Structure and Stratigraphy of South Texas and Northeast Mexico: Applications to Exploration

Program and Abstracts

San Antonio, Texas

April 11 & 12, 2003
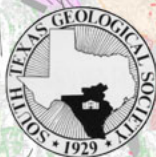
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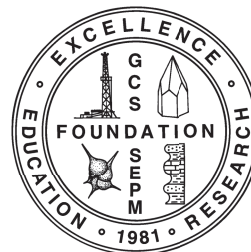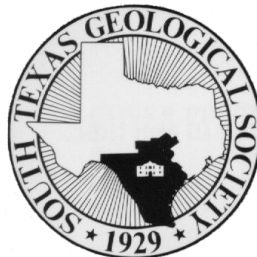
Program and Abstracts

Seminar	**Field Trip**
Omni San Antonio Hotel	Lower Cretaceous Carbonates
San Antonio, Texas	West of San Antonio
April 11, 2003	April 12, 2003

Edited by Norman C. Rosen

Foreword from the STGS

On behalf of the South Texas Geological Society and our co-sponsor, the GCSSEPM, I welcome all of you to this seminar entitled "Structure and Stratigraphy of South Texas and Northeast Mexico: Applications to Exploration." The seminar showcases a premier group of experts on the geology of this region, and their papers should stimulate new ideas that can be applied to the exploration of productive trans-border trends.

I would like to acknowledge the many people that have made this seminar possible. The first is Norm Rosen, Executive Director of the GCSSEPM Foundation. Last spring he extended to the STGS an invitation to work together on a program that could benefit the local geological community as well as other geologists in the Gulf Coast Region. Dr. James Lee Wilson submitted some great ideas for the program and agreed to invite a group of distinguished speakers. In a very short time, he and Program Co-Chairman, Bonnie Weise, put together this wonderful program. Gene Ames III has worked hard obtaining sponsorship funding, and John Waugh has diligently overseen the audio-visual arrangements. Nancy Engelhardt-Moore, GCSSEPM Foundation Trustee, provided much valuable advice on seminar arrangements, contracts, and scheduling. I also want to thank the field trip organizer Tom Fett and the Bureau of Economic Geology for putting together an excellent field trip to view some spectacular outcrops.

Many, many thanks go to all of the funding sponsors and to all of the oral, poster, and core presenters. I know how much time preparing these presentations takes, and your efforts are appreciated.

I hope that the success of this seminar will pave the way for many more meetings that will be joint efforts between the STGS and GCSSEPM. At this point, I want to extend an invitation to all of you to join the South Texas Geological Society. We are a group of over 300 geologists, and you would be a welcome addition. We publish nine bulletins per year with original articles. We have technical meetings once per month September through May, two field trips, and two short courses per year. There are also additional wonderful programs that have been put together. We are currently having a membership drive, and people are invited to "test drive" the society for free until June 2003. Just fill out an application and we will forward a bulletin upon your approval. Visit our website at www.stgs.org.

Michelle M. Debus
President
South Texas Geological Society

Foreword from the GCSSEPM Foundation

Founded in 1981, the GCSSEPM Foundation is a tax-exempt, non-profit organization whose primary objective is to promote the science of stratigraphy in the Gulf Coast region through research in sedimentary petrology, reservoir quality, paleontology, and any other related geological and geophysical fields, especially as it relates to petroleum geology. In the past, we have sponsored a December conference, which for the most part has been attended by people working the offshore Gulf of Mexico. It has been our goal for some time to try to sponsor an onshore meeting. When we approached the South Texas Geological Society about joint sponsoring a conference, we were met with complete enthusiasm. This is our first such joint conference with any geological society and hopefully will not be the last. No matter our desire to have such a meeting, this conference would never have occurred if it were not for (1) interest by members of STGS for a conference, (2) the efforts of Dr. James Wilson in putting the program together, (3) and the efforts of Bonnie Weise and Michelle Debus in making the arrangements for the conference as well as getting corporate sponsorship.

The GCSSEPM is the largest section of SEPM and perhaps the most active; we are proud to have members ranging from New Zealand to Brunei, across the United States, and in Europe. We believe that we have such people in such places because they recognize the quality of our publications and the fact that geological ideas have no geographic boundaries. That is why our fellowship grants range from the Navajo Sandstone to turbidites in Ireland. We hope that you also will recognize this and join the GCSSEPM.

Dr. Norman C. Rosen
Executive Director
GCSSEPM Foundation

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The image used on the cover of this Program and the companion CD ROM appears in a paper in this volume:

Ewing, *Review of the Tectonic History of the Lower Rio Grande Border Region, South Texas and Mexico, and Implications for Hydrocarbon Exploration*, Figure 1.

Structure and Stratigraphy of South Texas and Northeast Mexico: Applications to Exploration

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Omni San Antonio Hotel
San Antonio, Texas
April 11, 2003

Program and Abstracts

Oral Presentations

Morning Session—La Joya Ballroom

Session Chairmen: James Lee Wilson and Norman C. Rosen

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12:00   **Buffet Lunch and Poster & Core Presentations—Grand Ballroom**

Afternoon Session—La Joya Ballroom

Session Chairmen: Bonnie R. Weise and John R. Waugh

Poster and Core Presentations

Grand Ballroom

Posters and cores on display from 8:00 am to 6:30 pm. Presenters in booths from 12:30 pm to 1:40 pm and from 4:45 pm to 6:30 pm.

Booth

A Comparison of the Tectonic Histories of the Northern and Western Gulf of Mexico and Northern Venezuela

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Abstract

The Gulf of Mexico and northern Venezuela both formed as Mesozoic passive margins initiated by a Late Triassic-Early Jurassic rifting phase. Rifting was followed by an Early to Middle Jurassic sag basin phase characterized by the widespread deposition of evaporites in the Gulf of Mexico and the establishment of a Jurassic-mid Cretaceous carbonate passive margin. In Mexico, this passive margin also became a circum-Pacific backarc basin.

Beginning in the Senonian, the Gulf of Mexico and Venezuela evolved in different directions. The northern Gulf of Mexico evolved into one of the world's largest siliciclastic depocenters and a giant oil province characterized by complex growth faulting, spectacular salt tectonics, and an evaporite-based deep-water décollement folded belt. The western Gulf of Mexico includes the Paleogene Sierra Madre Oriental, the Neogene Sierra de Chiapas-Reforma/Campeche basins (a second giant oil province), and the Neogene uplift of the Mexican Plateau. Both folded belts are conjugate to the west-dipping subduction zone that was active on Mexico's west coast.

Northern Venezuela developed in an overall transpressional setting related to the relative eastward indentation of the Caribbean plate. This process led to the Neogene transpressional uplift of the Western Andes which defines the Maracaibo Basin—yet another giant oil province. An eastward migrating Upper Cretaceous-Paleogene-Neogene foredeep is associated with the relative eastward displacement of the Caribbean plate, leading to the formation of a fourth giant petroleum province in eastern Venezuela. Towards the Orinoco delta, the Neogene foredeep merges with the preserved Atlantic margin. The relatively underexplored northern Venezuela offshore is characterized by extensive transtensional faulting related to the complex strain partitioning associated with the Bocono-El Pilar strike-slip fault system and the boundary of the Caribbean and South American plates at depth.

Tables 1, 2 and 3 contrast the evolution of folded belts of the deep-water Gulf of Mexico with folded belts of Venezuela and emphasize the importance of the regional context. When contemplating the future of basin modeling, it may be useful to look ahead and plan for model sequences that follow the evolution of a given passive margin as it morphs into various types of active margins, such as those described in this abstract.

Review of the Tectonic History of the Lower Rio Grande Border Region, South Texas and Mexico, and Implications for Hydrocarbon Exploration

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Abstract

The Lower Rio Grande border region or "Rio Grande Embayment" (South Texas–Coahuila–Nuevo Leon–Tamaulipas) lies at the junction of the Gulf of Mexico and Cordilleran tectonic provinces. To explore for mineral resources in the region, we must understand the complex history of the two contrasting tectonic regimes.

Pre-Middle Triassic: The 1100-Ma Llano Craton, the southern extension of Laurentia, was rimmed to the east and south by the east- to northeast-trending Late Paleozoic Ouachita thrust belt, caused by northwestward closure of an ocean or marginal basin. To the southwest, inferred Ouachita hinterland crust was covered with Permian volcanics and intruded by Permian and Triassic igneous rocks–an inferred southeast-trending "Cordilleran" Permo-Triassic volcanic and plutonic arc. South of the Parras-Galeana linear, deformed Paleozoic and Precambrian rocks are related to North America, but were likely formed far northwest of their present location.

Opening of Tethys (Late Triassic–Late Jurassic) created a complex mosaic of crustal blocks, with "tiles" of high and low extension. At least four long northwest-trending discontinuities bound the mosaic tiles (Frio River Line/FRL; La Babia–Zapata Zone; San Marcos–San Carlos Zone; Parras–Galeana Zone); they are inferred transcurrent fault zones with hundreds of km of left-lateral shear. Thick Callovian evaporites were deposited over highly extended crustal blocks in the Louann (Gulf Coast Basin) and Minas Viejas (Monterrey Trough) salt basins.

Border Rift Zone faulting (Late Jurassic(?)–Early Cretaceous) extended from Coahuila northwest through the Chihuahua to the Bisbee Basin of southeastern Arizona. The less-extended tiles in Coahuila were reactivated as block uplifts, shedding coarse debris into the surrounding troughs. To the northeast, regional subsidence of the Gulf Coast Basin led to the creation of the peripheral graben system, and to the rise of salt pillows and diapirs.

Regional southwest-focused subsidence (Albian–Paleogene) created a major sedimentary basin, now highly eroded. Subsidence caused regional shelf-margin retreat in Aptian-Albian time. All later units (including significant Eagle Ford source rocks) thicken markedly southwest of the FRL hingeline. In latest Cretaceous time, clastic sediments filled the basin from the west, forming coal-bearing deltaic and shoreline complexes, and mobilizing salt structures northwest of Monter-

rey. Over five km of sediments were deposited above the presently-exposed rocks of the Monterrey area, possibly including Oligocene volcanics.

Northeast-directed "Laramide" compression (Late Cretaceous–Eocene) created a wide variety of folds and thrust faults. Folding diminished to the northeast, just crossing the Rio Grande. Basement blocks became structural buttresses with broad folds. The northern Minas Viejas salt basin was deformed by high-relief, salt-cored folds flanked by high-relief, basement-involved thrusts. The Monterrey salient of the Sierra Madre Oriental (tight, very high relief, Jurassic-cored folds) filled the southern part of the evaporite trough. The deep "Rosita trough" in South Texas, caused either by rafting of Cretaceous basinal carbonates or by evacuation of a salt wall, was filled with growth-faulted Lower Eocene deltaic sediments.

Large-scale, post-27 Ma uplift and exhumation was coupled with detachment faulting along the Gulf margin. The La Popa–Monterrey area was eroded to depths of 5-7 km during late Oligocene and early Miocene time. This erosion extended across the Rio Grande, accounting for higher coal ranks there. Oligocene–Miocene alkaline igneous rocks were intruded, with coeval volcanics preserved in the Trans-Pecos Texas region (NW) and in the Sierra de Tamaulipas (SE). The Edwards Plateau was also uplifted in Miocene time, bounded by Balcones extensional faults on the SE. An Early Oligocene shale-based detachment, expanding the Vicksburg Formation deltas, was followed by complex Late Oligocene to Miocene growth faulting in South Texas and adjacent Tamaulipas.

Implications for resource exploration in the Lower Rio Grande area: (1) The Triassic to Jurassic history of transcurrent faults and rift basins must have created complex structures, now masked by the post-Oxfordian stratigraphy. *(2)* Because of the southwest-focused Cretaceous subsidence, hydrocarbons may have migrated northeastward from the Mexican "oil kitchens" into basin-edge traps in South Texas. *(3)* Increased maximum burial depths towards the Rio Grande in South Texas suggest that the oil generation window of the Austin/Eagle Ford section becomes shallower in that direction, and may reach the surface in northeastern Mexico. *(4)* Small crustal blocks similar to those of northeastern Mexico may be found beneath South Texas. Such blocks could be exploration targets for Smackover reservoirs, and could affect subsequent sedimentation. *(5)* Salt activity south of the Frio River Line is different than the standard Northern Gulf history. The absence of a peripheral graben system is consistent with southwest-directed subsidence. Exploration opportunities in and around the salt structures of South Texas differ from those to the northeast.

Geologic Controls on the Organic Richness of Tithonian (Upper Jurassic) Source Rocks in the Burgos, Tampico-Misantla, and Sureste Basins of Mexico

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Abstract

Fine-grained marine deposits of the Tithonian are the most significant part of the Pimienta-Tamabra(!) petroleum system of Upper Jurassic and Lower Cretaceous age. These rocks consist mainly of argillaceous limestones and calcareous shales, deposited as a transgressive system tract, culminated by a maximum flooding event. These deposits are the prominent source of hydrocarbons for most major oil discoveries in deep US waters of the Gulf of Mexico in the last decade.

In the northern Gulf of Mexico these strata are generally too deep to be encountered by drilling. However, they are drilled in Mexico, and well cuttings samples and cores from the Tithonian have been made available to us by Pemex from nearly 100 wells all along the Mexican Gulf coast and offshore in Mexican waters, including the Campeche Shelf. We have collected about 800 samples for TOC and Rock-Eval analysis and also examined the samples petrographically. Sample coverage is good in the Burgos, Tampico-Misantla, and Sureste basins, but not the Veracruz Basin where a thick Tertiary package allows penetration of the Upper Jurassic only around the margins of the basin.

TOC is rich along the flanks and in the mouth of the Burgos Basin, ranging from 2.21 to 4.87 %. The same map pattern holds true for S1 and S2 analyses of Tithonian samples. An isopach map of the Tithonian clearly defines thickening basinward, with most data coming from the southwestern flank of the basin. A map of percent carbonate in the Tithonian here shows an increase basinward. Quartz silt and microfossils are spread across the basin, the presence of tinntinids apparently indicating deeper basin-centered waters.

In the Tampico-Misantla Basin, TOC maps show enrichments ("sweet spots") along the axis of the basin, localized in three places: the Poza Rica area, northwest of the Tuxpan Platform, and at Arenque at the open mouth of the basin. S1 and S2 maps show similar patterns for these basins. A Tithonian isopach map of this basin shows a thickening toward its center. A map of quartz silt shows that it is concentrated in three areas: the Poza Rica area, the area northwest of the Tuxpan Platform, and on isolated highs near Arenque. A map of percent carbonate shows an increase basinward and indicates two carbonate-rich sub-basins in the Tampico-Misantla Basin. A Tithonian microfacies map shows tinntinid radiolarian facies

as the deepest water deposits, located at the open Gulf side of the Burgos Basin and all along the axis of the Tampico-Misantla Basin.

In the Sureste Basin of southeastern Mexico, TOC values of Tithonian rocks generally increase from the southwest to the northeast; values range from 0.12 to 6.11%. Three areas of TOC highs occur in this general trend: (1) a small local high northeast of Comalcalco; (2) a broad northwest-southeast band of high TOC values across the center of the Campeche Shelf, running parallel to the trend of the Cretaceous shelf edge to the northeast; and (3) a northwest-southeast trending band of high TOC values to the extreme northeastern edge of Jurassic well control. Maps of S1 and S2 values for the Tithonian of this area show these same patterns. A series of geological maps accounts for these variations in source rock richness. A Tithonian isopach map shows a trough-like fill of sediments that trend from the northeast to the southwest, appearing as a string of thick sub-basins, ultimately leading to a remarkable thickness (some 1000 meters) to the southwest in the Chiapas fold belt. The axis of Tithonian thicks on the Campeche Shelf runs parallel to the northeast-southwest trend of the Macuspana Basin, immediately to the east. A map of Tithonian microfossil distribution (tinntinids and radiolaria) follows the isopach thicks, suggesting that deep water deposits accumulated as the thickest beds deposited along the bathymetric axis of the basin, which was most likely silled to produce a string of sub-basins along its axis. A map of percent carbonate lines up with the main axis of the isopach map, suggesting that percent carbonate increases in deeper waters. A map of quartz silt outlines the regional cul-de-sac of the Sureste Basin and shows silt content mainly on the east side of the axis of thickening. A microfacies map puts tinntinid-radiolarian faunas in deepest waters, which follows the track of the axis of Tithonian thickening. This places both types of Tithonian micro-dolomite in deep water settings.

In all these three Mexican basins where well control allowed data to be gathered, organic richness is demonstrated to be very good to excellent: source rock richness averaged 3-4% TOC and 45-70% of the samples fell into this category. The vertical extent of this richness throughout the Tithonian section has been estimated by a log-derived calculation of TOC, based on the GR and either a neutron-density or sonic log. These calculated TOC logs show that most of the entire Tithonian section is of source rock richness, except for some transitional beds at the base of the section.

The Influence of Syndepositional Salt Tectonics on Carbonate Platform Development and Stratal Architecture: Examples of (i) Coeval Diapiric Uplift (Paleocene La Popa Platform, Northeast Mexico) and (ii) Gravitationally Driven Extension and Rafting (Aptian-Albian Carbonates of the South Atlantic Basins and Upper Jurassic of the GOM)

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Abstract

One of the most underestimated factors influencing carbonate platform development and its internal architecture is the role of syndepositional tectonics, either in the form of high-frequency, regional tectonic "flexing" (e.g., tectonic reversals within strike-slip settings) or local uplift/subsidence related to underlying movement of mobile lithologies, such as evaporites or shale. In many, if not all, passive margin settings, thick layers of evaporite (principally halite or "salt") accumulate above the regional break-up unconformity above the syn-rift section; for example, the divergent Mesozoic margins of the Gulf of Mexico, west Africa (Angola/Congo), and South America (Brazilian margin). In all of these Mesozoic divergent margin examples (and many Paleozoic examples, as well), widespread carbonates overlie these evaporites; e.g., (1) the Upper Jurassic Smackover/Buckner/Haynesville ramp carbonate complex of the US Gulf of Mexico rests upon mobile Middle Jurassic Louann salt, and (2) the Albian carbonate systems of both west Africa (Congo and Kwanza Basins offshore Angola) and Brazil (Santos and Campos Basins) overlie thick Early Aptian salt associated with the breakup of Pangaea. Inspection of offshore seismic data is replete with numerous examples of syn-depositional salt tectonics that were active during the development of the carbonate ramp and rimmed shelf systems. Typically, two modes of salt-influenced activity occurs: (1) pillowing and diapiric uplift of mobile salt can create topographic highs that are favorable sites for carbonate accumulation (high-energy grainstones and reefs; e.g., the Holocene of the Persian Gulf), and (2) gravitationally-driven extension and downdip lateral migration of incipient thin carbonate deposits occur over the mobile salt unit in the form of "raft tectonics." In both scenarios, carbonate sedimentation is active while the local substrate is affected by salt-induced uplift, enhanced subsidence, and/or lateral sliding. The common occurrence of such phenomena in many Mesozoic divergent margins indicates that the role of syndepositional salt tectonics is very much a factor controlling the evolution of carbonate systems, something which is almost universally excluded in summaries of carbonate depositional models and stratigraphic evolution.

Gas Potential of the Sabinas Basin and Piedras Negras Areas, Northeastern Mexico

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Abstract

The Sabinas Basin and the Piedras Negras areas, are located in the states of Coahuila and Nuevo Leon in the north central part of Mexico. The Sabinas Basin formed during the opening of the proto-Gulf of Mexico during the Jurassic. The exploration activities began in the 1930s. However, it was not until 1975 that the Buena Suerte 2A well was completed as the first commercial hydrocarbon producer. To-date, five fields have been discovered and developed. The primary exploration play is the Lower Cretaceous La Virgen and Padilla which have produced 375 BCF. Currently the area produces 3.3 MMCFD. Original estimates of recoverable reserves are 406 BCF.

Due to high production decline rates, trap complexity, high drilling costs, and the discovery of giant fields in southern Mexico, exploration and drilling activities were suspended throught much of the 1980s and 1990s.

Interest in the area revived in 2001 due to a remaining potential study applying petroleum system and play analysis. Three petroleum systems were evaluated: the La Casita–La Virgen (the most important), the La Peña–La Peña, and Eagle Ford–Austin, all of which contain 13 identified plays. Currently, eight plays have been evaluated: the La Gloria–Olvido, La Casita Jurassic, La Virgen, Cupido reef, El Burro-Stuart City reef, Austin Chalk, and the Olmos. More than 95 prospects were evaluated, ranging from Cretaceous to Jurassic. Based on the fractal behavior of gas production of the main plays, the two proven productive plays, La Casita and La Virgen, are estimated to contain 0.5 to 2.2 TCF of undiscovered resources. The Piedras Negras area, is also attractive due to the large number of fields and plays exploited in the south Texas counties of Maverick, Dimmit, and Webb.

Pemex has approved a 14 wells exploratory program for 2003. The program is designed to evaluate the gas potential of Olvido, La Casita, La Virgen, Hosston, Cupido reefs, Austin Chalk, and Olmos. Proposed drilling depths range from 2500 to 5400 m. The Pmean resource to be evaluated is 580 BCF, having a probability of geologic success ranging from 55 to 11%. The programmed exploratory investment is $56.3 MM and includes the aquisition of 2,320 km of 2D seismic and part of a 3160 Km2 3D seismic grid.

Gas Potential of the Cupido Play, Northeastern Mexico

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Abstract

In an effort to revitalize and identify new areas for exploration, Pemex has focused on the Portal de Anahuac area along the western border of the Burgos Basin in northeastern Mexico. The Portal de Anahuac area is located in the states of Nuevo Leon and Tamaulipas. Paleogeographically, the area is located on the southeastern part of the Cretaceous Tamaulipas Platform. To date, 36 wells have been drilled; one is gas productive. Exploration began in the 1960s; however, the first commercial production was in 1976, when the Totonaca-3 well was completed in the Cupido. The initial production rate was 4 MMCFD and the Cupido Play was established. To date, 14 wells have been drilled in Totonaca field. Initial production rates ranged from 1 to 4 MMCFD. Nevertheless, only the Totonaca-3 was connected and produced. Initial production tests for this well were excellent, exceeding 9 MMCFD. Cumulative production from this well is 7.7 BCF in five years. The rest of the wells, however, had completion problems.

In 1994, 2D seismic surveys were completed, covering an area from Anahuac field to the city of Nuevo Laredo, to evaluate the Cupido Play. The seismic data were initially used to create a regional structural map on the reef facies. Subsequent analysis indicates that the Cupido is of Hauterivian-Barremian age. It has been divided into two seismic units: the Lower Cupido and the Upper Cupido. Distinct seismic facies were identified on the seismic lines. Detailed analysis of the seismic was completed using seismic stratigraphic techniques. The external geometries include banks and monoclines along the border of an extensive platform. Distinct patch reefs and other organic build-ups are present. Sigmoidal and wedge-shaped facies were also observed.

Along the paleo shelf edge, aggradational conditions persisted through most of Cupido time. A prominent barrier reef resulted. It trends northeast-southwest and continues to the northeast and the southwest outside of the study area. Isolated patch reefs and other organic build-ups have been identified within the inner platform (west of the barrier reef). Progradational geometries have been identified. The Cupido formation is comprised of gray to light gray limestone. It varies from a boundstone to a wackestone within the study area. The following facies have been described: (1) oolitic-peletoidal facies, which developed in a restricted lagoonal setting behind the barrier reef; (2) back reef, which is comprised primarily of wackestones and grainstones, and contains milliolids and rudist fragments; (3) main reef, which is comprised

primarily of boundstones and grainstones, and contains rudists, corals, oolites, peletoids, and milliolids; and (4) fore reef, which developed along the paleo slope in front of the barrier reef, and contains a mixture of reefal and basinal fauna. The Cupido is distributed throughout the study area. Downdip to the southeast, the platform changes to a more open marine facies. These basinal rocks are assigned to the Lower Tamaulipas Formation.

The most important diagenetic process for the development of porosity was the dissolution of clasts. Natural fractures are also an important factor in the development of secondary porosity. Fracturing resulted from the Tertiary tectonic activity associated with the Laramide compression. Various types of porosity are present, including vugular, interskeletal, moldic, and intercrystalline. The presence of secondary porosity in fractures is critical. Porosities range from 2% to 14%, and permeabilities range from 0.01 to 1.0 md.

An edgewater drive mechanism has been recognized as active in the Totonaca field. Based on material balance calculations, this field contained 37 BCF of recoverable gas. There is 28 BCF remaining to be produced. The drainage radius has been calculated to be about 440 meters. Abandonment pressure is set at 165 psi. This evaluation has resulted in the documentation of four new prospects along the Cupido shelf margin which will be drilled to check our model.

Evolution of Late Aptian/Albian Carbonate Platforms of the Northwest Gulf of Mexico

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Abstract

The Albian carbonate platforms of the northwest Gulf of Mexico are among the world's great examples of a carbonate-dominated passive margin. The Albian carbonates are part of a latest Aptian through latest Albian 2nd order supersequence that includes the James-Stuart City in Texas and the Tuxpan, Valles-San Luis Posti, and Coahuilla platforms in northern Mexico. Together, they form a continuous continental margin rimming the southern and eastern margin of North America that Wilson (1975) first synthesized.

Much work has subsequently been published on the stratigraphy and sequence stratigraphic evolution of this system such as the work of Scott (1993), Wilson and Ward (1993), Yurewicz *et al.* (1993), Fitchen *et al.* (1997), Moore (1996), Goldhammer (1999), Lehmann *et al.* (1999), and Kerans and Loucks (2002). More local treatments of different elements of this larger system have been provided by many authors over a course of the post WWII era, and this extensive literature base is both the boon and bane of developing a model of this system.

In order to develop a sequence model for the latest Aptian through latest Albian carbonate succession in the northwestern Gulf of Mexico, we will draw extensively on a combination of personal experience from outcrop and subsurface studies throughout this supersequence, as well as on available studies of detailed elements of this system by other workers. Perhaps the greatest challenge in defining the sequence framework of the Albian supersequence is not in recognizing the presence of numerous sequences, but in defining the nested cyclic hierarchy of cycles and emphasizing local versus regional or worldwide events.

Our working model includes eighteen 3rd-order sequences within the latest-Aptian–latest Albian supersequences including:

1. Lower Cow Creek–Hammett–Pine Island
2. Lower Cow Creek
3. Lower Bexar
4. Middle Bexar

5. Upper Bexar–Rodessa
6. Ferry Lake–Moringsport
7. Lower Glen Rose
8. Upper Glen Rose
9. Paluxy–Bull Creek
10. Bee Cave–Cedar Park–Edwards
11. Keys Valley–Whitestone
12. Comanche Peak–Moffat
13. Pecos 1 (Albian 18 of Kerans *et al.*, 1995)
14. Pecos 2 (Albian 19 of Kerans *et al.*, 1995)
15. Pecos 3 (Albian 20 of Kerans *et al.*, 1995)
16. Pecos 4 (Albian 21 of Kerans *et al.*, 1995)
17. Pecos 5 (Albian 22 of Kerans *et al.*, 1995)

18. Pecos 6 (Albian 23 of Kerans *et al.*, 1995).

Using the timescale of Gradstien *et al.* (1994), we show that these units represent evenly spaced packages of averaging around 1 Ma each. The chronostratigraphic chart and schematic cross section represent a working model of the evolving sequence framework that we are currently developing and are intended as a starting point for future studies rather than as a finished product. Where our framework differs from earlier publications (e.g., Goldhammer 1999; Scott, 1993; Yurewicz *et al.*, 1993) is that we have been able to carry out either subsurface or outcrop studies of all major units within the Albian. Thus, rather than depend on matching sequences to published stratigraphic names (e.g., "Moringsport" sequence) we can develop an even and genetically based existing sequence framework by either dividing traditional formations or combining them as is genetically relevant.

Bearing in mind the preliminary nature of the model, there are several important conclusions that evolve. First, the occurrence of producing hydrocarbons from this supersequence is predictive within the transgressive-dominated James through early highstand lower Glen Rose sequences. It is these sequences that have the high initial porosity within aggradational to retrogradational rudist/coral/algal buildups, such as the James and lower Glen Rose.

The Maverick Basin: New Technology—New Success

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Abstract

The Maverick Basin is a small carbonate basin geographically associated with the large sand and shale-rich Gulf Coast Basin. Oil company managers have often rejected exploration programs for the Maverick Basin in favor of more glamorous objectives in the Gulf Coast Basin. As a result, the Maverick Basin has remained under-explored. In the past 10 years, new technologies like 3-D seismic and directional drilling have led to new plays and significant increases in production in the Maverick Basin. Three-D seismic has been absolutely essential. It has defined the structural framework of the Basin and found new reef trends and unique structural plays. Directional drilling is now allowing operators to produce oil and gas from low permeability reservoirs that have been troublesome in the past. Current activities place the Maverick Basin at the threshold of prominence for oil and gas exploration in the Gulf Coast area.

Upper Cretaceous (Post-Edwards) Stratigraphic Framework of the Maverick/Rio Escondido Basin, Southwest Texas and Coahuila—A Progress Report

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Abstract

This brief report contains some significant observations obtained to date from regional stratigraphic sections stretching from the San Marcos Arch into the deeper Maverick Basin to the southwest, and extending northwest to outcrop. All units thicken southwestward off of the San Marcos Arch into the Maverick Basin, the northeastern part of the broad Mexican geosyncline. Many key stratigraphic changes occur along a northwest-southeast hingeline passing from Uvalde southeast through Frio County, a part of the 'Frio River Line'.

The Eagle Ford Formation (Turonian) is the major high-TOC source rock in the section. It thickens manyfold to the southwest, and develops four internal members. Highest TOC is probably in the bituminous shale of the lower member, followed by the top member (possibly correlative to the phosphatic beds of East Texas). The middle Eagle Ford is similar in petrophysical response to the typical chalks of the overlying Austin.

A full Austin stratigraphy appears to be present near the Rio Grande. The lower Austin (equivalent to much of the San Marcos Arch section) becomes relatively thinner and very resistive in the basin, where it is nearly indistinguishable from the underlying Eagle Ford. This is believed to be a basinal, organic-rich facies. Overlying this member is a thick middle chalk member, overlain by a chalk-shale upper member correlative to the Burditt and Dessau of the Austin area. This unit thins sharply with multiple internal unconformities near the hingeline.

The Upson Formation has three parts. The thin lower member, or "Pavo Tongue", exposed in the north face of the Anacacho Mountains, extends over the hingeline as a shale/marl marker (which makes a convenient Top Austin marker). The middle Upson is equivalent to the Anacacho Formation of the outcrop, and consists of marl and shale. The defining facies of the Anacacho (a coarse, porous biosparite) extends less than 30 km into the subsurface, except for local occurrences around Balcones volcanoes. The upper Upson is the prodelta shale of the overlying San Miguel Formation.

Published age information from the Anacacho Mountains indicates that the lower Anacacho there is of Gober age (upper Austin Division, lower Campanian). It is overlain by a disconformity with sparse phosphate pebbles, the "Pecan Gap Unconformity", over which is the Milam chalk member and additional thick biosparites. All units younger than the disconformity bear a Pecan Gap fauna (middle Campanian). This unconformity is not visible on well logs.

Two episodes of clastic progradation occur below the mid-Maastrichtian unconformity in southwest Texas: the San Miguel, characterized by relatively isolated wave-dominated deltaic sandbodies or shelf bars with no alluvial plains preserved; and the overlying Olmos, characterized by a major delta system with attached coal deposits, strandplains and alluvial plains. The San Miguel in Texas is upper Campanian at the oldest, overlying the Anacacho equivalents. In the Sabinas Coal Basin of Mexico, the coal-bearing Olmos has been dated as upper Campanian (and may correlate to the San Miguel of southwest Texas); the Olmos in Texas has been considered lower Maastrichtian. The sandy and coaly depositional systems seen in the subsurface of Maverick County should crop out less than 40 km to the southwest just across the Rio Grande, but this is not well studied.

A regional mid-Maastrichtian "Bigfoot Unconformity" cuts out Olmos equivalent rocks from Uvalde to northeast of San Antonio, and for about 40 km downdip from the present outcrop. It shows especially great relief over the "Uvalde Salient" (a local uplift related to Balcones igneous activity, where Escondido overlies Austin). Overlying the unconformity is a marly zone (Corsicana-equivalent, *"Lituola"* zone), followed by Escondido shales and sandstones which form a third, complex clastic progradation.

The youngest Escondido sediments are lost southward along the Mexican outcrops, and are absent at the latitude of Laredo. This apparent sub-Paleocene unconformity is confirmed on satellite photography. The origin of the unconformity is unknown.

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Abstract

This atlas pictorially summarizes the general depositional systems framework and structural features of each to the principal depositional episodes that constitute the South Texas coastal plain and adjacent Burgos Basin of Mexico. Episodes illustrated include the lower, middle, and upper Wilcox, Queen City, Yegua, and Frio. Each map displays the depositional systems geography, shelf margins and related features, mapped depocenters, and associated growth structures.

Raft Tectonics in the Gulf of Mexico?—A Possible Example in South Texas

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Abstract

Regional mapping of 2-D seismic data in South Texas has identified what is interpreted to be a large rafted block of Paleocene and older sediment, similar to rafts identified along offshore Angola. Called the "Wilcox Raft," it has been mapped from the U.S.–Mexican border northward over 200 kilometers to Live Oak County, but may extend farther north or south. The Wilcox Raft has one primary block 150+ kilometers long and 15 to 30+ kilometers wide. It also includes a number of smaller branching arms, ramps, and offset fault blocks. Various portions of the raft have downdip displacements from 5 to 30 kilometers. The raft is bound on the west by expanded upper Wilcox (early Eocene) sediment and on the east by expanded Queen City (middle Eocene) sediment. Other smaller detached blocks exist to the west beneath the Wilcox growth-fault zone.

The Upper Wilcox Trend of South Texas and its Relationship to the Burgos Basin of Northeast Mexico

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Abstract

The South Texas Upper Wilcox Trend (upper Paleocene to lower Eocene), is a prolific natural gas province. In the United States, this trend is part of the Rio Grande Embayment; its equivalent in Mexico is the Burgos Basin. Potential reserves in Mexico could be as high as 6.5 trillion cubic feet of gas. Within Texas Railroad Commission District 4, 5.4 trillion cubic feet of gas has been produced through 2002. With continued deep drilling, the final ultimate production is unknown. Production is dominated by structural closures on the high-side of down-to-the-coast growth faults.

Five depositional sequences are observed, termed the upper Hinnant, upper Zapata, lower Zapata, upper Lopeno, and lower Lopeno. Reservoir quality varies with each sequence. The upper Hinnant sands are clean, but the upper Zapata and lower Zapata sand sequences are shaley. The upper and lower Lopeno sand sequences typically are quartz and plagioclase rich; however, they are very fine grained and their permeability is low. Fracture stimulation is necessary for commercial production. As the Wilcox section extends into Mexico, the shallower Wilcox depositional systems become less important gas reservoirs. The upper Lopeno and lower Lopeno sands are the most prolific. The Lopeno, Bob West, and Arcos fields structural complexes are significant.

The upper Wilcox trend in the northern Texas Railroad Commission District 4 has a normal progradational pattern of extensional growth faulting associated with younger depositional systems expanding beyond older deposits on unstable prodelta-slope shales. To the southwest, however, the depositional pattern begins to show the impact of late movement in the Laramide orogeny from the Sierra Madre Oriental Mountains. Today, these sediments crop out just west of the Rio Grande River. The fully expanded upper Wilcox Section exceeds 10,000 ft of alternating sands and shales. An overall expansion ratio of 7 to 1 is noted. The late tectonic activity created changes in the sourcing and the direction for the deposition of terrigenous sediments and also altered fault patterns in the different sand sequences.

The tectonics of compression within the Sierra Madre Oriental and the extensional growth faulting to the east creates interesting scenarios for exploration. As new depositional centers were produced during the Laramide activity, Gulf Coast growth fault tectonics change. Overprinting by previous progradations is evident. Older depositional fault patterns are obliquely cut by younger ones. Severe rotation into the Gulf Coast Basin is also apparent. Multiple combinations of expansion within the separate upper Wilcox depositional sequences exist in different areas.

For the exploration geologist, all possibilities must be taken into account before drilling an expensive wildcat well.

Improved Characterization of the Compartmentalized and Overpressured Vicksburg Sandstone Reservoirs Using Integrated Sequence Stratigraphy, Diagenesis and Petrophysics

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Abstract

Low-resistivity/low-contrast (LR/LC) intervals in the Vicksburg Formation in TCB field of South Texas are composed of silty, very fine-grained reservoirs less than 2 ft thick separated by seals. Porosity in these sandstones is highly variable and permeability is reduced significantly because of calcite, silica, and clay minerals cements. The sequence stratigraphic framework of the Vicksburg Formation has been developed using 3-D seismic data integrated with facies derived from core, core calibrated logs, and ichnofaunal data. The Vicksburg strata have been deposited in a high accommodation depositional setting that is directly related to the variable rate of syndepositional listric normal fault movement and eustatic sea level fluctuations.

The Vicksburg Formation is overpressured and compartmentalized; upper and lower Vicksburg reservoirs are the two major compartments identified in this study. The overpressured Vicksburg is separated from the overlying Frio by a first order seal. The upper and lower Vicksburg compartments are separated from each other by second order seals. Intra-compartment seals subdivide the major compartment into smaller ones.

On formation micro-imaging logs (FMI), low-resistivity Vicksburg shale and claystone appear as dark brown to gray bands on the image. White color bands represent rocks having the highest relative resistivity (calcite) and/or silica-cemented sandstone having low porosity (<8%) and permeability (<0.003 md). Yellow bands represent the primary reservoir sandstone facies in the LR/LC interval: sandstone having high porosity (average 21%) and relatively high permeability (average 0.16 md). Orange bands are sandstone, containing abundant authigenic clay, showing high porosity (average 18%) but relatively low permeability (0.06 md).

Capillary-pressure measurements may be used to calibrate imaging logs in distinguishing reservoirs from seal intervals. The yellow bands exhibit low displacement pressures (Pd), whereas mercury-injection curves for samples from orange and yellow zones commonly indicate both macro- and micro-pores. White chromatic bands that form intra-formation seals show high injection displacement pressures and sealing capacity.

Seal zones may be identified using fluid-inclusion stratigraphy (FIS). Intra-reservoir seals usually contain abundant fluid inclusions, due to significant cementation. Integration of high-resolution and micro-imaging logs, capillary-pressure data, and fluid-inclusion stratigraphy may be the most suitable method in recognizing reservoirs and seal intervals.

Burgos Basin Play Analysis Reveals Frio-Vicksburg Exploration Focus Areas

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Future exploration focus areas in the Frio-Vicksburg play have been identified by a joint Scotia-Pemex play study of the Burgos Basin, north Mexico. The Frio-Vicksburg play is one of five Tertiary producing trends in the basin and its cumulative production of 4.1 TCF accounts for 63% of total Burgos Basin production. The study involves the (1) regional mapping of major structural elements, (2) definition of the Frio-Vicksburg stratigraphic framework, (3) mapping of depositional systems and reservoir sands, (4) analysis of well performance and show data, and (5) comparison with analogous Frio-Vicksburg production in South Texas. Fifty-two subplays have been identified within 13 stratigraphic units across the study

area, which have been recombined into six plays to aid in comparison with the South Texas producing analogs. Plays then have been ranked and stacked to identify future focus areas.

Three structural provinces are identified: a northwestern province where Vicksburg expansion dominates; a central province (east of the Frio Francisco-Cano fault system) where expanded Frio section dominates; and a southeastern province where the fault systems are oriented northeast-southwest, oblique to the typical north/south-oriented Gulf coast faulting style. The top of the Frio Formation is relatively unstructured in the Burgos Basin and displays a north-south structural grain and gentle east dip. Significantly, more structural relief exists at the lower Frio SB30 level, particularly east of the Francisco-Cano expansion fault. Sediments crop out in the west and reach greater than 5,000m depth in the east. In both the Frio and Vicksburg, traps include high-side and low-side fault-dependent structures, fault-independent structures, and combination structural-stratigraphic traps.

Major depositional systems identified by the depositional architecture mapping include bedload and coastal streamplain systems, fluvial and wave-reworked delta systems, strandplain and barrier lagoon systems, inter-deltaic embayments, and shelf and slope systems. Barrier-lagoon and wave-reworked delta systems are the most dominant subplay composing 24 of the 52 identified subplays. These cover 34% of the total area, yet contribute 74% of the Frio-Vicksburg production. The next largest contributors are bedload-fluvial and fluvial-dominated deltas, which cover 19% of the total play area, and have contributed 18% to Frio-Vicksburg production. Both shelf and slope have been historically poor producers, while interdeltaic embayment subplays have no production to date.

South Texas is geologically and geographically contiguous with the Burgos Basin and, because of its maturity of hydrocarbon exploration and development, offers a unique opportunity for providing insight into the future potential of the Burgos Basin. In the simplest comparison, over 83,000 wells were drilled in Railroad Commission District 4 (RRD4) of South Texas compared to 2,900 wells in the Burgos Basin. Similarly, there are currently 9,299 producing wells in RRD4, compared with 800 in the Burgos Basin. To facilitate comparison between South Texas and the Burgos Basin, the Frio-Vicksburg has been divided into six play regions based on tectonic and depositional systems and hydrocarbon trapping styles. Four of the Texas plays can be correlated with major producing regions in the Burgos Basin.

The results of this study indicate considerable exploration potential and reserves growth opportunities from field rehabilitation in Mexico's Burgos Basin. The greatest potential in Vicksburg reservoirs is interpreted to exist in the deeper stratigraphic units where extending the structural mapping along trend from current production may define additional anticlinal closures. Shallower Vicksburg and Frio units also have potential in untested fault blocks. In the deep Frio, predicted rollover anticlinal traps south of the Reynosa-McAllen fault zone and fault traps along other major growth faults are expected.

Paleogeographic and Sequence Stratigraphic Framework for Mesozoic Carbonate Exploration on the Northwest Gulf of Mexico Rim

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Abstract

Mesozoic stratigraphy of the northwest Gulf of Mexico (GOM) rim from east-central Mexico to Texas-Louisiana (USA) records: (1) Late Triassic–late Middle Jurassic rifting marked by creation of basement highs (e.g., Sabine uplift) and lows (e.g., Sabinas Basin, Mexico; East Texas and northern Louisiana salt basins), and deposition of red beds and Callovian-age salt (Louann); (2) Late Jurassic–early Late Cretaceous passive margin accumulation (15,000-20,000 ft); and (3) late Late Cretaceous Laramide foreland basin development (east-central northeast Mexico) and basement reactivation. Northwest GOM passive margin stratigraphy consists of four 2nd-order supersequences: SS 1—upper Bathonian to lower Kimmeridgian ("158.5"–"144" Ma), SS 2—lower Kimmeridgian to Berriasian ("144"–"128.5" Ma), SS 3—Valanginian to lower Aptian ("128.5"–"112" Ma), and SS 4—lower Aptian to upper Albian ("112"–"98" Ma). These supersequences are marked by regional patterns of facies retrogradation (2nd-order transgressive systems tract) overlain by facies progradation (second-order highstand systems tract). Productive carbonate reservoirs are assigned to specific second-order systems tracts of each supersequence, thus providing a predictive framework for exploitation (reservoir characterization), as well as providing a template for exploration.

Rift-generated basement structures and patterns of early salt movement influenced Late Jurassic and Early Cretaceous facies architecture and paleogeography, controlling the location of principally stratigraphic traps (e.g., grainstone reservoirs and pinnacle reefs of the Cotton Valley Lime/Troy Lime and James Lime in the East Texas and northern Louisiana salt basins). Structural traps affecting Barremian Sligo and Albian Edwards reservoirs in South Texas result from a combination of post-Late Cretaceous salt-influenced tectonics and Laramide basement reactivation (e.g., Totanaca, Sabinas Basin).

Second-Order Accommodation Cycles and Points of "Stratigraphic Turnaround": Implications for Carbonate Buildup Reservoirs in Mesozoic Carbonate Systems of the East Texas Salt Basin and South Texas

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Abstract

The Middle Jurassic-Lower Cretaceous stratigraphy of the onshore region of the Gulf of Mexico (GOM) Basin in Texas consists of five major second-order (approximately 15 Ma in duration) supersequences, defined as large, regionally-correlative, retrogradational-aggradational/ progradational accommodation packages. Each exhibits systematic vertical/lateral stacking patterns of subordinate third-order sequences (1–3 Ma duration) and component lateral/vertical facies and systems tracts. The five supersequences are: Supersequence 1 (SS1)—upper Bathonian to lower Kimmeridgian (158.5–144 Ma), SS 2—lower Kimmeridgian to Berriasian (144–128.5 Ma), SS3—upper Valanginian to lower Aptian (128.5–112 Ma), SS 4—lower Aptian to upper Albian (112–98 Ma), SS 5—upper Albian to Santonian (98–84 Ma).

An analysis of GOM regional Mesozoic sequence stratigraphy and paleogeography has direct application to enhancing our understanding of carbonate reservoirs of the East Texas Salt Basin (ETSB) and South Texas. In this system, carbonate buildup reservoir facies (pinnacle reefs, grain-support shoals, and biostromal banks) form as the terminal phase of carbonate deposition on top of regionally back-stepped ramps (Upper Jurassic) and low-relief rimmed shelves (Lower Cretaceous) within the transgressive systems tract (TST) of a second-order supersequence. Near the top of the TST the retrogradational carbonates are draped in regionally widespread marine shale facies (interval of second-order maximum flooding) which provide both source and seal. The top of the CVL/Haynesville carbonate is a diachronous surface characterized by appreciable depositional topography, onlapped by marine shales along a well-documented submarine condensed section. Little evidence exists for a significant relative sea-level drop at this surface in either system. The reservoir-bearing second-order TST's are separated from second-order progradational highstand systems tract carbonates by GOM-wide second-order supersequence boundaries which mark points of accommodation minima.

Description of a Lower Cretaceous Glen Rose "Patch Reef" in the Prime Operating Company #1-84 La Paloma Well from the Chittim West Field, Maverick County, Texas

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Abstract

Several important carbonate plays have developed in the Lower Cretaceous Glen Rose section in Maverick County in South Texas. As reported by Sams (2002) and O'Brien (2002), the two plays are (1) patch reefs and (2) nonreef-associated vug-enhanced fractured carbonates. The Prime Operating Company core consists of 85 feet recovered from a 120-foot section. The patch reef section is greater than 70 feet thick; however, 35 feet of the lower section was not recovered.

Fifty-two feet of stratigraphic section below the biohermal facies consists of several rock types deposited in deep to moderately deep water. Unit 1 is a burrowed, wispy-bedded Orbitolina lime wackestone to a mud-rich lime packstone. Unit 2 is a burrowed, wispy-bedded, argillaceous lime mudstone containing ostracodes, calcispheres, and echinoid and mollusk fragments. A collapsed burrowed zone marks the top of the unit. Unit 3 and is a lime packstone containing algal(?)-coated grains. Unit 4 grades upward from a lime wackestone to a mud-rich lime packstone. The top of the unit has Orbitolina forams and the first occurrence of requienid fragments.

Unit 5 is an intensely burrowed, mud-rich, slightly dolomitic lime packstone that increases in grain content upward. Requienid fragments (a few whole requienids) are present throughout the section. The section appears to grade into the biohermal facies above. The lower facies of the biohermal facies, Unit 6, consists of a mud-rich, slightly dolomitic lime packstone containing whole abundant requienids, along with a few caprinids, stromatoporoids, and corals. This unit contains the missing core section; however, the porosity curves on the wireline logs suggest that the missing section is probably similar to the rest of Unit 6.

The lime boundstone (bafflestone and bindstone) section, Unit 7, is 18 feet thick. It consists of requienids, stromatoporoids, corals, sponges(?), Chondrodonta, rare caprinids, binding stromatoporoids and Lithocodium, and echinoid and mollusk fragments. Above the boundstone facies is at least 5 feet of coarse-grained lime rudstone (Unit 8) that has the same components as the boundstone.

The bioherms are found in the transgressive systems tract of the longer term Glen Rose composite sequence but in the highstand of the lower Glen Rose high-frequency sequence, below the Corbula(?) beds. In this setting, we anticipate a

string of subparallel isolated buildups rather than a more continuous barrier associated with a late highstand prograding system. Depositional relief on the buildups was as much as 70 feet based on the vertical facies sequence.

The section having moderate reservoir quality includes Units 5 through 8 of the patch reef and associated facies. Pore types are dominated by moldic pores and micropores and some interparticle and intraparticle pores. Average porosity is 9.2% (range is 2.1% to 15.1%), and average permeability is 2.9 md (range is 0.02 to 36.2 md). Units 1 through 4 are deeper water, mud-rich units, and the reservoir quality is much lower than that of the patch reef facies. In these units average porosity is 1.8% (range is 0.8% to 4.1%), and average permeability is 0.5 md (range is 0.01 to 4.5 md). Some of the permeability in these tighter facies may be a result of fracturing of the core plug, as indicated by a near-vertical porosity versus permeability relationship, as displayed in Figure 3.

The well was perforated in the boundstone facies between 5,266 and 5,276 feet and had an initial production test (IPF) of 2.1 MMcf of gas per day with a bottom-hole shut-in pressure of 2,346 psi. It was treated with 1,000 gallons of 15% HCl. This well has produced 1.3 billion cubic feet of gas, 8,842 barrels of oil, and no water since production started in 1993.

Patch reefs, such as those seen in the Price Energy #1-84 well, should be common in the lower Glen Rose section in South Texas. The best exploration approach for these reservoirs is seismic analysis. Both subtle seismic buildups and amplitude anomalies may indicate patch reefs.

Applying the Patch Reef Model to South Texas Exploration:
An Example at South Charlotte Field, Atascosa County, Texas

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Abstract

Several recent oil and gas discoveries in the Glen Rose limestone in Maverick County, Texas, were based upon 3D seismic data, which identified patches of carbonate porosity. Subsequent drilling and coring of the objective zones suggested that the porosity in those reservoirs was related to the presence of either patch reef sediments, to fractures, or both.

A patch reef model proposed in 1981, but heretofore not widely applied to South Texas carbonate exploration, has been validated recently in the James Lime play, offshore Louisiana. As an effective exploration tool, this model can be applied to subsurface data throughout the Gulf Coast by making a "best-fit orientation" if cuttings or a core confirm the presence of a patch reef. A best-fit orientation includes proper aligning of the patch reef's long axis, determining its probable dimensions, and projecting a possible direction of transport of bioclastic debris. Constraints from both regional and local geology together with well data must agree with the best-fit orientation.

This paper illustrates how to best-fit the model to some actual data using the abandoned Edwards limestone patch reef reservoir in the South Charlotte Field, Atascosa County, Texas, as an example.

Stratigraphic Framework and Exploration Potential of Sligo Formation Carbonates (Lower Cretaceous) in South Texas

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Abstract

Based principally on seismic-stratal geometries, Sligo Formation carbonates, which range up to approximately 1000 m in thickness, comprise two complete third-order sequences and the transgressive phase of a younger third-order sequence in a 22,000+ km2 area that includes parts of Webb, La Salle, and McMullen counties, Texas.

The two complete third-order Sligo sequences and an older Hosston sequence form a transgressive-regressive second-order sequence. The architecture and facies mosaics of each of the third-order sequences have been influenced by available accommodation space, driven by thermal subsidence, eustasy, and paleotopography (mostly the result of tectonism, including salt movement, and inherited paleodepositional topography). In general, the oldest sequence (Sequence 20, Hosston) largely fills pre-existing accommodation space, most of which was tectonically controlled and shows little evidence of significant progradation. The oldest Sligo sequence (Sequence 30) continues to fill pre-Sligo topography, but its architecture is aggradational to progradational. The influence of inherited structural paleotopography is not as important for the youngest complete Sligo sequence (Sequence 40), which is strongly progradational and has a locally well-developed shelf-margin buildup. The onset of Sequence 50 to the top of the Sligo marks the initial flooding of the next second-order sequence, and this succession is retrogradational.

Viable Sligo exploration plays in this area include the "Structural Hinge Line Play," which produces from packstones and grainstones (based on core data) of the transgressive systems tract of Sequence 50 on small structural closures along the present-day structural hingeline; and an untested (?) "Debris Wedge Play" comprising structural/stratigraphic traps in potentially coarse-grained sediments shed basinward from Sligo shelf margins.

Revisiting Mature Fields with Modern Technology and Geologic Concepts: Examples from the Frio of South Texas

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Abstract

Subregional 3-D seismic volumes and wireline logs permitted definition of second- to fifth-order (~10 my–10 ky) Frio and Anahuac (Oligocene) sequences, systems tracts, and associated syntectonics. Third- and most fourth-order sequences were correlated within several subregional wireline-log and seismic networks. Vicksburg and Miocene sequences were of secondary interest. Composite sequence logs were used to characterize principal fields. Sequence analysis identified and correlated all key surfaces: type 1 unconformities, maximum flooding surfaces, and transgressive surfaces bounding systems tracts. Although microfossil occurrences are not necessarily required for sequence analysis, limited data were integrated with the final sequence frameworks, providing secondary verification of assigned ages.

Lithostratigraphic Frio and Anahuac strata comprise six chronostratigraphic, third-order depositional sequences (~32.0–23.38 Ma) and myriad fourth- and fifth-order sequences or parasequence sets. Except for incised valley fills, lowstand tracts comprise off-shelf systems deposited within active, growth-faulted, intraslope subbasins. Maximum Anahuac flooding (~24.57 Ma) provides a regional, dated marker to which latest published ages of sequence surfaces are calibrated. Maximum flooding surfaces and type 1 unconformities are essentially isochronous, but sand-rich lithofacies are mostly diachronous. Off-shelf and on-shelf deposition are temporally unique. Many previously inferred Frio "stacked barriers" are dip-oriented incised valley-fill facies.

Seaward, lowstand sedimentary wedges and superposed shelves become younger. Entrenched rivers supplied sediments via ephemeral deltas for gravity transport to basin floors and slope fans. Eventually, overloaded lowstand depocenters initiated gravity faulting, mobilized mud, and, hence, produced younger faulted, shale-withdrawal subbasins. Diminished faulting permitted lowstand deltas to extend shelf edges basinward until the deltaic ramps were anchored at the basinward margin of buried subjacent shale ridges. These shale buttresses stabilized the upper continental slope and shelf

edge. During a later cycle, highstand shorelines prograded basinward over the shallow, lowstand ramps. On-shelf regression eventually was stalled by increasing accommodation space near the continental shelf edge, establishing another depocenter and intraslope subbasin.

Gas in lowstand deltaic and distal valley-fill reservoirs is trapped updip against hanging walls of extensional faults overlying shale-cored anticlines. Combination trapping and basin-floor and slope-fan reservoirs are viable targets. Sequence ideas offer new, but deeper prospecting targets.

Facies and Environments of the Lobo Trend, Webb and Zapata Counties, Texas: Examples from Core

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Abstract

Slabbed whole cores from two wells illustrate some sedimentological aspects of reservoir development in the Lobo sands (lower Wilcox, Paleocene). The Lobo system constitutes a large gas play in Webb and Zapata counties, Texas, currently in a mature state of economic development as a result of extensive drilling over the past three decades. Geopressured gas is trapped beneath a regional seal of marine shale, in comminuted, rotated extensional fault blocks of a submarine gravitational slide complex. The original stratigraphy consists of stacked, laterally extensive nearshore progradational units in which silty shales grade upward into muddy fine to very fine sands.

Cores are presented from the Lobo 6 interval in a Webb County well and from the Lobo 1 interval in a Zapata County well as examples of Lobo reservoir facies. Core facies include muddy bioturbated sandstone, laminated sandstone and shale, structureless sandstone, disrupted and liquefied sandstone and siltstone, cross-bedded sandstone, bioturbated sandy shale, and clay shale. Associations of sedimentary structures and trace fossils are consistent with a generally shallow-water, marine origin. Transitions from wave-generated structures to tidally-influenced structures, together with log motifs and correlations, suggest that depositional environments varied cyclically from open marine shelf to prograding shoreface to transgressive barrier-lagoon systems. Transgressive tidal sands are less abundant but have higher reservoir quality on average than shoreface sands. Development and preservation of tidally-influenced sands was likely enhanced by high accommodation or significant transgressive barrier formation.

Subsurface Cretaceous Chronostratigraphy: Relation to Global Eustatic Changes

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Abstract

The Cretaceous System of the Gulf Coast has long been a rewarding and frustrating exploration target. Complications arise from a number of interrelated problems: (1) facies variability and complexity result in the lack of a thorough understanding of the lateral extent of the reservoirs, as producing fields occur in a wide variety of reservoir types, some of which have extensive lateral and vertical variations in porosity and permeability; (2) trapping mechanisms range over a wide variety of reservoir types and varied ages; (3) age determinations based on microfossils in the carbonates are hampered, as thin section analyses of the taxa, a practice highly perfected by Europeans, is not practiced by most of the Gulf Coast paleontologists; (4) facies relationships of the downdip section to their updip equivalents are not fully understood; and (5) in downdip areas, excessive depths require drilling into high pressure and/or temperature environments, resulting in a host of interactive problems including high operating costs. The Cretaceous System remains an attractive exploratory objective. However, it is imperative that careful analyses of the rocks and the fossils, and their integration with logs and seismic data, are required for a clearer understanding of the complexities of the different parameters.

Our purpose in this study is four fold: (1) to provide a framework and establish a chronostratigraphic section for the subsurface Cretaceous of the Gulf of Mexico Basin utilizing planktonic foraminifers as well as larger benthic forms and calpionellids for future work; (2) to tie in the sections with the worldwide planktonic zonation; (3) to establish a correlation between the global sequences recognized by Vail and the Gulf of Mexico section; and (4) to list the important index markers for each section so as to result in identifying and exploring more economical and profitable plays.

Analyses of over 350 deep wells using thin sections in the carbonates for identification of larger foraminifers and calpionellids and using traditional analysis for isolated forams (benthonics and planktonics) in the clastics has resulted in construction of several subsurface correlation charts for the onshore Gulf of Mexico, from the Rio Grande of South Texas, through Central and East Texas, Louisiana, and Arkansas, to western Alabama. The charts (one strike section and four dip sections) demonstrate the facies and age relationships of the sediments along strike and their relative changes dipward. The marker fossils are identified and the relationship to sediment onlap and or eustacy and sequence boundaries is attempted.

Availability of abundant subsurface data for the Cretaceous section of the Gulf of Mexico region makes it possible to determine the marker taxa (planktic and benthic foraminifers, and some of the calcareous nannoplanktons and calpionellids), their age relationship to the global zones, and the relationship of shelf carbonates, evaporites, and clastics to eustacy. As sedimentary deposition of the region has been in part controlled by somewhat gentle tectonic subsidence enhanced by eustatic variations, the major hydrocarbon fields found can be related to sea-level changes at the time of deposition and early diagenesis. We follow those who believe that, except for chalk, most of the carbonates in the section are related to highstand systems tracts; most clastics are related to lowstand systems tracts; and coaly sections and anhydrites indicate sequence boundaries.

Mesozoic Redbed Deposition vs. Coeval Terrestrial Volcanism along the Rim of the Gulf of Mexico: Where is the Boundary?

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Abstract

Volcanic, sedimentary, and granitic plutonic rocks that are part of the Early Mesozoic Cordilleran continental magmatic arc are exposed in a belt from the southwestern United States to Guatemala. In north-central Mexico, these volcanic arc suites, which are grouped into the Nazas Formation, record volcanic activity, crustal extension, and erosion of volcanic edifices in a subaerial volcanic arc that developed from Late Triassic to Middle Jurassic time along the México western continental margin. The Nazas arc consists of more than 3 km of volcanic flows, pyroclastic rocks and clastic sedimentary strata that were formed in extensional intra-arc basins within the upper arc structure. These sequences are characterized by drastic facies changes over short distances, highly variable thicknesses of basin-fill, mixed sediment composition, heterogeneous lithologic associations, and poorly known fluvial and alluvial facies distribution, all of which reflect the complexity of the arc environment. The size, original orientation and geometry of individual basins within the arc are unknown in detail due to younger tectonic events and erosion.

Early Mesozoic extension along the arc was contemporaneous with rifting along the western Gulf of México to the east. Rift basins along the Gulf were filled with Late Triassic and Early-Middle Jurassic redbeds, evaporite deposits and occasional intercalations of pyroclastic rocks that may have erupted from the arc and probably traveled east, reaching the zone of rifting that created the Gulf of México. In this scenario, two distinct extensional provinces overlapped within the Nazas arc, one with volcanic and pyroclastic rocks dominant in the west (Nazas Formation) and redbeds (Huizachal Group) in the east and offshore in the western part of the Gulf of Mexico. The complex interaction of geologic processes related to two distinct but coeval tectonic settings (subduction beneath the arc and rifting along the Gulf of Mexico rim) rule out previously proposed simple rift system models. Whether extension along the Nazas magmatic arc is the result of westward propagation of Gulf-related rifting, or extension along the Gulf of Mexico coastal region is related to back-arc extension is an issue to be resolved. The evolution of these two tectonic domains is critical in understanding the structural framework and the Late Jurassic source rock distribution of the prolific petroleum basins in Mexico.

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