both a “first carrier” for hydrocarbons expelled from Late Jurassic source rocks and as a potentially significant “container” for hydrocarbon accumulations as well.

Examined are the petroleum system elements and processes of eastern Mississippi Canyon. Emphasis is placed on the relative roles of vertical versus lateral secondary hydrocarbon migration from source to trap. Fluid properties from sampled accumulations help constrain model-derived estimates of thermal maturation, migration timing, loss en route and potentially available hydrocarbon yield.

The “carrier/container” nature of the Cretaceous is characterized through multiple scenarios that address: Subsurface pressure relationships, bed-seal and fault properties; as well as seismically derived lithology and facies distributions. Fetch area constrained source rock expulsion through the Cretaceous is modeled, taking into account known Miocene accumulations. The results of such analyses lend insight into hydrocarbon potential within the Cretaceous.

Evolution of Late Cretaceous Foreland Sediment-dispersal Systems of Northern and Central Mexico

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The Mexican Interior Basin of northern and central Mexico formed in early Late Cretaceous time as a narrow retroarc foreland basin. New petrographic data and U-Pb detrital zircon ages yield insights into stratigraphic age of the basin fill, sediment sources, and sediment dispersal pathways. The basin differs from the contemporary Cordilleran foreland basin to the north in having a dominant volcanic-lithic component in all of its sandstones. Like its northern counterpart, the Mexican basin migrated eastward through time, ahead of an advancing orogenic wedge.

Provenance data indicate that the dominant sediment source for all strata was the coeval continental margin arc of western Mexico. Nevertheless, temporal differences in zircon content indicate distant sediment sources in basement and derivative sedimentary rocks of southwestern Laurentia during early (Cenomanian-Turonian) and late (Campanian-Maastrichtian and Paleogene) stages in basin evolution; during an intermediate stage (Coniacian-earliest Campanian), the Laurentian sources were absent and most pre-arc grains were derived from accreted rocks of western Mexico. The initial basin possessed a narrow foredeep filled by sediment-gravity flow deposits with dominantly axial sediment transport. Carbonate platforms of eastern Mexico supplied calcilithites to the foredeep during early stages of basin formation, indicating the importance of pre-foreland paleotopography on sediment fill.

Sediment-dispersal systems evolved in concert with the stages of basin development. During the Cenomanian-Turonian stage, turbidites deposited in the Mesa Central had headwaters as far away as northern Sonora, but headwaters for Coniacian-Campanian deep-water deposits probably lay nearer, in western Mexico. Late-stage uppermost Cretaceous-lower Eocene shallow marine and continental strata that accumulated in the foreland of northeast Mexico were linked to a fluvial drainage basin whose extent was probably the greatest in Mexico; nevertheless, it is unclear if those clastic sediments reached the Gulf of Mexico. Partitioning of the distal foreland by inversion of Jurassic extensional basins in Santonian-Campanian time was probably effective

at isolating dispersal systems of northern Mexico from time-equivalent systems of northeasternmost Mexico and Texas.

The Mesozoic of Nuevo Leon, Mexico: An ancient extension of the Gulf of Mexico. Paleogeography and Tectonics

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The Mesozoic of Nuevo Leon is composed of more than 10,000 m of sedimentary rocks displaying abrupt physical changes and containing abundant planktonic foraminifera, allowing precise chronostratigraphic determinations. This succession has been deposited in the western extension of the ancestral Gulf of Mexico (Mexican Sea). Its paleogeographic setting corresponds to the oblique subduction of the Kula-Farallon plate under the North American plate. Active oblique subduction of the western margin of Mexico has resulted in the structural features of the Mesozoic sedimentary cover, forming a folded belt made of an intricate array of mountain ranges corresponding to the Nuevo Leones Cordillera characterized by: (1) kilometric-scale anticlinal ridges and narrow synclinal valleys of the Jurassic-Cretaceous sedimentary cover commonly displaying box (fan-shaped) folds; (2) a well-developed pattern of *en echelon* anticlinal folds; (3) juxtaposition of tectonostratigraphic domains; (4) asymmetrical, overturned, doubly plunging anticlines evolving into faulted anticlines; (5) disrupted, long and sinuous fold trends; (6) lack of large horizontal displacement due to overthrusting; (7) folding being predominant over faulting; (8) local thrusting with opposite vergence; and (9) lack of volcanism and regional metamorphism. Those features are the result of transpressional tectonics since the mid-Jurassic including a greater basement involvement in the tectonic deformation.

Analysis of the megastructures exposed in the region using SIR-A and LANDSAT imagery of northeast Mexico revealed that the megastructures of the Mesozoic Cordillera between parallels 22°00' and 26°00' and meridians 99° 00’ and 101°00’ can be referred to deformation of the thin sedimentary cover above transcurrent faults following the morphological pattern of the lab experiment by Odonne and Vialon. The folding styles of the Nuevo Leones Cordillera were analyzed in light of tectonic transpression and wrench-fault tectonics driven by transcurrent faults in the basement as established by Harland, Lowell, and Beck, resulting in the recognition of subsurface faults in the basement. We associate the geometric arrangement of the megastructural trends to sense of displacement of strike-slip (transcurrent) faults and fold patterns as demonstrated by Odonne and Vialon (1983) and the well-known strike-slip tectonic setting of New Zealand as described by Bishop (1967).

Earlier Lower Cretaceous Valanginian Calvin and Winn carbonate shelf platforms and margins, onshore North-Central Gulf of Mexico

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The Lower Cretaceous stratigraphic section around the Gulf of Mexico contains several well-documented carbonate systems having prominent shelf margins, which include the Berriasian Knowles ramp, Barremian Sligo shelf, Aptian Pearsall ramp, and Albian Glen Rose/Edwards/Stuart City shelf systems. Two lesser-known but large-scale Lower Cretaceous Valanginian carbonate shelf-to-shelf-margin systems are documented here using core, log, and regional 2D seismic data. The Calvin section (next carbonate unit above the Knowles Limestone) is a complex shelf-margin buildup and may be as thick as 2000 ft (610 m) and internally, it shows back-reef, reef, and fore-reef facies. Major reef-building organisms are *Lithocodium*, stromatoporoids, and corals. The Winn Limestone was deposited just above the Calvin Limestone, and at the shelf margin, it may have been 600 to 800 ft (180 to 245 m) thick and was composed of similar organisms as the Calvin reef complex. Considering the position of the Calvin platform, succeeding the major bypass of Calvin lowstand sands, it is suggested that the Calvin platform records a transgressive and highly aggradational depositional style. The Winn margin did not prograde as far seaward as the Calvin margin. Micropores between calcite microrhombs are the predominant pore type in each limestone. The recognition of these two Lower Cretaceous carbonate systems is important as they further detail the stratigraphic history and architecture of this deeply buried, earliest Lower Cretaceous section in the Gulf of Mexico and these sections are also potential deep-gas, tight-carbonate plays.

Expression of the Cenomanian-Turonian Oceanic Anoxic Event 2 in the Gulf of Mexico Region

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The Cretaceous Period's super greenhouse climate was punctuated by several severe perturbations of the carbon cycle, resulting in the increased burial of organic carbon and widespread anoxia and corresponding to the widespread deposition of black shales; these

perturbations are known as Oceanic Anoxic Events (OAEs). Perhaps the largest and most studied of these is the Cenomanian-Turonian OAE2. In most localities, OAE2 appears as an archetypal OAE: pelagic sedimentation, usually limestone, is interrupted by black shale having little to no carbonate, very high total organic carbon (TOC), and geochemical proxies for water column anoxia and euxinia.

However, this classic expression is not exhibited everywhere. The Western Interior Sea of North America records low oxygen and high TOC before the event and low TOC and increasing oxygen during the event. This is also reflected in local lithology, as dark-gray organic rich shale abruptly transitions to bioturbated limestone and marl at the onset of OAE2. Recent work has shown that phenomenon of locally increasing dissolved oxygen during the global anoxic event can be traced as far south as Texas, to the edge of the Western Interior Seaway on an Early Cretaceous reef margin. However, to-date no work has been done on OAE2 in the Gulf of Mexico, creating a gap in data that extends from south Texas to the Blake Plateau in the Atlantic and Demerara Rise in the Caribbean. This paper presents the first carbon isotope data from the Gulf Coastal Plain east of Texas, coupled with molluscan biostratigraphy and foraminiferal biostratigraphy and paleoecology to document the timing of OAE2 with respect to an observed sea level highstand and organic carbon enriched interval in the marine Tuscaloosa shale in a core in southern Mississippi. Data from this core is then correlated to a series of well extending from southern Mississippi into the deep water of the Gulf of Mexico. These electrical logs record the persistence of a high-resistivity interval (here related to TOC through the delta log R technique) from the shelf and into the deep water, providing the first real example of OAE2 in the deepwater Gulf of Mexico.

Mesozoic Fluvial System Evolution of the Gulf of Mexico: Application of Channel-belt Scaling to Drainage Basins

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Fluvial systems possess a range of scaling relationships that reflect drainage-basin controls on water and sediment flux. Quaternary channel-belt thickness (as controlled by bank-full water discharge) has been documented as a reliable first-order proxy for drainage basin size if climatic regimes are independently constrained. In hydrocarbon exploration and production, scaling relationships for fluvial deposits can be utilized to constrain drainage basin size with implications for sequence-stratigraphic interpretations. This study documents the scales of channel belts within Mesozoic fluvial successions from the Gulf of Mexico. Data on single-

storey channel-belt scales were compiled from well logs and utilized to constrain contributing catchment areas of fluvial systems. The data indicate that the Mesozoic fluvial systems were significantly smaller than the Cenozoic fluvial systems which can be related to drainage basin reorganization. These scaling relationships can be validated by regional paleogeographic maps and provide additional insight to the sediment routing systems through time.

Gulf of Mexico Tectonic Evolution from Mexico Deformation to Oceanic Crust

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Although the final stage of formation of the Gulf of Mexico is fairly well constrained, earlier evolution is still debated. The final stage was rotation of Yucatan about a Florida Straits Euler pole that created most of the observed oceanic crust. From observations of salt overlying seaward-dipping reflectors (diagnostic of volcanism during the rift to drift transition) in the northeast Gulf of Mexico, we suggest that salt was deposited at the onset of sea floor spreading, which coincides with initiation of the rotational motion of Yucatan. It is important to understand Yucatan motion that preceded this rotation because delineating any pre-salt play that might exist would be dependent on understanding of depositional systems developed during this early motion of Yucatan. Very little is known about the nature of pre-salt deposition in the northern Gulf of Mexico GOM. Salt is Callovian or earliest Oxfordian in age, and the next oldest rocks known from the northern Gulf of Mexico are Late Triassic red beds found in what are generally regarded as grabens formed during early rifting. This gap in knowledge, what we refer to as the ’50 million year gap,’ can potentially be bridged by incorporating analogues with known systems in Mexico and northern South America. There are uncertainties here, however, mostly based on how Mexico and northern South America are palinspastically restored. In particular, we note that there were long-lived continental margin arcs in Mexico that spanned the time from the Permian through the Middle Jurassic (Barboza-Gudino *et al.*, 2012). A lot of the rocks of these ages seen in Mexico that are linked to Gulf of Mexic rifting are in fact associated with these earlier arcs. In this presentation we will review reconstructions of the region and develop a tectonic model that forms the basis for further understanding of rifting in the Gulf of Mexico.

Barboza-Gudino, J.R.. R.S. Molina-Gma., and T.E. Lawton, 2012, Sierra de Cato-: Remnants of the Ancient Western Equatorial Margin of Pangea in Central Mexico, *in* J.J. Aranda-Górner., G. Tolsan, G. and R.S. Molina-Gana, eds., The Southern Cordillera and Beyond: Geological Society of America Field Guide 25. p. 1-18, doi:lO.l I30/2012.W25(01).

LATE TRIASSIC-LATE CRETACEOUS PALEOGEOGRAPHY OF MEXICO AND THE GULF OF MEXICO

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Most plate tectonic models for the opening of the Gulf of Mexico focus on the fit of different crustal blocks, regional faults, the areal extent of abnormal oceanic crust, transitional crust, and continental crust, as well as on today's geophysical data, but only a few include paleogeographic data. High quality paleogeographic maps are available for the northern part of the Gulf of Mexico, but the same type of information for the southern part is difficult to obtain. However, information from many published sources has been used to compile a series of maps of the entire country of Mexico, including the Gulf of Mexico.

The main objective of this project is to build-up palinspastic paleogegraphic maps of Mexico through the Mesozoic, where the various marine and transitional sedimentary facies are restored to their original geographical positions prior to folding and faulting, and then are overlapped on the tectonic blocks involved in the most popular plate tectonics models. The data contained in these maps correspond to outcrops in continental Mexico and to published subsurface data in the marine areas.

Constraints on the timing of Continental Rifting and Oceanic Spreading of the Mesozoic Gulf of Mexico Basin

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In 2012, 17,000 km of 2D PSDM regional reflection seismic data (*SuperCache)* was acquired across the US, deep-water Gulf of Mexico. The acquisition configuration of long-offset, powerful source and deep-tow of both source and receivers was designed to optimize the imaging of the crustal architecture of the Gulf of Mexico basin to a depth of 40 km. Based on these seismic data, the base of the Louann Salt and it correlative unconformity, continental and oceanic basement, and the Moho have been mapped over much of the area.

Geodynamic basin-modeling, including basin-wide 3D gravity inversion and targeted 2D flexural back-stripping, has been used to test, corroborate and quantify the kinematic and subsidence implications of the seismic interpretations, further constraining and quantifying the timing and spatial distribution of crustal thinning. In combination with the regional gravity data and vintage seismic data from the US shelf and Mexican deep-water, the basin-wide interpretation now extends over most of the offshore Gulf of Mexico Basin.

The area of investigation includes continental crust of near original thickness, highly attenuated crust, and oceanic crust. The latter exhibits along-strike (~2000 km) variations from anomalously thin in the west, to an area of thicker ocean crust approaching the opening pole of rotation in the Straits of Florida. The oceanic architecture of extinct spreading valleys and transform faults is closely analogous to modern slow to moderate spreading rate systems. Based on this analog, unconstrained by magnetic signatures or well control, it is proposed that the spreading phase of the basin occurred in less than 15ma within the Late Oxfordian to Early Tithonian.

The continental extensional phase extends from the Late Triassic to the Early Oxfordian (~80ma). Three distinct tectono-stratigraphic sequences are recognized, only the youngest of which has been drilled in the offshore Gulf of Mexico basin, represented by the Louann Salt and Norphlet aeolian sequences. The intermediate sequence is evident on seismic data from the zone of attenuated crust of the West Florida and Northwest Yucatan margins, and is characterized by steeply dipping strata with probable volcanic affinities. The oldest sequence corresponds to the Late Triassic sediments of the Eagle Mills Formation from the onshore US Gulf Coast.

Mesozoic Structure and Petroleum Systems in the De Soto Canyon Salt Basin in the Mobile, Pensacola, Destin Dome, and Viosca Knoll Areas of the MAFLA Shelf

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Guohai Jin and Denise J. Hills, Geological Survey of Alabama

The De Soto Canyon Salt Basin hosts numerous hydrocarbon accumulations, and large parts of the basin remain unexplored. The basin contains an array of salt structures, including peripheral faults, salt rollers, pillows, and diapirs. Jurassic-age Norphlet sandstone produces above salt rollers and pillows, and source rocks are thought to be in the overlying Smackover-Haynesville shale-carbonate succession. Additional reservoir potential exists in Cretaceous carbonates at the shelf margin.

Seismic data and well logs were used to characterize structure and petroleum systems. Check shot data and synthetic seismograms were used to tie well data with seismic data. Seismic profiles were depth converted, and structural cross sections were constructed, balanced, and restored. Stratigraphic, geochronologic, and geothermic data were used to construct 1-D and 3-D basin models that reveal the relationships among burial, structure, hydrocarbon generation, and entrapment. Results were synthesized into a structural chronology, and a petroleum systems model was developed.

The basin contains four structural provinces: (1) salt roller province, (2) Destin fault system, (3) salt pillow province, and (4) diapir province. The salt roller province contains a complex array of normal faults and rollover structures that record gravitational shelf spreading during Jurassic time. The Destin fault system bounds half grabens that formed near the updip limit of salt. Active mainly during the Cretaceous, the faults have variable displacement. Broad salt pillows occur

basinward of the Destin fault system, and the largest of these structures forms the core of Destin Dome. Salt pillows basinward of Destin Dome began forming during Smackover deposition, whereas Destin Dome largely post-dates the Destin fault system. The diapir province is in the structurally deepest part of the salt basin, and diapirism occurred from the Jurassic into the Tertiary.

Petroleum systems were characterized in terms of source rocks, seals, carrier beds, and reservoirs. Basin models show regional variation in the timing of thermal maturation, expulsion, and trap formation. Exploration efforts have thus far proven successful in structures that formed before hydrocarbon expulsion, and several such structures remain untested.

Integrating Seismic Data with Regional Geology and Aeromagnetic Data to Deduce Basin Evolution: Gulf of Mexico Case Example

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We integrate onshore and offshore seismic reflection and refraction data, Atlantic relative motions, pre-Mesozoic terrane restorations (Chortis, Andes), Gulf of Mexico aeromagnetic map interpretation, paleomagnetic data, and onshore field studies in Mexico into a working model for the Gulf of Mexico's Mesozoic evolution. The aeromagnetic map shows the central Gulf of Mexico rotational seafloor spreading fabric and approximate limit of ocean crust, corroborated and refined by new seismic data. Spreading occurred about two distinct stage poles of rotation. The paleo-ridge system seen in satellite gravity pertains only to the later pole.

Geometrical aspects of the magnetic pattern and western Gulf of Mexico transform are related to spreading history. Ocean closure provides an Early Oxfordian post-rift reconstruction that realigns the limits of ocean crust; abuts Louann and Campeche autochthonous salts and post-rift, planar sub-salt unconformities; places Chiapas Massif along Tamaulipas Arch, south of the Burgos marginal offset; and provides a template for assessing syn-rift history and salt deposition mechanisms. Continent-ocean transition adjacent to the limits of ocean crust denote magma poor breakup. Local magmatism occurs in the northwest Florida, northwest Yucatán, and northeast Yucatán margins, interpreted as synrift rather than breakup magmatism.

Marginal offset segments of the western Campeche continent-ocean transition show 2.5 km relief from base salt to top ocean crust, indicating that the syn-rift/sag section kept the Gulf of Mexico filled near sea level prior to salt deposition. Planar base salt unconformities tilt basinward from updip salt onlap limits to the continent-ocean transition where they are deeper than the adjacent

oceanic crust. The continent-ocean transitions form a trough between continental and ocean crust and are filled with slumped salt and early overlying sediment that are in turn onlapped by earliest oceanic abyssal plain strata. The slumped section over salt likely comprises initially shallow marine facies (<300m, Oxford) that deepen upward rapidly into Kimmeridgian-Tithonian source rock. The early slumping, the tilting of the planar base salt unconformity into the continent-ocean transition (outer marginal troughs), and the rapid upward deepening above foundered section record the outer marginal collapse. Base salt unconformities are faulted in the continent-ocean transitions only; the faults appear to enter the syn-rift/sag sections above exhumed mantle and not continental crust, and thus probably do not affect margin subsidence, suggesting that outer marginal collapse is a critical aspect of basin analysis.

The Lower-Middle Jurassic: Unconventional Tight Oil Play

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Tomas Rodríguez Cruz, Exploration Geologist retired from Pemex Exploration and Production

The integration and interpretation of geological and geophysical information in the Tampico Misantla Basin, leads us to establish that the Rosario Formation of the Lower-Middle Jurassic, which has oil production in the well Silozuchil 1001, can be considered an unconventional play. The proposed geological model corresponds to fluvial-marine sediments deposited during the Early-Middle Jurassic in the Huayacocotla Basin, when the waters of the Pacific Ocean invaded the nascent Gulf of Mexico.

This source-reservoir tight-oil rock has a maximum thickness of 1500 meters and an areal extent of approximately 8,000 km^2. In addition, it has a high organic content and vitrinite reflectance values that are within the oil and gas generation window.

It is considered that from the results of this study we can establish an exploratory drilling strategic program to propose locations in order to evaluate the economic potential of this play that already had production of light oil (44 ° API). This represents an alternative way to increase oil production and to restore reserves in mature areas where it already has production infrastructure.

An analog is located in the Paris Basin where it has begun a new phase of exploration unconventional plays, including Liassic formations.

Determining the Mesozoic Drainage System in Southern Alabama Through Provenance Analysis and Regional Correlation of Facies of the Haynesville Formation

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Mesozoic hydrocarbon production in the eastern Gulf of Mexico is dominated by the Middle-Late Jurassic Norphlet and Smackover formations. The younger Late Jurassic Haynesville Formation is also a proven hydrocarbon reservoir in the onshore eastern Gulf of Mexico; however, less is known about the unit because the distribution of rock types is very heterogeneous, making correlations challenging and hydrocarbon reservoirs less persistent.

We logged Haynesville Formation cores in southern Alabama, and used SP and gamma ray logs to correlate the facies for more than 100 wells. Sandstone compositions were analyzed using standard point counting techniques for 18 samples from seven cores. Six sandstone samples from four of those cores were analyzed to determine the detrital zircon ages as well as the distribution of zircons in each age, which provides a tracer for the provenance of the unit.

Core and well log analyses indicate that the Haynesville Formation can be subdivided into five facies: siliciclastic, limestone, dolomite, anhydrite, and halite facies. The thickness and distribution of these facies suggests that relict basement topography related to the opening of the eastern Gulf of Mexico during Late Triassic-Early Jurassic time remains persistent through Late Jurassic time, and thus is the primary influence on Upper Jurassic sediment distribution. Framework grain compositions indicate that the sandstone facies was primarily derived from a recycled orogenic provenance, indicating a primarily Laurentian terrane source with some mixing from Gondwanan Suwannee terranes. Detrital zircon age distributions from Haynesville Formation sandstones contain major age populations that correspond with derivation from both Laurentian Grenville Province and Appalachian Mountain source rocks, with some mixing from the Gondwanan Suwannee terrane. Haynesville Formation detrital zircon ages and sandstone compositions are similar to that of the older Norphlet Formation, indicating that the provenance and sediment transport pathways remained similar through deposition of the Upper Jurassic units.

INTEGRAL ANALYSIS OF THE OPENING OF THE GULF OF MEXICO AND ITS RELATIONSHIP WITH THE SEDIMENTARY BASINS GENERATION

Tomas Rodríguez Cruz, Exploration Geologist retired from Pemex Exploration and Production

This paper integrates, analyzes, and interprets the existing geological and geophysical information related to the opening of the Gulf of Mexico. The analysis of this information has the objective to consider the opening of the Gulf of Mexico as a result of global tectonic processes. Without doubt, the opening of the Gulf of Mexico has its origin in the interaction of two important tectonic events that generated the separation of Pangea: the Farallon Plate subduction in the Pacific and on the opening of the Central Atlantic, whose start is marked by the presence of the Central Atlantic magmatic province.

A proposal of this work is that as much oceanic crust was generated in the Oxfordian, as part of the stage in the Central Atlantic Jurassic opening. This Oxfordian period is characterized by a large positive geomagnetic chron, which explains the absence of polarity changes in the magnetic response for the Gulf of Mexico.

Another proposal is that the Sierra de Chiapas is the transpressional front that represents the final stage in the gulf opening and is associated with the edge effect of gravity anomaly that can be observed in the overall gravimetric maps.

The proposed model assumes that the magmatic arc causes continental rifting, creating basins containing red beds deposits that are located parallel to the orientation of the arc; these rifting areas evolve to form the sub-basins of Chihuahua, Sabinas, and Burgos in the northeast of Mexico and Tampico Misantla, Veracruz, and Southeastern basins in eastern Mexico.

Regional Stratigraphic Cross-sections, Fredericksburg and Washita Formations (Lower Cretaceous, Albian), North-central Texas, Balcones Fault Zone, Subsurface Central Texas Platform, Maverick Basin, Edwards Plateau, and TransPecos, Texas

Peter R. Rose

Rose (1972) recognized that the Edwards Group comprised two regional depositional cycles, Fredericksburg and lower Washita. In the subsurface of the Central Texas Platform, and in outcrops along the Balcones Fault Zone, they were the Kainer and Person Members, respectively. In the eastern Edwards Plateau, their counterparts were the Fort Terrett and Segovia formations, which were close but not exact stratigraphic equivalents. Thin marly units separate both successions, the Regional Dense Member and the Burt Ranch Member. However, articles by Waite, *et al*. (2007) and Phelps, *et al*. (2014) claim that the Person Formation belongs in the Fredericksburg Division rather than the lower part of the Washita Division.

Presented for inspection and discussion at this conference is a well-documented, physically mapped, interlocking regional network of long stratigraphic sections in TransPecos Texas, the Edwards Plateau, along the Balcones Fault Zone into north Texas, throughout the subsurface of the Central Texas Platform, and into the Maverick Basin. Merged from work by Wilbert, 1963; Lozo and Smith, 1964; Moore, 1964, 1996; Young, 1974, 1979, 1986; Smith, *et al*., 2000; Rose, 1972, 2016, and reinforced by ammonite collections, it re-affirms the following regional stratigraphic relations:

1) The basal member of the Segovia Formation (the Burt Ranch Member), the Regional Dense Member of the Person Formation, and the Kiamichi Formation of North Texas, are stratigraphic equivalents, all three being in the *Adkinsites bravoensis* zone;
2) The peritidal Person Formation is a lateral facies of the shallow marine Georgetown Formation, except for its uppermost member, the Main Street, which forms the thin remnant Georgetown Formation on the Central Texas Platform;
3) The Person Formation is lower Washita, not Fredericksburg.

A companion paper by R. W. Scott offers additional paleontological data as well as alternate stratigraphic interpretations, utilizing the same network of interlocking stratigraphic sections.

Albian Stratigraphy of the San Marcos Platform, Texas: Why The Person Formation is Upper Fredericksburg Group

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Whitney Campbell
Rachel Honacki
Yulun Wang
Xin Lai

New data of Texas Albian Comanchean carbonates supports an alternative correlation hypothesis to the long-held hypothesis that part of the Edwards Group correlates with part of the Washita Group. Petrologic, paleontologic, and sequence stratigraphic data indicate that the entire Edwards Group is older than any part of the Washita. The Person Formation in the upper part of the Edwards is correlated with the lower part of the Washita based on SP and resistivity well logs and the inferred argillaceous lithology.

Core and outcrop studies show that the Regional Dense Member (RDM) at base of Person is petrologically different from the Kiamichi Formation at base of Washita. The RDM is gray marly bioclastic lime mudstone-wackestone. In outcrop, the lime mudstone is light tan gray and contains small burrows. The Kiamichi on the other hand is dark gray shale containing oyster rudstone and thin bedded rippled siltstone beds.

Ammonites have never been found in the RDM although it has been shown to be continuous with the Kiamichi Formation and westward with the Burt Ranch Member of the Segovia Formation. Fredericksburg fossils are in cores: *Texigryphaea* oysters and the foraminifer *Barkerina barkerensis*. The bivalve, *Pleuromya knowltoni*, is only in RDM outcrops. Rudists are directly behind the shelf margin.

The Fredericksburg is a single long-term transgressive-regressive cycle. The Walnut and Kainer formations represent the transgressive system tract; the Keys Valley Member and the RDM are the deepest facies and are overlain by progradational rudist beds of the Person Formation. The Kainer is locally disconformably overlain by the deeper water RDM. The contact between the Person and the overlying Georgetown Formation everywhere is a disconformably iron-stained bored hard ground.

Key conclusions:

1) The RDM is a carbonate mudstone of a semi-restricted shelf lagoon limited to the San Marcos Platform.
2) The RDM is composed of Fredericksburg fossils and is overlain by Fredericksburg caprinids and *Dictyoconus walnutensis*.

3) The RDM represents maximum flooding of the Fredericksburg cycle and correlates with the Walnut or Comanche Peak formations.
4) The younger Washita Group Kiamichi Formation onlaps and pinches out north of Austin and the Burt Ranch Member of the Segovia Formation pinches out west.

New Models of Early Cretaceous Source-to-Sink Pathways in the Eastern Gulf of Mexico, USA

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This study provides an assessment of two source-to-sink systems of the Early Cretaceous and highlights sedimentologic changes that occurred in response to major tectonic reorganization of the eastern Gulf of Mexico during the Valanginian-Hauterivian stages. Depth-imaged 2D and 3D seismic data, well log correlation, sand grain size obtained from Valanginian intervals of the cores of a key well, and detrital zircon U-Pb dating of aforementioned grains allow for characterization and source-to-sink analysis of Early Cretaceous deep-water deposits, as well as a new depositional model of Hosston-Travis Peak equivalent-siliciclastics previously investigated only in the western Gulf of Mexico onshore areas.

U-Pb dating of detrital zircon grains suggests that Hosston siliciclastics observed in the 200-km-long base-of-slope sandy progradational delta-fed apron at the Florida Escarpment originate in a peninsular Florida source terrane – the Ocala Arch. Interpretation of 3D seismic data with nearby well control also allows conclusions to be drawn about the Appalachian-sourced Hosston fan system in Mississippi Canyon. This Appalachian-sourced sandy fan is believed to have terminated updip of the asymmetric expulsion rollovers, although we know the asymmetric expulsion rollover deposition is coeval to the Valanginian- Hauterivian Hosston and extended from the Jurassic Cotton Valley-Bossier supersequence to the Late Cretaceous Navarro-Taylor supersequence. Two plausible models of Appalachian-sourced fan length are considered, incorporating recent calculations of salt rafting to estimate a best-case scenario fan length of 90-km, while a more certain fan geometry is determined from seismic observations and well control, yielding a Valanginian-Hauterivian fan of 70-km-length.

The study presents a new paleogeographic model, with special focus on the eastern Gulf of Mexico and the sand-rich fan and sandy progradational delta-fed apron. It also provides a rich and robust model for source to sink transport during a critical phase of Gulf of Mexico evolution. The shorter fan length calculated in this study suggest the majority of asymmetric expulsion rollovers in Mississippi Canyon are either sandstone-poor or are sourced from a different, likely younger, source-to-sink system (*e.g.*, Late Cretaceous, Cenomanian-age Tuscaloosa fluvial system).

Mexican Carbonate Reservoir Types

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Productive carbonates in Mexico have a broad range of reservoir types based on the relative importance of the porosity of rock matrix, vugs/caverns and fractures. These in turn are related to the depositional environment, diagenesis, and structural deformation. The variation among these destinct reservoir types can be portrayed on a triangular diagram having the end members matrix, vuggy/cavernous, and fracture porosity at the apices.

The most abundant reservoir type is the Upper Cretaceous breccia debris-flow deposits, unique to Mexico. They are often dolomitized and highly fractured giving them a combination of all three porosity types. This triple porosity characteristic can best be illustrated by plotting them at various points within the porosity triangle. Upper Jurassic oolitic shoal deposits show grain lixiviation and dolomitization; they lie at the matrix porosity apex. In the south, these dolomites are intensely fractured; they lie along the matrix-fracture axis. Lower Cretaceous shelf margin limestones have matrix and vuggy to cavernous porosity; they lie along the matrix-vuggy axis. Cretaceous deep-water carbonates show poor matrix porosity but are productive when highly fractured, lying at the fracture porosity apex.

Carefull petrographic analysis needs to be undertaken to better characterize the carbonate reservoirs in Mexico in order to calibrate the electric logs and dynamic production data for input into reservoir simulation models with which to evaluate the investment opportunities for development and redevelopment that are opening up in Mexico.

Pre-Albian biostratigraphical and paleoecological observations from the De Soto Canyon Area; Gulf of Mexico, USA.

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A biostratigraphical review of six exploration boreholes located within the De Soto Canyon protraction area in the Gulf of Mexico yields a repeatable and predictive evolutionary and paleoecological sequence with implications to paleogeography. The Oxfordian section within these boreholes contains abundant terrestrial and freshwater palynomorphs (up to 40% of the assemblage) and primitive planktonic forams. Terrestrial and freshwater palynomorphs gradually decline (to <20%) in the Kimmeridgian to Tithonian sections. Near the end of the Kimmeridgian (or slightly above the the nannofossil *Calcivascularis cassidyi* extinction), a short pulse of lacustrine palynomorphs is observed, and quickly replaced by shallow-water marine palynomorphs. Nannofossils, in general, are of low abundance and dominated by *Cyclagelosphaera* spp. Weakly-developed benthic foram abundance gives rise to *Reinholdella* A which is coincident with a nannofossil dominance switch to *Polycostella* spp. Planktonic forams are not observed in this section

Higher up, an increase in *Epistomina* spp. is observed with the *Reinholdella* A extinction in the Earliest Tithonian. The foram and nanno assemblages suggest nutrient-rich, stratified oceanic surfaces waters and low oxygenated bottom-waters. The thickness of this section can vary greatly in this region most likely due to graben infill. Continuing in time, the Cretaceous-Jurassic boundary is associated with a pulse of terrestrial palynomorphs (up to 50% of the assemblage), the extinction of nannofossil genus *Polycostella*, the origination and dominance of *Nannoconus*, and minute benthic forams gradually increase. The Lower Cretaceous continues with multiple nannofossil originations that persist into the Valanginian, at which time a significant, diverse, and abundant benthic foram and ostracod assemblage occurs in multiple pulses of rapid increases followed by gradual upward decreases, suggesting cyclical change in the updip paleoenvironments due to speculative causes such as sea level change, progradation, and/or changes in ocean composition.

The shallower Hauterivian to Aptian section varies greatly in thickness with the maximum thickness in Northern Desoto Canyon area and thinning to the south. The Hauterivian begins with the disappearance of important index palynomorph genera *Muderongia* and *Druggidium. Nannoconus* continues to dominate the nannofossil assemblage through the Aptian, and benthic forams and ostracods disappear rapidly during the Hauterivian and remain sparse until the Albian with an increase of *Nezzazata spp.* Above the Aptian/ Albian boundary, planktonic forams and nannofossil assemblages exhibit the normal progradational fossil succession most likely caused by sea level change. The significance of these sequences and respective assemblages are discussed in paleoecological and paleogeographical context, as well as implications to depositional history, source potential, and correlation.

Triassic-Jurassic unroofing in the nascent Eastern Gulf of Mexico region from detrital zircon provenance analysis

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Eastern Gulf of Mexico Norphlet Formation provenance analysis reveal a northwest to southeast change in detrital zircon ages, indicating different source areas along strike of the erg trend. From the Mississippi Interior Salt Basin into the Mobile graben, detrital zircon ages reflect abundant Grenville (950-1250 Ma), Taconic (430-490 Ma), and Acadian (350-420 Ma) generated through recycling of Black Warrior basin strata. In contrast, Norphlet samples from the Conecuh Embayment in southeastern Alabama and western Florida panhandle show a ~20% component of 525-680 Ma zircon ages derived from the Gondwanan Suwannee terrane and ~10% less Grenville-aged zircon grains.

In the Apalachicola Basin, the proportion of Gondwanan zircon ages increases to nearly 40% of the total population and Grenville-aged grains constitute just ~20% of the population; this

signature is somewhat similar to detrital zircon ages observed in Triassic syn-rift clastics from the Tallahassee Graben and southern South Georgia Rift system. However, Triassic syn-rift samples contain an abundance of Acadian-aged detrital zircon grains, which are not observed in the Norphlet Formation. In addition, northward within the South Georgia Rift system, the abundance of the Acadian-aged zircon grains increases as the proportion of Gondwanan-aged zircon decreases. We interpret this difference to reflect significant unroofing of Acadian synorogenic rocks during Triassic rifting of the easternmost Eastern Gulf of Mexico. This unroofed material remained largely sequestered in the Triassic basins. Subsequent erosion of rift-flanking highlands that exposed older Gondwanan and Grenville rocks served as the main source of sediment that passed through the rift system to supply sediment to the Norphlet erg in the easternmost Eastern Gulf of Mexico.