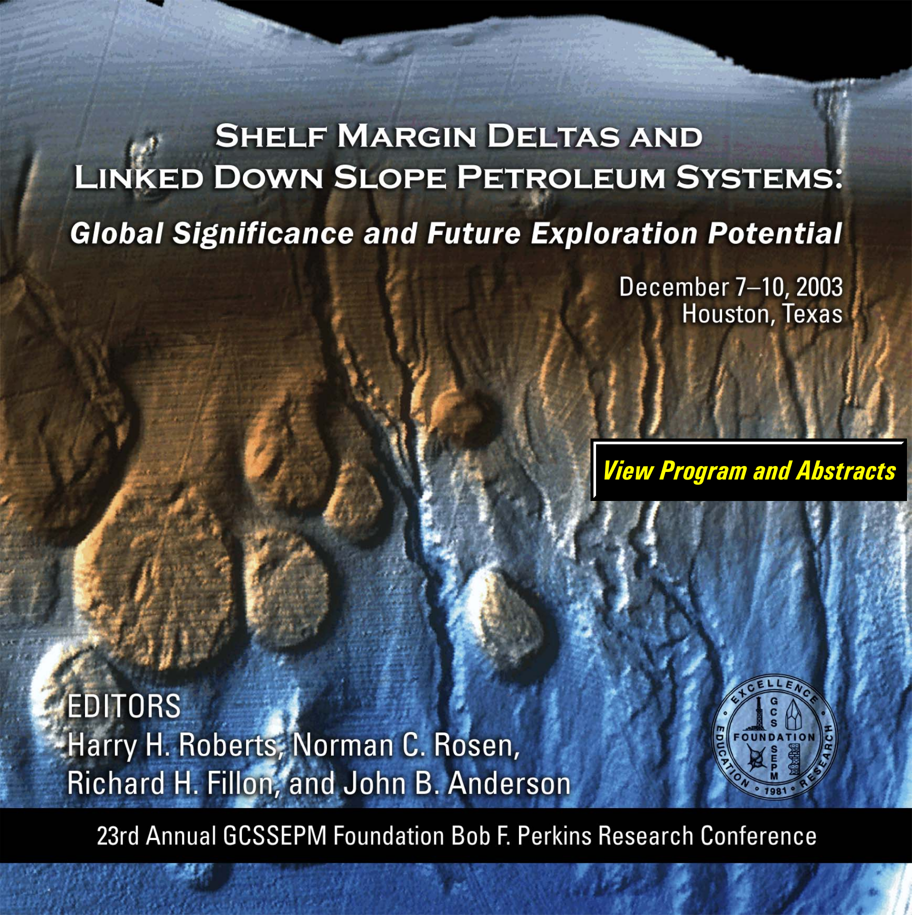

Shelf Margin Deltas and Linked Down Slope Petroleum Systems:

Global Significance and Future Exploration Potential

December 7–10, 2003
Houston, Texas

View Program and Abstracts

EDITORS
Harry H. Roberts, Norman C. Rosen,
Richard H. Fillon, and John B. Anderson

23rd Annual GCSSEPM Foundation Bob F. Perkins Research Conference

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Published December 2003

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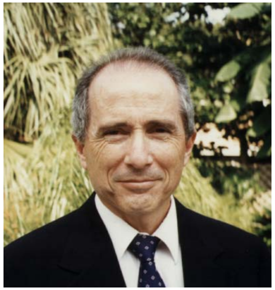
Foreword

The 21st century has dawned, bringing both increased demands for energy and a search for energy independence by both industrialized and developing nations around the globe. In response, the petroleum industry and academic institutions are striving to develop a sophisticated understanding of the complex shelf-to-basin siliciclastic depositional systems that hold great promise for large discoveries in the coming decades and, more importantly, will provide clues about the generative capacity and long-term sustainability of major petroleum systems. Fueled by impressive progress in seismic imaging, deep-water and deep-basin drilling, production and well logging technologies, the focus of deep-water exploration and production is rapidly moving down the continental slope and rise and out into abyssal environments, both modern and ancient. The advancing technical front may very well be outpacing the growth of our understanding of the geological systems needed to sustain successful exploration.

This year's Bob F. Perkins 23rd Annual GCSSEPM Foundation Research Conference, "Shelf Margin Deltas and Linked Down Slope Petroleum Systems: Global Significance and Future Exploration Potential," provides a forum for generating and discussing cutting-edge ideas and concepts that will lead to a better understanding of frontier petroleum systems that support productive deep-water reservoirs. The conference examines the

Harry H. Roberts
Committee Co-Chair



Richard H. Fillon
Committee Co-Chair

John B. Anderson
Committee Co-Chair

generative, migration, and reservoir links connecting terrestrial sediment sources and deep basinal hydrocarbon accumulations. The final program offers 35 oral presentations organized into two basic themes: (**1**) Modern and Quaternary Shelf-to-Basin Depositional Systems; and, (**2**) Shelf-to-Basin Subsurface Petroleum Systems. Examples gathered from around the world will be presented that explore complete siliciclastic petroleum systems in greater detail than ever before.

The technical program begins with process- and architecture-oriented keynote talks that focus on: (**1**) Sediment supply to the shelf-margin as a function of alluvial valley responses to sea-level change (summarized by Mike Blum); (**2**) Shelf margin delta deposition in the northern Gulf of Mexico (summarized by John Suter); and (**3**) An examination of slope–basin deposition fed by the East Texas Brazos-Trinity fluvial-deltaic system (summarized by Rick Beaubouef). These three keynotes examine sedimentary processes and depositional styles through informative late Quaternary examples. The program continues with sessions devoted to subsurface examples. Larry Meckel will give a keynote presentation summarizing productive shelf-margin delta trends from the circum-Gulf of Mexico region, including examples from the Tuscaloosa, Wilcox, Yegua, Vicksburg, and Frio deposystems. Conference-long poster displays will be provided by all those giving oral presentation and by authors who will not be presenting orally, offering abundant opportunity for one-on-one discussions between authors and attendees. In total, 97 authors are involved in this year's program. In addition to studies highlighting Gulf Coast geology, examples will be presented from Africa, Brazil, Brunei, Norway, Korea, Indonesia, and Trinidad.

The authors are to be commended for the high-quality ideas and data presented in their papers. The lavishly illustrated GCSSEPM CD ROM volume of the conference proceedings is truly a barometer of our understanding of shelf-to-basin siliciclastic deposystems and the dynamic petroleum systems they create. This high-quality publication should prove to be a valuable reference for geoscientists and petroleum professionals for a long time to come.

Those of us who organized this research conference are truly grateful for the authors' vigorous efforts in preparing and revising manuscripts at a time when the work loads at companies and universities have increased dramatically. We appreciate the support that industry has provided by releasing data and

encouraging their employees to participate in this focused research meeting.

This conference would not have been possible without the "behind the scenes" volunteer efforts of dedicated and indefatigable GCSSEPM trustees and officers, especially Norm and Rashel Rosen, Nancy Engelhardt-Moore, Paul Weimer, Lana Czerniakowski, and Mike Styzen. It is also important to acknowledge the many individuals who have provided insightful reviews of the many manuscripts and extended abstracts. They are too numerous to recognize individually. However, without their help, the conference proceedings CD ROM could not have been reviewed and produced in time for the conference.

We thank Gail Bergan and Leann Wagerle for preparing the conference proceedings CD ROM. They worked tirelessly as we stretched the final deadlines and everyone's spirits close to the breaking point to have the papers and abstracts submitted in final form and readied for inclusion on the CD ROM. They have produced a professional product that will be a significant reference work and valuable reminder of the exciting exchange of ideas generated at this conference.

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Cover Image

The image used on the cover of this CD ROM and the opening animation is used with permission from F. Diegel, Shell Offshore. The image is a computer-enhanced multibeam bathymetry image of the northern Gulf of Mexico continential slope, east of the active Mississippi River delta. The shelf-edge along this sector of the slope is composed of compensationally stacked clinoform wedges deposited during Pleistocene times of lowered sea level. Many of these shelf-edge deltas are connected to sediment by-pass systems clearly shown in this image as channel-levee systems that functioned as sediment transport pathways to deep-water depositional sites.

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23rd Annual GCSSEPM Foundation Bob F. Perkins Research Conference

2003

Adam's Mark Hotel
Houston, Texas
December 7–10

Sunday, December 7

4:00-6:00 pm	**Registration (Grand Foyer) and poster setup (Grand Pavilion)**
6:00-8:00 pm	**Welcoming Reception and Poster Preview (Grand Pavilion)**

Monday, December 8

7:00 am	**Continuous Registration (Grand Foyer)**
7:45 am	**Welcome: GCSSEPM Foundation**
7:50 am	**Introduction and Welcome: Harry Roberts, Program Co-Chair**

Session I—Modern and Quaternary Shelf-to-Slope Depositional Systems

Abstracts
Author

12:00-1:30 pm LUNCH

Session II—Shelf-to-Slope Subsurface Petroleum Systems

Tuesday, December 9

Session III—Modern and Quaternary Shelf-to-Slope Depositional Systems

Abstracts

Author

Wednesday, December 10

Session V—Shelf-to-Slope Depositional Systems

Abstracts

Author

10:00 am **REFRESHMENTS**

Posters

Abstracts

Author

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Author

Sediment Supply to the Shelf Margin and Beyond: Alluvial Valley Responses to Sea-Level Change

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Abstract

Shelf-margin deltas and linked downslope depositional systems are in most cases fed by alluvial valleys that serve to deliver sediment eroded from the hinterland. Accordingly, alluvial valleys provide the link between processes that control sediment flux to the continental margin and processes that control dispersal into the basin. Current research shows the volume of sediment delivered to the margin will reflect hinterland drainage areas and large-scale relief. Superimposed on this background rate will be an unsteadiness that reflects climate change in hinterland source regions, but the rates and directions of change in sediment supply will vary regionally. Alluvial valleys modulate unsteadiness in sediment supply through changes in sediment storage. However, regional variability in the rates and directions of change in sediment supply insures that responses to climate change are regionally circumscribed, and alluvial valley systems in different regions may respond in opposite ways to the same global climate change. Sea-level change has little effect on the total volume of sediment delivered to the margin, but instead forces channel extension and shortening, which plays a major role in determining the proximal to distal location of the river mouth point source through which sediment is dispersed to the shelf and beyond. Moreover, the widely used concept of incision and complete sediment bypass within incised valley systems during periods of relative sea-level fall should be abandoned. Instead, falling stage to lowstand fluvial deposition is actually common in well-studied Quaternary analog systems, and falling stage sand bodies may comprise a

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Author

significant proportion of reservoir-quality sands within many incised valley fill depositional sequences. Models for falling stage and lowstand systems tracts should therefore incorporate significant fluvial channel belt deposits that are likely connected to, and feeding, the offlapping shore faces, shelf-margin deltas, and linked downslope systems.

Abstracts

Author

Late Quaternary Shelf Margin Deltas, Northern Gulf of Mexico

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Abstract

Along the shelf margin of the northern Gulf of Mexico, numerous late Quaternary deltaic systems occur where ancestral rivers encountered the shelf-slope break. These shelf-margin deltas are products of deposition during glacio-eustatic fluctuations resulting from expansion and contraction of continental ice sheets. Lowered sea level shifts paralic environments seaward and creates widespread subaerial unconformities, well-defined drainage networks (incised valleys), and deltaic systems that prograded to the shelf margin. Shelf margin deltas are primary mechanisms for shelf margin and upper slope progradation, and serve as important conduits of sediment to deeper water environments.

Abstracts

Author

Basin 4 of the Brazos-Trinity Slope System, Western Gulf of Mexico: The Terminal Portion of a Late Pleistocene Lowstand Systems Tract

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Abstract

An ultra-high resolution, short-offset 3D seismic survey (EBHR3D) has been used to study the sedimentary fill of an intra-slope basin in the East Breaks area of the Gulf of Mexico. The site chosen for the seismic program is the fourth and southernmost basin (Basin 4) in the Brazos-Trinity Slope System. The Brazos-Trinity Slope System is a set of latest Pleistocene salt-withdrawal basins that are connected by channels in the upper to middle portion of the Texas continental slope. They are filled with sediment delivered to the slope by the ancestral Brazos and Trinity rivers and associated shelf edge deltas. Together, the linked shelf and slope depositional systems form a late Pleistocene lowstand systems tract. The seismic survey has been designed to target a large submarine fan at the top of the basin-filling succession (the Upper Fan), but imaging of the entire 250 m (maximum) of basin fill is excellent. The results are providing detailed information regarding deep water deposition far surpassing what is possible from outcrop or conventional subsurface studies. The data provide unprecedented images of the three-dimensional geometry and internal architecture of these deep-water deposits. The fill of Basin 4 records a stratigraphic evolution that includes a "ponded" fill stage followed by a "perched" fill stage. Contrasting deposit geometry and stacking patterns occur during these two stages of evolution. The perched fill of the basin contains the Upper Fan, which is located in the shallowest portion of the subsurface beneath an extensive Holocene drape. The Upper Fan represents the terminal, distributive complex of the lowstand system tract. It is a basinward-tapering wedge of sediment that contains both channel-form and sheet-like depositional elements.

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Author

The prominent stratigraphic features interpreted from the Upper Fan are: (**1**) off-lapping, clinoform reflection patterns; (**2**) distributary channel systems linked to channel mouth lobes; (3) down-fan progression in architecture from channel-form elements to more sheet-like elements; and (**4**) down- and across-fan decrease in sand percent and/or grain size inferred from seismic attributes. In these and other ways, the stratigraphy of the Upper Fan is similar to that commonly observed for modern and ancient river deltas.

Abstracts

Author

Late Quaternary Shelf-Margin Delta and Slope-Fan Complexes of the East Texas–Western Louisiana Margin: Variable Response to Eustasy and Sediment Supply

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Abstract

During the previous glacial-eustatic fall, the ancestral Brazos and western Louisiana rivers, which flowed across low gradient coastal plains and shelves, constructed large fluvial-dominated deltas that extend to the shelf margin. These rivers shifted to new locations prior to the lowstand, resulting in shelf-margin deltas that have no associated down-dip lowstand deltas or fans. The Trinity and Colorado rivers remained fixed in their locations throughout the eustatic fall and lowstand, resulting in linked valley/delta/fan complexes. Re-incision of lowstand valleys by these rivers over several eustatic cycles resulted in significant sediment bypass to the slope.

Factors that influenced the response of rivers to falling sea level include long-term sediment supply, diapiric controls on channel location, and the physiography of the shelf over which the rivers flowed.

Abstracts

Author

Late Pleistocene Sequence Stratigraphy of the Shelf-Edge and Upper Slope in the Viosca Knoll Area of the Northeast Gulf of Mexico

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Introduction

The late Pleistocene (isotope stage 2) Lagniappe Delta system (Kindinger, 1988, 1989) is located on the middle to outer Mississippi-Alabama shelf–upper slope in the northeastern Gulf of Mexico, just to the east of the Modern Mississippi Delta. In order to understand the sequence stratigraphy and stratigraphic architecture of this delta system in detail, a consortium of 10 oil companies, known as the Gulf of Mexico Shelf-Slope Research Consortium (GOMSSRC) drilled four continuously cored bore-holes and acquired high resolution seismic, supplementing the seismic already available (Kindinger, 1988, 1989). Several papers have been published as part of this consortium project addressing various aspects of the delta history (Sydow and Roberts, 1994; Winn *et al.*, 1995, 1998; Kolla *et al.*, 1997, 2000; Roberts *et al.*, in press; Fillon *et al.*, 2000; 2003, in press; Kohl *et al.*, in press) In this brief paper, we focus on the late Pleistocene sequence stratigraphy and the evolution of the shelf-edge to upper slope transition. We will not duplicate the previous studies, but will draw and expand upon some of their conclusions. We believe that the Lagniappe Delta Consortium data set is the best one to document the forced regressions (glacioeustatic sea level changes) that drive the evolution of the Lagniappe Delta. Lagniappe data, particularly that derived from the nearly continuously cored upper-slope VK774c1 corehole, and high resolution GOMSSRC and newer high-resolution seismic have helped explain the certainties and ambiguities of different types of sequence boundaries and other significant sequence stratigraphic surfaces in the important shelf-slope transition zone.

Detailed analyses of sedimentary structures, grain size, faunal and floral markers and abundances, paleobathymetric and isotopic data, gamma-ray well-log data, and high resolution seismic data in the Viosca Knoll area of the northeastern Gulf of Mexico provide an excellent opportunity to precisely identify key sequence stratigraphic surfaces. These data sets also help to develop an understanding of the sedimentary history of the upper slope during the late Pleistocene (0-550 Ka). In 240+ m of hydraulic piston core recovered from GOMSSRC corehole VK774c1, maximum flooding surfaces and condensed sections are characterized by high fossil abundances and shell-rich intervals, deep paleo-bathymetry, moderate to high gamma counts, light (^{18}O-depleted) oxygen isotope values, and strong continuous seismic reflections. In contrast, sequence boundaries are characterized by low fossil abundances, shallow bathymetry, abrupt lithological breaks, coarsening-upward intervals and clinoform packages, truncated surfaces of clinoforms (base of incised valley), and heavy isotope values. The data suggest that in the interval starting with the oxygen isotope stage 13/14 transition and ending in late stage 8, paleobathymetry decreased significantly, producing an interval of subaerial exposure at the end of isotope stage 8. This exposure is due mainly to high sediment supply and depositional rates relative to subsidence in the area during that time. Within the broad isotope stage 13/14 to 8 interval, however, intermittently deepening and shallowing bathymetries, faunal and floral abundances, several maximum flooding surfaces, heavy to light isotope values, abrupt lithological breaks, coarsening upward intervals, and included clinoform packages clearly show the imprint of high frequency eustatic sea level changes on the sedimentary record. Subsequent to stage 8, until present, the bathymetry deepened to upper bathyal and outer neritic depths. This deepening is due to the greater influence of subsidence relative to sediment supply and depositional fill. Again, this interval does record higher-frequency eustatic changes of sea level during isotope stages 7, 6, 5, 4, 3, 2, and 1.

Conceptually, depending on their location on the shelf-slope transition, major sequence boundaries during a particular glacial isotope stage may occur just above deltaic clinoform packages (Kolla *et al.*, 2000) or just below deltaic clinoform packages; *e.g.*, the "prograding wedge complexes" of Vail (1987). Of the two major deltaic clinoform packages cored in the Viosca Knoll area, the isotope stage 8 delta was deposited in a platform setting and the major sequence boundary, which is manifest in the form of prominent erosional scour and valley incision, clearly overlies this delta. Because of its resemblance to a better-studied stage 2 Mobile River delta located just updip, we consider that the sediments of the stage 8 delta were also derived from the Mobile River (*i.e.*, they are part of a greater Lagniappe Delta complex and depocenter).

The other major delta penetrated in the VK774c1 corehole was deposited during isotope stage 10. It does not show any indications of erosional or coarsening-upward stacking, but does show shallowing-upward bathymetry. There are no indications of subaerial exposure in the stage 10 delta. The stage 10 clinoforms sampled in the VK774c1 corehole are of very low angle, appear to consist of thicker beds than the stage 8 clinoform set, and are therefore entirely consistent with deposition in a prodeltaic setting. Oxygen isotope values are heaviest toward the top of the stage 10 clinoforms, suggesting that the main stage 10 sequence boundary lies on top of this delta also.

Abstracts

Author

Timing of Late Pleistocene Shelf-Margin Deltaic Depositional and Mass-Transport Events, East Breaks 160-161 Shelf-Edge Minibasin, Gulf of Mexico

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Abstract

Lithologic, biostratigraphic and isotopic data from cuttings provides calibration of three sigmoidal, clinoform packages separated by regionally continuous, parallel seismic facies. This depositional geometry is interpreted as a shelf-margin, deltaic wedge deposited within the East Breaks 160-161 minibasin. A chaotic seismic facies package extending over more than 84 mi^2 (218 km^2) occurs between two clinothem packages of Ericson Zone Y (71 ka BP to 12 ka BP). The chaotic package is interpreted to be a mass-transport complex that failed during the accelerated rate of sea level fall during late Oxygen Isotope Stage 3 (approximately 30 to 20 Ka). Clinothem foresets, bottom sets and the mass-transport complex are predominantly clay with minor siltstone. Sands are restricted to proximal topsets and fluvial channels.

The mass-transport complex consists of three subfacies: rotated-block, hummocky-mounded, and disrupted. Distribution and volume of these facies suggests that only the rotated-block subfacies has been significantly transported, and that the hummocky-mounded and disrupted subfacies result from different degrees of disruption of ponded, clay-prone layered sediments by compression and dewatering triggered by the submarine slide of rotated blocks.

Abstracts

Author

A Linked Shelf-Edge Delta and Slope-Channel Turbidite System: 3D Seismic Case Study from the Eastern Gulf of Mexico

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Abstract

Linked shelf edge deltas and slope channel systems are observed in the eastern Gulf of Mexico. The slope channels are characterized by deep incision into the substrate and moderate sinuosity nearly to the shelf-slope break. Channelized flows were not fully confined as evidenced by well-developed levees up to 90 m thick. This sinuosity suggests that turbulent flow within the channel was likely nearly from the uppermost slope. With apparent turbulence characterizing these channels nearly to the shelf-slope break, the dominant mode of sediment delivery to the slope and basin beyond probably was in the form of density underflow (*i.e.*, hyperpycnal flow) rather than shelf edge slump and/or slide progressively transformed into turbidity flow.

The stages of evolution of these slope channels are (**1**) clustering of small slope gullies on the slope at the initiation of lowstand deposition, (**2**) dominance of one of these slope gullies and formation of one significant channel, formation of a frontal splay fed by the dominant channel, (**3**) abandonment of frontal splay deposition in favor of leveed channel deposition across the entire slope, and (**4**) entrenchment of the leveed channel into the earlier deposited leveed channel and frontal splay.

Abstracts

Author

Asymmetric Rifting and the Northern Gulf of Mexico Supra-Salt Platform: Implications for the Initial Depositional Setting of Texas–Louisiana Tertiary Clastic Systems

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Abstract

Unravelling end-Cretaceous paleobathymetric dip-profiles along strike in the northern Gulf of Mexico continental margin (**nGoM**) is important because it provides us with the initial framework in which to assess the evolution of Cenozoic clastic systems and burial history. Light can be shed on the problem by integrating seismic and potential field data with analytical basin modelling techniques and palinspastic-kinematic paleogeographic analysis. Progressive palinspastic reconstruction of the Gulf is critical to setting up the appropriate lithospheric models to assess subsidence history. Kinematically, the opening of the GoM involved an early rift stage of northwest–southeast stretching (with minor counterclockwise [**CCW**] rotation) between North America and Yucatán (Triassic–Early Oxfordian), followed by a drift stage of seafloor spreading between the opposing rifted margins that entailed significant **CCW** rotation of Yucatán Block. This Stage 2 rotation was accommodated by transform motion of Yucatan/Chiapas Massif along the foot of the very narrow eastern Mexican margin, but transform motion stopped once the Central Gulf Spreading Ridge passed any point along this margin. Thus, the crustal boundary along eastern Mexico is ultimately an igneous, constructional contact that is overlain by the entire stratigraphy visible on seismic, and no transform faults are to be expected (Pindell, 1985).

The rift stage was asymmetric (Pindell *et al.*, 1986; Marton and Buffler, 1994) such that Yucatán collapsed off the mainly northwest-vergent Alleghenian Orogen of the southern USA. The **nGoM** margin (footwall) underwent large and rapid tectonic subsidence during the rift stage (because the crust was highly stretched), but little thermal subsidence during the drift stage and thereafter (because the lithosphere was NOT stretched much). In contrast, the Yucatán hanging wall underwent little syn-rift subsidence (because the crust was not stretched much), followed by considerable post-rift (Late Jurassic and younger) thermal subsidence (because the lithosphere was stretched). During the rift stage, thick red beds, possibly with lacustrine or even marine intervals, effectively buried basement in most **nGoM** areas and, toward the end of the rift stage (Callovian–Early Oxfordian), gave way to salt deposition across much of the half-open Gulf basin. Original salt thickness is generally considered to exceed what could have been achieved by thermal subsidence alone (~2km) during Callovian–Early Oxfordian time (presumed age-span of salt deposition); thus, salt accumulation was coeval with Stage 1 tectonic subsidence (syn-rift) and/or involved the marine inundation of pre-existing, isolated, sub-sea level accommodation space, which, by Oxfordian time, was almost definitely filled to sea level with salt. Together, red beds and salt probably are 5–10km thick beneath much of the **nGoM** rifted margin.

Oxfordian onset of **CCW** rotational seafloor spreading in the Gulf split the pre-existing red-bed/salt basin into the Louann and Campeche halves. Backstripping shows that ocean crust was generated near its typical 2.6km depth below sea level, and not at an Icelandic-setting near sea level. The continent-ocean boundary typically is marked by a large step up from continental to oceanic crust (*i.e.*, the rifted continental crust was already buried by red beds and salt far thicker than 2.6km ocean-generation depth, so the basement step to ocean crust is UP). As spreading ensued, a central, widening “chasm” was produced that was floored by oceanic crust and that, once Smackover open marine conditions were established, received no new depositional salt. To our knowledge, truly autochthonous salt cannot be shown to overlie definite oceanic crust; thus, initial spreading was effectively coeval with the onset of Smackover open marine conditions, and there may have been a causal relationship between the onset of spreading and the breaking of the evaporitic sill, wherever that was (Florida Straits or Veracruz Basin are equally viable guesses).

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As seen south of the Middle Grounds margin, the immediately adjacent shoulders of these salt walls halokinetically collapsed into the widening chasm, but, given the enormous width of the **nGoM** rifted margin, an important question is to assess how far north into the salt basin such early collapse occurred. The Red Sea analogue shows that the salt could have supported shelf platforms at least into the Cretaceous; we typically observe minor (<20km) extrusion of salt across the step up onto oceanic crust, but locally, such as at Sigsbee Escarpment, salt may have collapsed much farther (100km) onto the ocean crust, possibly as early as Late Jurassic–Cretaceous times. In such places, the term "parautochthonous salt" applies, because the salt still underlies most stratigraphy although it acquires a tapered-wedge cross-sectional geometry as it collapses.

Because the **nGoM** margin was the footwall during Jurassic asymmetric rifting, thermal subsidence had far less influence on paleobathymetry than is commonly believed. Thus, determination of paleobathymetry can be roughly gauged by structural analysis of halokinesis. Thus, for large areas of the **nGoM** margin, we propose (**1**) that a relatively shallow, "supra-salt platform" persisted until the Late Paleocene onset of the well-known Wilcox growth faulting, and (**2**) that the Upper Jurassic–Cretaceous supra-platform section remained shallow, and was never deeply buried until halokinetic collapse began. This contrasts sharply with the Campeche Salt margin of Mexico, which was drowned to truly basinal depths in the Late Jurassic–Early Cretaceous due to far higher rates of post-rift thermal subsidence and weak clastic sediment supply. Thus, in the north but not in the south, we envision a very broad, relatively shallow supra-salt platform with a thinner-than-often-assumed Upper Jurassic–Cretaceous section that extended well beyond much of today's coastline. In this case, the true continental slope and rise would have been located much farther out than the Stuart City carbonate trend (which is often inferred as the paleo-shelf edge). This platform may have been stepped due to early halokinesis, particularly at Sigsbee, and along its outer reaches probably sloped or ramped down to the area of oceanic crust.

Given this scenario for the paleobathymetry, it should not be surprising to find early Paleogene sands at the foot of that platform slope (*e.g.*, Perdido area). The sands could have been transported there from (**1**) the north or northwest by shelf bypass across the supra-salt platform, or (**2**) the west, out of a proto-Rio Grande river system, or both. By the end of the Paleocene, salt collapse in updip areas of the supra-salt platform began due to

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differential burial by prograding clastics, producing syn-depositional counter-regional faults and basin-facing half-grabens at the Wilcox and younger fault trends, which controlled the [new, syntectonic] position of the paleo-shelf edge. Such collapse fed downslope shortening behind (landward of) the Paleogene sands at the foot of the true continental slope. We infer detachment on salt, such that the Mesozoic marine supra-salt section was cut both updip and downdip by at least some of the faults. Apparent rafting of the Mesozoic shelf section at the landward limit of the Wilcox trend (*e.g.*, Anderson and Fiduk, 2003, and also observed in NE Mexico on seismic by the authors) demonstrates that the salt (and inferred Upper Jurassic–Cretaceous shallow shelf) was mobile during end-K/early T time. The concept of the Mesozoic supra-salt platform in the **nGoM**: (**1**) requires significant changes to commonly-accepted Late Jurassic through Paleocene paleo-bathymetric and paleogeographic maps of **nGoM**, and therefore of reservoir and source rock distribution; (**2**) indicates the need to develop maturation models for the inner shelf areas that do not assume a pre-existing deep-water setting outboard of the Sligo/Stuart City "reef trends" prior to Tertiary clastic deposition; and (**3**) provides a new paleo-geographic context for assessments and models of Cenozoic deltaic and progradational depositional systems along the northern Gulf of Mexico.

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Upper Miocene Depositional History and Paleogeographic Evolution of Central Gulf of Mexico Basin

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Abstract

The upper Miocene (late middle to early late Miocene) depositional episode (**UM** depisode) records a long-lived family of sediment dispersal systems that persisted for nearly 6 Ma with little modification. In the central Gulf of Mexico basin, this depisode records extensive margin offlap, primarily centered on the paleo-Tennessee River and Mississippi River dispersal axes, that began immediately following the *Textularia* W/*Textularia stapperi* flooding and is terminated by a regional flooding event associated with the *Robulus* E biostratigraphic top. Thickest sediments are deposited in the paleo-Tennessee River delta beneath modern southeast Louisiana, where three major depocenters are recognized. These depocenters have migrated in both strike and dip directions, and margin progradation is very prominent.

The composite fluvial-dominated paleo-Tennessee and Mississippi delta system rapidly built beyond the subjacent middle Miocene shelf margin to construct a sandy delta-fed apron. Margin outbuilding was locally and briefly interrupted by hyper-subsidence due to salt withdrawal and consequent slope mass wasting. Sediments also continuously bypassed into the Mississippi Canyon, Atwater Valley and Green Canyon OCS areas throughout the entire upper Miocene, forming two secondary depocenters composing the McAVLU

submarine fan system at the base of the paleo-continental slope. A broad, but relatively thin, sandy strandplain and clastic shelf succession, supplied by reworking of the deltaic deposits, extended eastward and westward from the delta system. Abundant strike-reworked sediment locally prograded the strand plain to the shelf edge, and slope offlap exceeds 30 mi (50 km).

The presence of extremely large volumes of high-quality shelf margin delta and deep-water fan sandstone reservoirs results in the great productivity of the central Gulf of Mexico upper Miocene, and upper Miocene production is dominated by a major deltaic oil and gas trend straddling the southeast Louisiana coast.

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Shelf Margin Deltas: The Key to BIG Reserves

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Abstract

Deltas that cross the shelf, either by prograding at a high stand or due to sea level drop during a low stand, produce distinctive depocenters which are important exploration targets at the shelf edge. The deltas become unstable as they try to prograde into deep water and deposit units that are geologically unique and very different from their counterparts that prograde across a stable shelf. These unstable deltas produce a variety of contemporaneous (early) structures including growth and glide plane faults numerous associated faults, diapirs, and gravity slides. The growth faults result in a greatly expanded reservoir section. These downdip delta systems are uncoupled from their updip feeder systems by these major growth faults and are typically encased in highstand deep water shales thus becoming excellent exploration targets: an over-pressured section, early structures, expanded reservoirs, and good seals.

Virtually all of the largest plays (the multiple TCF type) for the onshore and shelf parts of the Gulf of Mexico during the last 30 years have been in these shelf-margin delta systems. Examples from the Tuscaloosa, Wilcox, Yegua, Vicksburg, Frio, and offshore Miocene are examples. These plays are not unique to the Gulf Basin but will occur in any basin where deltas reach the shelf margin and prograde into deep water. The successes here in the Gulf Basin are simply the beginning of an ongoing worldwide exploration effort in these types of deposits. They provide both useful analogues and important exploration guidelines.

Shelf-Edge Delta Types and Their Sequence-Stratigraphic Relationships

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Abstract

Shelf-edge deltas are the main driver for the delivery of sediment to the deep water lowstand systems tracts. However, the mere presence of deltas at the shelf margin does not guarantee accumulation of deep-water sands. The two main reasons for this are: (**1**) deltas that develop at the shelf edge during relative sea-level fall generally need to be significantly incised by their own distributaries for sand delivery to be focused down to a basin-floor fan system, and (**2**) deltas that develop when sea level is rising (late lowstand) tend to be inefficient sand-delivery systems, and disperse sand mainly onto the slope as sheet-like turbidite lobes, with few or no basin-floor fans. Thus, given the presence of deltas at the shelf-edge, both the likely magnitude and direction of sea-level change at the shelf edge needs to be estimated, before significant time-equivalent, deep-water sand can be predicted on the basin floor.

Shelf-edge deltas are generally thicker, significantly more unstable, and markedly more turbidite-prone than inner/or mid-shelf deltas. These major differences are due to longer run-out slopes (greater water depths), steeper mud-prone

slopes, and greater accommodation at the shelf margin compared to deltas in more proximal shelf settings. There are four main types of shelf-edge deltas that have been documented from a database developed mainly from the Eocene shelf margin on Spitsbergen and the Miocene shelf margin of the Carpathian Foredeep:

Type A deltas develop on the outer shelf/shelf-margin transition but without significant progradation beyond the shelf edge onto the slope. These deltas usually form during the falling stage of a fall-to-rise cycle on the shelf.

Type B deltas develop at the shelf margin but are significantly cannibalized by fluvial-feeder erosion. Such deltas also form during falling stage, but base level falls below the shelf edge. The deltas are fairly sharp based on the outer shelf, are sand prone, and are deeply eroded by their own river distributaries. Because of the fluvial incision, only remnants of these deltas are preserved. However, their main significance and legacy is their time-equivalent, downslope suite of deep water, low-stand deposits including basin-floor fans. .

Type C deltas develop at the shelf edge, produce significant basinward growth of the shelf margin but rarely link down to basin-floor fans. They form during a late, rising stage of the fall-to-rise cycle, as they overlie earlier cannibalized deltas and older basin-floor fans of the same sequence. They are many tens of meters thick and consist of stacked, well-developed upward-coarsening and thickening units.

Type D deltas are progradational to aggradational delta complexes at the shelf margin, without underlying shelf-edge erosion, and only rare, linked basin-floor fans. Type A and C deltas simply amalgamate during a fall-to-rise cycle to become a single, thick (many tens of meters) deltaic wedge that is perched at the shelf margin and drapes far out onto the slope.

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Fluvially Incised Shelf-Edge Deltas and Linkage to Upper Slope Channels (Central Tertiary Basin, Spitsbergen)

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Abstract

Sandy shelf-margin clinoforms in the Eocene strata of the Central Tertiary Basin of Spitsbergen are usually generated by river-dominated shelf deltas, or by wave-dominated shorelines, though these two regimes can also be strike-equivalent to each other. Clinoforms occur in series or sets that show both sub-horizontal and rising trajectories of shelf-edge accretion. Clinothems involved in the former style of margin growth, however, tend to be dominated by delta deposits. Shelf-edge deltas of such clinoforms are commonly severely eroded by their own distributary channels, and this is especially noticeable at (though not restricted to) shelf-edge locations. Fluvially incised shelf edges are commonly linked directly across the shelf break, to turbidite-filled channels, gullies and small canyons on the slope.

Examples of this type of shelf-edge situation are present on Brogniartfjellet in Van Keulenfjorden, where the outer-shelf segment of the clinothem contains shelf-edge deltaic units that are 20-30m thick deposited during falling base level and lowstands. The deltas have been cut by deep erosive channels (up to 12 m) paved by shale rip-up conglomerates. The channel infill is dominated by up to 3 m-thick, flat and low-angle laminated,

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medium-grained sandstone bedsets deposited from upper-flow-regime conditions in riverine and shallow sand flats. Multiple phases of erosion can be demonstrated, separated by phases of minor re-establishment of delta-front facies. At peak regression of the delta system, still during falling relative sea level, the channels have reached the shelf break and allowed the river system to feed sediment directly into slope channels that were turbidity-current conduits to the basin floor. These are incised more than 25m deep on the upper slope, appear to have originated from fluvial input and retrogressive slumping on the slope, and link back up to the shelf-edge incisions. The infill of the slope conduits strongly suggests repeated phases of erosion/ bypass that alternated with phases of low-efficiency, hyperpycnal-flow deposition. The apparent off-lapping architecture within the slope conduits strongly suggests oblique or downslope accretion of infill during continued relative fall (forced regressive and lowstand conditions) of sea level, and probably during basin-floor growth of the fan.

In the latest stage of the lowstand, the shelf-edge deltas have re-established themselves onto the shelf, aggrading and prograding onto the underlying canyonized succession, thus forming a lowstand prograding wedge. Minor fluvial incision occurs, but overall the system is less sand prone. During the subsequent transgression of the shelf, when sea rose back up to and above the shelf edge, the slope is blanketed by mud, there is tidal reworking and infilling of the older shelf-edge channels and a transgressive barrier/lagoon or estuary system migrated landwards.

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Deep-Water Petroleum Systems of Africa's Major Rivers

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Abstract

Africa's major rivers are associated with some of the largest deep-water petroleum systems in the world. The most successful of these in terms of hydrocarbon discoveries, the Congo, Niger and Nile, are currently sites of intense exploration activity, while others (such as the Kwanza, Zambezi, and Rufiji-Ruvuma) have yet to yield a significant number of finds and remain under explored. The theme of this paper is to review examples of these systems, attempt to show why this has occurred and where some of the future offshore hydrocarbon provinces of Africa will be.

Seismic data will be used to review the deep water plays and prospectivity associated with each major river system. The deep-water systems reviewed include the Congo, Niger, Nile, Kwanza, Zambezi, and Rufiji- Ruvuma. The more mature deep-water hydrocarbon provinces will be compared with the less explored areas. Suggestions as to the reasons for limited exploration of some areas will be made, concluding that visible structuring is as least as important as the perceived presence of source rock in the initial decision to explore in a basin. Visible structuring in the form of salt or mud diapirs, anticlines, etc., undoubtedly makes exploration "easier" in choosing locations and "selling" prospects in the early stages of basin exploration. Seeking stratigraphic traps when there are few or no structures is very difficult in an unexplored basin.

The future exploration potential of the deep water provinces will be reviewed with particular reference to the currently less explored or less mature areas to show their untested prospectivity. As exploration has moved into deeper water in known hydrocarbon provinces such as Niger and Congo deltas, then the targets have been the deeper water analogies of existing plays; i.e., Niger delta mud supported anticlines and Congo fan channelized sands. In areas in which there are few or no existing working plays, extension by analogy into deep water breaks down or does not exist. So often in these areas new plays and source rock postulations have to be developed. Examples of new untested plays that do not exist in shallower water are shown from Tanzania Rufiji- Ruvuma and Mozambique deep water systems where there has been no drilling. Many of these involve structuring that does not exist in the shallower explored areas and are beginning to attract interest.

In areas such the Kwanza Basin where there is a very structured sedimentary section the (correct) perception that the play type is not the same as farther north in the Congo Fan has caused the area to be downgraded, despite the fact that hydrocarbons have been found here. This downgrading is partially due to recent wells targeting the same play as farther north and failing to find oil. In this case, the primary reservoir targets are not highly visible Tertiary channel sands but Cretaceous sands having a more subtle seismic expression, a play that has proven to work by the Semba-1.

The potential of the ultra deep water (i.e., water depths >3km) and abyssal areas beyond the Congo and Niger fans will be examined to demonstrate that as yet untested plays and prospectivity exist in these future exploration provinces.

Submarine Slope Bypassing of Sands Through Submarine Channels on a Modern Lowstand Delta, Fraser Delta, Canada

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Abstract

The Fraser River Delta is a large Holocene feature, locally >200 m thick, that has prograded into water over 300 m deep during a relative sea level lowstand (due to the interplay of eustatic sea level and isostatic rebound following deglaciation). The delta is, in many respects, analogous to ancient lowstand shelf margin deltas. We studied the delta slope and prodelta using very high-resolution seismic profiling ("boomer"), side-scan sonar imaging, multibeam bathymetry, and coring.

A relatively steep (2° to >7°) delta slope separates the delta front from the prodelta. Rapid deposition close to river mouths (sedimentation rates > 13 cm/yr) leads to oversteepening and the development of high pore pressures. These factors help contribute to various types of slope instability on the delta front and delta slope. Submarine channel and failure complexes are present seaward of past and present river mouths. Failure of sandy sediments near river mouths leads to submarine gravity flows that cut channels into the delta slope. The channels extend down to >200 m water depth at distances of over 6 km from the river mouth. Sand transported through the channels bypasses much of the delta slope to accumulate at its base. The channels, when active, are purely erosional on the upper slope. Later abandonment (due to channel migration on the delta plain) leads to passive infilling. A spill-cut-fill history characterizes channel development lower on the slope. Lobes of sand accumulate at the base of newly forming channels. These lobes later become incised as the erosive channel system grows down slope. Finally, the

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channels are passively filled once the system is abandoned.

Progradation of the Fraser Delta will lead to a stratigraphic section that has sandstones at the base of the slope and in the delta front/upper delta slope position. This type of deltaic complex mimics low-stand Pleistocene deposits of the Gulf of Mexico and elsewhere.

Sequence Boundary Ambiguities in Shelf-Margin Deltas and the Shelf-Slope Transition: Illustrations from the Pleistocene of the Gulf of Mexico

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Abstract

Pleistocene shelf-margin deltas (SMDs) of the northern Gulf of Mexico (Mobile, Mississippi, Brazos-Trinity, Colorado, Rio Grande) and the corresponding shelf-slope transition illustrate some of the conceptual and procedural issues pertaining to sequence stratigraphy of continental margins. As one approaches the shelf margin from the landward side, it is customary to pick the sequence boundary (SB) at the erosional base of channelized fluvial deposits, typically cut into marine clinoforms. Near the shelf margin, the sequence boundary could be picked at the erosional base of a submarine canyon cut into a SMD, or alternatively at the base of the SMD, especially if no submarine canyon is present. Thus, the SMD can be placed either below the SB (making the SMD part of the HST) or above the SB (making the SMD part of the LST). In practice, the latter is seldom done, because there is rarely a distinctive surface or break in stratal geometry to uniquely mark the change from shelf-phase delta to SMD. Therefore, SMDs are usually considered part of the HST.

In some cases the SMD is characterized by submarine landslide deposits within the clinoforms, resulting in hummocky or chaotic clinoforms, which can grade downdip into massively chaotic, sand-bearing deposits on the upper slope. Even in these cases, the change from shelf-phase delta to SMD is typically gradational, without a single distinctive surface to uniquely define the SB or to place the SMD in the LST. In general, there is no consistent rule as to where the SB should occur relative to a SMD, or where the SMD should fit into the systems tract classification.

As one approaches the shelf margin from the basinward side, where mini-basins are present on the upper slope, the SB is typically picked at a major onlap surface, which in late Pleistocene deposits can often be correlated across saddles between mini-basins with little ambiguity. In the Brazos-Trinity deposystem, the SB defined by this onlap surface is clearly different from (and stratigraphically below) the SB defined by the erosional base of fluvial deposits landward of the shelf margin. In the Mississippi deposystem, SBs defined by such onlap surfaces are also clearly different from SBs defined by erosional bases of submarine canyons. Onlap surfaces (and immediately underlying MFS shales) are useful for correlation along strike, especially on the upper slope. In contrast, submarine canyon surfaces are useful for long-distance correlation in the dip direction from shelf to basin plain, but are of very limited extent in the strike direction. The basin-floor fan (BFF) phase of slope deposition typically occurs just above the onlap surface, whereas the slope fan (SF) phase occurs at and above the submarine canyons. A composite framework of onlap surfaces and submarine canyons is useful for establishing temporal relationships within the Mississippi depositional province, although this framework does not fit readily within standard systems tract nomenclature.

In concept, sequence boundaries are isochronous surfaces which separate deposits that are less closely genetically related while grouping deposits that are more closely related. Two difficulties are recognized with this concept. First, sequence boundaries picked at erosional surfaces are subject to regional diachroneity, such that some fluvial deposits above the SB may be coeval with some marine deltaic deposits farther downdip below the same SB. Secondly, the SB typically groups slope deposits with immediately younger transgressive deposits while separating them from immediately older deltaic deposits. However, in map view, Pleistocene deposystems of the northern Gulf of Mexico consistently show a close paleogeographic relationship between slope systems and immediately older deltaic systems. Conversely, the paleogeographic relationship between slope systems and immediately younger transgressive and highstand systems is typically much more distant.

From studying a variety of Quaternary deposystems associated with Gulf Coast rivers, we recognize a composite succession, although not all phases will necessarily be present in any one deposystem:

1. Incised valleys are filled by a combination of estuarine transgression, fluvial aggradation, and deltaic progradation.

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2. Once the incised valley is filled, the alluvial plain continues to aggrade without the lateral confinement of valley walls. This aggradation may or may not be accompanied by deltaic progradation.

3. The delta progrades across the shelf, probably punctuated by minor transgressions and lobe switching. The net progradation is typically forced by sea-level fall, but may also occur purely by sedimentary progradation, as in the Holocene Mississippi delta. Forced regression of the delta is typically accompanied by valley incision farther updip.

4. As the delta approaches the shelf margin, the deltaic depocenter becomes thicker and smaller in areal extent, while the prodelta becomes steeper and increasingly prone to slope failure. Slope failures may be manifested in a variety of ways, such as a single slide complex which is healed by subsequent clinoform progradation, or as repeated slides during progradation, resulting in chaotic clinoforms. Also during this phase, turbidity currents may be generated at or near river mouths, which generate sinuous slope channels without significant incision of the shelf margin. Alternatively, the SMD can remain gravitationally stable, with minimal generation of sediment gravity flows.

5. The SMD is incised by a submarine canyon, typically connected to an incised valley. After a phase of sediment bypass to the slope and basin plain, the canyon is typically filled or healed by clinoform progradation.

6. Regional transgression resets the paleogeography, and the next depositional succession is likely to be offset along strike from the previous, due to large-scale lobe switching.

Overall, this depositional succession is controlled by eustacy. However, sea level and transgressive-regressive cycles are not necessarily in phase, and these phase relationships may vary from one one river to the next, and from one cycle to the next. In addition, the stratigraphic expression of a given eustatic cycle can be present in one locality and absent or cryptic in another. Therefore, inference of eustacy from a local stratigraphic record, or from a single dip section or corridor through one or more SMDs is likely to yield a sea-level history that is incomplete or otherwise inaccurate.

From an operational standpoint, we prefer a descriptive classification of major surfaces. The relationships of various kinds of stratigraphic surfaces define the stratigraphic framework. For sequence boundaries we use those surfaces that are most robust for regional correlation.

Late Quaternary Shelf-Margin Deltas in the Northern Gulf of Mexico: Implications for the Late Quaternary Sea-Level Elevation at the Culmination of the Last Glacial Maximum

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Abstract

New regional seismic-stratigraphic analysis of shelf-margin delta geomorpology at three locations in the northeastern Gulf of Mexico support the Hughes *et al.* (1981) view that sea-level elevation during the last glacial maximum (as opposed to the magnitude of eustatic rise since the last glacial maximum) was ~90 m below present-day sea level provided that the northeastern sector of the Gulf of Mexico has experienced only isostatic uplift since the last glacial maximum.

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The Impact of the Brazos Deltaic System on Upper Slope Stratigraphic Sequence Evolution

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Abstract

In the offshore of East Texas, fluvial deltaic systems did not significantly impact upper slope stratigraphic sequences until very late during a sea level fall. During the last glacial-eustatic cycle, the ancestral Brazos River system prograded across the shelf depositing six separate delta lobes that compose the highstand systems tract. Over the same period, sedimentation on the upper slope was characterized by a condensed section. During deposition of the late Highstand Systems Tract, the Brazos fluvial-deltaic system deposited a shelf-margin delta 5 km updip of the shelf-edge, causing an increase in sedimentation on the upper slope. As sea level continued to fall, the Brazos system shifted to the east to merge with the Trinity-Sabine shelf-edge delta system. However, upper slope sedimentation during formation of the lowstand systems tract did not dramatically decrease with the removal of the updip source, rather a thick healing phase wedge developed. Such sedimentary wedges constituted a significant component of slope stratigraphic sequences during both the last, and previous, glacial-eustatic cycles. Development of these healing phase deposits intrinsically was connected to a shelf-edge deltaic source, but this source did not need to be located directly updip. In the east Texas slope, the sediments were sourced by a shelf-margin delta to the east of the study area, and transported westward along the upper slope.

Despite its name, healing phase deposition is not tied to a specific interval of the eustatic cycle. It can occur at anytime between late highstand through the transgression, as long as a shelf-edge system exists.

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Downslope Sediment Transport Processes and Sediment Distributions at the East Breaks, Northwest Gulf of Mexico

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Abstract

Previous investigations of the East Breaks slide interpreted this site as having been formed by a single mass-wasting event at the terminus of a late Wisconsinan shelf-edge delta. According to these interpretations, after initiation, this slide/slump propagated downslope and divided into two major lobes as it encountered a bathymetric high formed by a salt diapir. This study used a large, new data base of high-frequency 3.5-kHz acoustic reflection profiles and piston cores that shows that the two lobes were genetically separate. Their formation involved the two major types of downslope sediment transport mechanisms that dominate continental slopes: gravity-driven slide/slump/debris flows and turbidity currents. As previously recognized, slumps and debris flows formed the western lobe, but the eastern lobe was formed by channelized turbidity currents. A locus of salt tectonism might have been involved in creating the turbidity current system in the eastern lobe. This large deposit may provide a useful model for subsurface exploration in a portion of the deep water frontier which is less dominated by salt tectonics than much of the central Gulf Coast offshore slope.

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The Influence of Local Gradients on Accommodation Space and Linked Depositional Elements Across a Stepped Slope Profile, Offshore Brunei

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Abstract

The modern continental slope offshore Brunei is an outstanding example of the relationship between syndepositional structure, slope accommodation space, and sediment dispersal systems. The bathymetric profile is a "stepped slope" characterized by elongate, structurally controlled mini-basins, in contrast to the elliptical salt withdrawal "intraslope" basins of the Gulf of Mexico. Progressive basinward thrusting, caused by updip sediment loading of the Baram delta and regional tectonics, divides the area into alternating thrust-cored structures and elongate, shelf-margin parallel mini-basins 2-10 km in width and 20-60 km in length. The dominant types of accommodation space are healing and bypass phase slope accommodation space associated with a subordinate amount of ponded accommodation space. The primary control on net deposition versus bypass is local sea floor gradients along sediment dispersal pathways that are structurally controlled. Gradients along primary flow paths range from 0.38O to 1.93O. Local gradients along the basinward margins of thrust structures and along submarine canyon walls are substantially higher (>15.0O). Sediment dispersal pathways can extend for >60km and are quite tortuous across the irregular bathymetry. Four bathymetric features and depositional elements have been defined along these pathways. These include: (1) local cohesive slump complexes up to regional mass transport complexes; cohesive slumps reflect short distance transport by down slope creep, whereas mass transport complexes reflect longer distance debris flows. (2) Submarine canyons have developed by gravity mass wasting along the forelimbs of thrust-cored features. Resultant bathymetric depressions

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locally act as sediment conduits which link mini-basins across intervening thrust cored structures. (3) Sediment dispersal fairways range from 2-5 km in width and contain multiple straight/erosional or sinuous/leveed channels. (4) Distributary channel/lobe complexes consist of sheet deposits are punctuated by low relief channel features.

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Lowstand Deltas and a Basin-Floor Fan, Pleistocene, Offshore East Kalimantan, Indonesia

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Abstract

The upper Pleistocene north of the Mahakam delta, offshore East Kalimantan has been studied from the inner shelf to basin floor, using 3D seismic data. Three cycles deposited between ~18 and ~370 ka are defined on the shelf by progradational packages separated by parallel reflectors with carbonate buildups. The prograding packages were apparently deposited during highstands and gradually falling eustatic sea level. Parallel reflectors and carbonate buildups are interpreted as transgressive deposits. During the lowest of the three cycles (~270-370 ka), a lowstand delta has prograded over the underlying shelf margin, and sand-rich sediment has spilled downslope, feeding a slope-channel complex and basin-floor fan. This slope-channel complex has: (1) a lower part consisting of an incised channel filled with high-amplitude reflectors that are inferred to be sand-rich, and (2) an upper part dominated by a low-amplitude channel-levee complex inferred to be shale-rich. The slope-channel complex passes downdip into a basin-floor fan. The basin-floor fan contains a lower part, which contains high-amplitude, continuous reflectors (interpreted as sand-rich fan lobes), and an upper part that represents an aggrading channel-levee complex. These levees also are inferred to be shale-dominated, whereas some channel-fills are apparently sand-rich. The channel-levee complex has prograded over the

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lower fan and fed additional unconfined high-amplitude (sand-rich?) lobes.

These Pleistocene cycles are significantly different from sequences and systems tracts defined in the late 1980s. Lowstand systems tracts can not be identified by onlap of the slope. Rather, lowstand strata on the slope and basin floor are generally parallel reflectors that have local variations caused by channels and fans. Lowstand strata extend down the slope from distal clinoforms of the prograding lowstand delta, and hence cannot be consistently separated from prograding highstand and falling stage systems tracts. Cycles are best separated at the tops of prograding packages (transgressive surfaces).

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Stacked Shelf-Edge Delta Reservoirs of the Columbus Basin, Trinidad, West Indies

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Abstract

Shelf-edge delta reservoirs of the paleo-Orinoco River are growth-fault expanded and stacked because of extremely rapid subsidence in the Columbus Basin growth fault province, offshore southeast Trinidad. Over 60 pay zones on the Trinidad shelf occur in deltaic reservoir intervals, each representing a fourth order sequence (40-100 Ka), and have been deposited within 6 mi (10 km) of the paleoshelf-edge. The resulting reservoirs are very thick (commonly 300 to 500 ft, up to 1000 ft), laterally extensive, highly continuous, and prolific producers. Six of BP's best producing wells worldwide are situated in the Southeast Galeota (**SEG**) structural complex on the Trinidad shelf. Stacking of multiple, thick deltaic pay zones within large structural culminations result in very high reserve density. The **SEG** complex covers an area of ~60 mi^2 (150 km^2) and contains some 14 TCF of resources. Subsurface data, outcrop descriptions, and seismic images of the last lowstand delta beneath the modern Trinidad shelf-edge are combined to develop a better understanding of the depositional setting. Reservoir quality and well production data highlight the tremendous deliverability of these shelf-edge delta reservoirs. A tentative depositional model is proposed by way of an idealized fourth order sequence dip section across the shelf and by representative log profiles from the subsurface.

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Plio-Pleistocene Shelf Margin Deltas From Trinidad—Outcrop and Subsurface Examples

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Abstract

Offshore of Eastern Trinidad in the Columbus Basin, oil and gas reservoirs are in stacked reservoirs within a sedimentary succession of 10,000–30,000 feet deposited during the Plio-Pliestocene. Many of these reservoirs represent shelf margin deltas, produced as the precursor to the present day Orinoco River prograded basinward and deposited thick wedges of sediment.

The outcrops of the Pliocene Mayaro formation along the Mayaro coastline of southeastern Trinidad comprise thick successions of sand and shale units that are the direct analogs for the subsurface fields being produced offshore. Syndepositional faulting, slumping, injection features and turbidites, a paucity of trace fossils, the absence of delta plain deposits or distributary channel deposits coupled with foraminiferal data that indicates a middle neritic setting, all point to a delta system at the edge of the shelf. Autocyclic processes can be discerned within the abandonment phase of the delta with strong evidence of burrowing by suspension feeders, during reworking by wave action and alongshore drift of the delta deposits.

Shelf Margin Deltas and Associated Deep-Water Deposits: Implications on Reservoir Distribution and Hydrocarbon Entrapment, Block VI-1, Ulleung Basin, East Sea, South Korea

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Abstract

Block VI-1 covers 13,000 km^2 (3.2 million acres) in the southwestern part of the Ulleung Basin in water depths from 30 to 1,700 meters (100 to 5,500 feet). Approximately 20 wells have been drilled on the block since 1973. The block has 12,865 linear km (8,000 miles) of 2D seismic data and 1,500 Km^2 (580 $miles^2$) of 3D seismic data. The block has three discoveries in Miocene sediments. One of these discoveries, in a shelf edge delta, is currently under development.

The majority of Miocene to Recent sediments in Block VI-1 are shelf edge deltas and their associated deep water/slope deposits. Progradation of the shelf margin began in a northeastern direction and migrated to a northward direction as tectonic activity increased in the basin (Chough *et al.*, 1997). Three distinct periods in the overall progradation relate to different tectonic periods: back-arc extension (16-12 Ma) associated with rapid basin subsidence, back-arc closing (12-6.5 Ma) associated with uplift in the disturbed zone and subsidence in the undisturbed zone, and continued back-arc closing (6.5 Ma–Present) characterized by slow subsidence in the basin.

The reservoirs and hydrocarbon accumulations in the Ulleung Basin occur in shelf edge deltas and deep water sandstones-conglomerates. The shelf-edge delta sandstone reservoirs are generally coarser grained and lower in porosity than age-equivalent deep water sandstones. Shelf- edge delta traps form by a combination of recent regional warping and stratigraphic pinch out against shale-filled canyons. Deep water sand-

stones tend to be finer grained than the shelf edge sandstones, but coarse grained deep water sediments are observed. Porosity of the deep-water sandstones is generally higher than the shallower water facies, but permeability is often lower. Observed hydrocarbon accumulations in the deep water facies occur in structural closures or truncation traps in areas of extreme structural deformation.

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Depositional Topography and Sequence Development

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Abstract

In siliciclastic systems, depositional sequences having distinct physiographic relief (clinoform development) can occur in epicontinental seas, across the continental shelf, along the continental margin, or even in lacustrine basins. Furthermore, this depositional topography can occur along sequence boundaries, within sequences, or downdip of the shoreline in any basin. However, not all sequences having distinct “shelf” (clinoform) breaks contain basin floor lowstand fans. It appears that only those sequences with clinoform breaks beyond a critical threshold of relief and inclination contain basin floor (lowstand) fans.

Integration of published seismic, well-log, and outcrop data from wide variety of basins, suggests that three types of depositional sequences (low-, moderate-, and high-relief) should be defined. Low-relief sequences lack basin floor (lowstand) fans. They have subtle clinoforms, typically with inclinations of less than 0.5 degrees and heights less than 30 meters (100 ft), both within sequences and along sequence boundaries. Moderate-relief sequences also lack basin floor (lowstand) fans. However, they display distinct clinoforms, typically with inclinations that range from 0.5 to 2.0 degrees and heights less than 150m (500 ft), both within sequences and along sequence boundaries. High-relief sequences contain basin floor (lowstand) fans. They have well-developed clinoforms, in which inclinations and heights, respectively, are greater than 2 degrees and 180 meters (600 ft), both within sequences and along sequence boundaries. These relationships suggest

that there is a ***stable limit to topographic development*** that controls clinoform stability or failure during relative sea level falls. In basins where the depositional relief is less than the ***stable limit to topographic development***, progradation continues during relative sea-level falls. The resulting low- to moderate-relief sequences lack basin-floor (lowstand) fans. In basins where the depositional relief is greater than the ***stable limit to topographic development***, slumping, canyon formation, fluvial capture, and sediment by-pass occur during relative sea level falls. The resulting high-relief sequences contain basin floor (lowstand) fans. In siliciclastic systems, this boundary condition appears to occur in the range of 500-600 ft (150-180m) of vertical relief.

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Shelf Margin/Upper Slope Sedimentation Patterns of the Lower *Cristellaria* "I" Depositional Sequence, Southeast Louisiana

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Abstract

The lower *Cristellaria "I"* depositional sequence is a type "2" third-order sequence composed of seven fourth-order sequences, which has elements of a type "1" sequence. The lower three fourth-order sequences are confined within the upper slope submarine canyon section and thin downdip. The upper four fourth-order sequences are not confined and have extremely progradational, shelf margin systems-tract architecture. The sand-rich submarine-fan section extending many miles basinward to upper- and middle-slope positions correlates with this upper, unconfined section. The submarine canyons cut down as much as 1400 ft into underlying lower Miocene strata creating, in places, a spectacular angular unconformity. This angular unconformity is the lower boundary of the third-order sequence. Its dramatic character also makes it an excellent supersequence (second-order) boundary candidate on reflection seismic. Superficially, this fits with the Hardenbol *et al.* (1998) cycle chart that shows this section to be the first third order depositional sequence within the Middle/Upper Miocene Supersequence. However, when the stratigraphic architecture and the stratigraphic occurrence of downdip slope sand deposits are considered, the original Haq *et al.* (1988) placement of this sequence at the top of the Lower Miocene Supersequence seems a better fit. Additionally, the lower *Cristellaria "I"* third-order depositional sequence is shown to have avulsed from a main lower Miocene depocenter positioned in southwest Louisiana into southeast Louisiana (Fillon and Lawless, 2000). Although transgressive sea-level change has caused the avulsion and main

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depocenter shift, local sediment instability related to underlying salt reactivation plays a larger role in creating the spectacular nature of the basal unconformity.

Viewed in well log cross sections, the canyon fill section expands from a 200 ft, very serrated blocky sand updip, to a very shaley 1400 ft thick interval of section on the upper slope. Most sands are thinly bedded and exhibit crescentic shaped log patterns. Well-developed blocky sands are rare. Viewed on seismic data, the three confined fourth-order sequences in the most updip parts of the canyons contain sharply defined channel-scale features. Downdip, however, strata are seismically dim, and channels the size of canyons cut into each other giving a nested look. Together these three confined sequences form the third-order slope fan for the lower *Cristellaria* "I" depositional sequence. They thin basinward and little section is deposited farther downdip in the study area.

The four younger, unconfined fourth-order sequences are aggradational and form the prograding complex and transgressive systems tract of the third-order depositional sequence. This section is typified by rapidly prograding shelf margins coupled with a locally very sandy bypass section. A typical shelf-margin signature on seismic consists of an onlapping bypass toe-of-slope reflector, which is downlapped by shelf-edge clinoform reflectors. In Lafourche Parish, where more salt-displacement accommodation is available, the prograding clinoforms are sigmoidal and associated transgressive systems tracts are well developed. In St. Charles and northern Jefferson parishes, where less salt-displacement accommodation exists, the prograding clinoforms are shingled and associated transgressive systems tracts are very thin.

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Eocene Depositional Model for the Brazil Santos Basin in the Vicinity of the BS-4—NE Discovery

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Abstract

The BS-4-NE discovery in Santos Basin, located in water depths of about 1500 meters, was drilled in March, 2001, by the consortium formed by Shell, Petrobras, and ChevronTexaco and operated by Shell. The discovery well encountered nearly 100 meters of very high net-to-gross clean sand in what appears to be a sand-rich fan system in a toe-of-slope setting of middle Eocene age.

Seismic sequence stratigraphic interpretation across the shelf-to-slope transition indicates that the lower Eocene consisted of low stand systems tract strata that are successively overlain by southeastward prograding then aggrading shelf and slope strata of middle Eocene. The late Eocene strata are predominantly progradational in nature.

Seismic volume interpretation on good quality 3D seismic data revealed that the structural and stratigraphic evolution of the BS-2 and BS-4 area were closely linked. Two counter regional fault systems, a southern east-west and a northern northeast-southwest trending system, were active throughout the early Tertiary. The resultant southward dipping tilted blocks had significant accommodation space in the southern portions of the blocks. Northwesterly sourced sediments infilled some of the accommodation space throughout the early Eocene, culminating in the flooding of the accommodation space in the late-early Eocene and the northeast-southwest fault system. Middle Eocene shelf-slope progradation and aggradation, in concert with renewed movement on the faults, resulted in the back stepping of fan deposition toward the northeast, contained between the fault systems. Late Eocene shelf-slope prograda-

tion, coupled with a shift in slope geometry, resulted in fan building from the northeast, into the central fault block.

The regional Eocene deposition system is dominated by mixed sand-mud systems in both BS-2 and BS-4 blocks. Synchronous fault movements and sedimentation has resulted in shifting of fan depocenters and compensation stacking of basin floor fans, which influenced subsequent Eocene sand distribution. Lower Eocene sedimentation, controlled by southeastward shelf and slope prograding and a late Paleocene turbidite channel delivery system, is characterized by a series of southeastward trending submarine channel systems displaying sinuous channel character. The upper lower Eocene and middle Eocene is characterized by more southerly trending channels and associated fans, which in-filled northern and central portions of the study area. Upper middle Eocene and upper Eocene sedimentation is dominated by northeastern sourced fans feeding southwestward, infilling the northeast portion of the central fault block. Slope channel length and width appears to be related to slope morphology; *i.e.*, longer and wider channels associated with planar morphologies, and shorter and narrower channels associated with a more sigmoidal morphology. Smaller more short-lived channels appear to be associated with mixed sand-mud depositional systems. More long-lived channels are associated with sandy depositional systems. The thick, moderately sorted, high net-to-gross sand package penetrated in BS-4-NE discovery is part of a sandy fan system.

Geometric measurements of depositional elements of the slope channel complexes and toe-of-slope fans are comparable to similar deep-water depositional systems found in offshore Angola.

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Author

Wilcox Depositional Systems: Shelf to Deep Basin

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Abstract

The Wilcox has long been recognized as an important petroleum resource, producing from deltaic, fluvial, and shallow marine sandstone reservoirs since the 1930s. Recent drilling in the Perdido Fold Belt (Alaminos Canyon OCS area) has confirmed a new exploration play in the deep basin component of the Wilcox petroleum system, with significant discoveries in distal turbidite systems.

The Wilcox Group in the Gulf of Mexico basin spans much of the Late Paleocene and Early Eocene. In outcrop the Wilcox is characterized by a variety of paralic and very shallow marine depositional settings, and is represented by interbedded sandstone and shale plus locally abundant lignite. Updip from the Lower Cretaceous shelf edge, relatively dense shallow subsurface well control allows documentation of fluvial, deltaic, and open shelf depositional systems. Downdip from the Lower Cretaceous shelf edge the Wilcox is comprised of delta front, open shelf, estuarine, and widespread prodelta depositional facies. Relatively sparse well control shows the prodelta and shelf depositional systems are mostly sand poor. Downdip from this shelf and prodelta, the next Wilcox well penetrations are 250 miles farther in the basin, in southern Alaminos Canyon OCS area, deep-water Gulf of Mexico.

Recently released drilling data sheds new light on play concepts and hydrocarbon potential of the Perdido Fold Belt (PFB). Located in the southern Alaminos Canyon OCS area and extending into Mexican waters, the PFB consists of a series of large, northeast–southwest trending, salt cored box folds containing Middle Jurassic to Holocene clastic and carbonate sequences. Based

on regional correlations and seismic facies analysis, the initial exploratory targets consisted of fractured Mesozoic carbonates and lower Tertiary turbidites. Given the absence of local stratigraphic control, the presence, distribution, and quality of the reservoir objectives were considered to be among the most significant risk elements for the trend. Among the key results of the BAHA wells (AC 600 #1 and AC 557 #1), a thick (>4000 ft) progression of lower Tertiary (Oligocene to Paleocene) sands were encountered establishing the presence of extensive Wilcox sands located greater than 250 miles down dip from their fluvial and deltaic equivalents. Sand character and distribution interpreted from wireline logs and seismic data demonstrate a systematic progression from regional basin-floor fans to distal turbidite channel/levee systems. Since the initial test at BAHA in 1996, five additional deep wildcats have been drilled, including three at the Trident prospect (AC 903 #1 and #2, and AC 947 #1) which was announced as a discovery in 2001, and two at the Great White Prospect, (AC 857 #1 and AC 813 #1), which was announced as a discovery in 2002. With continued success, and growing interest in the trend, the Perdido Fold Belt is likely to become an increasingly important exploration and development play in the deep-water Gulf of Mexico.

Influence of Shelf and Slope Processes on Deep-Water Sedimentation

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Abstract

Deposition of deep-water fan systems is, in part, influenced by a variety of shelf margin and slope processes that affect the sediment pathways into the receiving basins. Shelf and slope seafloor topographic changes that resulted from tectonic movement, mobile substrate deformation and/or relative sea level fluctuations, may lead to switching of the sediment pathways leading to deep-water basins and result in depositional pulses of shelf and slope material that interrupt the background pelagic and hemi-pelagic sedimentation in different areas through time. The sediment pathways of the Permian deep-water deposits in the Tanqua and Laingsburg subbasins seen in outcrops in the southwest corner of the Karoo Basin, South Africa, have been influenced by fluctuations in seafloor topography caused by tectonic forces associated with the adjacent fold thrust belt. The two subbasins have geologically near-contemporaneous formation and filling, and in part contain deep-water sediments. Studies on these deep-water deposits have allowed reconstruction of the shelf and slope environment. Tectonic compression in the area has led to the formation of a basin floor high (anticlinorium) that separates the subbasins and influenced sediment transport. The Tanqua subbasin has developed into a broad, open basin that received five stacked submarine fan systems, while the Laingsburg subbasin has built into a deeper, longer and narrower basin that also has received five stacked submarine fan systems. Petrologic and microprobe analysis of the sandstones in the submarine fan systems indicate that they have come from a common source area that is an extended distance away (as great as 400 km). The subbasins, most likely, share a single shelf edge canyon and slope transportation system that involves enough length to allow for switching of the slope pathways through the evolving topographic highs and lows over time.

Abstracts

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Source-to-Sink: The Importance of the Updip Coastal Area in Defining Deep-Water Sand Characteristics

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Abstract

Understanding the interactions of the source-to-sink sedimentary system is necessary to place a deposit in a receiving basin in its proper depositional perspective. This is true for any part of the source-to-sink system, whether it deals with fluvial, deltaic, shelf, slope, or deepwater, especially when the sink is now in the subsurface. One should look updip as well as downdip to understand better the environment of interest. Critical information to classify the variety of submarine fans, such as the range of grain size and the distribution of sand, can be found in the time-equivalent deltaic environment at the shelf margin.

Four major factors can be identified that influence all parts of the source-to-sink system: tectonic activity, climate, relative sea level fluctuations, and sediment characteristics. Tectonic activity, both local and regional, comprises the primary factor. Pre-depositional tectonic movements guide the location and elevation of the sediment-providing mountains, climatic conditions for weathering and precipitation, types of subaerial transport, development of the coastal plain and its delta (if any), the shelf width, slope characteristics, and the receiving deep-water basin characteristics. Climate influences several attributes, including sea level fluctuations and sediment transport to the coast and beyond. Sea-level fluctuations, controlled by large-scale tectonic activity and/or climatic changes, influence subaerial and coastal processes. During rising, high relative, or global sea level, coastal plains become submerged and

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sediments are stored on the continent and the shelf. During the lowering and initial rising stages, sea level can result in shelf-edge deltas or the feeding of sediment directly to a deep-water basin. The maturity of the sediment is strongly influenced by the type and duration of subaerial transport, where the majority of the mechanical and chemical weathering takes place. During subaqueous transport, significant amounts of clay-sized sediment facilitate transport of fine-grained sands far into the ocean basins.

Whether deep-water sediments are coarse-grained or fine-grained, the coastline dictates if the feeding sediment source is canyon-fed or delta-fed. Shelf margin deltas are typical for fine-grained sediment and are normally located on wide, low-gradient shelves. Lateral switching of the delta establishes a new location for the entry point of the sediment to a deep-water basin. Shelf margin deltas on narrow shelves do not always exist during low sea-level periods.

Abstracts

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Integrated Analysis of the Upper Jurassic Bossier Deltaic Complex, East Texas

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Abstract

The sandstones encased within the Bossier Shale Member of the Cotton Valley Sandstone in East Texas are subdivided into three genetically related stratigraphic cycles. The lower deltaic cycle is a seaward stepping unit that becomes reworked as a result of delta switching. The upper two cycles are aggradational to progradational units in which facies range from prodelta to delta-front to distributary channel deposits.

Previous interpretations have ranged from submarine-fan to braided river with individual cycles are interpreted to be bounded by regionally extensive marine flooding surfaces. Detailed sedimentologic, petrologic, and biostratigraphic analysis of cores, well-cuttings, and well-logs, however, indicate that the stacking pattern of the Bossier deltaic complex is controlled by autocyclic lobe-switching as a result of varying sediment supply (overall increase) associated with the large Cotton Valley fluvial system. In particular, detailed biostratigraphic analysis (palynology and kerogen) suggests that bounding shale intervals and "flooding surfaces" exhibit a high terrigenous/marginal marine signature. True marine flooding events are

associated only with the source-rock shales in the underlying lower Bossier Shale interval. Additionally, the abundance of distributary channels associated with all cycles suggests the entire Bossier Sandstone section is a river-dominated system subordinately influenced by marine processes.

Rock physics and seismic modeling of the Bossier sands have demonstrated a seismic response strongly dominated by large acoustic impedance contrasts associated with porous sandstones, low porosity siltstones and over-pressured shales. Depositional and sedimentologic characteristics of the Bossier sands are similar to those of modern fluvial-dominated deltaic systems undergoing processes of delta-switching and abandonment, such as the Mississippi River Delta.

Abstracts

Author

Two Contrasting Styles of Lowstand Deltaic Wedges: The Roda Sandstone (Spain) as Seen from Outcrops and the Late Pleistocene Mahakam Delta (Indonesia) as Imaged from 3D and 2D Hr Seismic Profiles

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Abstract

Despite the large number of outcrop studies published, few papers provide a precise documentation of stratal relationships and physical correlation of facies assemblages showing the transition from fluvial/flood related facies into shelf deposits. The detailed geometry of shelf perched deltas built during relative lowstand sea-level periods is of particular interest. Examples of Quaternary lowstand deltas have been described using high resolution seismic on the modern Quaternary shelf (*e.g.*, Mahakam, Rhone, and Gulf of Mexico) but few ancient examples have been compared with these Quaternary analogs.

Quaternary depositional sequences of the Mahakam Delta have been analyzed combining shallow portions of 3D seismic data sets together with high resolution 2D seismic profiles acquired by Roberts and Sydow (in press). Contrary to the seismically imaged Mahakam lowstand, the Roda Sandstone is an outcropping and well-studied example of a spectacular coarse-grained shelf perched lowstand delta developed along the northern margin of the Eocene South Pyrenean Basin. The Roda Sandstone offers a unique opportunity to study and understand the record of high frequency cycles from continuous outcrop exposures from fluvial/flood related facies to shallow marine and offshore marine deposits. The overall large scale stratigraphic pattern is a forestepping-backstepping cycle made of several seaward prograding verti-

cally stacked and finally landward stepping sandbodies separated by silty and muddy intervals with small calcareous fauna rich beds marking periods of terrigeneous starvation (transgressive peaks).

The observed succession of prograding, vertically stacked, and finally landward stepping sand bodies correspond to fourth or fifth order sequences forming seaward prograding shallowing-up cycles (parasequence scale). These sand bodies prograde onto a surface of conformity equivalent landward to the erosive base of channel-fills and associated with the development of a larger scale Figols 2 sequence (Mutti 1988, 1994). Despite it's complexity, the Roda Sandstone allows us to clarify the relationships between parasequences and elementary high-frequency sequences as recognized and discussed by Mutti (1994) in the South Pyrenean Basin. The most volumetrically significant facies assemblage preserved landward, is represented by fluvial/flood related deposits ranging from subaerial to coarse submarine grain flows. These flows form large scale clinoforms with steep avalanching faces as flood flows entered the receiving basin. Height of the observed large clinoforms (Gilbert-type deltas) increases seaward as fluvial/flood transported coarse sediments were transported onto a depositional slope partly inherited from the morphology of previously accumulated sediments that build into deep water.

The deltaic system, therefore, prograded in a pulsating fashion with autocyclic clinoform lobe switching at small scale and allocyclic switching and offsetting of sandstone wedges at larger scale. The physical correlation of the calcareous cemented beds and the associated continuous occurrence of muddy burrowed transgressive intervals separating the tide reworked internal sandstone wedges demonstrate the existence of large-scale abandonment periods that involved the entire deltaic complex. The maximum development of tide reworked and tide related facies occurs in strongly seaward-stepping wedges which form heterolitic, potentially isolated, and possibly detached reservoir compartments. These observed stratigraphically controlled differences demonstrate that when dealing with a similar subsurface example, missing stratigraphic compartimentalisation can result in an overestimation of reservoir continuity. In addition, there may be great difficulty in defining barriers and predicting the occurrences of sealing wedges made of shaly burrowed silts. The observed punctuated seaward progradation of the sandstone wedges followed by a punctuated rapid retrogradation occurs in relation with high frequency sea-level fluctuations probably in the range of less than 50,000 years.

As seaward progradation occurs, the deltaic clinoforms are progressively reworked by tidal currents. Tidal reworking and tidal related facies become predominant over flood/fluvial processes and a system of laterally juxtaposed tidal bars start accumulating at the front of the prograding wedges. These wedges form parallel to the strike of delta progradation, resulting in a coalescent belt of tidal bars separated by argillaceous burrowed intervals marking minor transgressions. There is no indication seaward of a major break in deposition between tabular bedded late highstand deposits to early lowstand clinoforms deposited during the initial lowering of sea-level and finally with tidally reworked clinoforms.

At large scale, the Roda Sandstone deposits could possibly be interpreted as a type 2 sequence of shelf perched shelf lowstand deposits (Posamentier and James, 1988). Thus, the model of a high sediment-supply fluvial system, incising down to the shelf break, does not apply to the Roda Sandstone, the shelf-break being structurally controlled by the thrust sheet geometry located far to the west from the seaward Roda Sandstone pinch-out. Contrary to the Mahakam lowstand deltas, clinoforms developed seaward of the early highstand deposits are never overriden and incised by the downcutting fluvial system as the delta progrades.

During a period of continuous sea-level fall, 3D images demonstrate that the Mahakam distributary channels are converted into incised valleys with adjacent characteristic dendritic tributary channels. These features, previously interpreted as shelfal tidal channels and hard to map using 2D-seismic data, clearly indicate that the northern part of the shelf has been exposed during a prolonged period of time and flooded during the Holocene rapid sea-level rise. Main incised valleys have reached the shelf break transporting sediments beyond the shelf break.

Thus, contrary to the Roda Sandstone, the Mahakam lowstand deltas fit with the model of a high sediment-supply fluvial system, incising down to the shelf break. In this case, the shelf-break is at least structurally controlled and located relatively closer to the seaward lowstand sandstone pinch-out. During sea-level rise, the incised valleys are flooded and remain largely underfilled with a thin drape of transgressive sediments while the interfluves are colonized by calcareaus *Halimeda* bioherms. Growth of *Halimeda* bioherms continues until it is stopped by highstand delta progradation.

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Author

The distribution of the bioherms is strongly influenced by the presence of tilted faulted panels on top of which *Halimeda* bioherms developed. The effect of tectonics is marked. Pronounced incision of the valleys occurs where they cross upthrown blocks. More sinuous patterns are found on downthrown blocks. The southern depocenter displays a thicker perched and prograding lowstand deltaic wedge. This wedge is capped with a network of channels showing limited incision and fewer *Halimeda* bioherms than in the north.

The 3D regional mapping of the Mahakam lowstand deposits demonstrates the effect of larger scale shelf physiography on the coeval development of a thick deltaic lowstand delta on the southern shelf while incised valleys occur on the northern shelf and appear to be tectonically induced features.

Abstracts

Author

Seismic and Sequence Stratigraphy of a Braided Fluvial Sheet, Lower Cretaceous Missisauga Formation, Offshore Nova Scotia, Canada: Implications for Deep-Water Exploration

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Abstract

In the inner to middle Sable Subbasin, offshore Nova Scotia, a thick (~100-200 m) and areally-extensive (>20 km x > 100 km) sheet-like fluvial-marine succession has been identified at the top of the Missisauga Formation using core, well log, and seismic (2D and 3D) data. Despite its relatively planar nature and significant width perpendicular to interpreted paleoflow (at least 20 km), the base of the fluvial sheet is interpreted to be a wide incised valley formed during slow relative sea level fall and lowstand. Deposition of the fluvial-marine succession has occurred during subsequent slow relative sea level rise, which was punctuated by several higher frequency relative sea level falls that episodically caused fluvial systems to bypass the shelf, allowing for continued shelf margin progradation.

McAllen Ranch, S.E. Texas–Vicksburg Shelf Margin Deltas

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Abstract

The sediments of the Oligocene Vicksburg Formation of the McAllen Ranch Field have been attributed to various depositional settings in the past, generally within some sort of deltaic through turbidite setting. Previous interpretations include deltaic deposits (Ritch and Kozik, 1971; Loucks, 1978; Han, 1981) whereas Berg, Marshall, and Shoemaker (1979) favor turbidite channel sandstones associated with overbank deposits. These authors have all described sedimentary features and processes that can be attributed to the depositional setting to which they ascribe, but still the final interpretation is somewhat unsatisfactory to encompass all the sedimentary structures and features comprising these depositional settings. Wach et al. (2002) in their discussion of casing failure in many of the wells in the area of McAllen Ranch have described the succession as a shelf margin delta and argue that it is this depositional setting that contributes to the failure of many of the well bores. This paper will take an in-depth look at the lithological and sedimentological evidence within the sandstone and shale units to support the interpretation of the succession as a shelf margin delta. This interpretation allows past interpretations of deltaic and turbidite features to be melded seamlessly into the interpretation.

Abstracts

Author

The Prospective Deep Miocene in the Gulf of Mexico Shelf: Compartmentalization Knowledge of the Geopressured Depositional System Sheds Light on Immense Exploration Potential

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Abstract

The new concept of integrating sequence stratigraphy and geopressure compartmentalization is a comprehensive risk assessment tool, and this concept is essential for the risk assessment of the deep gas (reserves) on the shelf area of the Gulf of Mexico. This is especially true in the mature West-East Cameron areas where untested large, deep Miocene structural closures exist. In the early 80's, the crests of some of these deep structural closures (>15,000 feet) were tested. Exploration of these deep Miocene closures was discouraging by the failure to find commercial hydrocarbon-bearing formations.

Building sedimentary models using well logs, paleoenvironment data, sand maps, and sequence stratigraphy helps project the pattern of the sediment influx from the outer shelf to the slopes and bathyal environments. Ponded sand sheets and basin floor fans are the reservoir facies in the slopes and the bathyal environment. The deep-water environment in the slopes and bathyal promote the forming of the maximum flooding seals. The paleoenvironment spatial distributions in relation to the structural setting of the sequence stratigraphic units, such as progradational and retrogradational deposition of sequences are responsible for the architectural development of lateral pressure compartments. Maximum flooding surfaces form effective seals and have great impact on the vertical partitions. These deep compartments are generally geopressured (abnormally pressured). The hydrocarbon entrapment capability

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in this deeply buried section is a function of the ratio between the pore pressure and the fracture pressures. Pressure transgression and regression are mainly impacted by the communication between these laterally and vertically partitioned stratigraphic systems.

Reservoir quality and the shale cap sealing capacity of the structural closure are determined by the inter-relationship of the sediment paleoenvironment and the subsurface pore pressure development. Several case histories in the deep Miocene promote some new exploration approaches and enhance old play concepts.

Abstracts

Author

Linking Shelf-Edge Deltas to Deep-Water Sheet Sand and Channel Turbidite Reservoirs: Three Examples from the Miocene–Pleistocene, Gulf of Mexico

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Abstract

Large-scale shifts in the shelf-edge location of deltaic depocenters have caused temporal and spatial fluxes in sediment supply that have exerted a significant control on the third-order reservoir stratigraphy of the Mars-Ursa, Auger-Macaroni, and Brutus-Bullwinkle intraslope basins, among the most productive areas in the deep water Gulf of Mexico. Each basin has a producing interval characterized by a remarkably similar up-section transition from more sheet-like turbidite deposits to more channelized deposits, despite locations hundreds of miles apart, and different geologic ages. The transition is directly related to the changing position of the deltaic depocenter with respect to the basins, and the associated increase in sediment supply to the slope with respect to accommodation, independent of fluctuations in eustasy.

Previous workers have described the transition from sheets to channels: Prather *et al*. (1998) describe a calibrated up-section change in Plio-Pleistocene sediments from a "ponded" seismic

facies assemblage to a "bypass" seismic facies assemblage, Booth *et al*. (2000) describe a similar transition for the Pliocene Auger-Macaroni Basin, and Meckel *et al*. (2002) describe such a transition in the late Miocene-early Pliocene stratigraphy of the Mars-Ursa area. However, the ubiquitous nature of the transition and its spatial dischroneity has not been previously described, nor has the relationship between the deep-water reservoirs and their coeval shelfedge deltaic depocenters been made explicit.

Paleogeographic reconstructions of the position of the shelf-edge systems (Winker and Booth, 2000) show that the deltaic depocenter migrated westward from a location updip of the Mars-Ursa basin in the late Miocene to a location updip and northwest of the Auger-Macaroni basin by the beginning of the late Pliocene. From the late Pliocene to present, the depocenter has migrated eastward, returning to a present-day shelf-edge position very close to where it was during the late Miocene. The depocenter passes updip of the Brutus-Bullwinkle area sometime between the latest Miocene and early Pliocene while migrating westward, and again in the late Pliocene to early Pleistocene, as it migrated eastward.

When the deltaic depocenter was in an updip, proximal position with respect to each basin, laterally extensive, high net-to-gross sheet sands dominated deposition there. In the Mars-Ursa area, sheet sands were deposited from 9.5 Ma or before until 7.5 Ma. This period correspondeded to deposition of the latter part of the Atwater Unit (terminology of Winker and Booth, 2000). In the Auger-Macaroni area, sheet sands were most prevalent in the section from 4-2.95 Ma, corresponding to deposition of the Keathly Unit (terminology of Winker and Booth, 2000). In the Brutus-Bullwinkle area, sheet sand deposition dominated from 3.5-1.95 Ma, during the early deposition of the Sigsbee Unit (terminology of Winker and Booth, 2000).

When the depocenter abandoned one fairway and migrated to a location more distal with respect to a given basin, less continuous, lower net-to-gross channels and overbank deposits dominated deposition. In the Mars-Ursa area, channelized deposition dominated from 7.5-4 Ma, when the depocenter had migrated westward. In the Auger-Macaroni area, channelized deposition dominated from 3-2 Ma, when the depocenter had migrated eastward (corresponding to the sheet sands in the Brutus-Bullwinkle area). As the depocenter continued migrating eastward, channelized reservoirs were deposited in the Brutus-Bullwinkle area from 1.95-1.04 Ma.

The transition from sheet sand deposition to channelized deposition occurs at different times in each basin-7.5 Ma in the Mars-Ursa area, 2.95 Ma in the Auger-Macaroni area, and 1.95 Ma in the Brutus-Bullwinkle area-yet the similarity of the transtion argues for a common explanation. The links between sheet dominated, delta-proximal conditions and channel dominated, delta abandonment conditions across space and time implies a fundamental genetic link between the updip and downdip systems that cannot be coincidental. Glacio-eustatic changes in sea level and other commonly invoked mechanisms of cyclicity, such as climate or tectonics, are inadequate to explain the observed transitions. Such factors are regional to global in nature, and would result in a more synchronous transition between the areas in question.

Furthermore, the magnitude, frequency, and timing of eustatic changes in particular do not correspond to the observed transitions in a meaningful way. Thus, as alternate explanations are neither convincing nor sufficient to explain the data, we conclude that the changing sediment supply associated with shelf-edge depocenter migration is the most reasonable explanation for the transition.

In our model, increased sediment supply associated with proximal shelf-edge deltaic systems overwhelmed other possible contributing factors, resulting in sheet sand deposition. Assuming that salt withdrawal created a relatively constant rate of creation of accommodation, the sandy turbidites deposited at this time were able to efficiently fill existing (and newly created) space. The decrease in sedimentation rate that occurred when the depocenter switched locations resulted in channelized deposition that was less efficient in filling the basin with continuous sands. Short-term fluctuations in relative sea level and topography within the overall supply dominated succession (or lack thereof) might have caused higher-frequency (fourth- and fifth-order) alternations between sheets and channels that appear to be another similarity among the basin fills.

Abstracts

Author

Benthic Foraminiferal Litho-Biofacies Correlations and Enhanced Reservoir Characterization of Hydrocarbon Accumulations in Deep-Water Turbidite Strata: King Kong—Yosemite Field, Green Canyon Lease Area, Northern Gulf of Mexico

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Abstract

An integrated stratigraphic study has been undertaken to provide the basis for constructing a detailed stratigraphic and geocellular model, which is essential for field simulation. As there are three structurally unrelated hydrocarbon accumulations in the King Kong–Yosemite area, detailed bio-, chrono- and litho-stratigraphic information is needed to clarify the depositional relationships. Regional accumulation rate studies suggest that strata contained in the three field structures developed within a single large linked depositional system that stretched from shelf-edge to basin in the early Pliocene.

The biostratigraphic portion of the investigation focused on identifying assemblages of foraminifera that live in, or are transported into the deep-water depositional environments of the northern Gulf and on recognizing key flooding surfaces. The interpretation of lithologically distinct litho-biofacies in eight well bores provided the basis for

an enhanced reconstruction of the local depositional environments and sedimentary characteristics, including basic reservoir properties. In the study, displaced delta /delta front and distal prodeltaic outer shelf-upper slope litho-biofacies have been correlated in the King Kong wells, indicating a pattern of prograding and aggrading reservoir-prone debrites. The distribution of debrites defines submarine fan architecture and reservoir quality trends top-lapped by 3.72 Ma, 4.0 Ma, and 4.3 Ma third-order flooding surfaces.

Superposition of litho-biofacies observed in the King Kong well bores onto a 3D seismic traverse provided an enhanced integrated reservoir correlation, even suggesting the possibility of repeat reservoir section caused by ~100 ft of reverse throw on a regional detachment surface. The 4.0 Ma and 4.3 Ma flooding surfaces bound most of the reservoir section in the wells. The study determined that all King Kong reservoir intervals lie below the 3.72 Ma flooding event.

Abstracts

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Foraminiferal Litho-Biofacies of Linked Delta—Fan Deposystems in the Northern Gulf of Mexico: Paleontologic and Lithologic Characteristics

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Abstract

Foraminiferal assemblages in deep-water sediments contain: (1) indigenous benthic taxa that represent combined bottom-water and bottom-sediment controlled benthic environments (biotopes); (2) planktonic taxa that settle, after death, from near-surface habitats into benthic biotopes; and, (3) allochthonous benthic shelf taxa that are transported downslope into deep-water biotopes either as empty tests or as displaced living populations. Each of these categories of foraminiferal taxa contained in deep-water foraminiferal assemblages carries information on the sedimentary processes, lithology, and reservoir properties of deep-water biotopes, and on derivative foraminiferal biofacies called litho-biofacies.

Turbidites and particularly associated poorly-sorted submarine fan deposits known as debrites are distinguished from other deep-water sediment types by the relatively large volumes of displaced shelf sediments they contain. Turbiditic sand bodies deposited preferentially in subtle topographic depressions or in less subtle bathymetrically isolated subbasins, *e.g.*, salt-bounded slope minibasins, are local in extent because they are limited to filling seabed relief as stacked fan lobes or prograding fan clinoforms. Between the pulses of high-energy bottom currents that deposit the sand, benthic environments in these topographic depressions frequently reflect low current energy, poor oxygenation of bottom water and sediments, and increased deposition of lighter detrital components such as clays and marine or terrestrial organic matter. These unique and contrasting environments support diverse diagnostic assemblages of indigenous benthic foraminifera that provide biostratigraphers with opportunities to make very detailed interpretations of depositional variables in complex deep-water settings.

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This paper reviews the extensive literature covering the foraminiferal ecology of the most common deep-water lithofacies and describes representative litho-biofacies, including: barren sand; flysch-type turbidite; deltaic biomechanical debrite; basin margin calcareous bank; drowned-shelf distal prodeltaic hemipelagite; dysoxic basin hemipelagite; sapropelite; confined subbasin ponded hemipelagite; unconfined slope and rise hemipelagite; pelagite; and condensed and transitional deposits. Definitions based on this work can be used in the detailed assessment of deep-water depositional systems.

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Biostratigraphic Techniques for Locating the Position of Ancient Shelf Margins: Examples from the Neogene of the Northern Gulf of Mexico

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Abstract

Cenozoic infilling of the northern Gulf of Mexico Basin with siliciclastic sediments occurred in a broadly offlapping pattern as successively younger shelf margins prograded basinward. Ancient shelf margins divide the basin profile into shelf and slope realms, with each realm containing economically important sandy reservoir units of fundamentally different geometries and stratal architecture. In the northern Gulf of Mexico, salt tectonics, related growth faulting, and shale com-

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paction severely hinder recognition of ancient shelf margins on dip-oriented seismic sections, often making prediction of potential reservoir sand distributions problematical.

We demonstrate that biostratigraphic signals derived from the quantitative analysis of benthic foraminifera preserved in well bore ditch cuttings are effective for constraining the position of ancient shelf margins. The signals are computed using the Integrated Paleontologic System (**IPS**) and include an objectively calculated paleobathymetry curve, similarity matrix, and curves showing the percentages of shelf, slope, and carbonate-bank assemblages (**CBA**). **IPS** is a data analysis software tool originally developed by UNOCAL and subsequently enhanced by an industry/academic consortium at the University of Utah.

Four coreholes taken along a shelf-to-upper slope dip profile across the latest Pleistocene Lagniappe Delta (located southeast of the modern Mississippi "Birdsfoot") have provided a wealth of geologic information on the dynamics of shelf-margin siliciclastic sedimentation in the northern Gulf of Mexico. To better understand the biostratigraphic response of prograding siliciclastic shelf margins in this region, we vertically stack age-equivalent paleontologic data from shelf margin and shelf coreholes on top of similar data from the upper bathyal site. This concatenated data set produces an upward stratigraphic succession that would be expected if the current shelf margin was to prograde over the bathyal corehole location.

Using **IPS**, we calculate key biostratigraphic signals for the concatenated Lagniappe section, and use them as a model for interpreting similar data sets from exploration wells with upward successions of bathyal, shelf-margin, and shelf facies. The following biostratigraphic signals characterize Neogene shelf margins in the northern Gulf of Mexico: (1) first upward appearance of *in situ* **CBA** (2) progressive upward shift in **IPS**-derived paleobathymetry curve from upper bathyal to outer neritic/upper bathyal (3) upward shift from predominantly slope-restricted to shelf-restricted taxa.

Biostratigraphy of a Pleistocene Shelf-Edge Delta System, Northeastern Gulf of Mexico: Recognition of Delta Subenvironments

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Abstract

The Lagniappe Delta complex formed on the Mississippi/Alabama continental shelf during the Wisconsinan glacial stage, within oxygen isotope stages 2-4. Data collected from four coreholes (Main Pass 242c1, 288c1, 303c1; and Viosca Knoll 774c1), which penetrate the Lagniappe Delta complex and older section provide the basis for our research. In our study of fossil foraminiferal assemblages from these coreholes we interpret paleobathymetric zones (inner neritic to upper bathyal) and paleo-water depths as well as subenvironments within the delta complex. The similarity of Pleistocene-Holocene fossil assemblages to those of the Recent allows us to use the Mississippi River Delta as a modern analogue. Five of the six modern Mississippi River Delta subenvironments are recognizable in the subsurface: fluvial, interdistributary bay, fluvial-marine, deltaic-marine, and sound. A marsh subenvironment is not present in our data set.

An occurrence of warm, carbonate-bank microfauna in a cold, glacial interval in Main Pass 288 is a paradox explained by the close proximity

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Author

of this site to the paleo-shelf edge during isotope stage 2 and the influence of a proto-loop current.

Based on a reconstruction of the paleoenvironments, paleogeographic maps were drawn at three time slices: 83 Ka (stage 5a/5b boundary); 24 Ka (stage 2/3 boundary); and 19 Ka (late stage 2). These maps show the basinward migration of the shoreline during sea-level fall and the progradation of accreting lobes of the Lagniappe delta during the late Wisconsinan glacial stage.

Abstracts

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Coarse-Tail Graded, Structureless Strata: Indicators of an Internal Hydraulic Jump

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Abstract

Enigmatic strata were observed intercalated with otherwise thin-bedded 'classic' turbidites in the Isaac Formation of the Neoproterozoic Windermere Supergroup in the southern Canadian Cordillera. To understand better the origin of these sharp-, planar-based, structureless, coarse-tail graded strata containg grains up to 0.5 mm and bed thickness up to ~0.30 m, experiments were conducted to replicate the conditions during deposition. In particular, the effect of an internal hydraulic jump on deposition from high-density (20% and 35% volume-sediment concentration), silt-sand, turbid bottom currents was investigated. Video records showed that turbulence generated in the hydraulic jump entrained coarse- and fine-grained sediment from the bed and temporarily maintained them in suspension. Analysis of the subsequent deposit, as photographed through the experimental-tank glass walls or seen on sediment epoxy peels, revealed faintly banded, graded strata in which sand grains float in a matrix of silt, similar to that observed in the Neoproterozoic outcrop examples. Strata like these should be easily recognized in core and therein indicate deposition in a hydraulic jump of a high-density sediment-laden flow.

Abstracts

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Review of Continental Margin Structural Strength and Stability

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Abstract

The classic passive continental margin model of previous decades has been one of stratigraphic evolution over a perceived structurally strong feature. That notion of stability is eroding, as the impact of interlocking geologic processes is better understood. The continental margin instead of being stable may itself be dynamic as it slides into the Gulf of Mexico. For this to be true, there must be processes that individually, collectively, and synergistically, are weakening the margin in such a way that it moves minutely, locally, and regionally, each unit possibly moving independently yet forming a single tapestry of deformation. To propose a hierarchy of operating processes of which one(s) may be dominant or subordinate is surely premature. Listing known processes and their interrelationships may be a worthy exercise, leading to fruitful avenues of research'

Major processes that require further exploration include: (**a**) the critical cohesive Coulomb wedges and their applications; (**b**) fold-belts at the base of the continental slope; and (**c**) potential stress fields in the lower continental rise and deeper abyssal plain.

The critical cohesive Coulomb wedge was originally described as a wedge of deformed/deforming material tapering toward the deformation front, a basal surface of detachment or decollement with most of the dynamics above the decollement and much horizontal compression within the wedge.

Originally this interpreted feature was applied to subduction zones. This interpretation may be profitably affixed to dynamic continental margins such as those of the northern Gulf of Mex-

ico and the Gulf of Cadiz, both of which have major gravitational tectonic overprints.

With large gravity-driven downslope mass-wasting, migrating critical wedges that develop can generate compression, yielding fold-belts. Farther downslope, the downdip generated compressive stresses may be more diffuse and ineffective.

How are pressures transmitted laterally at water depths of 3-4 kms? Prime candidates are the entire continental margin itself or the extrusives: salt (Gulf of Mexico), shale (West Africa/ Gabon margin), and/or crustal blocks/salt (Gulf of Cadiz). All are operative, yet at different rates, establishing a heterogeneous stress field, varying with time. With pore-pressure approximating fracture pressure, relatively small changes in lateral stresses could create fractures, keep fractures open, or close fractures.

At multi-kilometer depths, the water pressure commences to be sufficient so that natural gases remain in solution and hydrates may or may not be formed. The existence of hydrates changes stresses within sediments; hydrate absence minimizes the possibility of buoyant free gas buildups. The role of hydrocarbons, gas, liquid and/or solid, and of whatever source (biogenic or abiogenic), given their sheer abundance and ubiquity, needs to be re-examined.

Abstracts

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Late Quaternary Shelf-Edge Deltas from Northeastern Gulf of Mexico and Eastern Borneo (Indonesia): A Comparison

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Abstract

As the sea level low of the latest Pleistocene glacial maximum was approached, fluvial systems worldwide migrated across continental shelves and built their deltas at or near the shelf-edge. Two excellent data sets consisting of high resolution seismic profiles and cores have been acquired in recent years from two of these shelf-edge deltas in very different climatic and physical process settings, the temperate Lagniappe (Mobile River) delta of the northeastern Gulf of Mexico and tropical Mahakam River delta of the eastern coast of Borneo (Indonesia). Both of these late Pleistocene deltas were built during the latest Pleistocene falling-to-low relative sea-level conditions.

The Lagniappe Delta is defined by a complex clinoform wedge built in two simultaneous progradational thrusts resulting in western and eastern deltaic depocenters at the shelf-edge. Both depocenters contain individual clinoforms sets interpreted to be both the products of autocyclic switching of dominant distributaries and a stepped fall in sea-level. Clinoforms lap down on outer shelf shale overlying an oxygen isotope stage 5 condensed section. The tops of clinoforms sets are extensively eroded resulting in a complex north-

east/southwest-oriented fluvial scour. The eastern lobes of the Lagniappe Delta show evidence of wave reworking while the western depocenter is fluvially dominated.

The Lagniappe clinoforms built wedges on a relatively stable shelf under conditions of a low tide range, low wave energy, and seasonal storms. In this setting, siliclastic sedimentation dominated and carbonates had little impact on the sedimentary record. Dating (^{14}C methods) of both the eastern and western Lagniappe depocenters indicated an age of approximately 19 Ka BP. However, a deeper clinoforms wedge that was stratigraphically younger than the western and eastern deltaic depocenters occurred at a depth of approximately 119-126 m water depth. This clinoforms wedge has not been dated, but it is part of the falling-to-lowstand progradation.

The latest Pleistocene Mahakam River Delta was deposited on a tectonically active shelf and in an equatorial setting characterized by moderate tide, extremely low wave activity, low storm activity, a strong north-to-south flowing oceanic current, and upwelling. Tropical ocean conditions and upwelling of nutrient-rich water provided environmental conditions suitable for developing a mixed siliciclastic-carbonate depositional system. Below the Pleistocene-to-Holocene ravinement surface, two deltaic depocenters developed during the latest Pleistocene falling-to-low sea-level, a northern depocenter characterized by numerous distributaries that created off-set and overlapping individual clinoforms sets through autocyclic processes and a larger southern depocenter characterized by an actuate delta front and a central northwest-southeast oriented distributary network resulting in a broad fluvial scour. These Pleistocene deltaic deposits prograded to the shelf edge along most of shelf-slope break. Clinoforms of these falling-to-lowstand deposits lap down onto highly irregular shelf topography created by the growth of the calcareous green alga *Halimeda*. These isolated bioherms and aggregates of bioherms are seated on a prominent ravinement surface. A maximum flooding surface runs through these features. The success of *Halimeda* in building impressive shelf bioherms is attributed to the upwelling of nutrient-rich tropical water onto the Mahakam shelf thus stimulating plant growth as sea level rose across the shelf. Bioherm growth is terminated by siliciclastic influx as the delta progrades during a prolonged highstand or falling-to-lowstand conditions. During the lowstand turnaround, over half of the lowstand systems tract stratigraphy is related to delta plain aggradation. Modern equivalents to these delta plain sediments are found to have a lipid-rich organic content of sufficient concentration to be considered a source rock precursor.

Abstracts

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Transition from Shelf Margin Delta to Slope Fan—Outcrop Examples from the Tanqua Karoo, South Africa

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Abstract

Outcrop sections containing excellent physical and biogenic sedimentary structures within the Late Permian Ecca Group are exposed within the Tanqua Karoo that show the transition from shelf margin delta through to slope and basin floor fans. The Tanqua submarine fan complex comprises six regionally distinct fan systems, five of which form a progradational stack with the sixth fan, to the south, downlapping onto the fifth fan. Progradation of the deltaic deposits across the basin has been in response to a decrease in accommodation space created by relatively high rates of sedimentation within the foreland basin setting. The sedimentology and sequence stratigraphy of the Hangklip Fan represents a shelf margin delta feeding downdip slope fan deposits. Wave ripples, swaley cross-stratification and trace fossils, including *Gyrochorte*, suggest substantially shallower depositional conditions than slope fan deposits, which are devoid of such features. Erosional slump

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Author

scars, cutting into laminated shale with chaotic infill of sand intraclasts, point toward slope depositional processes that are not in evidence in the underlying submarine fan deposits.

Abstracts

Author

Connections Across the Shelf-Slope Transition, Late Quaternary Rio Grande Deltaic System

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Abstract

The Rio Grande Delta, offshore south Texas, has been a prominent feature on the continental shelf throughout the last glacial-eustatic cycle. Eight hundred km of high-resolution seismic data (20 in^3 airgun, single-channel) has been collected on the upper slope in order to extend previous interpretations of the shelf deltaic system. In addition, a series of cores collected in the 1960s on the Rio Grande slope have been incorporated into the project. During the last lowstand (~20,000 Ka), a large shelf-margin delta and related slope fan have developed. These lowstand deposits represent a large volume of sediment that formed partially by cannibalizing the highstand shelf deposits. Preliminary interpretation of the data indicates that the shelf-margin delta is a fluvial-dominated system and the slope fan is composed of a number of turbidites, characterized on seismic data by chaotic clinoforms interbedded with pelagic sediments. We believe the turbidites have originated directly at the shelf-margin delta front, and thus the development of the delta and fan are intricately linked. We will use this newly integrated data set to study the connection between the shelf and slope systems and to construct a chronology of the timing of slope fan development.

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