RioMAR Consortium represent a conglomerate of projects of 5 PIs and clusters of students with the scope to better understand and characterize the source-to-sink depositional systems. Projects vary in methods (such as physical experiments, numerical modeling, modern processes and morphologies, facies and architecture of outcrops or seismic interpretations) and some extends multiple years (or RioMAR phases) but what connects all of them is the S2S paradigm. We recognize that depositional systems are linked and despite a project focus on a particular segment (river sediment discharge, backwater processes, (tidal) deltas architecture, slope channels facies, or basin floor fan sandstone pattern) the projects results highlight conditions (size of the river, sediment caliber, shelf processes, slope gradients) for entire source-to-sink system. The scope of the consortium is twofold; first to understand sedimentary process mechanism, discover new “rules” or models for sedimentology or stratigraphy through individual projects, and second to build a suite of examples of S2S segments, or entire S2S systems to better understand variability and interconnectivity of sedimentary systems across major boundaries (shoreline, shelf-edge, base of slope).

1. FLUVIAL SYSTEMS
Hydrological regime and temperature as control on sediment transport, deposition and signal propagation. RioMAR studies in fluvial systems have focused on multiple aspects of river discharge, such as analyses of river hydrological regimes and the significance for S2S analyses, signal propagation and autogenic processes, and the effects of temperature on riverine sediment transport.

River discharge and signal propagation: River discharge is a significant component of S2S analyses (Q in BQART), and the carrier of sediment, and thus the carrier of environmental signal. River discharge is commonly used as average discharge (Qave) in estimates of drainage basin area, water power and sediment yields. Our results show that using Qave leads to drainage basin area estimates that can be erroneous at two orders of magnitude (Fig. 1), and that using Qave significantly underestimates the efficient discharge, water power and capacity to carry sediment in variable discharge rivers (Plink-Bjorklund presentation, Evan Jones Thesis, CSM). In rivers with high discharge range (variable discharge, Plink-Bjorklund 2015; 2017) Qave represents a flow event that is a transient flow state that inadequately characterizes either baseflow or flood conditions. Only rivers with extremely persistent discharge have discharge distributions that approach normal distribution and thus lack extremely low and high discharges. In variable discharge rivers base flow is commonly geomorphically inefficient, and the flood
discharge, although of short duration, is the formative flow that determines the fluvial facies and the stratigraphic architecture (Plink-Bjorklund, 2015; 2017).

This concept of efficient discharge in context of river hydrology, is a significant component of signal propagation analyses in within fluvial systems, as well as in S2S context. We hypothesize that variable discharge rivers, such as the Ganges drainage system allow for efficient signal propagation despite their large size (Haipeng Li presentation).

**Outcomes.** Recognition of distinct fluvial facies and stratigraphic architecture of variable discharge rivers is one of the outcomes of this project (Plink-Bjorklund, 2015; 2017). This work links river hydrological styles and thus also fluvial facies and stratigraphic styles to precipitation variability. Significantly, it shows that we need to consider precipitation variability in addition to humidity/aridity ($P_{ave}$) and temperature in S2S and paleoclimate analyses, as in some cases maximum efficient discharges and sediment yields may occur during the driest climates due to increased discharge variability. Other results include (1) a modification to the BQART analyses with new improved regressions utilizing bankful flow, rather than $Q_{ave}$, that works for rivers with different hydrological regimes (Fig. 2; paper 1 in Evan Jones thesis); and (2) a new probabilistic method for S2S analyses using Monte Carlo simulations and taking account river hydrology (papers 2 and 3 in Evan Jones thesis).

The new regressions using the bankful flow are currently the only scaling relationship that works for all rivers, including the extremely arid river systems. Furthermore, it is more appropriate for outcrop analyses as channel dimensions scale to bankful flow rather than $Q_{ave}$. A third outcome is global analyses of daily river discharge records with the aim to further understand the patterns of hydrological variability and their effect on the sedimentary record (Hansford poster). This latter work will continue into the next year. Signal propagation and autogenic process analyses has so far resulted in a review of autogenic and allogenic controls, and their recognizability in the sedimentary record (Haipeng Li presentation). This is also ongoing work.
Temperature control: This part of the report is based on the proposal written by a PhD student, Ye Jin Lim. It is clear water temperature exerts a control on sediment transport and influence settling velocity of moving particles through temperature-dependent fluid properties (i.e., viscosity and density) (Gibbs et al., 1971; Syvitski et al., 2017) (Fig. 3). Thus, considering the effects of temperature on particle settling velocity is essential to understand morphodynamic response, especially for systems such as Arctic rivers and deltas in cold environment undergoing water temperature changes. According to (Dietrich, 1982), dimensionless settling velocity ($w_{s*}$) and dimensionless grain size ($D^*$) are defined as:

\[ w_{s*} = \frac{\rho_p w_s^3}{(\rho_s - \rho_p) g v} \]  
\[ D^* = \frac{(\rho_s - \rho_f) g D^3}{\rho_f v^2} \]
where $w_s$, $\rho_f$, $\rho_s$, $g$, $\nu$, and $D$ represent settling velocity, fluid density, sediment density, gravitational acceleration, kinematic viscosity of the fluid, and grain size, respectively. Taking particle shape and roundness into consideration, dimensionless settling velocity ($w_s^*$) can be calculated using the set of equations presented in Dietrich (1982):

$$w_s^* = \frac{C}{(\rho_s - \rho_f) \frac{g \nu}{3 \rho_f}}$$

However, settling velocity calculations are typically carried out under the assumption of 20°C water temperature. In the calculation, estimated values of kinematic viscosity ($1 \times 10^{-6}$ m$^2$/s) and density (1 kg/m$^3$) of water at 20°C are used, and fluctuations in temperature-dependent fluid characteristics are not considered.

Figure 3. Kinematic viscosity and density of water in terms of temperature.

Outcomes: Considering an empirical relationship between kinematic viscosity of the fluid ($\nu$) and temperature ($T$) (García, 2008):

$$\nu = \frac{1.79 \times 10^{-6}}{1 + 0.03368T + 0.000217T^2}$$

Using equation (4), in addition to density variation based on temperature, we can accurately calculate temperature-dependent particle settling velocity (Fig. 3). For a given particle size, settling velocity increases with an increased temperature due to changes in fluid characteristics (i.e., dynamic viscosity and density) (Fig. 4). In theory, settling velocity of sand particles ($D_{50} = 170$ microns, CSF= 0.7, P= 3.5) at 0°C can decrease by approximately 33.8% if kinematic viscosity and density changes are considered. Our understanding of water temperature control on sediment transport (i.e., thermal-dynamic sediment transport) is limited, and not fully incorporated into sediment transport models (Syvitski et al., 2017). Moreover, morphologic and stratigraphic consequences of cold temperature in Arctic deltas are unclear. Incorporation of fluid viscosity and density fluctuations into settling velocity calculations is required for an accurate understanding and prediction of sediment transport in a wide range of temperature conditions.
Defining the transition from the quasi-uniform reach to backwater zone of Trinity River, Texas, using combined airborne lidar and bathymetric surveys. High resolution topographic data has been collected and analyzed to place quantitative constraints on the geomorphology of coastal river so that resulting fluvial stratigraphy is better defined and understood. This year’s focus was on two system components: using time-lapse lidar to quantify river bend migration and channel-belt development; and use bare-earth lidar to investigate the influence of both river and floodplain characteristics on proximal floodplain sedimentation.

Outcomes: Levee width, crest elevation, and supraelevation (depositional thickness), together with detrended floodplain elevation, and bankfull river width and depth were extracted from the bare-earth lidar plus bathymetric data. We found that the widest levees correlate with the lowest segments on the detrended floodplain. This relationship highlights the importance of antecedent topography on floodplain sedimentation. We also found that levee crest elevation in both the upstream and backwater segments of Trinity River closely align with water-surface elevation during the most common floods. These insights into the controls on levee morphology are making it possible to better understand sediment transport out of rivers onto floodplains and improve interpretations of floodplain deposits, including the thickness and lateral continuity of sands deposited outside of the main river channel.

Time-lapse airborne lidar on the coastal Trinity River in Texas, USA, shows profound downstream variability in point-bar growth and cut-bank erosion resulting from a historically large flood. The difference map generated from two surveys covers 55 river bends (65 river kilometers) and captures the geomorphic transition from quasi-uniform flow into backwater flow. In the upstream portion of the survey, an average of 100,000 m$^3$ of material was added to each point-bar and the same amount of material was removed along the outer bank. In the backwater zone, less than 20,000 m$^3$ on average was added to each outer bank, with about 50,000 m$^3$ removed along each outer bank. These measured changes in deposition, erosion, and river bend migration have implications for the resultant channel-belt geometry. The large point bars and lateral migration of channel bends within the quasi-uniform zone lead to a wide, sandy channel belt. Within the backwater zone, limited sand deposition on point bars and dampened outer bank erosion rates leads to a narrower, more compartmentalized channel belt. The data
supporting the results summarized here are found in the 2017 RioMAR posters by Hassenruck-Gudipati and Mason and Mohrig, respectively. Both studies are being worked into manuscripts that will be uploaded to the RioMAR website as soon as they are completed.

2. DELTAS
New field method for assessing the mix of processes in stratigraphy; discharge control on deltas and interaction with tides; characteristics of Wilcox deltas & estuaries and their feeder channel belts; how $10^8$ tons/yr of Amazon mud impacts paleo-Orinoco Delta lobes.

Assessing the process mix in in interpretation of delta stratigraphy. Most shallow-marine coastal systems are characterized by an intense interplay of river, wave, and tidal currents. These systems often host a great variety of ecosystems while being very sensitive to sea level and coastal morphology changes. The complexity of mixed-energy systems arises because the dominant process can change over short spatial and temporal scales (Porebski and Steel, 2006; Yoshida et al., 2007; Ainsworth et al., 2011). For these reasons, an interpretation of the mixed-energy input to delta stratigraphy is particularly challenging. The sedimentary structures generated and preserved by fluvial, wave, and tidal processes can produce very complex stratal packages. Therefore, in order to delineate the role of different processes there is a need for quantifying the variability present in the stratigraphic record. This is one of the Chapters in Valentina Rossi’s PhD dissertation in 2016.

![Fig. 5 Sedimentological log of a deltaic parasequence (A) and vertical process changes (B), where the probability graph delineates the relative importance of river, wave and tidal processes through time. Lower part of the parasequence shows high probability of being the result of wave action. Middle part shows a complex mixture of wave, river and tidal processes. The upper part shows similar probabilities of being the result of fluvial and tidal currents.](image-url)
**Outcomes:** We have therefore devised a new methodology (Rossi et al., 2016) that assigns (percentage) the likely wave (w), tide (t) and river (r) process-signal variability for a bed or set via a library of sedimentary structures and their non-unique process generators. Each bed or set can be characterized by a specific structure (bedform) or multiple structures (taking also account of lateral variations). Multiple percentages are averaged to create a final compound process probability for each bed. Vertical integration of process probability for individual beds in a rock succession creates probability graphs. Figure 5 illustrates an example of this method, and shows clearly how careful bed-by-bed observation, description and interpretation of strata is needed for more accurate environmental reconstruction.

**Flood and Interflood discharges:** The dimensions and organization of deltaic islands dictate morphology of delta channel networks. To understand the relationship between flood intermittency and delta network organization, PhD student Max Daniller-Varghese, in his thesis project, investigates the conditions that determine the morphology of a single channel island node within that network. In the following section, we present experimental results of mouth bar deposition and flow bifurcation in transport-limited turbulent conditions. The experimental mouth bar formation and channel bifurcation is achieved by producing two characteristic advection lengths using intermittent flood and interflood discharges and corresponding deposit types: one is associated with interflood bedload transport, and the other is with flood-suspended transport. These develop proximal low-angle deposits and distal steep deposits, respectively. We found that bifurcations occur when interflood and flood deposits are at equal elevation and encroach on one another. Varying the frequency of floods is also examined while keeping total sediment volume constant across experiments. Frequent flooding causes shorter bifurcations with shorter bifurcation incidence time, whereas infrequent flooding causes longer bifurcations with longer incidence time.

**Outcomes:** Experimental bifurcation can be described in two stages: 1) Development of leveed proximal deposit and lunate distal bar deposit and 2) channel bifurcation. In the initial stage, the two flow regimes resulted in two different types of sediment transport, and two consequent deposits. Interflood flow transported sediment as bedload (Rouse number, P=2.96) and resulted in an elongated radial deposit and a leveed channel near the inlet. Flood flow resulted in full suspension of the material at the inlet (P=0.18), and the advection length was determined by the settling velocity of the grain and the depth of the water (Fig. 6). The flood flow deposits built at ~1 m downstream from the inlet are reminiscent of lunate bars, first described by Bates (1953). The flood flow also waves through the leveed channel and re-entrain sediment at the bed. With time, distal flood deposits gradually rise over the water surface and became the highest point in the domain, though they sometimes are equal elevation to the levees in the proximal. Initially, experimental flood waves rework and distribute all the sediment deposited by interflood flow. However, given enough time, sediment can accumulate near the inlet mouth. Once this happens, lateral dispersive flux builds and maintains levees. While there is often scour very near the mouth, we know these levees are additive based on the altimetry scans. These built-up levees can focus floods to a small extent. Floods cover the proximal as a sheet flow, but scour the inlet channel deeper, and build levees taller. The proximal and distal deposits encroach on one another by progradation of the proximal deposit and back filling near the distal deposit. Bifurcation occurs as these deposits encroach on one another.
In the bifurcation stage, interflood flow does not uniformly cover the flood surface, and forms channels around it. Figure 7 shows time accumulative maps of focused flow (water depth deeper than a few mm) each over one fifth of the duration in an interflood period. In the earlier stage of bifurcation (Fig. 7a), floods develop a parabolic distal bar with two sides extended upstream. The flood is uneven laterally across the bar but flows over the center of the bar where the elevation is highest. Interfloods gradually erode the two sharp sides of the bar and change the bifurcation angle. Deposition starts at the downstream ends of the bifurcated channels and continues to the main trunk channel. In this early stage, however, the bifurcated channels are underfilled throughout the interflood period compared to the later stages in bifurcation. In the later stage of bifurcation (Fig. 7b), flood flow is split into two channels and makes deposit at each end of the channels. During the interflood, the channels are significantly filled and only the upstream end near the inlet is maintained deep focused flow. Toward the end of interflood periods in the later stage, the surface topography becomes smoother, and the distal bar deposit and proximal leveed deposit encroach against with each other more closely.
Further study will be focused on the effects of intermittency factor on the bifurcation length and time. We will also collect more natural data to compare with the experimental results.

**Tide-dominated and –influenced deltas.** To continue RioMAR effort on the complex tide-dominated and –influenced deltas we are reviewing modern and ancient deltas to produce a comparative database of modern and ancient systems (Michael Genecov poster).

**Outcomes:** The preliminary outcomes are that there are significant differences in modern and ancient tide-dominated and –influenced delta datasets. Many of the features emerging from modern systems are not recognized in ancient deltas, and sedimentary facies of modern and ancient deltas differ quite significantly (Michael Genecov poster).

**Characterization of Wilcox shelf deltas and feeder channel belts.** A new reconstruction of some 37 fairways of Wilcox delta regression and estuarine/barrier retreat, as well as their varying process drive, and their changing rates of progradation vs. retrogradation through Paleocene and Early Eocene, has been documented by PhD student Jinyu Zhang as part of his dissertation (see also Jinyu Zhang talk at RioMar annual meeting). The reconstruction is sited across parts of the Texas Paleocene-Eocene shelf, and is focussed at a time scale of a few 100Ky by using the concept of shelf-transit cycles (applied to the data extracted from 400 wells and calibrated to sediment cores from 10 wells) to reconstruct the basic building blocks of Wilcox stratigraphy (coastal plain to shelf edge).

In addition, the dimensions of feeder channel belts from bottom to top of the lower 18 sequences (Lr. Wilcox Formation; Fig. 8), the main interval that dispersed large volumes of sand to the ultradeep Gulf of Mexico, were calculated and their relationship to the changing shelf-edge trajectory was monitored.

![Fig. 8 Depositional-strike cross-section with interpreted Lr. Wilcox channel belts up to 10 km in width. Distance between each well is 200-900 m.](image)
Outcomes. With the new quantitative backdrop of high-frequency Wilcox Fm. sequences, the Lr. Wilcox shelf edge has been shown to have an early progradation rate of >10 km/My and aggradation rate of <100 m/My, whereas the late Lr. Wilcox shelf edge prograded <10 km/My and aggraded >10m/My. In sync with this vertical reduction in progradation rate, the average thickness of channel-fill also reduced significantly through time. The paleohydrology analysis (Fig. 9) based on grain size, bedforms and channel depths estimated from cores and logs indicate the bankfull water discharge of the largest Wilcox channel was up to 22516.8 m³/s, a very high water discharge value comparable with Mississippi River. The success of Lower Wilcox deep-water delivery (judged from the occurrence of ultradepth water fans of same age) is because of 1) the high sediment supply (>10 km/Ma shelf-edge progradation rate, presence of world-class large channel-belts); 2) limited accommodation on the shelf (aggradation <200 m/Ma) and presence of a cross-shelf incised valley. The initial of Lower Wilcox clastic wedge had the highest potential to send sands to deep-water because of its high shelf-edge progradation rate and distance.

These results are discussed in two manuscripts on the website, Zhang et al., 2016 and 2017 (accepted).

Fig. 9. Dimensions of Lr. Wilcox channel belts in Fig. 8. A) Range of channel-belt thickness and width, compared to modern fluvial database by Milliken et al. (2012); B) Relationship between channel-belt width and depth; C. width:depth ratio distribution of channel belts; D) low end, high end and average of channel-belt thickness, width and width:depth ratio.

Modern and shelf-edge deltas of the Rio Grande S2S system, south and offshore Texas. The modern Rio Grande and associated Holocene paleo-channels constructing the modern delta are quantitatively characterized through the use of airborne lidar topographic surveys, aerial photo analysis, hydrographic analysis, and previously published sediment borings. These data are connected to analyses of its Pleistocene shelf-edge deltas and submarine ramp system using ~24,500 km of 2D seismic lines covering the continental shelf and slope outboard of the modern
Rio Grande River delta. Age control was provided by previously identified nannofossil biostratigraphic markers from core located near the distal end of the submarine ramp and radiocarbon dates from the youngest shelf-edge delta.

**Outcomes:** Regional mapping of the linked systems yields a conservative estimate of > 1100 cubic km for the deposited volume of Tarantian (Wisconsin Glacial Episode) to early Holocene sediment. Accumulation of this very large sediment volume indicates a transport efficiency connected to the last glacial episode which cannot be predicted by analysis of the modern river. While most of this sediment is stored in the shelf-edge deltaic complex, a considerable amount accumulated on the upper-to-mid continental slope. We focused our attention on the first 140 km of slope, positioned immediately down-dip from the shelf-edge; over this distance, water depths systematically increased by 1500 m. The submarine system was composed of a network of aggrading submarine channels and overbank surfaces. Bed slopes for these channels decreased from ~0.05 to ~0.005 over the 140 km, defining a concave-up profile. The associated column of accumulated strata also systematically decreased with distance from ~450 m to ~60 m. On average, reduction in deposit thickness was proportional to the reduction in bed slope, with ~85% of the change in both occurring in the first 80 km. These reductions in deposit thickness and bed slope are correlated with systematic growth in the widths, depths and levees of the contributing submarine channels. A downslope change in character of the submarine-channel network was also observed. Parallel channels transition into a tributary network at a position located downslope of the high-deposition zone. We hypothesize that a highly avulsive Rio Grande shelf-edge delta system inhibited development of a submarine feeder canyon by limiting the amount of time any particular section of the deepwater system was active. Instead, the highly avulsive Rio Grande shelf-edge delta system promoted construction of a distributive submarine ramp.

New radiocarbon dates from the youngest shelf-edge delta reveal the system maintained its position until ~10,500 yr b.p., the mid-Holocene. Previously published radiocarbon dating indicate the oldest channel belt on the modern delta was active ~7000 yr b.p. These dates constrain a ~80 km back-stepping of the delta in only a few thousand years. This relatively old age, but similar channel characteristics suggests that the controlling environmental parameters have remained similar for some time. The Holocene delta has been constructed as these channels avulse and migrate across the delta surface, and sediment laden floodwaters are routed through these abandoned channels to continue aggrading and building the delta far from the active channel. The modern Rio Grande and preserved paleo-channels exhibit channel widths and depth of ~100-150 m and ~7-10 m that do not significantly vary along the nearly 300 river km covered by our lidar dataset. Similarly, all channel belts remain over 2km wide all the way to the coast and channel bend cut-offs are observed all the way to the coastal river mouths. We hypothesize that the consistent channel geometries and presence of significant migration and bend cut-offs all the way to the coast is linked to the high degree of discharge variability, where flood events are 2-3 orders of magnitude larger than baseflow conditions. These results highlight the potential role of extreme discharge variability on the stratigraphy of deltas.

The data supporting the results summarized here are found in the 2017 RioMAR slide presentations by Swartz and Mohrig and Swartz, respectively. Both studies are being
worked into manuscripts that will be uploaded to the RioMAR website as soon as they are completed.

**10⁸ tons/yr of Amazon mud impacts paleo-Orinoco Delta lobes.** The modern Orinoco delta is a major sink for the world’s largest alongshore fluid mud dispersal system; it receives some 10⁸ tons/yr from the Amazon river delta; fluid mud transported along the South American coast by the Guyanas littoral current on the innermost shelf. This has been happening since the late Miocene initiation of the Amazon Delta, though the mud delivery is likely interrupted or greatly decreased due to shelf-width decrease during eustatic sea-level fall and lowstand periods, i.e., for possibly two thirds of the duration of each 60-100Ky glacio-eustatic cycle. Correspondingly, the mud conveyer belt is likely to be at peak activity for the remaining one third of these eustatic cycles, i.e., during rising and high eustatic sea level when the shelf was widening. The influence of these huge volumes of Amazon mud on the coeval and actively building paleo-Orinoco Delta succession is now being investigated for the first time (PhD student Yang Peng). Fluid mud is recognized and differentiated from hemipelagic mud in the stratigraphic record as mud layers >0.5cm-thick that are unbioturbated and unlaminated, sometimes having a squishy or network-filling aspect. Fluid-mud deposits are preserved (Fig. 10) and partly reworked with different styles in tide-dominated and in storm wave-dominated delta lobes of the Pliocene Orinoco Delta deposits (Lower Morne L’Enfer, Manzanilla and Mayaro formations on Trinidad). The development of fluid mud in these formations is being investigated, (1) as regards where, in any stratigraphic sequence in space & time, it is best developed (as a test of the off-on, lowstand-highstand hypothesis) and as regards how the mud is handled by the receiving wave-dominated vs tide-dominated Orinoco Delta lobes.
**Outcomes:** Present results suggest that when Orinoco delta lobes were most strongly tide-influenced (the Morne L’Enfer and Manzanilla formations) they were able to trap muddy sediment in a relatively passive manner near the shoreline and on the subaqueous delta platform in water depth less than 10 to 20 m (Fig. 11, upper). In contrast, the storm wave-dominated delta lobes (the Mayaro Fm), that occur preferentially on the outer shelf and near the shelf edge, handled the fluid mud dynamically; the open marine storm waves tended to erode and re-suspend the fluid mud in shallow water, and re-deposit it into deeper water near the storm wave base (15-50 m water depth) (Fig. 11, lower). The characteristic details of the fluid mud layers and how they are preferentially trapped on the shallow, subaqueous platform of tide-dominated delta lobes that have a double clinoform system on the shelf are included in a current RioMAR website ms (Peng et al. now accepted). Storm-wave erosion and fluid mud resuspension by waves, and the association of swaley and hummocky strata with fluid mud is further described in a second report (Peng et al.) now being placed on the RioMAR website.

*Fig. 10. Fluid mud on paleo-Orinoco delta front (A) Very thick fluid-mud layers showing lack of lateral continuity (B) Thick, deformed fluid-mud layers interbedded with structureless sandstones. (C) Thin fluid-mud layers amalgamate to thick beds and drape along ripple laminae. (D) Fluid-mud intervals composed of thin fluid-mud layers.*

*Fig. 11. Schematic diagrams showing the distribution of the fluid-mud deposits in the tide- and wave-dominated delta fronts*
3. DEEPWATER

Wilcox canyons, deepwater antidunes & other supercritical flow deposits, wave effects on turbidity currents, a new look at lobe to channel proportions and lithology, tide- and wave-influenced turbidites in outcrop and experimental turbidity currents on mobile substrates. Deepwater represents the “sink” segment of the source-to-sink sedimentary systems with basin margin hinterland still acting as sediment “source” to the basin floor that represent the ultimate sink of the system. The 2016-2017 RioMAR projects advanced knowledge on different aspects of the deepwater segment of S2S from processes affecting individual gravity flows to architecture of deepwater deposits or basin margins.

Wilcox Canyons. Within a source-to-sink system, canyons often represent the main conduits for sediments delivered to the basin floor. The current model for shelf-margin canyon formation and evolution emphasizes the linkage of the canyon generation and its evolution with the large rivers that discharge in the basin landward to the position of the canyons. The mechanism for cutting canyons is generally seen in relationship with rivers that reach and incise the shelf-edge during the time of low relative sea level.

The outcome of this research shows that large scale tectonic uplift could be the main trigger for the initial formation and subsequent evolution of canyons in northern Gulf of Mexico. Review of the literature on Paleocene-Eocene Wilcox Formation in the Gulf of Mexico reveals canyons clustering in an area aligned with the axis of an “arch” or “dome” in the onshore areas (Figure 1). The canyon occurrence at multiple times during the accumulation of Wilcox Formation and along the axis of the San Marcos Arch, which according to some studies was coincident with tectonic uplift pulses, strongly suggests a direct tectonic control. The mechanism of tectonic uplift controlling canyon incision has not been previously considered in the Gulf of Mexico or other basins. As an outcome of this study, in addition to the lowstand model (well described in sequence stratigraphy) we propose two new possible mechanisms for canyon formation. A shelf edge bulge scenario proposes a slow vertical rise, extension of the sub-regional, elongate uplift onto the shelf and shelf-edge area that increased the shelf-edge gradient, triggered the initial incision and supported long term headward erosion. Secondly, a high uplift rate (HUR) scenario with a fast-vertical rise and extension of the uplift into the inner shelf area, the high uplift rate diverted the rivers away from the area and protruded the shoreline as a headland. The headland diverted the longshore currents and sediment transport basinward and eventually cascading over the shelf-edge initiating incision and formation of the canyons. A report summarizing this work will now be placed on the RioMar website.
Ancient antidunes as supercritical bedforms. Recent renewed interest in supercritical flows and associated deposits has resulted in a string of studies on supercritical bedforms: these have emphasized the conditions conducive to the generation of supercritical bedforms (physical and numerical experiments) or the ubiquity of such bedforms, especially in deepwater environments (mostly from seismic data or modern bathymetry data). However, there is no facies model for supercritical deposits because there are no studies that have described these in the rock record that come close to the examples observed in seismic data (match the dimensions, thickness).

In this project PhD student Logan West has identified, mapped and characterized large scale (few tens of meters thick and hundred meters wavelength) antidune deposits in outcrops of relatively steep, fairly coarse-grained, deepwater slope to basin-floor deposits on the western side of the newly opening Gulf of California. The large antidune bedforms (Fig. 13) occur within the thick Late Miocene slope stratigraphy (Lycium Mbr.) in the Valecito - Fish Creek Basin. The deepwater antidune bedform interpretation is based on the recognition of individual beds as “turbidites”, but despite variable thicknesses, wavelengths, and bedding orientations, all have low-angle, undulating dip-view waveform geometries and stack successively to the upflow direction (southwest). A report summarizing this work is on the RioMAR website.

Outcomes: The Lycium supercritical slope deposits contain three primary facies: 1) 10-45 cm-thick, medium-grained, normally graded sandstones, 2) 1-15 cm-thick, fine-grained sandstones interbedded with silty mudstones, and 3) 50-100 cm-thick laminated silty mudstones. 5-10 m-thick bedsets of ~20-30 distinguishable beds occur as either isolated bodies or stacked bundles between regional bounding surfaces. What is extraordinary and makes the Lycium deposits suitable for construction of supercritical-flow facies models is that the large bedforms identified (Figure 13) are not built by single flow events (as described in physical experiments), but were generated from long-lived series of turbidity-current episodes that preserved the larger upslope-migrating bedset and bundled bedset geometries.
Figure 13: Image of slightly oblique dip view of deposits and tracing of individual beds. Major bounding surfaces in black, erosional where dashed. Paleoflow from left to right.

A second field area of supercritical flow studies are the southern Californian outcrops of Juncal Fm. and LaJolla Group. This work has resulted in documentation of supercritical flow structures in conglomeratic to mud-prone deposits in slope channels (Kenya Ono thesis; Ono and Plink-Bjorklund, 2017). In order to test the origin of the sedimentary structures recognized in outcrop. We followed up with experiments with a wide range of grain sizes (clay to gravel). These experiments produced sedimentary structures very similar to those documented in outcrop.
**Water surface wave impact on turbidity current dynamics.** Turbidity currents composed of quartz silt and very fine sand were released into a 10m long, 1.2m deep tank. Currents ran down a 9-degree ramp with a motor driven wave-maker positioned at the distal end of the tank. The currents interacted with the wave field as they travelled downslope into deeper water. While oscillatory velocities measured within the wave-influenced turbidity currents decreased with distance downslope, the maximum oscillatory velocities measured in the combined-flow currents at depth were five to six times larger than those measured under a wave field without turbidity currents. These results suggest that combined-flow turbidity currents can transmit oscillating-flow signals beneath the effective wave base and deposit combined-flow bedforms below the effective wave base, indicating that additional lines of evidence should be used to unambiguously define the effective paleo-wave base.

The data supporting the results summarized here are found in the 2017 RioMAR poster by Koo et al. and the slide presentation by Daniller-Varghese. Both studies are being worked into manuscripts that will be uploaded to the RioMAR website as soon as they are completed.

**Where are the depositional lobes in active depositional systems?** Purpose of the deepwater projects on Eocene active margin in southern California was hypothesis that active margin systems are different due to their S2S high gradients. The original approach was to compare two slope systems, one channelized and confined in a canyon (La Jolla Group) and the second a slope fan system (Juncal Fm., Frazier Park; Kenya Ono thesis, Ono and Plink-Bjorklund, 2017). As a second stage we now added the documentation of Juncal Fm basin-floor fans (Dessy Sapardina poster).
Outcomes. The Californian active margin slopes (Kenya Ono thesis; Ono and Plink-Bjorklund, 2017; Plink-Bjorklund presentation) are intensely channelized. Amalgamated channels occur both in the previously interpreted slope fan (Juncal Fm) and canyon settings (La Jolla Gr). Lateral channel mobility was controlled by avulsions rather than channel migration as seen by the cross-cutting channel relationships. Slope channel fills are highly variable and consists of conglomeratic to sandy to heterolithic deposits. Independent on the fill lithology, the channels indicate active infilling where individual beds are separated by erosion surfaces and coarse lags. This occurs even where channels are dominantly mud filled. Such dominantly mud-filled channels form in places large volumes of the slope succession, which contrasts the draping mud-prone deposits documented from other RioMAR shelf margins (Spitsbergen, Karoo; Washake – Dessy Sapardina poster). Mudstone facies are commonly structureless indicating rapid mud deposition from rapidly decelerating flows. Erosion and bypass features range from a few centimeters in smallest bedforms to 100 meters at channel base. Channel-fill facies are dominated by Froude supercritical flow structures, such as backsets and low-angle long-wavelength features. Experiments with variable grain sizes (gravel to clay) at Froude supercritical flow conditions at Eurotank produced sedimentary structures very similar to those observed in outcrops and suggest deposition from cyclic steps (Fig. 3). These experiments also confirm that muds can be rapidly deposited in hydraulic jumps where flow abruptly decelerates. Preliminary outcomes of the documentation of basin floor fans indicate the presence of large-scale erosion surfaces and thus support ideas on a larger proportion of channelized basin-floor facies (Dessy Sapardina poster).

Tide- and wave-influenced turbidity currents and turbidites. The Eocene Elkton Siltstone at Cape Arago, Oregon, USA, is interpreted as an upper-slope succession that contains rhythmically bedded turbidites. The rhythmically bedded section is interpreted as the product of tidally modulated hyperpycnal flows from shelf-edge deltas. A paleo-topographic reconstruction has the proximal measured sections located a short distance down-dip of the shelf slope-break and the distal sections located ~1.5 km further offshore in > ~125m water depth. Sedimentary structures within the rhythmites change in character from proximal to distal sections, but both sections preserve combined-flow bedforms within the beds, implying wave influence. Exactly how turbidity currents transport an oscillatory flow field generated by water-surface waves into deeper water was investigated in the Morphodynamics Lab at UT-Austin. These experiments sought the answer the following questions. How do oscillating and unidirectional flow fields combine to produce wave-influenced turbidity currents? Can wave-influenced turbidity currents transport an oscillating flow signal beneath effective wave base and what is the magnitude of this signal? Outcomes: Evidence for the interpretation of tidal influence in the Elkton Siltstone is taken from couplet thickness measurements consistent with semidiurnal tides arranged into monthly cycles. Semidiurnal couplets representing one high tide – low tide cycle are typically 5 – 20 mm thick with a median grain size of very-fine sand and a maximum grain size within the upper-fine to lower-medium sand range. These deposits were likely sourced from suspended-sediment laden river plumes with the thinner, finer-grained fraction of a couplet representing deposition during flood tide, and the thicker, coarser-grained fraction representing deposition during ebb tide.
Turbidity currents composed of quartz silt and very fine sand were released into a 10m long, 1.2m deep tank. Currents ran down a 9-degree ramp with a motor driven wave-maker positioned at the distal end of the tank. The currents interacted with the wave field as they travelled downslope into deeper water. While oscillatory velocities measured within the wave-influenced turbidity currents decreased with distance downslope, the maximum oscillatory velocities measured in the combined-flow currents at depth were five to six times larger than those measured under a wave field without turbidity currents. These results suggest that combined-flow turbidity currents can transmit oscillating-flow signals beneath the effective wave base and deposit combined-flow bedforms below the effective wave base, indicating that additional lines of evidence should be used to unambiguously define the effective paleo-wave base.

The data supporting the results summarized here are found in the 2017 RioMAR poster by Koo et al. and the slide presentation by Daniller-Varghese. Both studies are being worked into manuscripts that will be uploaded to the RioMAR website as soon as they are completed.

**Experimental study of interactions between turbidity currents, turbidites, and a mobile substrate.** Progress on this project has been hampered by the lack of a suitable laboratory proxy for a salt that can be used in underwater experiments. The widely used PDMS is less dense than water and therefore susceptible to a gravitational instability that limits both the duration and total accumulated strain within with substrate before system failure. A new polymer that is denser than water has been found and its rheological properties relative to PDMS have been determined. With the new polymer in hand we expect this project to rapidly move forward during the next year.

**Outcomes:** Supporting data are found in the 2017 RioMAR poster by Liu.

**SUMMARY**
By way of summary and to make the point that although RioMar consists of very many projects (because there are many PIs and many students), we do have an overarching theme of Source-to-Sink. Further, we believe that real progress in source to sink study will come from asking questions about the details of the component parts, as well as looking at the larger scale linkage of the parts. We offer the summary diagram below, to emphasize the coverage of RioMAR component parts. The project numbers on the diagram refer to both presentations and posters at our 2017 Annual Meeting in Houston.
References


Milliken, K.T., Blum, M., Martin, J., 2012, Scaling relationships in fluvial depositional systems. AAPG Annual Convention and Exhibition. Long Beach, California.

Plink-Bjorklund, 2015, Morphodynamics of rivers strongly affected by monsoon precipitation: Review of depositional style and forcing factors. Sedimentary Geology 323, 110-147


Syvitski, J. P., Cohen, S., and Best, J. L., 2017, Do We Need Thermal-Dynamic Transport Models?, River, Coastal, and Estuarine Morphodynamics: Padova, Italy.


Zhang, J., Steel, R.J. and Ambrose, W., in press, Paleocene Wilcox cross-shelf channel-belt history and shelf-margin growth: Key to Gulf of Mexico sediment delivery. Sedimentary Geology, 362, 53-65.