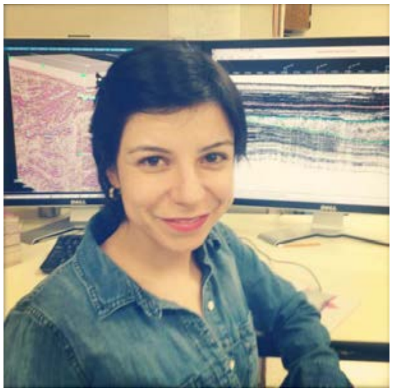

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# Gravity-driven versus current-controlled processes and interactions: An ultra-high resolution study of multiple geomorphological domains in the ultra-deep water region of the central Gulf of Mexico and comparison with global systems

## PROJECT SUMMARY

Studies of modern depositional systems can be used as models to interpret the ancient rock record. However, ultra-deep water modern systems are much more difficult to directly observe (as opposed to modern fluvial and near-shore marine environments) (Nibbelink, 1999). The increasing use of geophysical and well data has contributed to increase our understanding of deep-water slope systems. Despite the extensive work done towards developing depositional models to predict reservoir distribution and architecture in these types of environments, these models usually do not account for along-slope processes and local structural controls that can influence the way sediments are being transported and distributed in ultra-deep water settings.

My research project focuses on the analysis of gravity-driven and current-controlled deposits in three different geomorphological provinces located within the ultra-deep water region of the central Gulf of Mexico (GOM). The main objective of my research is to understand how local structural controls (salt tectonics) affecting the bathymetry of the basin, as well as environmental factors can influence the character and intensity of processes associated with the formation of gravity and current-controlled deposits in these provinces. It is also the intent of my research to better understand the relevance of gravity-driven versus current-controlled processes in the lower continental slope to abyssal plain transition, as well as to understand the character of the interaction between these two very distinctive sedimentary processes in these ultra-deep water domains. I seek to attain these objectives through the description of structures affecting the sea floor and near- sea floor section, the identification and detail description of gravity versus current-controlled deposits in the shallow stratigraphic succession and the characterization of the interrelationships and potential links between occurrence of deposits and structural background.

The data sets available for my study were donated by BP and partners in 2011 and consist of four ultra-high resolution geophysical surveys that were acquired in the central GOM during 2001. These surveys cover four major fields (Thunder Horse, Atlantis, Mad Dog and Holstein) and were acquired for geohazards evaluation purposes (Fig. 1). The geophysical surveys include three types of high-resolution data: multi-beam bathymetry, side-scan sonar images and chirp sub-bottom profiles (8-10 kHz) (Fig. 2). In addition to shallow penetration high-resolution geophysical data, a conventional three-dimensional seismic reflection data set from the Mad Dog area (Sigsbee Escarpment) is also available for my study. Piston cores and borings were also taken within the study areas as part of the geohazards evaluation and previous authors have established lithological and age controls (Al-Khafaji and Young, 2003; Brand et al., 2003; Niedoroda et al., 2003b; Young et al., 2003; Slowey et al., 2003; Eddy Lee and Taylor, 2003; Eddy Lee and George, 2002). This previous information derived from core data will be also incorporated into the present study by mapping horizons associated with key stratigraphic markers and associate lithological character to stratigraphic units. Deep Sea Drilling Project (DSDP) Leg 96 drilled 7 wells that lie in relatively close proximity (93~150 km) to the study areas. These data will be reviewed in order to identify similarities/differences with my data that allow any type of correlation within a broader spatial range in the GOM. Three geomorphological provinces were defined based on the character of the underlying structures (salt tectonics) and the four study areas were grouped into these subcategories: (1) Minibasin province (Holstein), (2) Sigsbee Escarpment (Mad Dog and Atlantis), and (3) Disconnected Canopy Province (Thunder Horse). Each of these geomorphological provinces has characteristic morphological and architectural elements that are believed to differentially influence the way in which currents and gravity-induced processes interact with the associated bathymetry.

The following research questions will be pursued during this work: Are any aspects associated with the local structural configuration of the study areas controlling the occurrence of erosional and/or depositional features that are observed within the pre-defined geomorphological provinces? What are the key environmental and geological variables that govern sediment deposition within the ultra-deep water region of the central GOM? To what degree can deepwater bottom currents in the GOM redistribute sediments deposited by gravity-induced processes and suspended sediment load? Are modern processes governing the ultra-deep water region of the central GOM representative of older depositional environments? Are ultra-deep water processes and effects active in the Gulf of Mexico basin unique to this setting or more generically representative of processes worldwide?

My methodology involves the interpretation of the four ultra-high resolution geophysical surveys that were acquired within the Green Canyon and Mississippi Canyon protraction areas in the central GOM (water depths of 3600-7100 ft) (Table 1). This high resolution data set will allow me to map in detail stratal relationships and provide a detailed view of the structural and geomorphological elements that are present in the shallow subsurface. The generation of structural and isochron maps will allow me to document the vertical and lateral evolution of the main stratigraphic units. A systematic collection of morphometric information associated with individual depositional elements will allow me to link morphometric parameters with particularities of transport mechanisms. Integration of core data will provide a link between geophysical observations and the rock character of some of these units. In the Mad Dog area, observations of the seafloor and shallow subsurface section will be made independently using both the ultrahigh resolution geophysical data, as well as the conventional 3D seismic survey so that sensitivity parameters associated with vertical and horizontal resolution at shallow depths for these different data sets can be calculated. My findings will contribute to the increasing effort of highlighting the importance of connecting deep-sea topography, gravity-driven and current-controlled processes into previous conventional deep and ultra-deep water depositional models. I intend to compare these observations with other deep-water systems around the world, including the eastern Trinidad margin, offshore Morocco and the Taranaki Basin in New Zealand, where I have similar deep-water data at my disposal. The final objective of my research is to generate an updated depositional model for the ultra-deep water region of the GOM that can also be used as an analog for understanding more ancient ultra-deep water depositional systems, many of which deposited hydrocarbon reservoirs, which are difficult to image seismically and which have very limited well information available.

**Regional context of study area**

The present rugged topography and seafloor morphology of the slope in the central GOM area is the result of the interplay between shelf-edge progradation, shale and salt diapirism, sediment loading, dynamic topography of salt, subsalt deformation and slope instability induced mass movements (Liu et al., 2000; Hudec et al., 2009). The Sigsbee Escarpment, a ~2300 ft relief bathymetric feature, represents the boundary between the upper continental rise and the base of the continental slope; this boundary also defines the downslope limit of the shallow allochthonous salt in the GOM (Niedoroda et al., 2003a; Orange et al., 2004). Towards the abyssal regions the relief is mainly smooth, however at the base of the escarpment, big sedimentary furrows that run parallel to it are present (Fig. 3). These furrows run for several kilometers, and in the study area, they have been measured to be 20 to 30 m wide and 3 to 8 m deep. Strong bottom currents have been measured and directly observed flowing parallel to these furrows (Niedoroda et al., 2003b). Current measurements indicate that bottom currents range up to 100 cm/s and more (Bryant and Bean, 2000; Niedoroda et al., 2003b).To the northeast, a prominent U-shaped erosional feature cutting through the shelf break represents the Mississippi Canyon (Fig. 1). The canyon has a width of about 30 km and it was the major sedimentary pathway that linked the continental shelf to the Mississippi Fan. East from the canyon, the seafloor morphology is shaped by the underlying influence of a series of "pancake-shaped" (5-15 km wide) salt domes that become more scattered and smaller in size in a basinward direction (Liu et al., 2000).

**Water circulation and current development in the Gulf of Mexico**

The Loop Current is a warm-water current that originates in the Caribbean Sea and enters the GOM through the Yucatan Strait (National Oceanic and Atmospheric Administration). Upon entering the gulf, the Loop Current flows in a clockwise direction (Fig. 4), until it exits the gulf through the Florida Strait. At this point, it meets the Gulf Stream in the Atlantic (National Oceanic and Atmospheric Administration). Within the gulf, eddies are detached from the Loop Current and disperse into the western GOM (Oey et al., 2005; National Oceanic and Atmospheric Administration). Together, the Loop Current and associated eddies dominate the upper (surface to depths of 500 to 1000m) circulation within the gulf (Oey, 2008). Some studies have attempted to understand the dynamics of bottom circulation within the gulf at depths greater than 1000m, and it has been suggested that the Loop Current and associated eddies influence the hydrodynamics of the deepest portions of the water column within the GOM (Oey, 2008; Hamilton, 2007). This last observation might suggest that deep circulation in the GOM could be linked to energy from the Loop Current and eddies. It is also important to keep in mind that bottom-current velocity is heavily affected by frictional stresses at the seabed (Hernández-Molina et al., 2011). This is particularly relevant in the GOM where bottom currents may be periodically stronger due to interaction with steep slopes associated with bathymetric irregularities such as the Sigsbee Escarpment.

**Objective**

This research seeks to understand the dynamics of sediment transport mechanisms in ultra-deep water settings within the central GOM, and to investigate how these processes impact sediment distribution and preservation. My approach includes studying the relationship between the geomorphological character associated with each province (Minibasin, Sigsbee Escarpment and Disconnected Canopy) and the processes that dominate sediment erosion and deposition within these regions. The intent is to establish the nature of the interaction between gravity-driven and current-controlled processes in the lower continental slope to abyssal plain of an extensional mobile substrate. The highly variable topography of the Sigsbee Escarpment and more proximal minibasins provide a scenario that will allow evaluation of the impact that seafloor morphological expressions have on the definition of sediment pathways and how different localized structural regimes might affect sediment distribution through time.

**Hypotheses**

1. If architectural elements generated by gravity-driven and current-controlled processes may show similar morphological characteristics (i.e. turbidites, contourites, sediment waves); then, the successful identification of classic turbidites versus sediment waves and/or contourites will require collection of morphometric data associated with their geomorphological expression (i.e. thickness, width, length, area, wavelength, etc.) and proper placement into the context of the geomorphological provinces where these deposits occur.

2. If underlying salt play a major role in defining the present configuration within the study area; then, underlying structural controls play a greater role than previously documented on processes

associated with deepwater sedimentation since variations on the local structural style define the location of sinks and sedimentary pathways. This structural variability also influences the nature of the interaction between current-controlled and gravity-driven processes with existing bathymetric irregularities.

3. If the controlling parameters that determine the geomorphological characteristics observed in deepwater environments rely to a big extent to the rugosity of the seafloor and local structural controls and alternatively, relative sea level fluctuations can also influence prevailing bottom-current conditions; then, by establishing the relative influence of these processes, we can determine the nature and character of specific controlling parameters (autogenic versus allogenic).

4. If sediment transport mechanisms in ultra-deep water settings cannot be exclusively attributed to gravity-induced processes; then, processes associated with the action of bottom currents in deepwater environments have been underestimated; mainly because tracking of these processes in the rock record is difficult and because adequate analog models are currently lacking.

**Preliminary observations**

The three geomorphological provinces within the study area experienced different degrees and types of substrate deformation. Bottom- current activity also affected these areas differently and pathways associated with sedimentary sources were also from a diverse nature. In terms of structural controls, it is the underlying salt that plays the largest role in deforming and destabilizing the seafloor. This effect is felt most dramatically in the Sigsbee Escarpment, where salt is actively advancing southward. This generates stresses at the seafloor, creating fault systems that are predominantly parallel to the slope and that have clear sea floor expression as shown in the high resolution bathymetry at the Mad Dog and Atlantis areas. The associated deformation and uplifting also favors the initiation of mass failures that flow perpendicular to the general slope orientation into the abyssal plain. Bottom-currents seem to preferentially run parallel to the Sigsbee Escarpment gouging furrows and remobilizing sediments across this boundary. Within the Minibasin geomorphological province, the majority of movement seems to be vertical due to inflation of diapirs (Hudec et al., 2009). These uplifts can completely isolate an area, leaving it sediment starved for certain periods of time but sediments always infill the accommodation by a combination of suspension, gravity-driven and current-controlled processes.

East from the Mississippi Canyon, in the Disconnected Canopy Province, a major shallow allochthonous salt feature lies beneath the study area and has positive bathymetric expression at the seafloor. The general texture of the seafloor is hummocky; however there is a transitional area that defines the boundary between the domal structure and the lower elevations where the seafloor is smoother.

**Implications**

Further analysis of the high resolution geophysical data used in this research will allow for a broader and more detailed analysis of sedimentary processes that are active in ultra-deep water settings. These analyses will also allow me to pinpoint the influence that local structural controls, relative sea-level fluctuations, sediment supply and other environmental controls have in the distribution of gravity-driven versus current-controlled processes in ultra-deep water environments. The outcome from my observations will be used to generate an updated sedimentary model for ultra-deep water environments with special application to the GOM. This updated sedimentary model will be constructed using high resolution shallow data but it will be useful as an analog model for interpreters working with older stratigraphic units within the GOM where seismic resolution is low and well data limited. Through comparison of results obtained in the GOM (this study) with data from other continental margins (Trinidad, New Zealand and Morocco) I also seek to test the universality of the model and assess similarities or dissimilarities that may exist among different geographic locations and tectonic regimes.

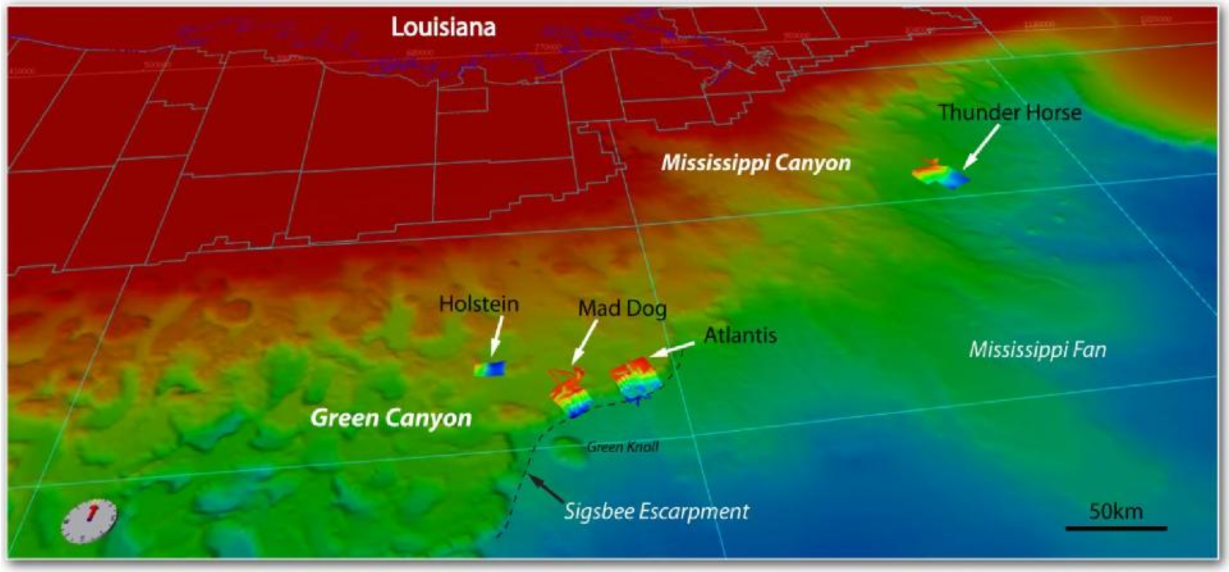


Figure 1. Regional bathymetry, central Gulf of Mexico. The four portions within the gulf subject to study are highlighted by arrows: Atlantis, Mad Dog and Holstein surveys in the Green Canyon area and Thunder Horse survey in the Mississippi Canyon area. Three main geomorphologic provinces are present, Minibasin (Holstein survey), Sigsbee Escarpment (Atlantis and Mad Dog surveys) and Disconnected Canopy Province, east from the Mississippi Canyon (Thunder Horse survey).

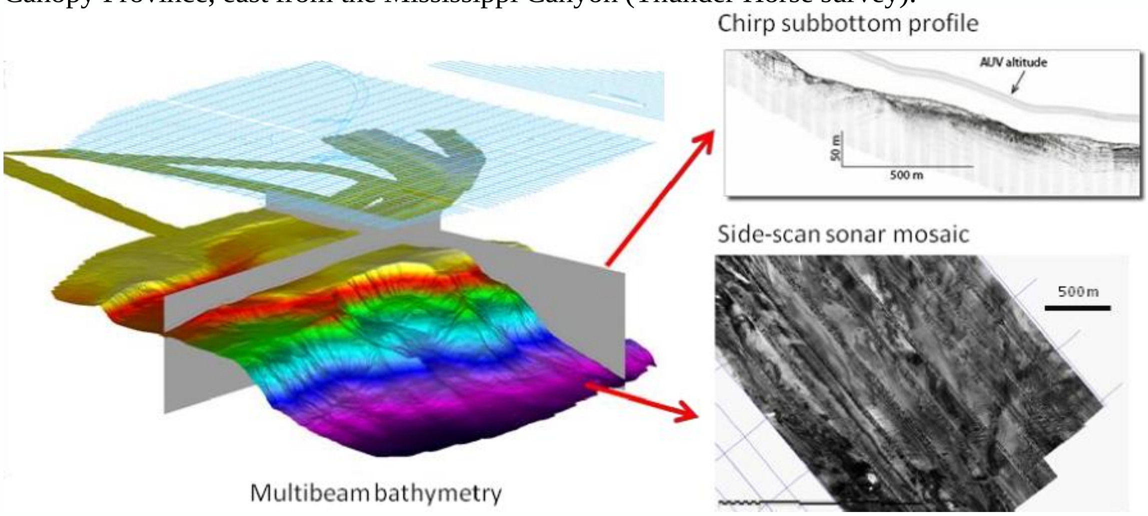


Figure 2. Examples of high resolution geophysical data from the Mad Dog area. The data was acquired using an autonomous underwater vehicle that traveled along grids of 200 - 500 m line spacing keeping a constant distance above the seafloor. Three data types were collected: multi-beam bathymetry, side-scan sonar images and sub-bottom profiles. Together, these data provide a detailed image of the seafloor and near sub-seafloor.

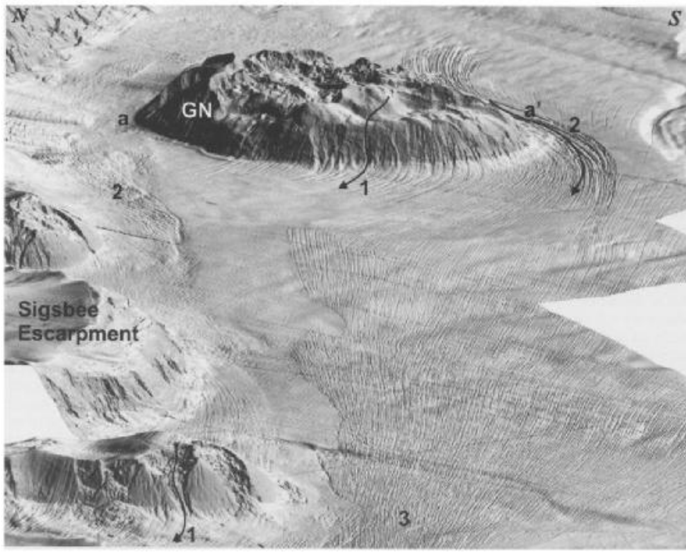


Figure 3. A 3D rendered surface showing the presence of a large field of mega-furrows at the foot of the Sigsbee Escarpment. The depth and alignment of the furrows indicate the intensity of the currents. The currents pass over eroding the Green Knoll (GN) (Viana, Almeida, Nunes, & Bulhoes, 2007) .

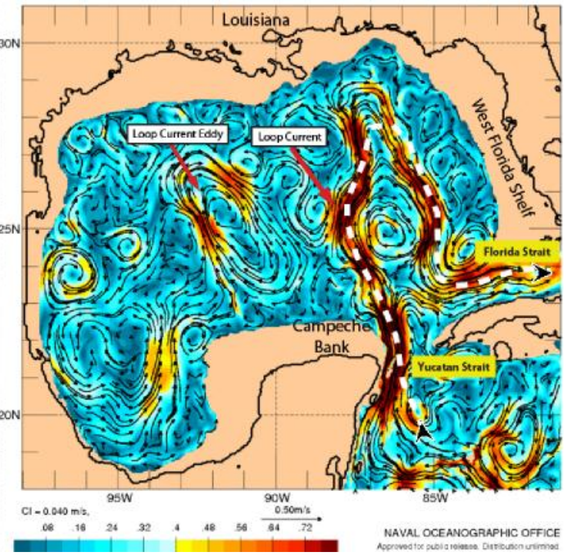


Figure 4. Loop Current enters the gulf through the Yucatan Strait flowing in a clockwise direction until it exits the gulf through the Florida Strait. Within the gulf, eddies are detached from the Loop Current. Source: NOAA.

Table 1 - Area coverage of ultra-high resolution geophysical data

| Survey | Geomorphological Province | Area ($km^2$) | *Line Length (km) |
|---|---|---|---|
| Holstein | Minibasin | 67 | 1310 |
| Mad Dog | Sigsbee Escarpment | 133 | 2823 |
| Atlantis | Sigsbee Escarpment | 185 | 4000 |
| Thunder Horse | Disconnected Canopy Province | 266 | 5450 |

* Addition length of all lines within each survey/grid

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