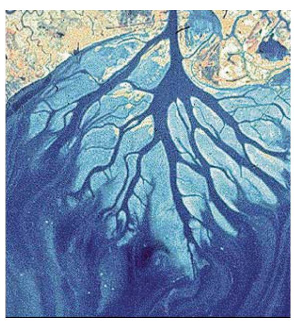
Continental Margins II: Interdisciplinary Perspectives on the Building of a Passive Margin

IRESS 2017

Industry-Rice Earth Science Symposium

February 23-24, 2017
Rice University

EARTH SCIENCE
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The importance of passive Margins

The development of a passive margin is one of the most important processes on Earth. Passive margins mark the transition between continents and ocean basins. They bear the scars of continental breakup, manifested by the presence or absence of rift-related magmatism and the deep structure of the ocean-continent transition. They hold the sedimentary archives of the opening and development of ocean basins and recorded in these archives are changes in depositional environment related, on long timescales, to deep Earth processes governing rifting and the eventual subsidence that leads to accommodation space for sediments. Superimposed on these long wavelength and timescale mantle processes are the effects of climatic and environmental changes, including relative sea level fluctuations. Major unconformities, time correlative across large length scales, may speak of profound global environmental change whereas variations in sedimentary facies on smaller length scales may speak of short timescale internal changes within sediment distributary systems and relative sea level change. Deconvolution of all these signals is key to understanding what passive margin sediments have to tell us about Earth history. Importantly, throughout Earth's history, passive margins have been the dominant repositories of carbon, in the form of carbonate platforms and organic carbon rich shales. Understanding passive margins is not only key to understanding hydrocarbon energy potential for the 21st century but is also key to understanding the global carbon cycle, which is intimately linked to the evolution of climate and life on Earth.

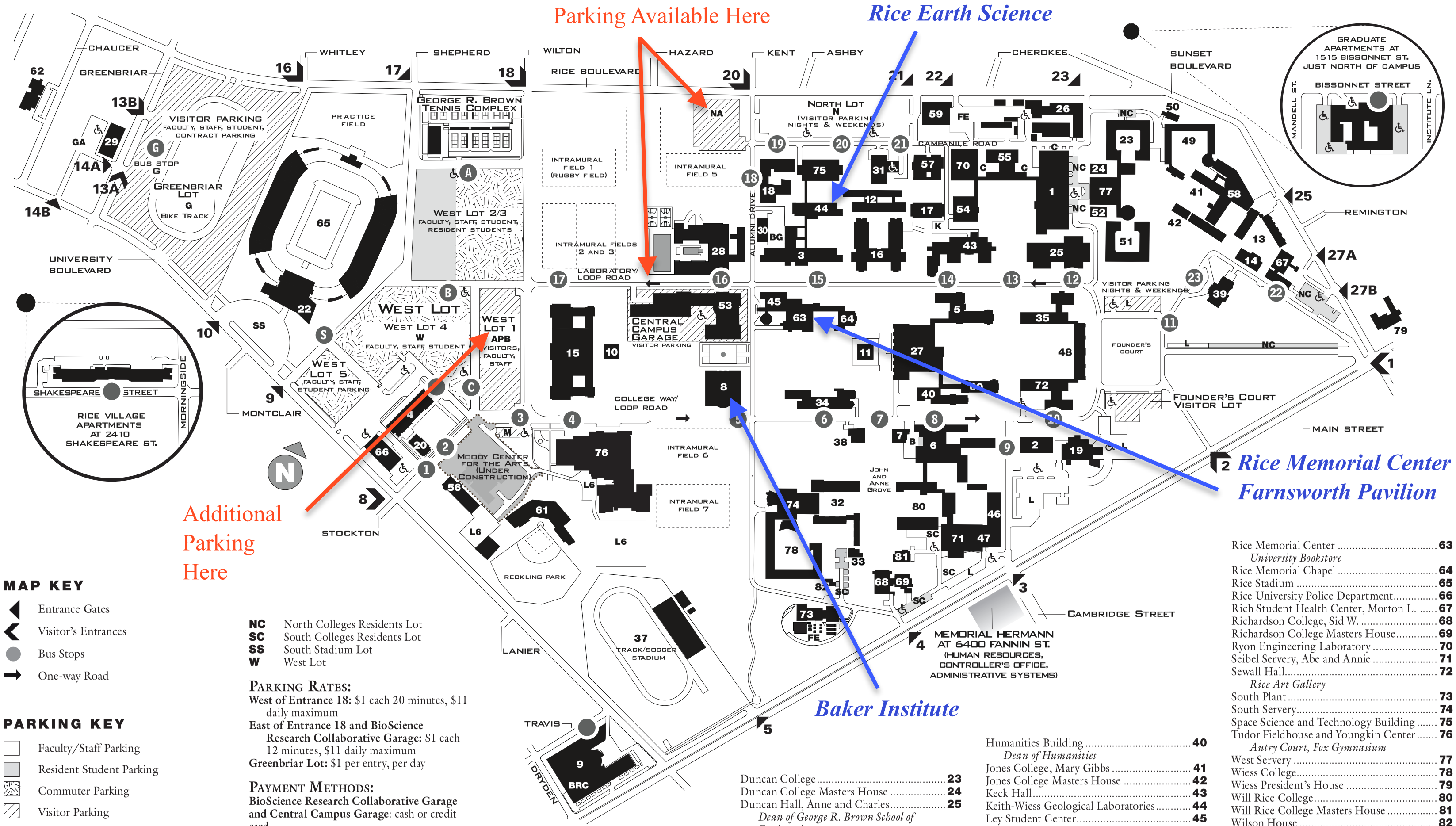
A new framework for understanding passive margin development

The purpose of this workshop is to bring together industry and academic leaders from different disciplines to critically examine past and current paradigms on the origin and evolution of passive continental margins. Much of our initial understanding of passive margin development was established forty years ago. Industry and academic leaders had joined forces to bring together vast and seemingly disparate datasets, ranging from geophysics to stratigraphy to geochemistry. This was a time when new technologies opened up the ability to generate new datasets never seen before, and the synthesis led to the paradigm of sequence stratigraphy, arguably one of the most important and successful examples of thinking about the Earth as a holistic, fully integrated dynamic system.

The last decade, however, has seen an explosion of technological and conceptual advances, which have provided new information on the nature of continental margins, which in turn has challenged certain aspects of the sequence stratigraphy paradigm. Seismic stratigraphy and the characterization of geochemical and physical properties of sediments through the availability of cores and high resolution well-logs have reached an unprecedented level of resolution, which combined with a revolution in data processing and imaging, are providing new insights into the structure of continental margins. Of particular importance are the recent advances in geochemistry and geobiology, which are changing our views of how carbon and nutrients are transported and sequestered in continental margins. Over the last twenty years, we have also seen major shifts in our understanding of the geodynamics of rifting and passive margin development as well as the interactions between Earth's deep and surface processes.

Important, unsolved questions are as follows. What are the relative roles of climate, relative sea level, ice volume, tectonics, mantle dynamics and sediment transport dynamics in controlling major sequence boundaries? Does magmatism play an active or passive role in continental rifting? How dynamic is the continental shelf and what role does it play in terms of global carbon and biogeochemical cycling (source or sink)? What controls long and short term climate variability (My to ky) and how is this manifested in the stratigraphic framework of passive margins? How do we interpret the lithospheric and sedimentologic evolution of a developing passive margin in the context of glacio- and tectono-eustasy, mantle dynamics, climate, erosion and weathering? How do we identify and interpret relative sea level change? We now know that all of these processes are intimately linked, but no holistic framework, tying deep and surface Earth processes, across different length and timescales, currently exists.

Rice University Campus Map



Map Key

- Entrance Gates
- Visitor's Entrances
- Bus Stops
- One-way Road

Parking Key

- Faculty/Staff Parking
- Resident Student Parking
- Commuter Parking
- Visitor Parking
- Accessible Parking

Parking Lots:

- **APB** Alice Pratt Brown Hall Lot
- **B** Baker College–Housing & Dining Lot
- **BG** Biology–Geology Lot
- **BRC** BioScience Research Collaborative Garage
- **C** Campanile Lot
- **CG** Central Campus Garage
- **FE** Facilities, Engineering and Planning Lot
- **G** Greenbriar Lot
- **GA** Greenbriar Annex
- **K** Keck Lot
- **L** Lovett Lot
- **L6** Lot Six
- **M** Moody Lot
- **N** North Lot
- **NA** North Annex Lot
- **NC** North Colleges Residents Lot
- **SC** South Colleges Residents Lot
- **SS** South Stadium Lot
- **W** West Lot

Parking Rates:
West of Entrance 18: $1 each 20 minutes, $11 daily maximum
East of Entrance 18 and BioScience Research Collaborative Garage: $1 each 12 minutes, $11 daily maximum
Greenbriar Lot: $1 per entry, per day

Payment Methods:
BioScience Research Collaborative Garage and Central Campus Garage: cash or credit card
Greenbriar Lot, Founder's Court, North and West Lots Visitor Section: credit card

Buildings

Abercrombie Engineering Laboratory ... 1
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President's Office
Anderson Biological Laboratories, M.D. ... 3
Anderson-Clarke Center ... 4
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Anderson Hall, M.D. ... 5
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Baker College ... 6
Baker College Masters House ... 7
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Natural Sciences, Wiess School of ... 16
Social Sciences, School of ... 8

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IRESS 2017

Industry-Rice Earth Science Symposium

Welcome to IRESS 2017

This workshop will consist of two parts. The first will be to redefine our understanding of sequence stratigraphy in the context of contemporary concepts in sedimentary transport, climate, sea level, tectonics, mantle dynamics, and whole Earth system models. We will highlight key developments in technology and geologic data that have made scientific advances possible. The second part will consist of understanding the complex interplays between mantle and surface processes on the origin and development of the passive margin basement from the initiation of rifting to the maturation of an ocean basin. One of the goals of this workshop is to develop a new text, outlining passive margin evolution for the next generation of students and researchers. The workshop will be published as a journal special issue to be edited by Kevin Biddle, Gerald Dickens, and Cin-Ty Lee.

Chatham House Rule

This Symposium is held under the Chatham House Rule, under which participants are free to use the information received, but neither the identity nor the affiliation of the speaker(s), nor that of any other participant, may be revealed. The use of this rule is intended to encourage openness in discussion and, it is hoped, will make this IRESS event more useful to all the participants.

SCHEDULE- Baker Institute

Day 1: Thursday, February 23, 2017

7:30-8:00 am	Registration and Coffee
8:00-8:10 am	Opening remarks, André Droxler- Rice University
Session 1:	Moderator: Cin-Ty Lee- Rice University
8:10-8:50 am	Manik Talwani- Rice University *The tectonic origin of the Bay of Bengal and Bangladesh: a detective story*
8:50-9:30 am	Donna Shillington- Lamont Doherty Earth Observatory *Constraints on the temporal and spatial evolution of faulting and magmatism from ancient and active rifts*
9:30-10:10 am	Roger Buck- Lamont Doherty Earth Observatory *Reconciling mantle plume initiation of continental breakup with the inferred direction of rift propagation and the development of Seaward Dipping Reflectors (SDRs)*
10:10-10:30 am	Break
10:30-11:30 am	Discussion
11:30 am –1:00 pm	Lunch- Doré Commons, Baker Institute for Public Policy
Session 2:	Moderator: Jerry Dickens- Rice University
1:00-1:40 pm	Shanan Peters- University of Wisconsin *Sediment cycling: the long and short of it*
1:40-2:20 pm	Ken Miller- Rutgers University *The role of sea level and mantle dynamic topography on passive-aggressive continental margin architecture*
2:20-3:00 pm	Becky Dorsey- University of Oregon *Big Rivers, Sediment Flux, and the Crustal Evolution of Rifted Continental Margins*
3:00-4:00 pm	Discussion
4:00-6:00 pm	Poster Session- Farnsworth Pavilion, Rice Memorial Center
6:00-8:30 pm	Dinner- Doré Commons, Baker Institute for Public Policy Keynote Speaker: Kirsten Siebach- SUNY Stonybrook *Sedimentary Records from Another World: Exploring Gale Crater Basin with the Curiosity Rover*

Day 2: Friday, February 24, 2017

7:30-8:00 am	Registration and Coffee
8:00-8:10 am	Opening remarks, John Anderson- Rice University
Session 3:	Moderator: Mitch Harris- Rice University
8:10-8:50 am	Vitor Abreu- Rice University *Sequence Stratigraphy: Past, Present and Future*
8:50-9:30 am	Blake Dyer- Lamont Doherty Earth Observatory *Extracting sea level change from carbonate stratigraphy with hidden Markov models*
9:30-10:10 am	Jerry Mitrovica- Harvard University *The dynamic topography of passive margins*
10:10-10:30 am	Break
10:30-11:30 am	Discussion
11:30 am – 1:00 pm	Lunch- Doré Commons, Baker Institute for Public Policy
Session 4:	Moderator: Jeff Nittrouer- Rice University
1:00-1:40 pm	Nick Christie-Blick- Lamont Doherty Earth Observatory *Is sequence stratigraphy dead?*
1:40-2:20 pm	Kevin Bohacs- ExxonMobil *"E pur si muove"— the active role of mud in building passive margins, from turbidites to clinothems*
2:20-3:00 pm	Chris Paola- University of Minnesota *What is a sandy continental shelf?*
3:00-4:00 pm	Discussion and closing remarks
4:00-5:00 pm	Poster Session- Farnsworth Pavilion, Rice Memorial Center
	Post-Mortem and plans for next steps, ESCI 100 Keith-Wiess Geological Laboratory
5:00-6:30 pm	Reception- Keith-Wiess Geological Laboratory

Poster Presenters by Number

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Ma, Hongbo	Riverine conditions necessary for the formation of hyperpycnal-plumes entering basin seawater	DC*
Miller, Clint	Low methane concentrations in sediment along the continental slope north of Siberia: Inference from pore water geochemistry	15
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Stibbe, Emily	Distinguishing upper plate vs. lower plate and volcanic vs. non-volcanic, conjugate margins of the Central, Equatorial, and South Atlantic Oceans	4A
Swanson, Travis	Connecting morphodynamic depth of closure to shoreline change along the Texas coast	DC*
Vora, Harsha	Evolution of Porosity, Permeability and Velocity in Mudstones upon Fluid Injection	10
Wang, Chengzu	Rates of Motion of Groups of Hotspots Estimated from the Dispersion of Hotspot Trends	17
Woodworth, Daniel	Hawaiian Hotspot Motion, Hotspot Reference Frames, and True Polar Wander	16
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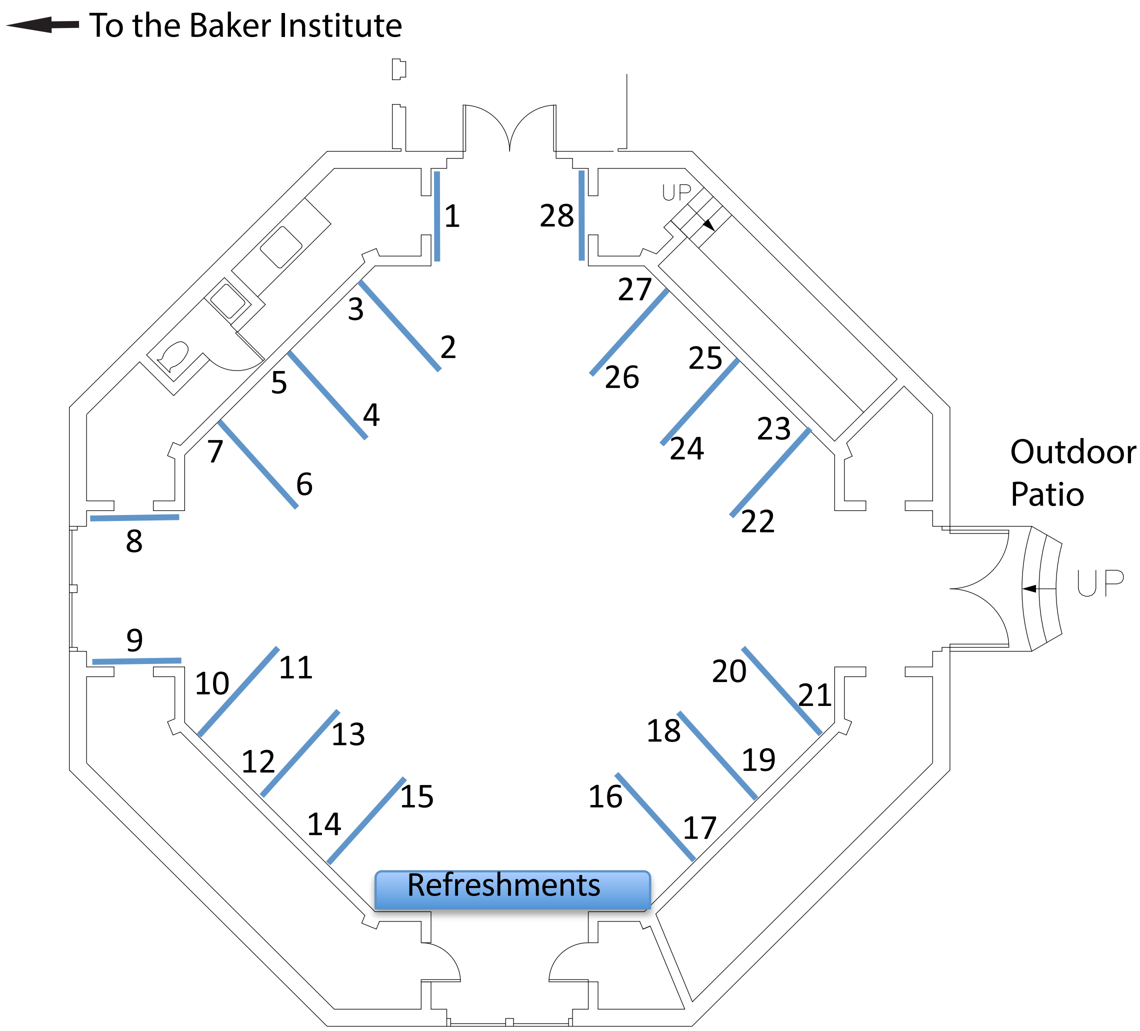
Zhang, Tuo	Plume Flux, Spreading Rate, and Obliquity of Seafloor Spreading	6
Zhou, Yuanquan (Nancy)	The "Cover" of an Upper Cambrian microbial reef complex: drowning unconformity and ultimate demise of the reefs	9

DC*- Posters will be in Doré Commons in the Baker Institute of Public Policy

Poster Session

Farnsworth Pavilion
Rice Memorial Center



Notes:

Guest Speakers
Session 1:

Manik Talwani – Rice University

Manik Talwani is the Schlumberger Professor Emeritus of Advanced Studies and Research in Earth Science at Rice University. His research focuses on interpreting the results of an airborne gravity gradiometer survey over the San Andreas Fault drill site. Talwani also examines the potential application of a very sensitive gravity gradiometer to trace the leakage of CO2 sequestered in drill holes, studies the feasibility of increased use of Venezuelan heavy oil and investigates the structure of continental margins.

Donna Shillington – Lamont Doherty Earth Observatory

Donna Shillington is an associate research professor of Marine Geology and Geophysics. She uses active-source seismology together with other geophysical and geological data to investigate deformation and magmatism at plate boundaries, including continental rifts and rifted margins, subduction zones, and transform boundaries.

Roger Buck – Lamont Doherty Earth Observatory

Roger Buck is a research professor and Associate Director of Marine Geology and Geophysics. His research interests lie in developing theoretical models for processes that affect the solid earth, including recent work on creating computer models of mantle upwelling in the region of melting below a mid-ocean ridge and investigating how it leads to the structural and topographic features we observe on ridges. In particular, he is interested in the effect of a weak lower crust on patterns of deformation that occur at the surface. His interests also extend to deformation patterns and topography on other planets such as Venus.

Session 2:

Shanan Peters – University of Wisconsin

Shanan Peters is a Dean L. Morgridge professor at the University of Wisconsin at Madison. His current research emphasis involves quantifying the rock record in order to better understand which lines of earth history have been preserved, why they have been preserved, and to what effect. Specifically, he uses macrostratigraphy to test hypotheses that span a range of earth systems, including the evolution of marine and terrestrial life, the carbon cycle and global climate, and cycling rates of geologic materials via tectonic uplift and subsidence.

Ken Miller – Rutgers University

Kenneth G. Miller is a distinguished professor in the department of Earth and Planetary Sciences at Rutgers University. A veteran of 9 scientific cruises (6 as co-chief including ODP Leg 150), he has integrated offshore seismic and drilling activities with onshore drilling: since 1993, he has been Chief Scientist of the New Jersey Coastal Plain Drilling Project (Ocean Drilling Program Legs 150X and 174AX) that continuously cored thirteen sites. He has recently participated in IODP Leg 113 (Drilling the New Jersey Shallow Shelf).

Becky Dorsey – University of Oregon

Becky Dorsey is a professor of Geological Sciences at the University of Oregon. Her research focuses on field studies of tectonically active sedimentary basins, with the goal of understanding the complex tectonic, sedimentary, and geomorphic evolution of active regions. Stratigraphy provides unique insights into past environments and tectonic events that often cannot be gained from other disciplines. Integrated basin analysis informs us about the dynamic interplay between ancient fault systems that create sedimentary basins, and the surface processes that fill them with sediment. Stratigraphy also provides a useful tool for analyzing the complex evolution of streams and geomorphology in active fault zones. She is working primarily in two areas: (1) Miocene to Pleistocene evolution of basins along the San Andreas plate boundary system in southern California and NW Mexico; and (2) Mesozoic stratigraphy and regional tectonics related to accretion and translation of oceanic terranes in central and eastern Oregon.

Keynote Speaker:

Kirsten Siebach – SUNY Stony Brook

Kirsten Siebach is a post-doctoral research associate at Stony Brook University working with Scott McLennan to interpret the geochemistry of sedimentary rocks observed by the Mars Science Laboratory. She completed her Ph.D in Geology with John Grotzinger at Caltech on the formation and diagenetic history of sedimentary rocks at Gale Crater, Mars. She is currently a member of the Science and Operations Teams for the Mars Exploration Rovers and the Mars Science Laboratory. Her research focuses on understanding the history of water interacting with sediments on Mars through analysis of sedimentary rock textures and chemistry. She is also actively engaged in promoting education and outreach related to Earth and Planetary science and regularly presents at schools and outreach events.

Session 3:

Vitor Abreu – Rice University

Vitor Abreu received his PhD at Rice University and has 28 years of experience in the oil industry in petroleum exploration, development production and research. His areas of expertise include exploration, development and production of deep water reservoirs, regional studies to define the petroleum system elements and key plays in frontier exploration, tectono-stratigraphic evolution of basins in different tectonic settings, maturing opportunities to drillable status, and play to prospect risking assessment. His experience in development and production includes several field studies in different depositional environments, with high-resolution stratigraphic interpretation integrated to engineering data to define reservoir connectivity and main baffles and barriers for effective field development plans. Vitor is considered one of the world leaders on reservoir characterization of deep water systems, proposing new deep water models with strong impact in development and production.

Blake Dyer – Lamont Doherty Earth Observatory

Blake Dyer, a 2010 Rice alum, is a post-doctoral research scientist working with Maureen Raymo. The goal of his research is to better understand how sediments record the Earth-system response to changing boundary conditions. The information from the sedimentary rock record offers a broad range of past environmental variability that serves as a powerful baseline to differentiate naturally occurring change from human induced change and can reveal feedbacks that may become critically important in predicting future climate change. He investigates the sedimentary record by merging modern data science tools and models with geospatial, geochemical and stratigraphic data collected over extensive field seasons.

Jerry Mitrovica – Harvard University

Jerry X. Mitrovica joined Harvard in 2009 as a Professor of Geophysics and is the Frank B. Baird, Jr. Professor of Science. His work focuses on the Earth's response to external and internal forcings that have time scales ranging from seconds to billions of years. He has written extensively on topics ranging from the connection of mantle convective flow to the geological record, the rotational stability of the Earth and other terrestrial planets, ice age geodynamics, and the geodetic and geophysical signatures of ice sheet melting in our progressively warming world. Sea-level change has served as the major theme of these studies, with particular emphasis on critical events in ice age climate and on the sea-level fingerprints of modern polar ice sheet collapse.

Session 4:

Nick Christie-Blick – Lamont Doherty Earth Observatory

Nick Christie-Blick is a Professor in the department of Earth and Environmental Sciences. His current research is aimed at such varied topics as how sedimentation responds to sea-level change, deformation and other phenomena; mechanisms of crustal extension, with particular reference to the low-angle normal fault paradox; and the geology of the Neoproterozoic Era, an interval of time that is unusual for its climatic extremes and as a threshold in the history of life.

Kevin Bohacs – ExxonMobil

Kevin M. Bohacs is a sedimentologist and stratigrapher with ExxonMobil in Houston, TX. He joined Exxon Production Research Company in 1981 and has conducted field work and training on six continents and in more than 25 countries. He worked with petroleum geochemists to investigate the sedimentology and stratigraphy of hydrocarbon source rocks. His studies of the Green River Formation (GRF) launched his lake studies around the world, which in turn resulted in formulation of the Lake-Basin-Type model which has proven quite useful for a range of applications, from source-rock prediction to vertebrate evolution—and even to evaluating landing sites for the Mars Science Laboratory rover.

Chris Paola – University of Minnesota

Chris Paola's major research focus has been the development of techniques for experimental stratigraphy, the centerpiece of which is the Experimental EarthScape system (XES or "Jurassic Tank"), a large experimental basin equipped with a subsiding floor. There are three major current efforts growing out of these experiments: an investigation of how sediment mass extraction can be quantified and used to predict downstream facies changes; quantitative comparison of shoreline dynamics and sequence stratigraphy in passive-margin versus foreland basins; and study of channel steering by subsidence and how this influences subsurface channel architecture. They are also working on the filtering processes that convert topography into preserved stratigraphy; experiments and modeling of deltas and how they are influenced by waves and tides; and vegetation-sediment interaction, emphasizing fine sediments.

RICE EARTH SCIENCE MODERATORS

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John Anderson
W. Maurice Ewing Professor of Oceanography

Research Summary: John Anderson is a sedimentologist who splits his time between studying fluvial and coastal processes in the Gulf of Mexico and the geological record of ice sheet movements in Antarctica, all in the context of Global Climate Change.

Jerry Dickens
Professor of Earth Science

Research Summary: Jerry Dickens is a chemist and oceanographer who combines these interests to look at a range of topics, mostly in sediments and sedimentary rocks.

André Droxler
Professor of Earth Science

Research Summary: André Droxler is a carbonate sedimentologist, marine geologist, and paleo-oceanographer with interests in past ocean, and sea-level changes. He is an expert on reefs and carbonate platforms from the Cambrian to the Holocene.

Mitch Harris
Visiting Scientist from University of Miami CSL-Center for Carbonate Research and Rice University Adjunct Faculty

Research Summary: Mitch Harris research interests are centered on facies-related, stratigraphic and diagenetic problems that pertain to carbonate reservoirs and exploration plays in most carbonate basins worldwide.

Cin-Ty Lee
Professor and Chair of Earth Sciences

Research Summary: Cin-Ty Lee studies petrology, geochemistry, geochronology and geodynamics to investigate the dynamic and compositional evolution of the Earth's interior and crust and how the solid Earth interacts with the oceans and atmospheres.

Jeffrey Nittrouer
Assistant Professor of Earth Science

Research Summary: Jeff Nittrouer uses field observations and geophysical modeling to examine dynamics of rivers, deltas, and coastlines, to evaluate morphodynamics and stratigraphy of modern and ancient sedimentary systems.

Speaker Abstracts: Session 1:

The tectonic origin of the Bay of Bengal and Bangladesh: a detective story

Manik Talwani, Maria Ana Desa, Mohammad Ismaiel, and Kolluru Sree Krishna, Rice University

We are able to decipher the tectonic evolution of the Bay of Bengal by examining a variety of geophysical and geological data, both on land and at sea and across international boundaries. Thus we examined seismic reflection as well as gravity data in the Bay of Bengal, seismic seaward dipping reflectors and magnetic data in Bangladesh, land gravity and Deep Seismic Sounding data in Bengal, India, as well as petrological inferences regarding the Rajmahal traps in Bengal, India, and the Sylhet traps in Assam, India. This exercise in forensic geology also shed light on three geologically perverse entities:

1. Bangladesh, which is reported to have an oceanic rather than an expected continental crust
2. The 85°E Ridge lying in the Bay of Bengal has a negative gravity anomaly rather than an expected positive gravity anomaly, and The Kerguelen plateau, a very large LIP which is reported to have a core of continental rather than an expected oceanic crust.

Constraints on the temporal and spatial evolution of faulting and magmatism from ancient and active rifts

Donna Shillington, Lamont Doherty Earth Observatory

Our understanding of rifts is hampered by the limited observations that we possess on their structure and evolution and by the extraordinary variation observed within and between rift systems in deformation style and magmatism. Active rifts provide an invaluable snap shot of processes taking place during a particular stage of rifting, but we cannot fast forward and see how they will turn out. Rifted margins record a complete, 'successful' continental breakup, but the later stages of rifting often overprint records left behind by preceding stages, making it difficult to decipher processes during the early phases of rifting. Our understanding of rifts is also hampered by their diversity. Enormous variations are observed within and between different rift systems in terms of rifting style and volume and distribution of magmatism.

Here I present new observations from different rifts and rifted margins at different stages in their evolution: 1) the weakly extended Malawi rift in the southern part of the East Africa Rift System, 2) the South Georgia Basin, the largest failed rifted basin along the eastern rifted margin of North America, 3) the Black Sea intracratonic basin; and 4) the Atlantic rifted margins. I will focus on recent seismic imaging results of basin, crustal and/or mantle structure from each of these locations and compare them with constraints from other geophysical, geological and geochemical data. In particular, I will focus on two related issues regarding rift formation and evolution: controls on the distribution of magmatism in rifts, and the temporal and spatial evolution of brittle deformation. Each of these rifts exhibits intriguing and different patterns of magmatism as indicated by velocity models from wide-angle reflection/refraction data and/or from passive seismic data, which I suggest are related to inherited or rift-generated lithospheric topography and variations in pre-existing mantle composition. Recently acquired seismic reflection data and seismicity from the Malawi rift provide new constraints the temporal and spatial evolution of faulting within and between two rift basins and the possible influence of pre-existing structures. I compare these results with faulting patterns in ancient rifts.

Reconciling mantle plume initiation of continental breakup with the inferred direction of rift propagation and the development of Seaward Dipping Reflectors (SDRs)

W. Roger Buck, Lamont Doherty Earth Observatory

One of the strongest arguments that plumes are needed for continental breakup concerns the force needed to drive rifting. The topographic uplift produce by a plume should produce an extension force of several TN/m. Many lines of evidence indicate that normal continental lithosphere would only tectonically extend (or stretch) with about an order of magnitude more extensional force this. However, intrusion of basaltic dike cutting through normal continental lithosphere can occur with only few TN/m of extensional force. Also, the addition of magmatic heat due to intrusion of such dikes can greatly weaken the lithosphere enough to allow it to extend by accelerated tectonic stretching. Numerical models show that only 2-3 kilometers of extension accommodated by lithosphere cutting dike intrusions is sufficient to produce an acceleration of extension consistent with observations. The weakening effect of magma intrusion may explain why plume related volcanism precedes most major continental breakup events.

Recent suggestions of a major role for faulting and even lithospheric scale detachments in the construction of volcanic rifted margins challenges the importance of magma in allowing rifting at moderate force levels. Though there is evidence for faulting associated with some SDRs, this paper considers the range of structures that can be produced by magmatic and volcanic loading alone. To do this an idealized mechanical model for the construction of rift-related volcanic flow structures is developed. Dikes open as plates move away from the center of a model rift and volcanic flows fill the depression produced by the load caused by dike solidification. The thin elastic plate flexure approximation allows a closed form description of the shape of both the contacts between flows and between the flows and underlying dikes. The model depends on two independent parameters: the flexure parameter, α, and the maximum isostatically supported extrusive layer thickness, w0. For reasonable values of these parameters the model reproduces the observed down-dip thickening of flows and the range of reflector dip angles. A numerical scheme using the analytic results allows simulation of the effect of temporal changes in the locus of magmatic spreading as well as changes in the amount of volcanic infill. Either jumps in the location of the center of diking or periods with no volcanism result in separate units or "packages" of model SDRs, in which the flow-dike contact dips landward, consistent with observations previously attributed only to listric normal fault offset.

One of the strongest arguments against a critical role for mantle plume in inducing continental breakup concerns the direction of rift propagation. Spreading centers, as defined by lineated magnetic anomalies, propagate from the distal to the central part of several rifted margins, including the North and South Atlantic. It is assumed that the rifting that precedes seafloor spreading also propagated from the distal to the central part of the margins. However, plume uplift and melting in the center of volcanic rifted regions would be expected to drive rifting from the central to the distal parts of a rift. We suggest that magnetic lineations should not develop when the across-axis length of thick lava flows in SDRs is large compared to the distance of plate spreading during a given magnetic anomaly interval. The lavas do record the magnetic direction of the prevailing field, but the overlapping flows do not produce magnetic stripes. Only when the flux of volcanism and distance of lava flows decreases will the lineated magnetic anomalies that define seafloor spreading develop. If the along axis extent of extreme volcanism were to 'retreat' toward the center of the rift then a region of seafloor spreading lineated magnetic anomalies would appear to 'propagate' from the distal to the central part of the rift.

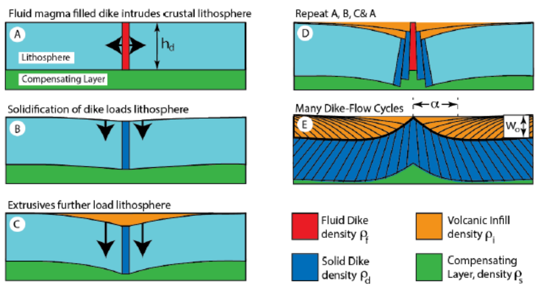

Illustration of the volcanic flexure model for the development of SDRs. Panel (A) shows a dike filled with fluid magma open between two lithospheric plates. The density increase caused by solidification of the dike in (B) loads the bends the plates. Panel (C) shows how extrusion of magma amplifies the deflections. The results of 2 dike intrusion plus extrusion events is shown schematically in (D). The size of dikes and flows is exaggerated in A through D. (E) shows the results of many small dike intrusion plus extrusion events and emphasizes that the model depends on two length scales, α and w0.

Session 2:

Sediment cycling: the long and short of it

Shanan Peters, University of Wisconsin

Sedimentary rocks are often described as declining in quantity with increasing age due to the cumulative effects of crustal deformation and erosion. One important implication of such a model is that the geological record becomes progressively less voluminous and less complete with increasing age. Here we show that the predictions of a model in which the destruction of sedimentary rock is the predominant process signal are borne out only among sediments deposited on oceanic crust and among sediments deposited above sea level in non-marine environments. Most of the surviving volume of sedimentary rock (~75%) was deposited in and adjacent to shallow seas covering continental crust in geographically expansive, long-lived sedimentary basins and does not exhibit any steady decrease in quantity with increasing age. Instead, shallow marine sediments exhibit large fluctuations in quantity that were driven by shifting global tectonic boundary conditions, such as those that occur during the breakup and coalescence of supercontinents. The accumulation of sediments on the continents has not been uniform in rate, but it does record a primary signal of net growth that has many implications for the long-term evolution of Earth's surface environment.

The role of sea level and mantle dynamic topography on passive-aggressive continental margin architecture

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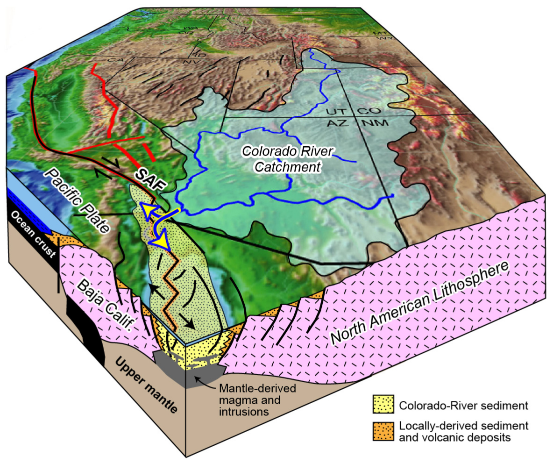
Tectonism and ice-volume driven sea level changes leave distinct imprints on the stratigraphic record of passive continental margins. During icehouse intervals such at the last 34 Myr, the waxing and waning of ice sheets dominated sea-level changes on distinct Milankovitch periods, not only short periods (e.g., dominated by the 41 kyr tilt cycle, but also reflecting the 19/21 precession, and quasi-100, and 405 kyr eccentricity cycles), but also on the long 1.2 Myr tilt cycle. Tectonics is superimposed not only on long time scales (10-100 Myr) due to thermal cooling, loading, and flexure, but also shorter time scales to due changes in mantle dynamic topography (>1-2 Myr scale) and Glacial Isostatic Adjustment (5-30 kyr scale). Drilling on the "passive" continental mid-Atlantic U.S. margin (New Jersey to Virginia) has provided unprecedented recovery of Upper Cretaceous to Holocene sequences. Ocean drilling has provided a global array of ocean coreholes allowing application of the $\delta^{18}O$ proxy and Mg/Ca for ice volume. Together, these cores allow two approaches to estimating sea-level changes: 1) scaling deep-sea $\delta^{18}O$ records using Mg/Ca to remove temperature effects; and 2) backstripping of coreholes from the onshore coastal plain and continental shelf. Comparison of the two methods addresses the long-standing debate about the roles of global average sea-level change (eustasy) and tectonism on the stratigraphic record. Our scaled-isotopic and onshore backstripped eustatic changes show similar changes on the Myr scale for the interval 34-10 Myr and testify to the importance of glacioeustasy. The dominant beat in the icehouse world of the past 34 Myr is the 1.2 Myr tilt cycle, though in regions of high sediment supply quasi 100 kyr variability is preserved. However, there are differences between the onshore and offshore and between New Jersey, Delaware, and Virginia on the 1-5 Myr scale that we attribute to the changes in mantle dynamic topography due to the influence of the subducting Farallon slab. The amplitudes of uplift and subsidence are consistent with predictions of mantle dynamic topography models and can be used to further calibrate these models. We conclude that mantle dynamic changes overprinted the stratigraphic and geomorphologic evolution of this passive-aggressive margin, primarily on the >1-2 Myr scale. Such changes in continental elevation explain the patchwork preservation of sequences and regional differences on this "passive-aggressive" margin; they also complicate estimates of the absolute position of globally averaged sea level, though glacioeustatic amplitudes of 20-120 m are constrained within errors of ±10 m.

Big Rivers, Sediment Flux, and the Crustal Evolution of Rifted Continental Margins: An Example from the Colorado River and Gulf of California

Becky Dorsey, University of Oregon

Sedimentary deposits at rifted continental margins contain a valuable record of climate and tectonic processes. In addition, in some settings sediments may exert an *active* control on the geologic evolution of rifted margins. In the Gulf of California – Salton Trough oblique-rift system, recent studies show that simply the presence or absence of sediment derived from the Colorado River exerts a primary control on crustal composition, architecture, and extension style. In the sediment-starved southern Gulf of California, the Pacific-North America plate boundary has completed the transition from continental rifts to seafloor spreading centers with basaltic ocean crust and magnetic lineations. In contrast, sediment-filled and overfilled basins in the northern Gulf and Salton Trough are characterized by thick new transitional crust formed by rapid input of sediment from the Colorado River, with no evidence of oceanic crust or seafloor spreading. River sediment is rapidly buried, heated, mingled with intrusions, and converted to metamorphic rock that forms a new generation of intermediate-composition crust. The volume of post-5.3 Ma Colorado River-derived sediment in deep rift basins is ~2.8 ± 0.6 x 10^5 km^3, similar to the volume of rock eroded from the Colorado Plateau in the past 5-6 Myr. The rate of crustal growth by sedimentation is about 80-130 km^3/my/km, comparable to growth rates in subduction-related island arcs. Thus the presence or absence of voluminous sediment appears to determine whether, and how fast, continental rifting will progress to formation of a new ocean basin floored by basaltic crust. Questions about how sedimentation affects rift efficiency and time to rupture are debated (Bialas and Buck, 2009; Martín-Barajas et al., 2013), reflecting a need for new work in this area. Sedimentation clearly plays a first-order role in crustal recycling and rift-margin architecture in this setting, and may be important at other rifted margins where a large river system is captured following tectonic collapse of a pre-rift orogenic highland.

Correlation of late Cenozoic deposits in the Salton Trough to the lower Colorado River (CR) corridor provides evidence for surprisingly unsteady, punctuated river initiation. Dispersal of sand through the lower CR valley into the marine basin first turned *on* at ~5.3 Ma, turned *off* at ~5.1 Ma, and turned *on* again at ~4.8 Ma. Punctuated sand output during river initiation could have been controlled by changes in: sediment discharge from the upper catchment, eustatic sea level, and/or rate of fault-controlled subsidence along the lower CR corridor. Lack of correlation between the stratigraphic record and the global eustatic sea-level curve suggests this behavior was controlled by variations in subsidence rate. The total mass of crust transferred from the Colorado Plateau to receiving oblique-rift basins is 5.1-11.5 x 10^{14} metric tons, representing an average flux of 156 ± 60 Mt/yr since 5.3 Ma, or 172 ± 66 Mt/yr assuming primarily post-4.8 Ma discharge. The long-term flux is similar to the modern pre-dam sediment discharge of 172 ± 64 Mt/yr measured at Yuma in the early 1900s. This comparison suggests that rates of erosion and sediment discharge have been similar, on average, over modern to geologic time scales. Positive feedback between erosion and flexural uplift in the source – Colorado Plateau – is a mechanism that may explain steady sediment-production rates during the past 5-6 million years.



Sedimentation and lithospheric rupture in the northern Gulf of California - Salton Trough region. Deep basins are filled with syn-rift sediment derived from the Colorado River to form a new generation of recycled crust along the active oblique-divergent plate boundary.

Keynote Speaker:

Sedimentary Records from Another World: Exploring Gale Crater Basin with the Curiosity Rover

Kirsten Siebach, SUNY Stony Brook

Since landing on the floor of Gale crater in August 2012, the Mars Science Laboratory *Curiosity* rover has explored over 200 m of basin-fill stratigraphy primarily consisting of fluvio-deltaic deposits and lacustrine mudstones. *Curiosity's* findings have revolutionized our understanding of Mars: the planet had more igneous diversity than predicted, long-lived liquid water in rivers and lakes at the surface, environments that would have been habitable for life, multiple episodes of diagenetic fluids, and multiple cycles of crater fill and erosion. The instrument suite onboard *Curiosity* has enabled the highest resolution ever achieved in in-situ imaging of planetary surface samples, the first age date on another planet, ongoing chemostratigraphy based on multiple scales of compositional measurements, and mineralogy of over ten rock samples. I will present the developing story of the history of the Gale crater basin, and the basin analysis work I have done to understand source-to-sink processes by separating effects from source rock diversity, sediment transport, and diagenetic influences for multiple sedimentary cycles.

Session 3:

Sequence Stratigraphy: Past, Present and Future

Vitor Abreu, Rice University

Past

Sequence stratigraphy is a methodology for stratigraphic interpretation, pioneered by Vail and colleagues in the mid 70's, which explains the complex geometries that sediments create as they fill accommodation in response to changes in rates of sedimentation, subsidence/uplift and eustasy. This methodology was developed based on observations and concepts developed as early as in the 1800's. In the 1800's, the concept of Facies triggered a revolution in the stratigraphic thinking. At that time, Geology was dominated by the ideas of the Universal Ocean Doctrine, which is the precursor of Lithostratigraphy. Facies concepts and definition of facies associations led to the understanding of facies stacking (Walther's Law) and lateral movement of shoreline caused by relative changes in sea-level (Transgressive-Regressive cycles). Later in the 1800's, Chamberlin proposed the Diastrophism concept, as catastrophic geologic events would cause eustatic changes that "should produce a stratigraphic record with natural units separated by widespread hiatuses".

Based on this strong scientific foundation, pioneer work from Caster, Sloss, Wheeler, Campbell, and Asquith established the basis for the methodology. These researchers established a new way to correlate stratigraphic units, demonstrating the time-transgressive nature of lithostratigraphic formations. In 1949, for the first time the term "sequence" was used to defined unconformity-bounded cratonic stratigraphic units named in North America. These ground-breaking ideas from Sloss were further developed by Vail and Mitchum, at first as graduate students from Sloss and later as scientist working for the Exxon Production Research Company. At that time, the Exxon approach to sequence stratigraphy included a global sea-level chart and a model of sequence-architecture as the result of one cycle of falling and rising eustatic sea level.

During the 1980's and 90's, there was a proliferation of scientific publications proposing new names for surfaces and systems tracts, as well different approaches and models for interpretation. Donovan called it the "Tower of Babel" in Stratigraphy, where stratigraphic taxonomy is emphasized (see work from Catuneanu for summary of most of the terminology). The consequence was the development of a rich and cumbersome nomenclature. At the heart of the confusion, is the close association between sea level changes, the formation of surfaces, and specific stratal stacking that define systems tracts, common in the literature since the original works of Vail and Posamentier. In some cases, terms like highstand and lowstand have been used to identify systems tracts based on specific stratal stacking. In other cases, stratal stacking has been inferred to reflect a relationship to sea level. These terms conflict with others that are related to shoreline position and movement, or processes that can be directly observed from the geologic record, such as "transgression", "regression", "progradation", and "retrogradation". Thus, a clear way to communicate is to keep sea level position and systems tracts terms separate, not as interchangeable terms. For example, for clarity one should use "high sea level" when referring to absolute position of sea level at a given time, rather than "highstand of sea level".

Present

Is recommended to emphasize the five key observations that can be made from any geologic data: lithofacies, lithofacies association, vertical stacking, stratal geometries, and stratal terminations. From these observations, the interplay of changes of accommodation and sedimentation rates can be detected. In transitional marine systems, the key facies to observe is the shoreline. Currently, the position and trajectory of the shoreline are used in all definitions for surfaces and systems tracts in sequence stratigraphy.

Rather than sea level changes alone, the resulting stacking of parasequences is a consequence of the interplay of accommodation and sediment supply, which are controlled by eustasy, tectonics, climate and initial depositional profile. The accommodation succession method emphasizes this interplay and uses it to help define a chronostratigraphic framework. The recorded in a sequence progresses: from negative accommodation that is marked by a significant unconformity on the shelf; after which accommodation slowly begins to increase, at an increasing rate, resulting in progression from progradational to aggradational stack of strata (defining the Lowstand Systems Tract). This is succeeded by a maximum rate of accommodation creation expressed by a retrogradational stacking pattern (defining the Transgressive Systems Tract), and finally slowing rate of accommodation creation, turning to negative accommodation marked by an aggradational to progradational (to possibly degradational) stack of strata (defining the Highstand Systems Tract). Eventually, the increasingly negative accommodation generates another shelfal unconformity and significant basinward shift in coastal onlap forming another sequence boundary, and the succession starts over again.

Future

A significant source of uncertainty in prediction resides in the stratigraphic interpretation. Since current stratigraphic interpretation methods are mostly empirical, a step change in prediction can be achieved by quantitatively constraining interpretations and geologic models using the physics of fluid flow (fluid mechanics) and sediment transport. ExxonMobil recently proposed the term Process Stratigraphy to mark this new development. Process Stratigraphy involves the integration of process sedimentology and sequence stratigraphy in creating a new approach to interpret geologic data. Sequence Stratigraphy combine the analyses of facies stacking, regional surfaces tied to base level changes and extra-basinal controls to create predictive models of lithology distribution and reservoir architecture. Currently, sequence stratigraphy utilizes a somewhat qualitative, analog-based approach to define the facies distribution in a region of interest. This analyses works well at a more regional scale, but fails in predicting sub-seismic reservoir architecture and lithology distribution. Process sedimentology includes the study and understanding of fluid dynamics, morphodynamics and sedimentary transport mechanisms including deposition and erosion.

In Process Stratigraphy, analog-based stratigraphic concepts are combined with physics-based analytical and numerical modeling to more realistically predict lithology distribution and reservoir architecture. Through this process, it is possible to populate property distributions in reservoir models to more accurately characterize reservoir uncertainty and to enable improved business decision-making, representing a paradigm shift from analog- to physics-based stratigraphic predictions. The work flow in Process Stratigraphy is to (1) interpret sedimentary flow parameters (e.g., flow height, density, velocity, local gradient, Froude number) from the available stratigraphic/ sedimentologic information (e.g., sedimentary structures, stratal geometries and stacking, geomorphology from seismic patterns – or "from rock to sedimentary flow"), and (2) use the sedimentary flow regimes (hydraulics + sedimentary transport) interpreted from the geologic record to predict sedimentary facies away from well control; and to create facies volumes (e.g., reservoir property volumes) from resultant flow regimes through inversion using local calibration (seismic, wells, cores) to condition reservoir models (or, "from sedimentary flow to rock"), aiming at generating improved reservoir simulations with multiple scenarios.

Extracting sea level change from carbonate stratigraphy with hidden Markov models

Blake Dyer, Lamont Doherty Earth Observatory

Carbonate facies traditionally are used to reconstruct paleo water depth and define parasequence structure in ancient sedimentary basins. We are interested in the uncertainty associated with the assumptions used to make these inferences. Here, we present a quantitative method that uses modern maps of bathymetry and the geographic distribution of facies in the Bahamas to extract relative sea level change from facies transitions in vertically stacked carbonate strata. This probabilistic approach incorporates the observed complexity in the water depth distribution of immediately adjacent carbonate environments, and allows for the objective interpretation of stratigraphic data with quantified uncertainties. Moreover, this analytical tool can be used to improve correlation of stratigraphic sections based on the aggregate transitions between facies, and provides insight into the absolute magnitude and variability of water depth change associated with a sequence of carbonate facies transitions.

The dynamic topography of passive margins

Jerry Mitrovica, Harvard University
Jacqueline Austermann, Alessandro M. Forte, Robert Moucha, David B. Rowley, Harvard University

The terms "continental drift" and "seafloor spreading" emphasize the notion of plate tectonics as a description of horizontal motions within rigid plate interiors. However, the forces that drive plate tectonics, namely viscous stresses coupled to thermochemical convective flow in the mantle, also lead to vertical deflections of the Earth's crust that have come to be known as dynamic topography. The earliest viscous flow modeling of dynamic topography focused on broad, regional scale deflections at active plate margins; these studies provided a physical mechanism to explain many episodes of large scale sea-level transgression and regression evident in the geological record as a manifestation of epeirogeny (i.e., vertical crustal motions) rather than eustasy. Over the past decade, a new generation of numerical models based on improved constraints on mantle buoyancy and viscosity has allowed global predictions of basin scale dynamic topography fluctuations that extend across the past 100 Myr. These calculations have demonstrated that passive margins are not immune to large amplitude topographic deflections and that long time scale trends in eustatic sea level curves inferred from sequence stratigraphic analyses at such margins are not robust. In this talk I will review the history of dynamic topography calculations, discuss the implications of recent work for interpretations of passive margin architecture, and end by highlighting applications of the research to studies of ice age sea level change and polar ice sheet stability.

Session 4:

Is sequence stratigraphy dead?

Nick Christie-Blick, Lamont Doherty Earth Observatory

Seismic and sequence stratigraphy revolutionized the field of stratigraphy in the late 1970s and 80s by providing an interpretive framework for integrating diverse geological and geophysical data with reference to three-dimensional stratal and reflection geometry. The presentation will focus on some unresolved questions, with implications for petroleum exploration. 1) How exactly do stratigraphic discontinuities arise, both spatially and as a function of time? Do incised valleys and submarine canyons propagate landward by headward erosion or seaward, or both? What is implied about the distribution of lowstand reservoirs? 2) How do discontinuities relate to the ups and downs of sea level when eustasy is involved (the phase issue)? Given that both leads and lags are observed or suspected in different settings, global synchrony isn't expected. Global syntheses (e.g., Haq et al., 1987) are therefore less useful than may once have been hoped in the interpretation of frontier basins. 3) How is sedimentation modulated by a plethora of non-eustatic phenomena: e.g., the propagation of faults and associated folds, the 3D tilting of fault blocks, salt tectonics, the efficiency with which sediments are advected across shelves, mass wasting, deep-ocean currents, lithospheric flexure, and dynamic topography? The net result of these phenomena is to localize stratigraphy, and to produce facies arrangements in three dimensions that depart from the expectations of the two-dimensional 'slug model'. 4) To what extent and and at what spatial scale are discontinuities diachronous (i.e., overlain by sediments that are in places older than sediments beneath the same surface elsewhere)? This question is relevant to the tracing and dating of sequence boundaries in three dimensions. A project recently started in the Gulf of Suez in co-operation with colleagues at the University of Cairo relates to several of these overarching issues, and specifically to how early Miocene sea-level change, the tilting of extensional fault blocks, and the development of fault-propagation folds may each have played a role in the development of sedimentary cyclicity and stratigraphic discontinuities. While much of what is published in sequence stratigraphy today is conceptually conventional, there is still much to learn about how exactly sedimentation responds to an array of phenomena.

"E pur si muove"— the active role of mud in building passive margins, from turbidites to clinothems

Kevin Bohacs, ExxonMobil

Mud and mudstone comprise about 80% of the stratal record, contain the best archives of Earth history, play a key role in global cycles of biologically relevant elements, and are essential for many resources, from groundwater to hydrocarbons and rare earths. A fundamental question for sequence stratigraphy in general, and for mudstones in particular, is whether the stratigraphic record can be understood as "sand/grainstone" and "not sand/grainstone" with mud serving only as passive 'filler', or do various grain-size categories each have their own inherent geometry and the stratal record of continental margins is the resultant of the vigorous interaction among the grain sizes.

Observations accumulated over the last 35 years, accelerated by the 'shale-gas revolution', indicate that mud is a quite active component at many scales, from being essential to many sediment-transport mechanisms to forming distinctive types of parasequences and complex stratal geometries at depositional-sequence to sequence-set scales.

At the bed to bedset scale, a wide variety of sedimentary structures occur in mudstones that indicate a comparably wide range of transport mechanisms, in many of which the presence of mud alters the fluid and transport properties of the flow. A substantial portion of mud appears to travel in bedload as a variety of composite grains (pellets, floccules, organo-mineralic aggregates, and intraclasts) that are sand-sized or larger. Our observations indicate that waves and wave-induced and thermo-haline currents are effective transport agents of mud even in distal-shelf and upper-slope water depths. Mud is also essential in the transport of coarser grains, from turbidity currents to debris flows.

At the parasequence scale, most marine shelfal mudstone strata appear to have accumulated in one of three end-member types that can be differentiated quantitatively and related to depositional regimes dominated by storm waves, river floods, or tidal currents through characteristic modes of sediment transport and accumulation, as well as variations in benthic-energy and oxygen levels. Close examination of the lateral distribution of mudstone-dominated strata reveals that progradation of parasequences on the continental shelf is not always by simple avalanching or successive accretion of foresets, analogous to progradation of a ripple— we observe bedset-scale bypass, onlap, downlap, and toplap within parasequences that are defined by regionally extensive flooding surfaces. Parasequence boundaries in mudstones can be subtly expressed in terms of physical attributes, but tend to have distinctive biogenic and authigenic character. For example, these stratal surfaces are commonly associated with distinctive authigenic products that form so early (< 1 m burial) that they record information about the depositional environment when little or no sediment was accumulating on the sea floor. The extent of these microbially induced cements or nodules is a function of the duration of the pause in sediment accumulation and their stacking patterns help identify key sequence-stratigraphic surfaces. These attributes give rise to characteristic well-log motifs that aid correlation and mapping, the patterns of which can help differentiate allogenic from autogenic controls.

At the depositional-sequence scale, most marine biogenic-rich (carbon, silica, carbonate) mudstones tend to occur in one of three physiographic settings (constructional shelf margin, platform/ramp, continental slope—basin), each of which has a commonly recurring pattern of biogenic enrichment distinctive from the other settings. At the depositional-sequence-set scale, all major shale-gas plays can be grouped into four main families, based on repeated patterns of stratal stacking of depositional-sequence-scale biogenic-rich physiographic settings.

Although these observations imply that most mudstones accumulate discontinuously, they still preserve detailed records of paleoenvironmental conditions and depositional history in their physical, biogenic, and chemical attributes, especially in microbially mediated authigenic products. Despite their potentially subtle expression, one can recognize all scales of sequence-stratigraphic units and surfaces in mudstones, using the standard geometric criteria augmented by detailed examination of sedimentary structures, body and trace fossil distribution, organic and inorganic geochemistry, early authigenic components, and their stacking patterns. The sequence-stratigraphic approach is particularly useful for organizing all these discontinuities and varying rock properties into a hierarchy of nested scales. The resulting sequence-stratigraphic framework is essential for integrating the wide range of physical, biogenic, and chemical attributes of mudstones into a comprehensive understanding of continental-margin systems.

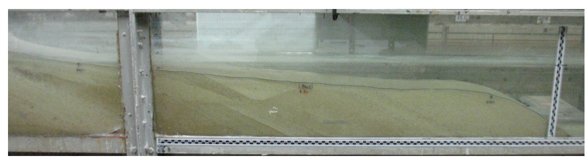
What is a sandy continental shelf?

Chris Paola, University of Minnesota

Of all the sedimentary environments in the source-to-sink chain, sandy continental shelves are the most enigmatic: They are the only environment for which there is no obvious first-order description of the process by which they are built and maintained. In large part this is because, unlike any other major global transport environment, the large-scale topography and sediment properties of modern sandy continental shelves reflect current transport conditions only to a limited degree. Rather, they seem to be largely drowned low-stand coastal plains being superficially reworked by modern processes. The main modern process thought to create cross-shelf transport of sand is some combination of wind waves, cross-shelf currents, and wave-supported turbidity currents. It is not clear if these mechanisms, which are episodic and relatively weak, can really transport large amounts of sand across shelves and create margin-scale topography. This leads to the possibility that sandy shelves do not exist as a steady-state transport system, or at least, not over very long distances. However, the stratigraphic record shows examples of sandy, wave-dominated deposits that extend over hundreds of kilometers. If these cannot be explained as sandy shelf transport systems, that would require relative sea level (RSL) fluctuations, or some other mechanism, to explain them. With these ideas in mind, we will consider the following questions:

1. What fundamental processes are available to transport sand on continental shelves, and what about them makes shelf construction such a challenge?
2. What do the large-scale topography and sediment properties of modern sandy shelves suggest about processes of steady-state shelf construction and maintenance?
3. What would a (quasi) steady-state sandy shelf look like? Could such a shelf deliver sand efficiently to the continental slope?
4. Are ancient sandy shelves compatible with the idea of a coherent sandy shelf transport system, or do they require RSL fluctuations? If so, what evidence should we see of these fluctuations?

We will also review very early findings from a new effort we have underway at St Anthony Falls Laboratory to produce steady-state prograding 'sandy shelf' transport systems. An image of a steady-state subaqueous sandy 'shelf' maintained by a combination of waves and a downwelling current is shown below.



Notes:

Poster Abstracts:

Margin development: mechanics and formative processes

Investigation of Fault Systems Controlling Breakup and Deposition in the Deep Galicia Margin

Ara Alexanian, Rice University

The Galicia Margin has been studied extensively with seismic and drilling data. In particular, three research groups: the Institut Français du Pétrole, Maurice Ewing 9705, and Marcus G. Langseth 1307, have collected seismic data along East-West transects through this margin. Only a few 2D segments have been processed in depth. Ray-based reflection tomography methods have been used to create a migration velocity model to focus the seismic data and spatially locate reflection events. This method, combined with previously published refraction velocity models, improves the imaging of features in sediment, crust, and the mantle.

This poster presents a pre-stack depth migration of part of the greater 3D survey from MGL 1307. This reprocessed portion of the survey is called the Western Extension 1 and is a 160 kilometer long and roughly 400 meter wide swath of data. This swath was processed in 3D. An interval velocity model was obtained from migration velocity analysis in the sediments. These velocities and a refraction velocity model in the crust have been combined to create a final depth image of the data. Unpublished seismic data to the west of Western Extension 1 was also processed, but only in 2D pre-stack time migration due to lack of geometric positioning control. This new data may image the boundary between exhumed mantle of the Galicia domain and regular oceanic crust.

Sediment production and dispersal: catchment scale

Stream Width Dynamics in a Small Headwater Catchment

Eric Barefoot, Rice University

Changing streamflow conditions cause small, ephemeral and intermittent stream networks to expand and contract, while simultaneously driving widening and narrowing of streams. The resulting dynamic surface area of ephemeral streams impacts critical hydrological and biogeochemical processes, including air-water gas exchange, solute transport, and sediment transport. Despite the importance of these dynamics, to our knowledge there exists no complete study of how stream widths vary throughout an entire catchment in response to changing streamflow conditions. Here we present the first characterization of how variable hydrologic conditions impact the distribution of stream widths in a 48 ha headwater catchment in the Stony Creek Research Watershed, NC, USA. We surveyed stream widths longitudinally every 5 m on 12 occasions over a range of stream discharge from 7 L/s to 128 L/s at the catchment outlet. We hypothesize that the shape and location of the stream width distribution are driven by the action of two interrelated mechanisms, network extension and at-a-station widening, both of which increase with discharge. We observe that during very low flow conditions, network extension more significantly influences distribution location, and during high flow conditions stream widening is the dominant driver. During moderate flows, we observe an approximately 1 cm rightward shift in the distribution peak with every additional 10 L/s of increased discharge, which we attribute to a greater impact of at-a-station widening on distribution location. Aside from this small shift, the qualitative location and shape of the stream width distribution are largely invariant with changing streamflow. We suggest that the basic characteristics of stream width distributions constitute an equilibrium between the two described mechanisms across variable hydrologic conditions.

Paleoclimate and deep marine sedimentation

Paleogene carbonate dissolution events in the North Pacific Ocean

Joyeeta Bhattacharya, Rice University

A series of carbon isotope excursions (CIEs) mark variations in the global carbon cycle and significant changes in climate through the early Paleogene. The Paleocene Eocene Thermal Maximum (PETM) ca. 56 Ma is the most pronounced and well documented of these events, having been described in many sections across the globe. The large CIE across the PETM is marked by a clay rich layer in many deep-sea sections, resulting from widespread carbonate dissolution on the seafloor, which is in turn related to shoaling of the carbonate compensation depth and lysocline. Several studies have suggested that other CIEs have a similar response, but this information is sparse. There is also debate as to how carbonate saturation in the ocean varied over the long_Ñêterm. Importantly, we observe that though the Eocene climate shows an overall cooling trend, yet it is punctuated by several short term hyperthermals which have been studied sparsely. Here we document changes in carbonate preservation in Eocene sediments at ODP Site 1209A (Shatsky Rise, North Pacific Ocean). This site presently lies in a middle bathyal (2387m) water depth but has undergone negligible subsidence since the Cretaceous. We generate a record of carbonate content, and couple this with magnetic susceptibility (MS) and gamma ray attenuation (GRA) records to locate possible intervals of reduced carbonate accumulation. We then examine the planktonic foraminiferal assemblages for their fragmentation which helps us to better constrain the dynamics of lysoclinal depth at this location of North Pacific Ocean in the Eocene. Throughout the Eocene there are long-term variations in carbonate preservation, as well as some pronounced events of carbonate dissolution. Such documentation allows us to better constrain models for early Paleogene carbon cycling.

Fault mechanics

Simulating megathrust earthquakes using the discrete element method

David Blank, Rice University

Large earthquakes that occur on convergent plate margin interfaces have the potential to cause widespread damage and loss of life. Recent observations reveal a wide range of different slip behaviors take place along these megathrust faults, which demonstrate both their complexity, and our limited understanding of fault processes and their controls. In this study, we use the discrete element method to simulate earthquake slip along a megathrust fault with heterogeneous properties to gain unique insights into observationally elusive behaviors such as rupture initiation, propagation, along fault interaction, and stress transfer. Strain is induced between a simulated forearc and subducting plate, causing localization along the cohesionless interface between the two units. Variable friction is introduced along the length of the fault, reflecting the heterogeneity that exists along natural subduction zones. A wide range of slip behaviors are observed, ranging from creep to stick slip. We are able to characterize slip events by duration, stress drop, rupture area, and slip magnitude, and to correlate the relationships among these quantities. These characterizations allow us to develop a catalogue of rupture events both spatially and temporally, for comparison with slip processes on natural faults. Our simulations provide a unique window into behaviors that are not yet fully understood from purely observational studies.

Margin development: mechanics and formative processes

Subsurface structure, stratigraphy and petroleum systems of the Port Isabel passive margin foldbelt, northwest Gulf of Mexico

Muhammad Nawaz Bugti, University of Houston

The Port Isabel passive margin foldbelt (PIFB) of Oligocene age in the northern Gulf of Mexico (GOM) is lesser known from hydrocarbon exploration than its younger, Miocene age, deeper-water neighbor, the Perdido passive margin foldbelt (PFB), because the PIFB has had no commercial hydrocarbon production, while the PFB contains three giant fields with a peak production of 100 kboe/day. In order to better understand this major gap in the hydrocarbon productive zone of the US GOM, I have mapped a grid of 25,000 line km of 2D seismic lines with penetration from 14 to 25 seconds TWT that extends across the from the Texas coastline from the Corsair normal fault zone on the updip end of the PIFB to downdip compressive structures of the PFB in water depths of 2450 meters. My mapping results include: 1) the sharp “corner” in the shape of the NW GOM margin has influenced the evacuation of salt by the process of radial gliding from a amphitheater-shaped area of the outer shelf and slope; 2) this evacuated salt has accumulated as a salt canopy towards the downdip and it also accumulated as cluster of diapirs along the bisector line of the corner; and 3) structurally, the transition is abrupt between the Corsair normal fault zone and the convergent features of the downdip thrust belt. Previous workers have generated 2D petroleum systems models based on northwest to southeast-trending 2D lines that pass through the few wells drilling in the PIFB. None of these wells have penetrated source rock intervals so previous models for the PIFB assume two, underlying source rock intervals: the Tithonian and Turonian. Previous model results show that expulsion from both sources started at 64 Ma and peaked during 55-20 Ma and that assumed reservoirs of Oligocene and Miocene age were charged with vertical migration. As part of my structural mapping I have reexamined open and blocked migration pathways from both sources to well PI 525 which flowed some oil and to well PI 654 which was dry.

Processes-to-stratigraphy framework: good, bad and ugly

The coastline evolution of an abandoned deltaic lobe and the fate of its relict distributary channel: a case study from the Huanghe (Yellow River) delta, China

Brandee Carlson, Rice University

A high sediment load and frequent flooding events drive rapid modification to the coastline of the Huanghe (Yellow River) delta, China. Distributary channel avulsions occur every 7-10 years, and each event results in the shifting of fluvial sediment supply over hundreds of square kilometers across the deltaic coastline. Upon lobe abandonment, the shoreline erodes at rates that reach kilometers per year, and low-lying regions of the delta are routinely inundated by tides. These processes rework the sediment deposit, and while much of this material is dispersed basinward, some is transported landward via tidal channels that occupy the abandoned distributary channel. Over a yearly timescale, the relict channel fills with sediment, the delta lobe converts to a tidal flat, and the rate of coastline retreat decreases. The focus of this study is to evaluate the morphodynamics of these observations by validating a physical model for its time evolution using data collected from field studies, as well as time-series satellite imagery. Sedimentological analysis of seventeen 6-m cores extracted from a lobe abandoned in 1996 is used to document the abrupt transition from the relict channel bed (comprised of sand) to the ongoing tidal flat sedimentation (comprised of mud). The thickness of the tidally-influenced mud deposit varies across the old channel, and is based on the inherited bed morphology and proximity to the active tidal channel. For example, sedimentation rates, as estimated using a numerical model, are higher near the tidal channel and decrease with lateral distance from this source, and are also a function of the local elevation of the tide flat surface relative to the tidal amplitude. Overall, predicted sedimentation rates on the tide flat reaching several centimeters per year are in agreement with field observations. Our results indicate that after 20 years of morphological adjustment following abandonment, this particular Yellow River delta lobe remains highly dynamic as result of active reworking of the shoreline.

Margin development: mechanics and formative processes

Mapping the distribution and thickness of OAE1 and OAE2 source rock intervals on Cretaceous passive plate margins of the Atlantic, Gulf of Mexico and Caribbean

Presly Carr, University of Houston

Oceanic anoxic events are short-lived periods of global oceanic oxygen deficiency thought to have been triggered by massive volcanic eruptions and recorded stratigraphically by the conformable deposition on the world's passive margins of continuous intervals of dark gray to black, pyrite-rich shale with total organic carbon contents ranging from 1 to 20%. Because these intervals are widespread and reach such high TOCs, they are considered some of the best and most prolific source rock intervals for hydrocarbon accumulations especially when inter-fingered with sandy, turbiditic reservoirs in deepwater, passive margin-type settings. I have compiled the extent and thickness using published geologic literature of two important Cretaceous "OAE's" from passive margins of the Atlantic, Gulf of Mexico, and Caribbean: OAE 1 of Aptian-Albian age and OAE2 of Cenomanian-Turonian age. Correlations between adjacent areas are shown and areas of missing OAE1 and 2 are highlighted.

Processes-to-stratigraphy framework: good, bad and ugly

The signature of bankfull hydraulic conditions reflected by properties of the channel bank: a case study from the Selenga River delta, Lake Baikal, Russia

Tian Dong, Rice University

Bankfull condition in alluvial rivers is defined as the discharge associated with flow spilling from the channel and onto its floodplain. For most rivers, it is equal to 1.5-2 year reoccurring flood discharge. A central question in fluvial geomorphology is what controls bankfull channel geometry. One closure of the bankfull geometry relations is the bankfull shields number, which predicts bankfull channel depth and bed slope under the assumption of steady, uniform flow. A recent model developed to describe variable Shields number proposed that the bankfull shear velocity value is nearly independent of bed material grain size, and instead is dependent on adjacent floodplain properties, such as bank sediment grain size. This study here aims to explore the relationship between bankfull depth and the sedimentary properties of the bank sediment. An analytical bank failure model is developed to test this hypothesis. The failure model estimates strength of the channel bank by considering parameters such as bankfull depth, vegetation density, clay content and sediment grain size of the bank. These parameters are constrained by field data collected during two expeditions (2014, 2016) to the Selenga River Delta, Lake Baikal, Russia. This is an ideal system to test the failure model because the Selenga River possesses significant changes in bank material and flow hydraulic conditions across the distributary channel network. The data include: 1) channel geometry measurements, 2) bank and floodplain sediment samples, 3) flow velocity measurements, and 4) bank vegetation type, to estimate sediment trapping efficiency. Preliminary findings showed that shear strength of channel bank is directly related to bankfull channel depth and cohesion. This result implies that channel bank strength dictates at-a-site channel geometry during formative discharge event. This analysis is the first to establish a connection between bankfull geometry, bank material properties, and Shields number, and therefore provides insights regarding fluvial-deltaic morphodynamics.

Igneous Petrology: late-stage magmatic processes

On the timing of K-feldspar crystallization and implications for the origin of megacrysts

Michael Farner, Rice University

K-feldspar megacrysts in granitic rocks have prompted an ongoing debate on the timing of K-feldspar crystallization and growth of exceptionally large crystals. Field-based observations of megacrysts have suggested early saturation while experimental work indicates K-feldspar crystallizes late. Here we resolve this apparent paradox by assessing the timing of K-feldspar crystallization in granitic rocks from the Bernasconi Hills pluton in the Peninsular Ranges of southern California. Textural observations show that rocks with K-feldspar contain relatively inclusion-free subhedral to euhedral crystals and have in excess of 1.5 wt % K_2O, whereas those without K-feldspar are comprised of quartz and plagioclase with interstitial biotite and contain < 1.5 wt % K_2O. Interestingly, the appearance of K-feldspar coincides with an increase in slope on a K_2O versus SiO_2 variation diagram that defines a continuous trend from K-rich, K-feldspar-bearing rocks to K-poor, K-feldspar-absent rocks. This suggests that K-feldspar-bearing rocks represent K-rich liquids segregated from plagioclase-quartz cumulates. We estimate that alkali feldspar crystallization began late, with 10-16 % melt, relative to a gabbroic parental composition, but occurred early in the crystallization of the segregated liquid. Comparison of our study with work on megacrystic granites suggests that megacrysts originate in a similar fashion and also crystallize late, compared to parental compositions. Near constant Zr-in-titanite temperatures reported for titanite inclusions within megacrysts indicate that crystals grow under near-isothermal conditions. Previous thermodynamic modeling on tonalitic compositions shows that near isothermal conditions are reached when the melt is H_2O-saturated, resulting in delayed release of latent heat. Collectively, this suggests that megacrysts grow under H_2O saturated conditions, late in the life of a magma body.

Petrology

Evolution of South African cratonic peridotites based on micro-XRF mapping and reconstruction of bulk rock compositions

Sarah Paschal Gerenday, Rice University

Peridotite xenoliths erupted with kimberlites are can provide useful information about the conditions of formation of the Kaapvaal craton. This study examines eight primarily harzburgitic peridotites from the Bultfontein kimberlite pipe which are approximately 2.7 billion years old. The textures indicate that most of the peridotites underwent shearing following their formation. Based on thermobarometers using pyroxene and garnet compositions, as well as bulk rock magnesium, iron, and silicon oxides, we determined that the peridotites cooled from an initial temperatures around 1700^{o}C to near 900^{o}C before eruption. This dramatic change in temperature combined with low aluminum diffusion rates in orthopyroxene would be expected to cause significant aluminum zonation in orthopyroxene grains, but this is not observed even on the millimeter scale. It is therefore proposed that the shearing caused grains to recrystallize until the grains were two orders of magnitude smaller. Orthopyroxene grains of this size could be expected to homogenize on the billion year timescale using the diffusion parameters of Chin and Lee 2012. The after shearing stopped, the smaller, homogenized grains could anneal to form the larger, unzoned orthopyroxene grains present in the samples.

Sediment production and dispersal: catchment scale

Transgressive Lag of Flat Rip-Up Clasts - Substratum for Initial Growth of Upper Cambrian Large Microbial Buildups

Heath Hopson, Rice University

The discovery of large oil and gas fields in microbial carbonates has motivated studies of key outcrops, as potential reservoir analogs, to understand better the initial establishment, overall evolution, and demise of the buildups. In the past three years, a Rice/Trinity Industry Microbial Research Consortium has analyzed in great detail world class Upper Cambrian microbial reefal outcrops (Point Peak Member of the Wilberns Formation) in Central Texas. A unique carbonate unit, covering as much as 25 km2, beautifully crops out in cliffs and pavements along the Llano and James Rivers and Mill Creek.

This unit consists of multiple 8-15 m-thick and 10-40 m-wide microbial buildups, linked laterally by a series of inter-reef grainstone beds alternating with thinner silty mostly siliciclastic levels. This unit sharply contrasts with the underlying section made of alternating mixed, mostly recessive, thin carbonate-siliciclastic silty and sandy beds, interpreted to record very shallow subtidal and even intertidal marine environments during a general sea level regression. The sharp transition between both units stands out on the cliffs as the most developed overhangs and corresponds to the flat bases of the microbial buildups and the contemporaneous initial accumulation of a 1-2 m thick inter reef resistant grainstone bed. This bed usually dips towards each buildup on both sides, thins, and in many instances disappears towards their center.

Along the James River, cores were drilled through a very small "embryonic" buildups and the upper part of the underlying bed. Analyses of the cores clearly show that the microbial growth was initiated on a low relief small pile of flat rip-up clasts of similar lithologies as the bed itself, covering an erosional unconformity.

Along Mill Creek, a fully developed 8 m-thick buildups, rotated 90 degrees and lying on its flank, offers its flat base for observation and sampling. The buildup detached itself from the nearby cliff where a small depression in the first inter reef bed, often with flat rip-up clasts at its very base, still matches the shape of the rotated buildup edge. The flat center of the buildup base consists of a10 cm-thick sheet of flat rip-up clasts, interpreted as a transgressive lag, on top of which the microbial growth was initiated. A core drilled through the very bottom of the buildup confirms this interpretation; at its very bottom a few small rip-up clasts are mixed with stromatolitic columns.

Current contributions to sequence stratigraphy

Late Quaternary Transgressive Coralgal Reef growth along the South Texas Continental shelf edge

Pankaj Khanna, Rice University

Transgressive regressive cycles in the last 800 ky have deposited six distinct depositional sequences in the Gulf of Mexico. In the latest three sequences, transgressive carbonate banks along the South Texas Shelf edge, including the transgressive coralgal reefs accumulating since the last glacial maxima (LGM), apparently grew on top of lowstand siliciclastic coastal deposits. The transgressions become a window of opportunity for reef growth along the shelf edge, on top of former lowstand coastal system, when the siliciclastics accumulate further towards the hinterland along the newly formed coast. Earlier seismic studies indicate that the establishment of these coralgal reefs occurred on tops of paleo highs, interpreted as lowstand coastal siliclastic deposits. Radiocarbon dates of coral material collected on these banks bracket well their post-LGM initiation and final drowning somewhat after 12,300 Cal BP. These reefs thrived and grew vertically up to 40-50 m in less than ~ 8000 years tracking sea-level rise during the upper most Pleistocene. This most recent reefal accumulation serves as a unique analogues to study similar transgressive carbonates deposited along continental margins in low latitudes.

To better understand the establishment, growth, and demise of the upper most coralgal reefs along the South Texas shelf edge, a research cruise on the R/V Falkor was conducted during which 10 different carbonate banks were mapped with high resolution multibeam echo sounder and 3.5 kHz chirp shallow seismic systems. This survey clearly establishes that the carbonate banks are true coralgal reef morphologies, as indicated by spurs and grooves along their margins, clear atoll development, and a series of distinct terrace levels. The growth history of these carbonate reefs is dominated by common terraces (flat areas) bounded by steep slopes, possible origin of which might be the stress on the system due to episodic rapid sea level rise events during last deglaciation, representing typical backstepping morphologies. The depth to the crests of these 10 banks lie within a very narrow range of 3-4 meters (58.5-62 mbsl) indicating a contemporaneous demise. Siliciclastic sediment influx, temperature, salinity are found not to be the main drivers of their demise rather the coralgal reef shrunk themselves to their end. A couple of thousand years following their drowning, their partial burial was initiated by the accumulation of the Texas Mud Blanket.

Margin development: mechanics and formative processes

3D Seismic observations of the Peridotite Ridge in the Deep Galicia Margin

Gary Linkevich, Rice University

The west coast of the Iberian Peninsula is a classic magma-poor rifted margin, where slow crustal hyperextension allowed rising mantle to cool/harden instead of melting. Within this transitional zone of exhumed mantle lies a long, margin-parallel peridotite ridge (PR). Over the past few decades, the PR has been dredged, cored, and imaged with 2D seismic, but the data offered limited resolution of its internal structure. While there are competing hypotheses regarding the PR's origin, there is no consensus, and almost no discussion of its post-emplacement evolution. Finally, the biggest uncertainties may lie not in the PR itself, but in the jumbled-up material surrounding it.

The recently-acquired Galicia3D dataset reveals several internal structures within the PR, including a prominent landward-dipping normal fault cleaving off its eastern flank, and a western/central boundary separating an upper reflective / chaotic layer from a more homogeneous core. The eastern fault dives to at least 10 s TWT, and is hypothesized to restore in some way to the S detachment fault in the east. It also appears to continue into the post-rift sediments overlying the PR, offsetting material up to 100 myr younger than the PR itself. The reflective upper layer of the PR probably represents the extent of its serpentinization, but could theoretically also include prerift, synrift, or volcanic material.

On the surface of the PR, the western flank contains several arcuate, scoop-like scarps that appear to correspond to substantial mass wasting events. A serpentinite slump on the eastern flank has been mapped in 3D, and RMS amplitude extraction of its surface reveals sub-linear features that correspond to thrust faults in the slump's contractional domain (backing up a study that found similar results in 2016). Valuable progress has been made in understanding the PR, but many questions remain unsolved, and are under ongoing investigation.

Structural and Geomechanical Modeling

Microstructural Evolution of Stress and Porosity during the formation of a Brittle Shear Fracture

Tami LongJohn, Rice University

Brittle fracturing in rocks is a progressive process involving changes in stress, porosity and strain. An understanding of how these properties change is essential to ensure safety of embankments, slopes and dams, and during drilling and excavations. However, it is often difficult and expensive to make observations of microstructural changes from laboratory and field measurements only. This study uses the discrete element method (DEM) to show that fractures correspond to zones of low particle abundance, high porosity, generally low stresses, and highly localized dilation and distortional strain. We probe the internal conditions of rocks during brittle deformation by conducting numerical biaxial experiments at different confining pressures. When biaxial compression begins at 5 MPa confining pressure, the bulk porosity is decreasing and differential stress is increasing. Internally, however, the stresses within the granular body have a heterogeneous spatial distribution with an abundance of high and low stress chains. At the yield stress of 43.4 MPa and axial strain of 2.38 %, defined as the point where the slope of the stress-strain curve starts to decrease, multiple fractures with a conjugate orientation start to open up. These microcracks have a length of 0.01 mm and are sub-parallel to the orientation of the maximum principal stress. There are also fewer high magnitude stress chains transmitting stress through the sample. At the peak stress of 48.2 MPa and axial strain of 3.11 %, the degree of localization of porosity, volumetric strain and distortional strain is more prominent. The internal stresses become more heterogeneous with an increase in high magnitude stress chains adjacent to the position of the developing through-going fracture. Finally, at 6.63 % axial strain before stable sliding begins, the through-going fracture is fully developed. This fracture may not follow some of the individual dilational bands. We are now using the model to further examine the microstructural evolution at different confining pressures.

Sediment production and dispersal: catchment scale

Riverine conditions necessary for the formation of hyperpycnal-plumes entering basin seawater

Hongbo Ma, Rice University

The riverine hyperpycnal plume is characterized by sediment-laden flow that is able to plunge into the still-standing receiving basin water body, due to the density contrast between the fluids. At a river mouth, the hyperpycnal plume provides a crucial linkage between the fluvially-derived sediment from the adjacent continent and accumulation of this material in marine settings, and therefore has been intensively investigated in term of mechanical processes, morphology, and evidence in the rock record. Despite so many claimed hyperpycnal-plume deposits in rock outcrops, few direct observations have been made in large lowland river systems, with exception for the Huanghe (Yellow River) estuary, China, which is the most sediment concentrated large river worldwide. The contrast between the many ancient records and few modern observations inspires us to ask what physical conditions are required to produce a hyperpycnal-plume, and what evidence is required to support the claims of the rock record recording such events. In short, why does such a contrast emerge between ancient and modern systems? To answer this, we use a physically-based sediment transport formulation developed from a database surveyed at the lowermost Yellow River, which covers well the sediment concentration range of both normal suspended sediment and high concentrations required for hyperpycnal plumes. We investigate the physical threshold required for the formation of a hyperpycnal plume. An inverse model is used to deduce the resistance coefficient and channel slope from the bankfull water depth and grain size distribution; these are also data which can be obtained from the rock record. Hence, the physical method can be used to predict the conditions of hyperpycnal plume for both modern and ancient systems. Our analyses indicate that the hyperpycnal plume is likely to occur for fine-grain river basins (i.e., < 200 microns) with steep slopes. This implies that hyperpycnites can be good signatures of tectonically active source-to-sink systems where the production of fine-grain sediment is robust. Modern examples include the island of Taiwan, where lightly-indurated marine shale is rapidly eroded to produce fine-grain sediment, and steep slopes associated with this tectonically-active island provide the key components for generating hyperpycnal flows as rivers debouch into the sea.

Carbon and sulfur dynamics on passive margins

Low methane concentrations in sediment along the continental slope north of Siberia: Inference from pore water geochemistry

Clint Miller, Rice University

The Eastern Siberian Margin (ESM), a vast region of the Arctic, potentially holds large amounts of methane in sediments as gas hydrate and free gas. Although this methane (CH4) has become a topic of discussion, primarily because of rapid regional climate change, the ESM remains sparingly explored. Here we present pore water chemistry results from 32 cores taken during Leg 2 of the 2014 SWERUS-C3 expedition. The cores come from depth transects across the slope and rise sediments off the Chukchi and East Siberian Sea (CESS) of the ESM between Wrangel Island and the New Siberian Islands. Upward CH4 flux towards the seafloor, as inferred from profiles of dissolved sulfate (SO42-), alkalinity, and the ïâ13C-dissolved inorganic Carbon (DIC), is negligible at all stations east of where the Lomonosov Ridge abuts the ESM at about 143 degrees E. In the upper eight meters of these cores, downward sulfate flux never exceeds 9.2 mol/m2-kyr, the upward alkalinity flux never exceeds 6.8 mol/m2-kyr, and δ13C-DIC only slowly decreases with depth (-3.6 ‰/m on average). Additionally, ZnS precipitate, indicative of dissolved H2S, was not observed in these cores. Phosphate, ammonium, and metal profiles provide evidence for very low organic carbon turnover rate and reveal that metal oxide reduction by organic carbon dominates the geochemical environment. A single core on Lomonosov Ridge differs, as diffusive fluxes for SO42- and alkalinity were 13.9 and 11.3 mol/m2-kyr, respectively, the δ13C-DIC gradient was 5.6‰/m, and Mn2+ reduction terminated within 1.3 m of the seafloor. These are among the first pore water results generated from this vast climatically sensitive region, and they imply that significant quantities of CH4, including gas hydrates, do not exist in any of our investigated depth transects spread out along much of the CESS continental slope. This contradicts previous assumptions and hypothetical models and discussion, which generally have assumed the presence of substantial amounts of CH4.

Sediment production and dispersal: catchment scale

Exogenic and autogenic controls on the location and migration of continental divides

Andrew J. Moodie, Rice University

Channel networks dynamically respond to exogenic and autogenic drivers that influence regional topographic gradients, drainage area, and hydrology. The mobility of continental divides is an integrated expression of those channel responses at a large scale. Divide migration creates disequilibrium in channel longitudinal elevation-profiles that have headwaters at the mobile divide, whereby sediment production is accordingly increased or decreased at the headwaters. Changes in sediment production manifest as long-term (> 10^5) changes in the delivery of sediment to continental margins. Exogenic drivers are perhaps most obvious in active tectonic settings, where traditional views hold that the drainage divide develops along the spine of highest topography because of the strong coupling between surficial and tectonic processes. In the absence of tectonic forcing, divide location and migration becomes increasingly dependent on rock-type, the thermo-chemical evolution of isostatically compensated topography, and dynamic topography forcing in post-orogenic landscapes, all of which act to locally and regionally change topographic gradients. In both tectonically active and decaying orogens, there are curious examples in which the continental divide is not co-located with the highest mountain peaks but rather follows the regional-scale highest-standing topography. The Gibraltar Arc and Appalachian Mountains, two diverse settings with ongoing drainage system reorganization are chosen to explore the dependence of drainage divide migration on exogenic tectonic, isostatic, and dynamic topography forcing. Long-wavelength topography isolated from local-scale features reveals the regional-scale topography atop which a "synthetic divide" is defined along the main axis. Further, the X (chi) transformation of stream long-profile mapping and a compilation of erosion rate and sedimentological data are synthesized to argue that where there is a disequilibrium in the landscape, divide migration occurs in the direction of the "synthetic divide". Autogenic controls and feedbacks cause divide migration to be unsteady and occur through pulses of drainage capture and drainage network reorganization that may be recorded in sedimentological, geomorphic, or denudation rate data.

Sediment production and dispersal: catchment scale

What if it doesn't leave a trace: Quantifying the importance of moderate magnitude and frequency submarine mass failures using the Mississippi River Delta Front as an analogue

Jeffrey Obelcz, Louisiana State University

Before the advent of sub-meter resolution swath bathymetric sonars and computationally intensive numerical models, the majority of subaqueous mass failure studies were limited to three main methodologies: coring (large temporal range, high temporal resolution, small spatial coverage), in situ observation (high spatial resolution, small temporal duration and spatial coverage), or sidescan sonars and single-beam echosounders (low spatial and temporal resolution, large spatial coverage). This has led to an observational bias towards high frequency, low magnitude events (captured by in situ observation) and low-frequency, large magnitude events (which leave depositional and erosional features identifiable via coring and low resolution sonars). The advent of high resolution swath bathymetric sonars and precise positioning systems offers the opportunity to bridge this gap and quantify a potentially important piece of the source-to-sink puzzle.

We present here a case study demonstrating the importance of moderate mass failures, using recently collected data from the Mississippi River Delta Front (MRDF). Three repeat bathymetric surveys were conducted in 2005 (post-Katrina), 2009, and 2014 approximately 10 km seaward of Southwest Pass, the most active distributary of the Mississippi River in terms of both water and sediment discharge. Despite a lack of major (> category 3) hurricanes passing within 100 km of the survey site, appreciable seafloor movement was observed, including ~1 m/year deepening of mudflow gullies and similar rates of shoaling at the distal lobes of the gully complexes. The seafloor outside of existing failure complexes remained relatively stable between surveys, and the overall geomorphic "footprint" of the mudflow gullies/lobes remained stable (<100 m of lateral migration). Volumetrically, these failures are smaller than those triggered by major hurricane passage (~10e6 m3 for mass failures, ~10e7 for hurricane-induced mass failures), but when rate-normalized the smaller failures mobilize approximately half the sediment hurricane-induced failures transport downslope (5.5 x 10e5 m3/yr and 1.1 x 10e6 m3/yr, respectively). The snapshot nature of bathymetric surveys cannot constrain the periodicity of the aforementioned mass failures, but nonlinear wave modeling demonstrates that storms with a 1-year recurrence interval can generate seafloor pressure differentials sufficient to destabilize the gas-charged, underconsolidated sediment characteristic of the MRDF. Through a combination of repeat geophysical surveys and nonlinear wave modeling, we provide both evidence and a potential triggering mechanism for moderate periodicity and magnitude mass failures on the MRDF. Our findings indicate that such historically "undersampled" events are an important agent in moving sediment from the littoral zone to the deep sea fan, and should therefore be further studied.

Mineralogy from Computed Tomography

Jacob Proctor, Rice University

The life cycle of a newly discovered field in the petroleum industry has four main stages: exploration, appraisal, developmental, and finally production stages. Seismic, drilling, well logs, drill cuttings, and in rare occasions cores are made available in the early to middle stages of an oil or gas field life cycle. However, mineralogical analyses, key for understanding lithofacies, depositional environment, diagenesis, and sequence stratigraphic surfaces are often not acquired until later in the middle stages of a field life cycle. The lack of mineralogical information in an exploratory well during its initial assessment places large risk on accurately appraising its production potential.

Computed Tomography (CT) is a tool that allows precise mineralogical determination to be made and logged along whole core when a relatively new multiple energy X-ray CT imaging technique called *Dual Energy Scanning* and a spectral core gamma logging (SGR) tool are integrated. X-ray attenuation depends on both chemical composition of the rock matrix and bulk density, while imaging with multiple energy levels allows bulk density and effective atomic number to be separated and logged along a core at 0.5mm level of resolution. This new method can generate porosity, grain density, and up to three different mineralogies such as calcite, dolomite, and silica/clay.

The objective of this study is to compare calcite, dolomite, and silica/clay logs derived from Dual Energy and SGR logging to the mineralogy defined in thin sections sampled from core plugs, extracted from the whole core. 126 cores from an Upper Cambrian microbialite reef complex, outcropping on pavements and in vertical sections in Mason county (Texas), were analyzed for mineralogy by integrating Dual Energy scans and SGR logs of Uranium, Thorium, and Potassium. 30 horizontal core plugs, measuring 2.54 cm in diameter and predominately 3 cm in length, were drilled to validate the precision of the mineralogy logs generated by Dual Energy. For each plug, a thin section was prepared to define mineralogy and porosity types via classic microscopic observations. The thin sections were used to translate CT greyscale from multiple CT scan imaging resolutions (0.5mm to 0.005mm of voxel resolution) acquired in three dimensions, to mineralogy. Each voxel in a greyscale volume is attributed to a mineral and tabulated to define volume fractions of different minerals in each plug. All CT image resolutions are registered back to each plug, and can then be upscaled and used to validate the mineralogy logs.

The thin section analyses demonstrate how precisely integrating Dual Energy and a SGR logger can determine key mineralogical variability. In carbonates, the mineralogy logs and CT scanning can be used to log the extent of diagenetic alteration, which would be invaluable for rapid early stage rock typing.

Processes-to-stratigraphy framework: good, bad and ugly

Glaciomarine sediment facies: Using geomorphic contexts and multi-proxy analysis to build ice-sheet retreat models

Lindsay Prothro, Rice University

Existing glaciomarine facies models provide a framework for interpreting deglacial stratigraphic sequences, but lack geomorphic contexts that can further constrain ice behavior. Recently improved high-resolution multibeam swath bathymetric technology allows us to revisit these models with a geomorphic understanding. Recently acquired data from the Ross Sea reveals numerous ice-sheet retreat features, iceberg furrows, and subglacial meltwater channels not clearly observable in lower resolution datasets. This dataset is coupled with targeted sediment cores to refine facies models.

Using detailed grain-size analysis, geotechnical properties, and microfossil analyses, we identify distinct units and infer facies based on relationships to geomorphic features. Key retreat facies include grounding line proximal, open marine, and subglacial meltwater deposits. With the addition of legacy cores, we have a dense dataset for examining spatial constraints of facies. We find evidence for multiple grounding line proximal processes ranging from passive basal melt to subglacial meltwater expulsion, identified by varying degrees of sorting and sand content. The open marine facies is composed of diatomaceous sandy silt that is either barren or contains only agglutinated foraminifera. Subglacial meltwater deposits are distinguished by sorted fine silt with little to no coarse material, display a massive to laminated character, and are found within other retreat facies. We do not recognize a distinct sub-ice shelf facies. Rather, sediments found in the sub-ice shelf environment consist of grounding line proximal deposits, meltwater deposits, and advected open marine material. Calcareous benthic and some planktonic foraminifera occur in grounding line proximal deposits while open marine deposits contain only arenaceous foraminifera. Preliminary examination of Pine Island Bay and Marguerite Bay cores indicate similar facies character and distribution patterns, including widespread meltwater deposits. This revised facies model will be useful for understanding processes that influence grounding line stability, and for interpreting cores without geomorphic context, such as drill core and surface sediment cores from early cruises.

Margin development: mechanics and formative processes

Revisiting and redefining the S-reflector as a fault zone: New 3-D constraints from the Galicia margin, offshore Spain

C. Nur Schuba, Rice University

The majority of our understanding of rift evolution comes from passive continental margins and interpretations of their tectonic framework. The Galicia Margin, located offshore western Spain, is an archetypical magma-poor rift margin that is part of the Newfoundland-Iberia rift system. Here we focus on the major low-angle detachment fault in the hyperextended Deep Galicia Margin, called the S-reflector. Interpretations, attribute and isopach maps are presented from a 3-D seismic reflection dataset that was acquired in 2013, processed to prestack time migration by Repsol S.A. in 2015 and noise-reduced by Chevron E.T.C. The final volume has an azimuth direction of ~87 degrees, and is 68 km wide (E-W) and 20 km long (N-S). The record length is 13 seconds, which penetrates well into the upper mantle.

In cross-section view, the S-reflector detachment fault is mapped as two distinct, non-parallel surfaces that define the top and bottom of a zone with a thickness range of 0-224 m. A new nomenclature for this zone, which we term the "S-interval" is presented, and this reflection package is interpreted as the top and base of a thick gouge zone. The gouge layer shows internal reflectors that could potentially be R-type reidel shears. In map view, a general trend of corrugations is visible with a NW/SE angle. Amplitude attributes reveal localized patches with corrugations trend at 109, 103 and 128 degrees suggesting that there may have been local variations in the minimum stress directions during rifting. These angles are on average perpendicular to the M0 magnetic anomaly (~125 Ma), which supports an interpretation that the corrugations formed +/- perpendicular to the rift axis.

Sediment production and dispersal: catchment scale

Size delineation and possible origins of a regional, Late Cretaceous unconformity affecting the Mesozoic passive margin of northwest Africa

Beatriz Serrano-Suarez, University of Houston

I have used 14,812 km of 2D industry seismic data tied to 6 exploration wells to map the lateral extent of a major, regional unconformity eroding Mesozoic clastic and carbonate units of the Guinea-Bissau passive margin. The hiatus of the unconformity spans the Coniacian through Santonian. The unconformity forms a prominent surface across all of my seismic grid that covers 60 km2 of the Guinea Bissau passive margin and has been recognized as a continuous surface by previous workers as far north as the Moroccan passive margin. Comparison of regional dip lines show that the amount of erosion at the unconformity increase southward with a maximum amount of erosion on the Guinea nose adjacent to the Guinea fracture zone. Three possible hypotheses to explain the presence of such a large, extensive, and regionally-variable erosional event affecting the passive margin of northwest Africa include: 1) far-field compressive and uplift effect produced by a convergent pulse around 84 Ma that accompanied the progressive closure of the Neo-Tethyan Ocean between Africa and Eurasia; 2) Transpressional folding and thrusting that accompanied the opening of the Equatorial Atlantic and has been documented on the conjugate margin of the Guinea nose on the Demerara Rise of northwestern South America; and 3) thermal uplift effects related to hotspots - including the Canary and Cape Verde - in the passive margin area.

Structure of the Red Sea Neoproterozoic Margins and Cenozoic Magmatism: Constraining the Opening of a Young Ocean and the Formation of its Passive Continental Margins

Robert J. Stern, University of Texas at Dallas

As the Earth's best known example of an active, incipient, ocean basin, the Red Sea provides crucial information about continental rifting and the tectonic transition from extended continental crust to seafloor spreading. Study of the Red Sea over the past decades has given answers to many aspects of rifting, but significant questions are unanswered because of lacking or ambiguous data. Two important issues are the geometry of the pre-rift join between the Arabian and Nubian Shield that form the basement flanking the Red Sea and the nature of the crust beneath the Red Sea. The Neoproterozoic basement rocks flanking the Red Sea contain prominent shears and fold belts that constitute sutures between amalgamated tectonostratigraphic terranes, regions of transpressional shortening, and brittle-ductile faults related to Ediacaran orogenic collapse and tectonic escape. These structures vary in orientation from orthogonal to oblique with respect to the Red Sea coast lines. Importantly, they correlate across the Red Sea, and provide piercing points for a near coast-to-coast palinspastic reconstruction of the Arabian and Nubian Plates along the entire Red Sea of the type proposed since the 1970s. A tight pre-rift fit of the Arabian and Nubian Shields implies that most of the Red Sea is underlain by oceanic crust, not merely its southern part. Potential-field data are compelling evidence for oceanic crust along the axis of the Red Sea south of ~22^0 N, persuasive for the margins of the southern Red Sea, and suggestive for the northern Red Sea. Dikes, gabbros, and basaltic flows emplaced during the early stages of Red Sea rifting are consistent with Miocene asthenospheric upwelling, partial melting, and intrusion that would have weakened and facilitated rupture the ~40-km thick continental crust and thicker mantle lithosphere of the then contiguous Arabian and Nubian Shields. The dikes, gabbros, and basaltic flows emplaced during the early stages of Red Sea rifting are strong evidence furthermore that the Red Sea is an example of a volcanic-rifted margin.

Margin development: mechanics and formative processes

Distinguishing upper plate vs. lower plate and volcanic vs. non-volcanic, conjugate margins of the Central, Equatorial, and South Atlantic Oceans

Emily Stibbe, University of Houston

I have compiled information from previous geologic and geophysical papers studies to designate upper plate and lower plates of conjugate margins in the North, Central, and South Atlantic Oceans. Upper plates are recognized from: 1) their thicker and higher-standing, un-thinned area of continental crust; 2) their narrow zone of thinned, seaward-dipping continental crust with more restricted hydrocarbon fairways; 3) their fewer and higher-dip, syn-rift normal faults; 4) their lack of post-rift, salt-filled sag basins; and 5) their cross-sectional asymmetry when compared to their conjugate margin. Lower plates, in contrast, are commonly identified by: 1) their thinner and lower-standing crust; 2) their broad area of thinned continental crust commonly overlain by post-rift, salt-filled sag basins; 3) their more expansive, hydrocarbon fairways; 4) their pervasive, lower-dip, syn-rift normal faults; and 5) their cross-sectional asymmetry when compared to their conjugate margin. On top of the upper-plate lower plate map, I have overlain a map of proposed volcanic and non-volcanic Atlantic margins based on the most recent seismic refraction and reflection studies and drill results. Finally, I have overlain a map of producing oil areas to show how upper plate-lower plate margins and volcanic margins can profoundly affect the along-strike distribution of hydrocarbons on the Atlantic margins.

Processes-to-stratigraphy framework:good, bad,and ugly

Connecting morphodynamic depth of closure to shoreline change along the Texas coast

Travis Swanson, Rice University

Morphodynamic depth of closure describes the depth at which the energy associated with waves, tides, and other near shore processes decays below the threshold for sediment transport and morphodynamic change ceases. Protective coastal barriers, such as peninsulas and islands, are nourished by the sediments brought onshore through the scouring action of transgressive ravinement. Morphodynamic depth of closure controls the depth of ravinement, and therefore, may limit or enhance beach nourishment, depending on the relative concentration of sand in substrate. Using linear wave theory (Oritz and Ashton, 2016), high resolution cross-shore elevation profiles, and hindcast wave information, the morphodynamic depth of closure is estimated along the Texas coast. The consequence of morphodynamic depth of closure variability is explored using a morphodynamic model of barrier motion (Lorenzo-Trueba and Ashton, 2014). Morphodynamic depth of closure is found to significantly control barrier shape and fate under reasonable scenarios of sea level rise for the Texas coast.

Rock Physics

Evolution of Porosity, Permeability and Velocity in Mudstones upon Fluid Injection

Harsha Vora, Rice University

Over the past decade there has been a significant rise in fluid injection activity for the purposes of hydraulic fracturing, wastewater disposal and carbon sequestration. The abundance of mudstones in the sedimentary rock record and renewed interest in mudstones for hydrocarbon exploration make it essential to understand their mechanical response to fluid injection. Upon fluid injection, a rock undergoes a reduction in effective stress, known as unloading.

I conduct experimental measurements of porosity, permeability, strain and acoustic velocities to understand evolution of storage and transport properties of mudstone upon unloading induced by fluid injection. Geomechanical modeling using Lattice Boltzmann Method is conducted simultaneously to build analogs of permeability response under different mechanisms of fluid accommodation in mudstones. Initial results indicate that inter-bed pores expand elastically to accommodate fluid at low injection pressures, yielding small changes in porosity and permeability. Increasing injection pressures causes dilation of intra-bedding pores, resulting in significant changes in permeability. Dilated pores coalesce to form a fracture as injection pressures approach the confining pressure on rock. Numerical responses support correlation between experimental permeability trends and proposed preferential accommodation mechanisms of injected fluid.

Tectophysics

Rates of Motion of Groups of Hotspots Estimated from the Dispersion of Hotspot Trends

Chengzu Wang, Rice University

While it is widely believed that groups of hotspots in different regions of the world are in relative motion at rates of 10 to 30 mm a-1 or more, recent work on plate motions over the past ___50 Ma indicate no significant motion between hotspots beneath different plates and furthermore place an upper bound on such motion of ___10 mm a-1. Here we further examine this question. We present a new method for analyzing geologically current motion between groups of hotspots beneath different plates. In an inversion of 56 globally distributed, equally weighte3d trends of hotspot tracks, misfit magnitudes range from 0° to 83° (median= 9°; σ=22°). The dispersion is dominated by differences in trend between different plates rather than differences within plates. The absolute value of mean angular difference for a given plate decreases significantly with increasing absolute plate speed. When these angular misfits are converted to vperp, the rate of hotspot motion perpendicular to the direction of absolute plate motion, there is no significant dependence on absolute plate speed. Moreover, vperp differs significantly from zero for only three of ten plates and then by merely 0.3 to 1.4 mm a-1. The overall mean upper bound on |vperp| is 3.2 ±2.8 mm a–1. Therefore, in the direction perpendicular to plate motion, groups of hotspots move slowly, merely 0.4–6.0 mm a-1, relative to the mean hotspot frame, much slower than found in most prior work.

Hotspot Fixity

Hawaiian Hotspot Motion, Hotspot Reference Frames, and True Polar Wander

Daniel Woodworth, Rice University

Currently popular hypotheses for the kinematics of the Hawaiian hotspot embrace a set of proposals in which the hotspot moves through the mantle, as well as relative to hotspots in other ocean basins, at rates of 12 to 80 mm/yr. While there is much disagreement over how fast the hotspot has moved, these hypotheses agree that the rate of motion is substantial and prevent the hotspots from providing a useful frame of reference. Here we use paleomagnetic poles determined at Rice from the skewness of marine magnetic anomalies [Horner-Johnson and Gordon, 2010; Zheng and Gordon, 2017] along with paleo-spin axis locations inferred from equatorial sediment facies [Parés and Moore, 2005] to track the location of the spin axis relative to the Pacific plate from 44 to 12 Ma B.P. By using the known rotation of the Pacific plate relative to Pacific hotspots [Koivisto et al., 2014], we transform this Pacific plate apparent polar wander path into the reference frame in which Pacific hotspots are fixed, thus obtaining an apparent polar wander path of Pacific hotspots. During this time interval, the spin axis has been fixed in location, within uncertainties, but at a location that is different by about 3° from the present location of the spin axis, indicating that true polar wander has occurred since 12 Ma ago, and perhaps much more recently than that. Given that historical rates of motion of the spin axis relative to the solid Earth, when extrapolated to geologic time, are ~1°/Ma, it's plausible that the entire 3° has occurred in just the past few million years. We use the Pacific hotspot apparent polar wander path to estimate the paleolatitude of the Hawaiian hotspot from 44 to 12 Ma. The mean paleolatitude is 22.6 ± 0.2°N, which is 3.4° north of the present latitude of Kilauea. Over this time interval, the best-fitting straight line has a slope of 1 mm/yr ± 2 mm/yr (95% confidence limits) of southward motion. Thus, over this 31-Ma-long interval, the hotspot moved relative to the spin axis by no more than 3 mm /yr. We conclude that the motion of the Hawaiian hotspot relative to the mantle has been very slow, at most a few millimeters per year. Superimposed on this has been a recent shift of the entire solid Earth relative to the spin axis.

Processes-to-stratigraphy framework:good, bad,and ugly

Backwater control on fluvial-deltaic stratigraphy, tested in the Western Irish Namurian Basin, County Clare, Ireland

Chenliang Wu, Rice University

The hydrodynamics of rivers approaching a basin are influenced by the onset of non-uniform ‘backwater’ conditions that give rise to decelerating flow velocity and decreasing boundary shear stress. These changes occur across a spatial gradient, in which decreasing sediment transport capacity triggers morphodynamic responses that include sediment deposition at the transition from uniform to non-uniform flow near the outlet. As a consequence, channel width-to-depth ratios and bed sediment grain size decrease downstream. While non-uniform flow and associated morphodynamic responses are well understood in modern fluvial-deltaic systems, the influences on the rock record remains a subject of active debate. This represents a significant, unresolved gap between morphodynamic concepts established in geomorphology and fluvial-deltaic stratigraphy. This proposal seeks to identify linkages between strata and morphodynamics by measuring variability in fluvial deposits across the backwater zone identified for the Tullig Cyclothem in the Western Irish Namurian Basin (WINB). The results of this analysis will bolster analytical models that seek to link observed stratigraphy with predicted sediment accumulation patterns. Furthermore, the proposed research provides a basis for a direct assessment of the diachronous nature of the fluvial-deltaic stratigraphy in the WINB by combining time-and-space variable changes in grain size and channel dimension with reconstructions of paleo-hydraulics. This research will produce quantitative metrics to evaluate the dimensions, connectivity, and grain size variation of channel bodies produced by ancient fluvial-deltaic systems, and thereby provide valuable geological insights into hydrocarbon bearing rocks.

Margin development: mechanics and formative processes

Comparison of tectonic and subsidence events of the Demerara (South American) and Guinea (West African) rifted, conjugate margins

Omar Zavala, University of Houston

Previous workers have shown that he Demerara-Guinea conjugate margin of South America and northwest Africa experienced two rifting phases: during the initial phase of Pangean breakup, northwest Africa and South America formed a single, larger plate that separated during the Oxfordian (158 Ma) in a northwest-southeast direction from North America to form the proto-Central Atlantic Ocean. Following a passive margin phase related to earlier Jurassic rift event, a second rift phase started in the Aptian (124 Ma) that obliquely rifted northwest Africa from South America to form the proto-Equatorial Atlantic Ocean. I have compiled well data from the Demerara-Guinea conjugate margins to examine the subsidence histories controlled by the two-phase rifting and passive margin history of these poorly studied margins. As wells do not penetrate significantly into the Jurassic, subsidence plots from both conjugates show the passive margin phase in the early Cretaceous followed by a period of rapid subsidence related to the Albian rifting event and uplift event. Uplift is thought to have formed as a result of folding and thrusting as the South American and North African plates were transpressional deformed during the early plate opening. For the Guinea, a large Aptian unconformity is also present although folding is less apparent than on the Demerara Rise. A second unconformity occurs by the end of the Cretaceous that was followed by the passive margin phase. Local uplifts during the Cenozoic on both conjugates may reflect the influence of igneous activity.

Margin development: mechanics and formative processes

Plume Flux, Spreading Rate, and Obliquity of Seafloor Spreading

Tuo Zhang, Rice University

Most of Earth's surface is created by seafloor spreading, a fundamental global tectonic process. While most seafloor spreading is orthogonal, i.e., the strike of mid-ocean ridge (MOR) segments is perpendicular to transform faults, obliquity of up to ~45° occurs. Here, building on the work of DeMets et al. [2010] we investigate the global relationship between obliquity of seafloor spreading, spreading rates, and the flux of nearby plumes. While we confirm the well-known tendency for obliquity to decrease with increasing spreading rate [Atwater and Macdonald, 1977], we find exceptions at both intermediate (up to 18°) and ultra-fast (up to 12°) rates of spreading. Thus, factors other than the minimization of power dissipation across mid-ocean ridges and transform faults [Stein, 1978] may influence the amount of obliquity. Abelson & Agnon [1997] modeled spreading centers as fluid-filled cracks and found that the variation of segment orientation depends on the ratio of the magma overpressure to the remote tectonic tension that drives plate separation. A high ratio promotes oblique spreading and a low ratio promotes segmentation that results in orthogonal spreading. They further argued that if a hotspot lies near a MOR segment, the hotspot contributes to magma overpressure along the segment. We quantify their argument as follows: (1) that magma overpressure increases with increasing flux of a plume. (2) that effective magma overpressure decreases with increasing distance between a MOR segment and a plume. From this we estimate the effective plume flux delivered to each mid-ocean ridge using published plume flux estimates. Not only does obliquity tend to decrease with increasing spreading rate, but also it tends to increase with increasing effective plume flux delivered to a MOR segment. Many exceptions occur, however. Along slow spreading centers, many segments are less oblique than along the Reykjanes Ridge and western Gulf of Aden despite having higher effective plume flux. Similarly, along intermediate spreading centers, some ridge segments are less oblique than along the western Galapagos spreading center, despite having greater effective plume flux. We conclude that neither the minimum power dissipation model nor the hotspot proximity model fully explain the globally observed variations of oblique spreading.

Current Contributions to Sequence Stratigraphy

The "Cover" of an Upper Cambrian microbial reef complex: drowning unconformity and ultimate demise of the reefs

Yuanquan (Nancy) Zhou, Rice University

Upper Cambrian 10-14m-thick microbial reefs, occurring along the Llano/James Rivers and Mill Creek in Central Texas, serve as good 3D analogues for microbial reservoirs. Periodic siliciclastic influx from nearby landmasses played an important role in microbial reef growth from an initial transgressive "colonizing" Phase 1, a "vertical aggrading/lateral expanding" Phase 2, and a well-defined "capping" Phase 3. The reef complex is onlapped by inter reef sediments and buried by a distinct unit, together referred to as the cover. The cover sediments consist of mixed siliciclastic silts grading into pure carbonates. They record variations in paleo-environmental conditions during late stages of reef growth and contains clues as to what stressed the reef growth and eventually killed them. The general cover architecture and its relationship with the underlying microbial complex were defined through field observations and photogrammetry data. The study integrates core facies analyses and CaCO3 content values with thin section observations. The cover sediments directly overlie an ooid-rich bioclastic grainstone bed, interpreted to represent shallow subtidal conditions with eventual deepening at the end of Phase 2. The deeper subtidal setting allowed Phase 3 reefs to develop 2-3 m high synoptic relief and densely cemented thrombolytic rinds. The Phase 3 reefs clearly overlie the ooid-rich bioclastic packstone bed, and lack coeval inter reef sediment accumulation. The sediments, immediately overlying this ooid-rich bioclastic bed and clearly onlapping the adjacent Phase 3 reef, display the lowest CaCO3 content values (16 %) of the entire inter-reef section and initiate the burial of the reefs by sediments grading from mixed siliciclastics into pure carbonates. Moreover, the contact between reef tops and overlying pure carbonates was recovered in several cores. Those sediments consist of poorly sorted skeletal-rich rudstone with large irregular intraclasts, evolving into a series of grainstone and packstone fining-upward beds with often-erosive bases. Above observations indicate a sudden increase in siliciclastic influx at the end of Phase 3 reef growth which led to prolonged turbidity increase in the water column, thus inhibiting cyanobacteria's photosysnthetic ability and ultimate leading to the reef demise. The lack of inter reef sediment during the "capping" Phase 3, the subsequent siliciclastic influx, the later carbonate sedimentation and the related depositional environment change also suggest a possible sequence boundary at the top of Phase 3.

Notes:

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– André Erlich, Chief Information Officer, Schlumberger Ltd. (retired)

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- André Droxler, Track Director, SG, Professor, Earth Science
- Dale S. Sawyer, Advisor, Earth Science
- John B. Anderson, Earth Science
- Andrew R. Barron, Chemistry
- Gerald R. Dickens, Earth Science
- Alan Levander, Earth Science
- Helge Gonnerman, Earth Science
- Jeff Nittrouer, Earth Science
- Fenglin Niu, Earth Science
- Julia Morgan, Earth Science
- Colin A. Zelt, Earth Science
- Adjunct Faculty: Vitor Abreu, Gary Gray, Mitch Harris, Malcom Ross, Eric Scott
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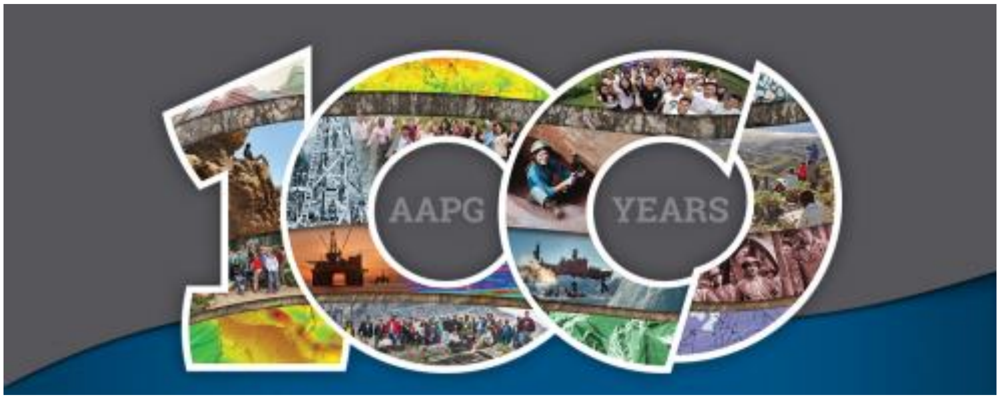

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