Episodic flooding of estuarine environments in response to drying climate over the last 6,000 years in Baffin Bay, Texas

Daniel Livsey^{1*} and Alexander R. Simms¹

¹University of California at Santa Barbara, Department of Earth Science, 1006 Webb Hall - MC 9630, Santa Barbara, California 93106, USA

*email of corresponding author: livsey.daniel@gmail.com

ABSTRACT

Recent studies along the northwestern Gulf of Mexico document rapid, centennial-scale, landward retreat or back-stepping of estuarine environments up to 20 km ca. 8.0 ka, 4.8 ka, and 2.6 ka. If such rapid changes in coastal environments occurred today along the urbanized coast of the Gulf of Mexico major economical and ecological loss would occur. Although the 8.0 ka event occurs at a time of increased rates of sea-level rise, the latter two do not; leading to the hypothesis that they may be the result of past climate change. In this study, 121 cores, 4.3 km of high-resolution seismic profiles, and 53 radiocarbon dates are utilized to characterize the stratigraphic architecture and constrain the timing of stratigraphic flooding surfaces in the estuarine fill of upper Baffin Bay, Texas over the last 6 ky. Five flooding surfaces, which formed between 1.1 - 1.0 ka, 2.7 - 2.1 ka, 3.8 - 3.0 ka, 5.2 - 4.9 ka, and 6.5 - 5.7 ka, occur within error of drying in southern Texas driven by warming in the North Atlantic and recorded in independent paleoclimate archives. We suggest that these flooding surfaces, which occurred when sea-level in the Gulf of Mexico was rising < 2 mm/yr, were primarily driven by declines in fluvial sediment supply to the coast due to past climate changes.

INTRODUCTION

Modern estuaries, sites of significant population and industry centers, are highly sensitive to changes in relative sea level and sediment supply. Numerous bays within the Gulf of Mexico including Galveston Bay (Anderson et al., 2008), Matagorda Bay (Maddox et al., 2008), Corpus Christi Bay (Simms et al., 2008), and Mobile Bay (Rodriguez et al., 2008) exhibit, rapid, centennial-scale landward retreat (i.e. back-stepping) of estuarine environments of up to 20 km at 8.0 ka, 4.8 ka, and 2.6 ka (Fig. 1A; Anderson et al., 2014). Proposed forcing mechanisms for these back-stepping events include increased rates of relative sea-level (RSL) rise (Rodriguez et al., 2010), flooding of relict fluvial terraces (Rodriguez et al., 2005), and decreases in sediment

supply (Simms et al., 2008; Anderson et al., 2010). Understanding the causes of these back-stepping events is crucial in understanding how estuarine systems will respond to changes in sea level and climate expected over the next century.

Previous studies addressing the causes of the afore-mentioned back-stepping events in the Gulf of Mexico (Anderson et al., 2010; 2014) lack locally derived paleoclimate records and sub-meter resolution RSL data and focus on the lower reaches of the estuarine systems wherein the influence of fluvial systems, and hence terrestrial sediment supply, is dampened (Anderson and Rodriguez 2008). The main objective of this study is to incorporate new records of past sea level and paleoclimate changes and analyze the relative roles of these two forcings on the backstepping of estuarine environments across the Gulf of Mexico over the last 6,000 years, a time period of ever-decreasing rates of relative sea-level rise across the Gulf of Mexico (Tornqvist et al., 2006; Milliken et al., 2008; Livsey and Simms, 2013).

In order to test the relative roles of climate and sea-level changes on estuarine backstepping, we collected 121 shallow-marine cores and 4.3 km of high-resolution seismic profiles from upper Baffin Bay, Texas. The stratigraphy was mapped and the timing of stratigraphic flooding surfaces, was constrained with 53 radiocarbon dates. The timing of these flooding surfaces are compared to locally derived records of past sea-level (Livsey and Simms 2013) and climate (Livsey et al., in review; Buzas-Stephens et al., 2014) to determine the causal mechanism(s) of these back-stepping events.

STUDY AREA

Geologic setting

Baffin Bay, Texas represents the late Pleistocene/Holocene infill of the incised valley created by Los Olmos, San Fernando, and Petronilla creeks during the last glacial cycle (Fig. 1B; Behrens, 1963; Simms et al., 2010). The valley is cut into the Beaumont Formation. The Beaumont Formation is comprised of fluvial-deltaic deposits comprised of sand and sandy-clay and locally overlain by 3 to 8 m of Quaternary eolian sand and silt deposits (Foremen et al., 2009). Catchments soils of the Beaumont Formation around Baffin Bay also contain abundant caliche deposits, which are thought to act as a shoreline stabilizer preserving the dendritic form of Baffin Bay (Behrens 1963). The surrounding central Texas coastal plain has a mean gradient of < 0.8 m/km along the 80 km closest to the coast (Simms et al., 2010). The region is subsiding at a rate of 0.05 mm/yr (Paine 1993; Simms et al., 2013).

62 A large barrier Island, Padre Island, dampens tidal exchange between waters within Baffin
63 Bay and the open Gulf of Mexico. Upper Baffin Bay experiences a mixed tidal regime with a
64 mean tidal range of 0.06 m, a great diurnal tidal range of 0.29 m (difference between mean
65 higher high water and mean lower low water), and a mean spring tidal range of 0.58 m (Livsey
66 and Simms, 2013). Water level variations are controlled primarily by astronomic tides and wind
67 direction (Livsey and Simms 2013).

68
69 Mean annual evaporation within the region exceeds mean annual precipitation (60 to 80
70 cm/y) by ~ 60 cm/y (Behrens 1969). As a result Baffin Bay is generally hyper-saline with
71 monthly salinity averaging between 40 and 50 ppt (Behrens, 1969). However, salinity may vary
72 widely depending on local meteorological and oceanographic conditions; historically ranging
73 between 2 ppt during cloudbursts (Gunter 1945) and up to 85 ppt during droughts (Behrens,
74 1969a).

75 As a result of general aridity, the drainages of Los Olmos and San Fernando creeks, and to a
76 lesser extent Petronilla Creek, are disrupted by aeolian dunes that formed no later than ca. 2.6 ka
77 to the south of Baffin Bay (Foreman et al., 2009). The average annual discharge for stream
78 gauges 40 km inland on Los Olmos Creek and 60 km inland on San Fernando creeks are 0.12
79 m/s from 1969 - 2008 and 0.64 m/s from 1966 - 2008 respectively (United States Geologic
80 Survey, 2009). No stream gauge data are available for Petronilla Creek. The creeks deliver an
81 unquantified amount of sediment to the bay; however, with low mean stream discharge and
82 disrupted drainages sediment discharge is thought to be isolated to episodic rainfall events
83 (Behrens, 1969).

84 Cores and seismic stratigraphy show that Baffin Bay environments experienced backstepping
85 events ca. 8.0 ka, 5.5 ka, and 4.8 ka (Simms et al., 2010; Rodriguez et al., 2010). Prior to 5.5 ka,
86 Baffin Bay exhibited environments typical of other bays around the Gulf of Mexico including a
87 well-developed bayhead delta and oyster reefs (Simms et al., 2010). Since onset of drier
88 conditions at ca. 5.5 ka and the formation of Padre Island ca. 5.0 ka (Fisk, 1959; Rusnak, 1960),
89 numerous environments unique to bays in arid settings have developed within Baffin Bay
90 (Dalrymple, 1964; Behrens and Land 1972; Simms et al., 2010). Typical bayhead delta deposits
91 within Baffin Bay have been replaced by expansive mud flats covered with intertidal microbial
92 mats. The mud flats contain only one main channel and are seasonally submerged by wind tides

93 due to increased prevailing southeast winds that average from 15 to 24 km/h from spring to
94 autumn (Fig. 1C; Simms et al., 2010). Additional depositional environments found in Baffin Bay
95 and unique to bays in arid settings include: serpulid worm-tube reefs, shelly internal
96 spits/beaches/internal islands, mud flats, laminated open bay carbonate mud, and ooidal beaches
97 (Dalrymple, 1964; Behrens and Land 1972; Land et al. 1979; Simms et al., 2010).

98 *Holocene sea level*

99 Compiled Holocene sea-level records from the northwestern Gulf of Mexico indicate
100 decreasing rates of RSL rise through the Holocene with RSL rising at ~ 9 mm/y in the early
101 Holocene to ≤ 1.4 mm/yr after 5.5 ka (Milliken et al., 2008a; Tornqvist et al., 2004). A RSL
102 record spanning the last 5.0 ka and derived from radiocarbon dated buried microbial mats found
103 in upper Baffin Bay indicates a similar trend of decreasing rates of RSL rise since 5.0 ka (Livsey
104 and Simms 2013).

105 *Climate Controls*

106 The hydrograph of southern Texas is bimodal with peak precipitation in late spring and early
107 fall (Livsey et al., 2016). Tropical cyclones may ameliorate drought in southern Texas (Maxwell
108 et al., 2013) but only account for 8% to 12% of rainfall over the study area (Gleason, 2006). The
109 primary moisture source for Texas, the Great Plains Low Level Jet (Forman et al., 2001), is
110 modulated by the zonal position of the Bermuda High (Zhu and Liang 2013). When the Bermuda
111 High is strengthened and displaced westward as a result of either warm winter temperatures in
112 the East Pacific (Zhu and Liang 2013) and/or warm temperatures in the North Atlantic (Maxwell
113 et al., 2013) the Great Plains Low-Level Jet is strengthened resulting in more precipitation in the
114 Midwest United States but less precipitation and higher temperatures in Texas (Zhu and Liang
115 2013).

116 Droughts in Texas are initiated by upper tropospheric anticyclonic disturbances originating
117 from enhanced convection over the Rocky Mountain and Mexican Plateau (RMP) and
118 maintained by surface processes through a soil moisture-precipitation positive feedback
119 (Myoung and Nielsen-Gammon 2010). Enhanced convection over the RMP driven by northward
120 shifts in the Pacific and Bermuda highs (Higgins and Wang 1997) may be driven by poleward
121 shifts in the Intertropical Convergence Zone (ITCZ) through decreased El Niño Southern
122 Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) and/or increases in the Atlantic
123 meridional overturning circulation (AMOC), and Atlantic meridional oscillation (AMO).

During years of enhanced convection over the RMP the North American monsoon is enhanced while precipitation is dampened over the United States Great Plains and Texas (Higgins and Wang 1997). This anti-phased relationship appears in foraminifera assemblage data from Baffin Bay, Texas with dry conditions inferred from saline tolerant genera increasing during enhanced North American monsoon conditions and less saline tolerant genera during weaker North American monsoon conditions (Buzas-Stephens et al., 2014). The strength of convection over the RMP is primarily driven by the mean position of the ITCZ (Higgins and Wang 1997). Since the mid-Holocene the ITCZ has migrated south resulting in a weakening of the North American monsoon (Poore et al., 2003) and overall wetter conditions in south Texas since the hot and dry mid-Holocene climate optimum from ca. 6 ka to 4.5 ka (Nordt et al., 1994; Nordt et al., 2002; Wong et al., 2015). After ca. 4 ka climate conditions over Texas became more variable with a shift to wetter and cooler conditions sometime between 4.0 ka and 2.4 ka (Toomey et al. 1993; Humphrey and Ferring 1994; Nordt et al. 1994, 2002; Buzas-Stephens et al., 2014).

On millennial time-scales the mean position of the ITCZ is modulated by Earth's obliquity (Haug et al., 2001). On sub-millennial timescales the position of the ITCZ may be modulated by sea surface temperature changes in the East Pacific and/or North Atlantic (Haug et al 2001; Poore et al, 2003; Monterro-Serrano et al., 2010; Fensterer et al., 2013). Since the mid-Holocene the Earth's obliquity has decreased resulting in a southerly shift of the ITCZ while concomitant changes in the seasonal distribution of insolation over the tropical Pacific is hypothesized to have enhanced this southerly shift through enhanced ENSO and resultant warming in the East Pacific (Haug et al., 2001; Clement et al., 2000). Foraminiferal assemblage data from Baffin Bay follow this trend with wet conditions inferred from saline tolerant genera decreasing during enhanced ENSO and vice-versa (Buzas-Stephens et al., 2014). During years of warm North Atlantic SST (i.e. + AMO) the ITCZ may also be shifted north and the North American Monsoon enhanced (McCabe et al., 2004) resulting in drier conditions over the study area (Livsey et al., 2016). Numerous studies from the Gulf of Mexico region indicate correlation between precipitation patterns that would result from warm temperatures in the North Atlantic and hence northerly shifts in the ITCZ including studies from: Laguna Salada, a playa < 50 km inland of Baffin Bay (Livsey et al., 2016), foraminiferal assemblage data from Baffin Bay (Buzas-Stephens et al.,

2014), deep marine cores in the Gulf of Mexico (Monterro-Serrano et al., 2010), and speleothem records from the Caribbean (Fensterer et al., 2012, 2013).

METHODS

Coring

Two core types, vibracores and jack-hammer push cores, were utilized to sample the upper reaches of the incised-valley fill of Baffin Bay. Vibracores were collected using a gasoline-powered cement vibrator attached to aluminum core-tubes. Jack-hammer cores were collected using 1.5 m long, 5.7 cm diameter, DT22 Geoprobe® sections pushed into the valley fill using a gasoline-powered jack-hammer. Vibracores up to 4 m in length were collected aboard the *R/V Trinity* and *R/V Tom Sawyer* to a maximum depth of 4.47 m below MSL (Fig. 1C). Jack-hammer push cores up to 7.3 m in length were collected aboard the *R/V Trinity* to a maximum depth of 9.2 m below MSL (Fig. 1C). Core top elevations were measured in the field using a Topcon differential GPS with cm-scale vertical precision. Base station elevations were calculated using the Online Positioning User Service (OPUS) provided by the National Geodetic Survey with the elevation and precision of GPS observations calculated using Topcon Tools software. All elevation data are referenced to upper bay MSL calculated in Livsey and Simms (2013). Cores were split and described at the cm-scale. Observations included grain size, sorting, sedimentary structures, and macrofauna.

Core data including core descriptions, depositional environment interpretation, laser particle-size data, radiocarbon data, microfossil data from Buzas-Stephens et al (2014), and macrofossil data from Simms et al (2010) were compiled into RockWorks16®, a 3D subsurface data visualization software. This data was supplemented with cores from Simms et al (2010) collected in the lower reaches of Baffin Bay but to depths of 17.7 m below MSL. Use of core data from this previous study provides additional constraints on stratigraphic interpretations.

Seismic

An Edgetech® SB-216S chirp subbottom profiler towed from the *R/V Tom Sawyer* ~ 2 m above the bay floor was utilized to collect a 4.3 km seismic profile in upper Baffin Bay (Fig. 1C). Water depths < 1 m in the upper bay precluded seismic collection further up-dip within the bay. A 20-millisecond (ms) linear sweep from 2 to 15 kHz with 6 Hz ping-rate was used to provide ~ 0.1 m vertical resolution. Automatic gain control and band-pass filtering removing lower frequency noise (e.g. boat engine) was conducted during the survey using an Edgetech®

3100P Portable Topside Processor. No other post-processing was conducted. An on board GPS system provided track-line locations. We utilize a two-way travel time (TWTT) seismic velocity of 1500 m/s used by Simms et al (2010). In addition to the new seismic data we incorporated the seismic data and stratigraphic surface interpretations of Simms et al (2010) into RockWorks16®.

Radiocarbon analyses

Five buried microbial mats were measured by accelerator mass spectrometry (AMS) at the Department of Earth Science UC Irvine AMS facility. Three articulated bivalves, and 1 bulk organic carbon sample were also measured by AMS at DirectAMS laboratory in Seattle, Washington, USA (Table 1). In addition, 47 previously published AMS radiocarbon dates were compiled and recalibrated for this study. All samples were corrected for $\delta^{13}\text{C}$ fractionation prior to calibration (Table 1). Simms et al (2009) established a radiocarbon reservoir estimate of 220 yr for Baffin Bay by obtaining an optically stimulated luminescence age from a sand lamina and a ^{14}C age from a mollusk within the same sand lamina. A mean global marine reservoir of 404 yr was used from Reimer et al (2013) to compute the ΔR value, defined as the difference between the global marine reservoir and the local radiocarbon reservoir, of -184 yr. Following Livsey and Simms (2013) we utilize an error of ± 100 yr for a conservative estimate of error in ΔR . All radiocarbon samples were calibrated using calibration curves in CALIB 7.1 (Reimer et al., 2013). Microbial mats were calibrated using the northern hemisphere mixed marine/terrestrial curve with a 50% estimate of marine carbon following Livsey and Simms (2013). Mollusks were calibrated using the marine curve and the bulk organic carbon sample was calibrated using the northern hemisphere terrestrial curve.

Stratigraphic interpretation

RockWorks16® was utilized to visualize core, seismic, and radiocarbon data and interpret stratigraphic flooding surfaces (FS). Following Simms et al (2010) FS were identified as abrupt sedimentary contacts within cores and prominent and widespread continuous seismic reflections between seismic facies in seismic data. To correlate FS identified in core and FS identified in the seismic survey gridded surfaces, made from core contacts for each FS, were compared to the elevations of surfaces identified in the seismic profile in the RockWorks16® 3D viewer. All gridded surfaces in this study were made using the inverse distance algorithm of RockWorks16®. FS closest in elevation to FS identified in the seismic profile were correlated. Final gridded surfaces of each FS were made using elevations from core and seismic data.

Flooding surface chronology

Three methods were utilized to provide chronologic constraints on FS timing. First, radiocarbon samples taken above and below each FS identified in our study were used to correlate our FS with the FS identified by Simms et al (2010). The timing of each FS is reported as the 2σ minimum age of the oldest radiocarbon sample from above a given FS and the 2σ maximum age of the youngest calibrated radiocarbon sample from below a given FS (Table 2).

Second, we compared the mean elevations of the three youngest FS plus the mean modern water depth of upper Baffin Bay to a RSL curve computed from the RSL data of Livsey and Simms (2013). We only utilize this method for the three youngest FS because these FS are characterized by inundation of a sedimentary facies interpreted as intertidal mud-flat deposits. Livsey and Simms (2013) established a relationship between microbial mats found in intertidal mudflats and RSL; therefore we hypothesize that these surfaces can be related to the local RSL curve of Livsey and Simms (2013) to provide additional constraints on FS timing. The 95% error-range for the timing of each FS was computed from the continuous RSL curve with 95% error ranges (Fig. 2; Table 2). The continuous RSL curve was computed using a nonparametric Bayesian RSL regression tool in Bchron, an open-source non-parametric Bayesian software (Parnell and Gehrels, 2015), that accounts for error in both the X and Y directions.

The RSL method assumes that mean water depth provides an upper age-limit on the FS since mean water depth has not increased since the formation of the mud flats after ca. 5.5 ka (Simms et al., 2010) and that each FS represents a paleo-bathymetric surface. Two points support the first assumption. Firstly, water level variations in upper Baffin Bay are primarily controlled by astronomic tides and wind direction (Livsey and Simms 2013). Astronomic tides in the study area have not appreciably varied in the Holocene (Hill et al., 2011). Today the prevailing wind direction is aligned with the bay axis; therefore, any past changes in wind direction would act only to decrease mean water depth (Livsey and Simms 2013). Secondly, fetch would have been less in the past as a result of lower RSL and the confinement of the bay to the v-shaped incised valley. To test the validity of the second assumption we compared volume percent differences between two volumes: 1) the volume between each FS gridded surfaces and a Pleistocene gridded surface (described below) and 2) the volume between a gridded plane that estimates the modern bathymetry (described below) lowered to the mean elevation of each FS and the Pleistocene gridded surface. The gridded plane that estimates modern bathymetry has a slope of

0.01°, computed by the elevation difference between the maximum and minimum bathymetric depths in the study area divided by the distance between these points. The strike of the plane, 146°, is equal to the azimuth of the modern-bay axis. The volume percent difference between the modern bathymetry and Pleistocene and between the gridded plane that estimates modern bathymetry and the Pleistocene is < 1.8%. The volume percent differences for the three youngest FS and the lowered gridded plane are all < 1.6%. We interpret the small volume percent differences to indicate that the interpreted FS grids represent paleo-bathymetric surfaces.

The third method used to constrain the age of the flooding surfaces was to correlate each FS identified in this study to the same surfaces identified by Simms et al. (2010) in an open-bay core BB07-01 with seven radiocarbon dates. Each FS, constrained by radiocarbon data and the RSL method described above, from this study is accompanied by drying events indicated by foraminiferal assemblage changes in BB07-01 (Fig. 3A). 95% age ranges for each FS depth in BB07-01 were selected from a depth-continuous age-model with 95% age-errors computing using seven radiocarbon dates and the age-model regression tool in Bchron (Fig. 3B; Table 2; Parnell et al., 2008). The timing of each FS is reported as the 2σ maximum age of the oldest time constraint of the three methods and the 2σ minimum age of the youngest time constraint (Table 2).

Accommodation change calculations

Changes in accommodation as a function of depth from MSL were computed from a Pleistocene gridded surface and compared to the mean elevation of each FS (Fig. 4). The Pleistocene grid was generated from Pleistocene depths from core contacts, seismic data collected in this study, and Pleistocene depth contours from Simms et al (2010; Fig. 5A). Volumes were computed at 0.1 m intervals from a block-model with cells 100 m² x 0.1 m deep truncated by the Pleistocene gridded surface.

Sedimentation rate changes

To estimate changes in sediment supply with respect to time sediment volumes were computed from a lithostratigraphic model between each FS grid. The volume deposited between the present seafloor and the youngest FS was computed between a gridded surface of modern bathymetric sounding data (NOAA, 1998; Fig. 5B) and the youngest FS (Fig. 5C). The lithostratigraphic model was generated using the RockWorks16® lithostratigraphic modeling tool. The RockWorks16® lithostratigraphy model generates a lithostratigraphic model by

laterally assigning categorical grain-size data (e.g. mud, sand) from core data. Cells are assigned a grain-size category based upon a nearest-neighbor search. Contacts between different grain-size categories are randomized to emulate interfingered contacts. Core data was input based upon the following grain-size categories: mud, sandy mud, muddy sand, sand, and shell hash. Two lithostratigraphic models each with 100 m² cells (the average distance between cores) but one with 0.1 m deep cells and another with 0.01 m deep cells were generated for a portion of the study area with the greatest core coverage (Fig. 6A). Volume percent difference for each grain-size category was < 2% between each model; therefore we utilized the model with 0.1 m cells to decrease computation time needed for the larger model that covered the entire study area (Fig. 6B). Sediment accumulation in m³/yr was estimated by dividing the grain-size category volumes by the median time difference between each FS (Fig. 5C-G). Lower and upper error bounds on sediment accumulation were derived from dividing volumes by the maximum and minimum time difference between each FS respectively (Fig. 7).

RESULTS

Cores and core descriptions

A total of 121 vibracore and jack-hammer cores were collected between 2009 and 2012. Nineteen sedimentary facies were identified in core descriptions from the 121 shallow-marine cores and similar to Simms et al (2010) we group the facies into two primary sedimentary assemblages. Simms et al (2010) described 11 of the 20 sedimentary facies. Nine additional sedimentary facies are identified in this study. Sedimentary facies 1 to 16 in facies assemblage 1 are interpreted to represent the 16 modern depositional environments identified in upper Baffin Bay. Sedimentary facies 17 to 20 in facies assemblage 2 have no modern analogue in Baffin Bay today; however, they are similar to sedimentary facies described in modern estuaries to the north of Baffin Bay. Table 3 provides a list of the sedimentary facies with an abbreviated description and depositional environment interpretation along with the equivalent sedimentary facies of Simms et al (2010). Field and core images of select sedimentary facies are provided in Figure 8. Facies new to this study are indicated by bold-font and asterisk.

Facies assemblage 1

Fluvial system

Sedimentary facies 1 (Floodplain) Sedimentary facies 1 consists of light greenish-grey clay with plant fragments, darker-clay lamina, and few distinct sedimentary structures or fauna

309 preserved in cores. This facies was sampled in cores from the modern floodplain of the creeks
310 flowing into Baffin Bay (Simms et al., 2010). Based upon the location this facies was sampled it
311 is interpreted as fluvial floodplain deposits.

312 *Sedimentary facies 2 (Modern creek-channel deposits).* Sedimentary facies 2 consists of
313 massive brownish-grey, poorly sorted fine sand with some plant fragments and gravel. The
314 gravel component is composed of rounded caliche nodules. This facies was sampled in cores
315 from creeks flowing into Baffin Bay (Simms et al., 2010). Based upon the location this facies
316 was sampled it is interpreted as fluvial bedload deposits.

317 *Sedimentary facies 3 (Tidal-influenced channel sand deposits*).* Sedimentary facies 3
318 consists of a light grey to blue muddy sand with massive and flaser bedding. Occasionally, 1 to 2
319 cm grains comprised of rounded caliche nodules are present. The lower contact of this facies is
320 sharp or wavy. The facies is found in core tops sampled from the main mud-flat distributary in
321 the Cayo De Grullo arm of Baffin Bay (Fig. 1). Based upon the location this facies was sampled
322 and flaser bedding this facies is interpreted as a tidally-influenced channel deposit with
323 intermittent higher-energy flow capable of transporting 1 to 2 cm grains.

324 *Mud flats*

325 *Sedimentary facies 4 (Mud flat).* Sedimentary facies 4 was sampled in core tops along bay-
326 margin mud flats covered in microbial mats. In place of bay-head delta deposits, typical of Texas
327 estuaries north of Baffin Bay, the upper bay contains extensive mud flats (Simms et al., 2010).
328 This facies consists of interbedded and interlaminated light-blue, blue, and green muds with
329 white 1-3mm thick carbonate and clay laminations and microbial mats. The microbial mats and
330 white carbonate lamina are a diagnostic feature of this facies (Livsey and Simms 2013). The
331 contacts between the light-blue, blue, and green muds are gradational or sharp and vary in
332 thickness between 1 cm and 4 cm. Light-blue and grey muddy sand lamina are found at the base
333 of some mud units. Modern microbial mats are characterized by dark vitreous blue-green to
334 black undulating surface with thicknesses ranging from 0.2 cm to ~3 cm. Microbial mats down-
335 core are characterized by wavy dark vitreous blue-green to black lamina ranging in thickness
336 between 0.1 cm to 0.5 cm. An elevation survey of 1,297 modern microbial mats indicated that
337 microbial mats formed between mean high spring water level and mean low spring water level
338 (Livsey and Simms 2013). Based upon the location this facies was found and the presence of

339 preserved microbial mats and carbonate lamina this facies is interpreted to represent intertidal
340 mud flat deposits.

341 *Sedimentary facies 5 (Supratidal mud flat*)*. Sedimentary facies 5 consists of mottled tan to
342 brown sandy mud with sand filled burrows and occasional root casts. Plant fragments ≤ 2 mm
343 are occasionally found. This facies is found in core tops sampled from the central mudflat of
344 Cayo De Grullo (Fig. 1C). Muds sampled from the front ~ 20 m of the central mud flat was very
345 stiff and difficult to core. Core description indicated that these muds are dewatered and
346 structureless. Muds from the interior portion of the central mud flat were similar to muds from
347 the frontal edge but were softer and not as desiccated. The front ~ 20 m of the central mud flat is
348 vegetated with saline-tolerant grasses and succulents. Beyond ~ 20 m vegetation gives way to
349 microbial mats dissected by shallow, cm-deep, tidal creeks. A GPS survey of the central mud flat
350 indicates that the vegetated mud flat front and interior have mean elevations of 0.35 m and -0.02
351 m from MSL respectively. Based upon the location this facies was sampled and elevation above
352 mean high spring water level this facies is interpreted as supratidal mud flat deposits.

353 *Sedimentary facies 6 (Pro mud flat*)*. Sedimentary facies 6 consists of mottled light blue and
354 green clay with abundant plant fragments and lenticular bedding. Shell fragments ≤ 2 cm are
355 occasionally found. This facies is found in core tops sampled from the seaward margin of the
356 modern central mud flat and bay-margin mud flats. Based upon the location this facies was
357 sampled this facies is interpreted to represent sediments deposited proximally to either supratidal
358 mud flats or bay-margin mudflats herein termed “pro mud flat” deposits.

359 *Upper bay*

360 *Sedimentary facies 7 (Valley-margin sand*)*. Sedimentary facies 7 consists of bioturbated
361 muddy light blue to grey medium sand with few shell fragments. 1 to 3 cm well-rounded caliche
362 nodules are occasionally found. This facies is found in core tops < 30 m from the bay margin.
363 The facies resembles nearby muddy sand beach deposits that contain well-rounded caliche
364 nodules and few shell fragments. Similar, albeit less-rounded, caliche nodules were noted
365 eroding from the Pleistocene bluffs < 20 m from the bay shoreline. Based upon the location this
366 facies was sampled and the presence of well-rounded nodules this facies is interpreted to
367 represent sandy bay-margin beaches herein termed “valley-margin sand”.

368 *Sedimentary facies 8 (Upper-bay/bay margin)*. Sedimentary facies 8 consists of bioturbated
369 dark greenish-grey muddy sand with several sand laminae. Plant fragments and foraminifera are

found throughout. This facies contains *Mulinia lateralis* and *Anomalocardia cuneimeris* shell fragments, fauna tolerant of hypersaline conditions. The facies is found in core tops sampled from upper Baffin Bay (Simms et al., 2010). Based upon the location this facies was sampled and the presence of foraminifera and articulated bivalves, this facies is interpreted as upper-bay to bay/margin deposits.

Sedimentary facies 9 (Upper-bay mud)*. Sedimentary facies 9 consists of blue and light blue mottled mud with fine sand-filled burrows and ~ 0 - 15 % shell fragments. Shell fragments are comprised of *M. lateralis* and *A. cuneimeris*. Similar to sedimentary facies 8 this facies is found in core tops from upper Baffin Bay. Based upon the location this facies was sampled and less sand content this facies is interpreted as upper bay mud deposited in a more distal position relative to sedimentary facies 8.

Sedimentary facies 10 (Erosive bayfloor lag)*. Sedimentary facies 10 consists of structureless shelly sandy blue to gray clay. When found in core tops and down-core the lower contact of this facies is wavy. This facies was found in core tops in water depths ≤ 0.5 m. Based upon the location this facies was sampled, the abundance of shell fragments, lack of sedimentary structures, and wavy lower contacts this facies is interpreted to represent wave-reworked upper bay deposits herein termed “erosive bayfloor lag”.

Open bay

Sedimentary facies 11 (Open-bay or distal upper-bay). Sedimentary facies 11 consists of homogenous black to greenish-grey clayey silt/silt with occasional faint laminae and sparse occurrences of the molluscs *M. lateralis* and *A. cuneimeris*, some of which were articulated. This facies, sampled in core tops from the modern open bay by Simms et al. (2010), was not sampled in core tops from this study but was found in deeper portions of the cores from this study. This facies is comprised of 1 to 15% sand-size material and contains foraminifera (Simms et al 2010). Based upon the location this facies was sampled this facies is interpreted as open-bay or distal upper-bay deposits (Simms et al., 2010).

Sedimentary facies 12 (Open bay). Sedimentary facies 12 consists of well laminated and interbedded blue, greenish-grey, and light grey white interbedded muds. This facies, sampled in core tops from the modern open bay by Simms et al. (2010), was not sampled in core tops from this study but was found in deeper portions of the cores from this study. The light-grey to white muds are composed of aragonite, magnesium calcite and dolomite and are hypothesized to be

deposited under sulfate reducing conditions (Morse et al., 1992) or when bay salinity exceeds 60 ppt during drought conditions (Behrens & Land, 1972; Behrens, 1974). Based upon the location this facies was sampled, well-laminated character of the sediment, and lack of bioturbation this facies is interpreted as open-bay deposits.

Sedimentary facies 13 (Nephloid mud)*. Sedimentary facies 13 consists of black, very soft, homogenous mud. The lower contact of this facies when found in core was always sharp. Lighter-black sandy mud-filled burrows are occasionally found. The muds contain 30% clay, 69% silt, and 1% sand. This facies was sampled from core tops behind shelly-spits and in water depths > 1 m. The mud contains a high water content and has the weakest shear strength of any of the facies identified in this study. This facies is similar to estuarine deposits described by Poppe et al. (2008) wherein very fine-grained, water-rich sediment were suggested to be deposited from nepheloid layers in Long Island Sound, New York. Based upon the location this facies was sampled, high water content, and very fine-grained nature of this facies we interpret this facies as muds deposited from nepheloid layers in a back-spit lagoon or deeper protected quiescent water.

Spits

Sedimentary facies 14 (Shelly-spit or fetch-limited barrier island). Sedimentary facies 14 consists of grey-tan shelly fine sand or shell hash. Plant fragments are occasionally found in the shelly fine-sand and shell hash. This facies is found in core tops sampled from modern shelly spits and a fetch-limited barrier island (Fig. 1C; Simms et al., 2010). Shell-fragments deeper in cores are primary comprised of *M. lateralis*, *A. cuneimeris*, *Chione cancellata*, *Nuculana acuta*, *Lucina multilineata* and *Retusa canaliculata* (Simms et al., 2010). While shell fragments in shallow cores and those sampled from modern shelly spits, internal barrier islands, and beaches are primary composed of *M. lateralis* and *A. cuneimeris* (Simms et al., 2010). Based upon the location this facies was sampled and high shell content and the fragmentary nature of the shells, this facies is interpreted to represent shelly-spits or fetch-limited barrier islands.

Sedimentary facies 15 (Back-spit lagoon)*. Sedimentary facies 15 consists of green mud with lenticular and continuous, sharp-based, fine-sandy laminae, abundant plant fragments, and shell-hash and sand-filled burrows. This facies is found in core tops sampled from lagoons landward of modern shelly spits. Commonly this facies is found above or below sedimentary facies 14. Based upon the location this facies was sampled, stratigraphic position, and presence

of lenticular sands and sand lamina, interpreted as washover deposits from nearby shelly spits, this facies is interpreted as back-spit lagoon deposits.

Serpulid worm-tube reef

Sedimentary facies 16 (Serpulid worm-tube reef). Sedimentary facies 16 consists of randomly oriented serpulid worm tubes ~ 1 cm in diameter. This facies was not sampled in core tops but found in one core 1.64 m below the modern seafloor and is very similar to modern serpulid worm tube reefs described by Simms et al. (2010). Modern serpulid worm tubes have replaced oyster reefs typical of Texas estuaries north of Baffin Bay (Simms et al., 2010). Serpulid worm tubes form only along the bay margins in water depths between 0.5 and 2.5 m and may extend up to 0.08 to 0.15 m above MSL (Andrews 1964). Serpulid worm tubes are only found in Baffin Bay after the onset of drier conditions ca. 5.5 ka. This facies is interpreted as a serpulid worm tube reef that formed in hyper-saline water ≤ 2.5 m MSL.

Facies assemblage 2

Sedimentary facies 17 to 20 have no modern analogues in Baffin Bay but as noted by Simms et al. (2010) have similarities to modern environments in other Gulf of Mexico estuaries farther to the north. Facies assemblage 2 is only found in deeper portions of the estuarine fill at depths > 2 m below MSL.

Sedimentary facies 17 (Wet upper bay). Sedimentary facies 17 consists of structureless green and dark-grey muds with sand-filled burrows, plant fragments, and a diverse array of molluscan fauna including: *C. Cancellata*, *A. Cuneinermis*, *Rangia Cuneata*, *L. multilineta*, *Crassostrea virginica*, *Macoma Tenta*, *N. acuta*, *Turbonilla sp.*, and *Neverita duplicatus*. The bivalves are commonly articulated indicating relatively quiescent water. Based upon the diversity of molluscan fauna, abundant articulated bivalves and plant fragments, and location in the upper reaches of Cayo De Grullo this facies is interpreted as upper bay muds deposited during a wet period.

Sedimentary facies 18 (Seagrass flat).* Sedimentary facies 18 consists of structureless dark-green muds with a high abundance of plant fragments, and diverse array of molluscan fauna including: *C. Cancellata*, *Lucina Pectinata*, *Argopecten irradians amplicostatus*, and *R. canaliculata*. The bivalves are commonly articulated indicating relatively quiescent water. Plant fragments are composed of 1 mm to 5 mm (unidentified) grasses. Inside an articulated 3 cm *L. Pectinata* numerous 5 mm grass blades were found. Today the distribution of *A. i. amplicostatus*

is closely tied with seagrass habitats (Withers and Hubner 2009 and refs. therein). Along the Texas coast *A. i. amplicostatus* are found in the greatest abundance in seagrass habitats in Laguna Madre (Withers and Hubner 2009). Based upon the presence of *A. i. amplicostatus*, abundant grass plant fragments, and modern distribution of *A. i. amplicostatus* this facies is interpreted as seagrass flat deposits.

Bay-head delta

Sedimentary facies 19 (Fluvial floodplain). Sedimentary facies 19 consists of dark bluish-grey sandy mud with plant fragments. The mud is stiff indicating that the sediment was dewatered through subaerial exposure and lacks marine foraminifera. Based on the fine-grained nature of the facies, presence of abundant plant fragments, and lack of foraminifera this facies is interpreted as fluvial floodplain deposits.

Sedimentary facies 20 (Bayhead-delta mouth bar). Sedimentary facies 20 consists of structureless muddy medium blueish-grey sand with little to abundant shell fragments and plant material. Shells fragments are comprised of the mollusks *Linea P.*, *A. i. amplicostatus*, *C. Cancellata*, *A. Cuneinermis*, *R. Cuneata*, *L. multilineta*, *C. virginica*, *M. Tenta*, *N. acuta*, *Turbonilla sp.*, and *N. duplicatus*. This facies, barring the molluskan fauna, is similar to mouth-bar deposits described by Simms et al. (2008). Based on the structureless nature of the sand and diverse array of shell and plant fragments indicating rapid deposition and/or reworking and similarity to mouth-bar deposits described by Simms et al. (2008) this facies is interpreted as bayhead-delta mouth bar deposits.

Seismic facies

From a 4.3 km seismic profile four seismic facies were identified in this study.

Seismic Facies A (continuous, horizontal, wavy-parallel). Seismic facies A is found in the shallow portions of the chirp seismic survey and is characterized by continuous, low to medium amplitude parallel reflections (Fig. 9). Sediment facies 3, 4, 6, 8, and 9 are sampled in cores near the seismic survey at depths where seismic facies A is found. Based on correlation with nearby cores this facies is interpreted as upper bay deposits.

Seismic Facies B (Sub-parallel oblique to sigmoid oblique reflections) Seismic facies B is found in the shallow portions of the chirp seismic survey and is characterized by sub-parallel oblique to sigmoid oblique reflections that abut incised-valley walls (Fig. 9). This facies was described by Simms et al (2010) and has the appearance of clinoform packages indicative of

494 progradation. Using a shallow vibracore Simms et al (2010) sampled one prograding package
495 and recovered shelly sand similar to sedimentary facies 14. Based on the geometry of this
496 seismic facies and recovered shell sand this seismic facies is interpreted as prograding shelly
497 spits.

498 *Seismic Facies C (Discontinuous to continuous, with internal chaotic reflections).* Seismic
499 facies C is found in the deeper portions of the chirp seismic survey and is characterized by
500 chaotic reflections with low to strong discontinuous parallel reflectors (Fig. 9). This seismic
501 facies is thickest in the middle of the estuarine fill and commonly forms U-shaped geometries
502 similar to fluvial-channel cross-sections. No nearby cores sampled depths where this seismic
503 facies was found; however, down-dip cores collected at similar depth sampled bayhead delta
504 deposits. Based upon the U-shaped geometry of the facies, chaotic reflections, depth, and
505 similarity to seismic facies F of Simms et al. (2010) this seismic facies is interpreted as fluvial or
506 bayhead delta deposits.

507 *Seismic Facies D (Transparent, chaotic).* Seismic facies D is found in the deeper portions of
508 the chirp seismic survey and is characterized by chaotic low amplitude reflections truncated by
509 seismic facies C. The seismic facies shallows near the coast and deepens to ~ 12 m below MSL
510 towards the bay center. At the bay-margin the seismic facies forms terrace-like steps that
511 progressively step deeper towards the bay center (Fig. 9). Vibracores taken at the valley margin
512 and at depths wherein this seismic facies is found sampled stiff, dewatered, green mud with
513 caliche and tan sands with caliche. These deposits are similar to the Pleistocene bluffs
514 outcropping along the bay-margin. Based on the geometry of the seismic facies and sediment
515 sampled from cores this facies is interpreted to represent Pleistocene deposits.

516 *Stratigraphic interpretation*

517 Five stratigraphic flooding surfaces (FS), representing abrupt changes from more proximal to
518 more distal depositional environments, were identified in cores (Figs. 10,11), four of which were
519 also identified in seismic profiles (Figs. 12,13).

520 FS1 is identified by sedimentary facies 17 sharply overlying sedimentary facies 18.
521 Radiocarbon ages from articulated bivalves from sedimentary facies 18 below FS1 range in age
522 from 6.03 to 6.52 ka in core AM12-02 and 6.33 to 6.82 ka in core AM12-15. A radiocarbon date
523 from an articulated bivalve from above FS1 in sedimentary facies 17 ranges in age from 4.70 to
524 5.27 ka in core AM12-01. Articulated bivalve dates from core AM12-02 and AM12-01 constrain

FS1 between 6.52 and 4.70 ka (Table 2). This surface is correlated to the 5.5 FS identified by Simms et al (2010) and constrained by two articulated bivalve radiocarbon samples in core BB07-01 between 6.81 ka and 5.73 ka (Table 2). Using the older range of the calibrated radiocarbon sample from AM12-15 and the younger range of the calibrated radiocarbon sample from BB07-01 provide a age constraint for FS5 between 6.52 ka – 5.73 ka.

FS2 is identified by sedimentary facies assemblage 1 facies sharply overlying facies from sedimentary facies assemblage 2 (Fig. 10). For example, in core AM10-05 sedimentary facies 20, is overlain by sedimentary facies 8 (Fig. 10D). Below FS2 the diverse array of bivalves found in sedimentary facies assemblage 2 are found. Above FS2 only *M. lateralis* and *A. cuneimeris*, bivalves indicative of hypersaline conditions, are found. A microbial mat and a radiocarbon date from an articulated bivalve from core AM09-05 and AM12-01 constrain FS2 between 5.27 ka and 4.89 ka (Table 2).

FS3, FS4, and FS5 are primarily identified by the contact between sedimentary facies 4, interpreted as intertidal mud flat deposits, and sedimentary facies 3, 6, 8, 9, 10, or 12, all facies that may form within or below the intertidal zone. Abrupt sedimentary contacts at similar depths allowed correlation of FS3, FS4, and FS5 to nearby cores (Fig. 10).

FS1 did not have a recognizable seismic expression in the seismic line collected in this study (Fig. 13). FS2 is identified by the boundary between seismic facies D and seismic facies C (Figs. 12,13). FS3, FS4, and FS5 are identified by high-amplitude continuous reflectors that bound three units characterized by laterally varying seismic facies (Figs. 12,13). The lowest of the three units contains seismic facies B and C. The second deepest unit contains seismic facies C. The shallowest unit is characterized by seismic facies C and A. Near the bay margin seismic facies C unconformably overlies seismic facies B and is expressed within the seismic profile as a high-amplitude continuous reflector; this surface is FS3 (Fig. 12). FS4 is a high-amplitude continuous reflector that marks the contact between the third unit and second most shallow unit (Fig. 12). FS5 is a high-amplitude continuous reflector that marks the contact between the second unit and most shallow unit identified by the contact between seismic facies C and seismic facies A (Fig. 12). The elevations of each FS were digitized and utilized along with elevations from core data to compute new gridded surfaces for each FS (Fig. 5C-G).

Flooding surface chronology

The methods used to constrain the timing of each FS and the 2σ error range for each method is provided in Table 2. The 2σ ranges from each method and for each FS overlap within error (Table 2). FS1 occurred between 6.5 - 5.7 ka. FS2 occurred between 5.2 – 4.9 ka. FS3 occurred between 3.8 - 3.0 ka. FS4 occurred between 2.7 - 2.1 ka. FS5 occurred between 1.1 ka – 1.0 ka.

Accommodation changes

Changes in accommodation with respect to MSL exhibit a linear trend ($R^2 = 0.99$) with bay volume increasing with higher RSL, a trend reflecting the flooding of the antecedent incised-valley morphology (Fig. 4). The mean elevations of the FS occur at depths near no apparent step-wise increases in accommodation (Fig. 4). We interpret the linear change in accommodation with respect to MSL (Fig. 4) to indicate that the morphology of the Pleistocene incised valley did not drive changes in accommodation and therefore, is not a causal autogenic mechanism for the FS identified in this study (e.g. Rodriguez et al., 2005).

Sediment supply changes

The greatest change in sediment accumulation is a decline after FS2 (Fig. 7). Total sediment accumulation declines after FS2, increases after FS3, and remains constant after FS3 time (Fig. 7A). Mud accumulation decreases after FS2 and increases after FS3 (Fig. 7B). Sandy mud accumulation increases after FS3, declines after FS4, and increases after FS5 (Fig. 7C). Sand and muddy sand accumulation decrease after FS2, increase after FS3, and decrease after FS5 (Fig. 7D,E).

DISCUSSION

Timing of FS compared to GOM bays and to the lower reaches of Baffin Bay stratigraphy

FS1 formed ca. 6.1 ka $\pm$ 0.8 ka (Table 2). FS1 is accompanied by a change in foraminiferal assemblages in the lower reaches of the bay indicating a shift to drier conditions in BB07-01 at ca. 5.5 ka (Fig. 14; Buzas-Stephens et al., 2014) and occurs stratigraphically below FS2, which ca. 5.0 ka $\pm$ 0.3 ka (Table 2). Therefore, FS1 is correlated to the 5.5 ka FS identified in the lower reaches of Baffin Bay by Simms et al. (2010). The FS at ca. 5.5 ka is within error of FS documented in Calcasieu Lake, LA and Sabine Lake on the TX-LA border (Milliken et al., 2008b,c).

FS2 formed ca. 5.0 ka $\pm$ 0.3 ka (Table 2). FS2 is accompanied by a change in foraminiferal assemblages in the lower reaches of the bay indicating a shift to drier conditions in BB07-01 at ca. 4.8 ka (Fig. 14; Buzas-Stephens et al., 2014). Sedimentary facies changes across FS2 indicate

a shift to more xeric conditions with sedimentary facies assemblage 2 forming below this surface and sedimentary facies assemblage 1 forming above FS2 (Fig. 10). Faunal changes also indicate a shift to drier conditions with 9 mollusk species identified below FS2 and only 2 mollusk species, indicative of hypersaline conditions, found above FS2. Therefore, FS2 is correlated to the 4.8 ka FS identified in the lower reaches of Baffin Bay by Simms et al. (2010). The FS at 4.8 ka is documented in estuaries just north of Baffin Bay including: Corpus Christi Bay (Simms et al., 2008), Copano Bay (Troiani et al., 2011), and Matagorda Bay (Maddox et al., 2008).

FS3 formed ca. $3.4 \text{ ka} \pm 0.7 \text{ ky}$ (Table 2). Foraminiferal assemblage data at this time are absent due to a core break in core BB07-01; although, foraminiferal assemblage data do indicate a drying trend from 4.2 ka to 3.1 ka (Fig. 14). Timing of FS3 occurs within error of FS identified in Sabine Lake, Calcasieu Lake, and Matagorda Bay (Milliken et al., 2008b,c; Maddox et al., 2008). Simms et al. (2010) did not identify a FS in cores or seismic data near this time in the lower reaches of Baffin Bay. FS3 is the least developed FS identified in this study (Fig. 11). The absence of FS3 development in the lower reaches of Baffin Bay is interpreted to reflect the decreased influence of fluvial versus marine processes.

FS4 formed ca. $2.4 \text{ ka} \pm 0.7 \text{ ky}$ (Table 2). FS4 is accompanied by a shift to drier conditions indicated by foraminiferal assemblage data at ca. 2.8 ka, an increase in drought frequency in the Laguna Salada playa record at ca. 2.7 ka, and dune migration just south of Baffin Bay ca. 2.8 ka (Fig. 14). Timing of FS4 occurs within error of FS that formed ca. 2.6 ka in Corpus Christi Bay (Simms et al., 2008) and Matagorda Bay (Maddox et al., 2008). Therefore, FS4 is correlated to the 2.6 ka FS identified in the lower reaches of Baffin Bay by Simms et al. (2010).

FS5 formed ca. $1.0 \text{ ka} \pm 0.2 \text{ ky}$ (Table 2). FS5 is accompanied by a shift to drier conditions indicated by foraminiferal assemblage data at ca. 0.9 ka, an increase in drought frequency in the Laguna Salada playa record at ca. 0.9 ka, and the Medieval Climate Anomaly, a time period of dry conditions in southern Texas, that occurred between 0.7 ka and 1.0 ka (Fig. 14; Mann et al., 2009). No other FS have been identified in other Gulf of Mexico Bays at this time (Anderson and Rodriguez, 2008); neither was it identified in cores or seismic data from the lower reaches of Baffin Bay (Simms et al., 2010).

All FS identified in this study, except FS5, occur within error of FS identified in other Gulf of Mexico Bays. We interpret this to indicate that FS1 through FS4 formed as a result of allogenic mechanism(s). Although FS5 is not identified in other Gulf of Mexico bays we also

interpret FS5 as being forced by allogenic mechanisms as FS5 occurs within error of the hemispheric-scale Medieval Climate Anomaly (Fig. 14). Previous studies in Baffin Bay and other Gulf of Mexico bays (Anderson and Rodriguez 2008) focused on the lower-reaches of estuarine systems wherein the relative influence of fluvial input is dampened; therefore, FS at ca. 1.0 ka may have formed in the upper reaches of these systems. If the FS at ca. 1.0 ka is not expressed in estuarine systems in more humid climates to the north one explanation may be that the decrease in sediment supply during this time was not sufficient for those estuarine systems to undergo retrogradation.

FS causal mechanisms

The RSL curve of Livsey and Simms (2013) does not extend prior to FS1 time; however, RSL data from the Northern Gulf of Mexico indicates that RSL was rising between 1 - 2 mm/yr after ca. 6 ka with no observed pulses of increased rates of sea-level rise. However, with neither the Baffin Bay RSL record nor other RSL data from the Northern Gulf of Mexico can the possibility of cm-scale RSL rise events as suggested by Anderson et al (2013) be ruled-out, thus we cannot completely dismiss the possible causal role of RSL changes less than the resolution of the existing RSL records for FS identified in this study (Fig. 14).

To determine if climate changes may have played a role in causing the back-stepping of estuarine environments, we compare the timing of FS identified in this study to changes in paleoclimate records derived from the North Atlantic, the Gulf of Mexico, and Baffin Bay (Fig. 14). We utilize the ice-rafted-debris record from Bond et al (2001) as this record is shown to correlate with basin-scale changes in North Atlantic SST similar to those of the AMO (Feng et al., 2010), to changes in drought frequency in southern Texas (Livsey et al., 2016), and to changes in precipitation in the Caribbean (Fensterer et al., 2013; Kilbourne et al. 2008) and Mexico (Bernal et al., 2011). Following Monterro-Serrano et al (2010) we utilize a composite Gulf of Mexico SST as a proxy for the boreal summer position of the ITCZ. Timing of each FS is within error of decreases in ice-rafted debris indicative of a shift to + AMO conditions, warming of Gulf of Mexico SST indicative of a northern shift of the ITCZ, and shifts to drier conditions indicated by paleoclimate records from within and nearby Baffin Bay.

Decreases in sand and muddy sand supply after FS2 and FS5 time support the interpretation that climate change was the primary cause for these FS (Fig. 7). Since no sand facies are observed in open Baffin Bay (Dalrymple, 1964) we suggest that sand is conserved within the

upper bay and thus changes in sand supply reflect changes in fluvial input and hence changes in climate. However, mud with a grain-size $< 6 \mu\text{m}$ is not conserved and may be re-suspended and exported from the system (Shideler 1984; Troiani et al., 2011). An increase in sand and muddy sand supply after FS3 time may suggest that RSL rather than climate was the primary cause for this FS (Fig. 7); however when interpreting these data one should note that the calculations average all time between each FS. Hence a centennial-scale decline in sediment supply prior to a given FS may be masked by prior centuries with higher sediment supply. A decrease of sand may have occurred before and after FS4 time; however, large error bars preclude a conclusive interpretation.

Implications for Coastal Evolution

Our data suggests that climate changes independent of decimeter-scale changes in RSL can drive changes in coastlines. This observation has implications for coastal managers and communities that although facing dampened RSL rise over the next century (e.g. in high-latitude areas and/or in tectonically uplifting area) may face changes in coastal systems due to potentially drying climates. In addition this study highlights the importance of considering land-use changes that alter sediment supply to the coast. Climate change altered sediment supply to the coast driving changes in coastal systems at least during FS2 and FS5 time. Therefore, land-use changes (e.g. changes in agriculture practices, damming of rivers) that limit sediment supply to the coast may have similar effects as a drying climate on coastlines.

CONCLUSIONS

Five flooding surfaces forming ca. 5.5 ka, 4.8 ka, 3.4 ka, 2.6 ka, and 1.0 ka are identified in upper Baffin Bay, TX. These flooding surfaces occur through the late Holocene a time period of ever decreasing relative sea-level rise rates and coeval with local, regional, and far-field climate changes. Flooding surfaces at ca. 5.5 ka, 4.8 ka, and 2.6 ka are documented in numerous Gulf of Mexico estuaries. The flooding surfaces at 4.8 ka and 1.0 ka are accompanied by decreases in sediment supply and clearly point to a coastal response induced by climate. Although similar decreases in sediment supply are not shown ca. 3.4 ka and 2.6 ka all flooding surfaces occur through the late Holocene at times of regionally documented changes in climate and with ever decreasing RSL rates suggesting that climate likely played a more significant role than RSL in causing the FS identified in this study. Relative sea-level data with cm-scale precision are needed

to determine if cm-scale changes in relative sea level also contributed to the formation of these flooding surfaces.

ACKNOWLEDGEMENTS

Funded by grants from the National Science Foundation (NSF) (EAR 0921963), NSF Graduate Research Fellowship Grant No. DGE-1144085, and the Ed Picou Fellowship Grant for Graduate Studies in Earth Science. Zach Poland, Baird King, Anna Cruse, Taylor Troiani, Greg Federko, David Milburn, Sloan Anderson, Emma Hansen, and Jon Baskins helped in the collection of cores.

REFERENCES

- Anderson, J. B., and Rodriguez, A. B., 2008, Response of Upper Gulf Coast Estuaries to Holocene Climate Change and Sea-Level Rise: Geological Society of America Special Papers, v. 443, p. 146.
- Anderson, J. B., Rodriguez, A. B., Milliken, K. T., and Taviani, M., 2008, The Holocene evolution of the Galveston estuary complex, Texas: Evidence for rapid change in estuarine environments: Geological Society of America Special Papers, v. 443, p. 89-104.
- Anderson, J., Milliken, K., Wallace, D., Rodriguez, A., and Simms, A., 2010, Coastal Impact Underestimated From Rapid Sea Level Rise: Eos, Transactions American Geophysical Union, v. 91, no. 23, p. 205-206.
- Anderson, J. B., Kirshner, A. E., and Simms, A. R., 2013, Constraints on Antarctic Ice Sheet configuration during and following the last glacial maximum and its episodic contribution to sea-level rise: Geological Society, London, Special Publications, v. 381.
- Anderson, J. B., Wallace, D. J., Simms, A. R., Rodriguez, A. B., and Milliken, K. T., 2014, Variable response of coastal environments of the northwestern Gulf of Mexico to sea-level rise and climate change: Implications for future change: Marine Geology, v. 352, p. 348-366.
- Andrews, P. B., 1963, Serpulid Reefs, Baffin Bay, Southeast Texas.
- Behrens, E. W., 1969, Surface salinities for Baffin Bay and Laguna Madre, Texas: Contributions in Marine Science, v. 11, p. 168 - 173.

707 Behrens, E. W., 1974, Holocene sea level rise effect on the development of an estuarine
 708 carbonate depositional environment: Baffin Bay, Texas Mem. Inst. Geol. Bassin
 709 Aquitaine, v. 7, p. 337 - 341.

710 Behrens, E. W., and Land, L. S., 1972, Subtidal Holocene Dolomite of Baffin Bay, Texas:
 711 Journal of Sedimentary Petrology, v. 42, no. 1, p. 155 - 161.

712 Behrens, F., 1963, Buried Pleistocene river Valleys in Aransas and Baffin Bays, Texas:
 713 Publications of the Institute of Marine Science, v. 9, p. 11.

714 Bernal, J. P., Lachniet, M., McCulloch, M., Mortimer, G., Morales, P., and Cienfuegos, E., 2011,
 715 A speleothem record of Holocene climate variability from southwestern Mexico:
 716 Quaternary Research, v. 75, no. 1, p. 104-113.

717 Bond, G., Kromer, B., Beer, J., Muscheler, R., Evans, M. N., Showers, W., Hoffmann, S., Lotti-
 718 Bond, R., Hajdas, I., and Bonani, G., 2001, Persistent solar influence on north Atlantic
 719 climate during the Holocene: Science, v. 294, no. 5549, p. 2130-2136.

720 Buzas-Stephens, P., Livsey, D. N., Simms, A. R., and Buzas, M. A., 2014, Estuarine
 721 foraminifera record Holocene stratigraphic changes and Holocene climate changes in
 722 ENSO and the North American monsoon: Baffin Bay, Texas: Palaeogeography,
 723 Palaeoclimatology, Palaeoecology, v. 404, no. 0, p. 44-56.

724 Clement, A. C., Seager, R., and Cane, M. A., 2000, Suppression of El Niño during the Mid-
 725 Holocene by changes in the Earth's orbit: Paleoceanography, v. 15, no. 6, p. 731-737.

726 Dalrymple, D. W., 1964, RECENT SEDIMENTARY FACIES OF BAFFIN BAY, TEXAS
 727 [Ph.D. 6410164]: Rice University, 250-250 p. p.

728 Feng, S., Hu, Q., and Oglesby, R. J., 2009, AMO-like variations of holocene sea surface
 729 temperatures in the North Atlantic Ocean: Climate of the Past Discussions, v. 5, no. 6, p.
 730 2465-2496.

731 Fensterer, C., Scholz, D., Hoffmann, D., Spotl, C., Pajon, J. M., and Mangini, A., 2012, Cuban
 732 stalagmite suggests relationship between Caribbean precipitation and the Atlantic
 733 Multidecadal Oscillation during the past 1.3 ka: Holocene, v. 22, no. 12, p. 1405-1412.

734 Fensterer, C., Scholz, D., Hoffmann, D. L., Spotl, C., Schroder-Ritzrau, A., Horn, C., Pajon, J.
 735 M., and Mangini, A., 2013, Millennial-scale climate variability during the last 12.5 ka
 736 recorded in a Caribbean speleothem: Earth and Planetary Science Letters, v. 361, p. 143-
 737 151.

738 Fisk, H. N., Padre Island and the Laguna Madre Flats coastal south Texas, *in* Proceedings
739 Coastal Geography, Washington DC, 1959 1959, National Academy of Science, p. 103 -
740 151.

741 Forman, S. L., Nordt, L., Gomez, J., and Pierson, J., 2009, Late Holocene dune migration on the
742 south Texas sand sheet: Geomorphology, v. 108, no. 3-4, p. 159-170.

743 Forman, S. L., Oglesby, R., and Webb, R. S., 2001, Temporal and spatial patterns of Holocene
744 dune activity on the Great Plains of North America: megadroughts and climate links:
745 Global and Planetary Change, v. 29, no. 1–2, p. 1-29.

746 Gleason, B., 2006, Characteristics of Tropical Cyclone Rainfall in the United States, 27th
747 Conference on Hurricanes and Tropical Meteorology: Monterey, California, American
748 Meteorological Society.

749 Gunter, G., 1945, Studies of marine fishes of Texas: Publications of the Institute of Marine
750 Science, v. 1, p. 1-190.

751 Haug, G. H., Hughen, K. A., Sigman, D. M., Peterson, L. C., and Rohl, U., 2001, Southward
752 migration of the intertropical convergence zone through the Holocene: Science, v. 293,
753 no. 5533, p. 1304-1308.

754 Higgins, R. W., Silva, V. B. S., Shi, W., and Larson, J., 2007, Relationships between climate
755 variability and fluctuations in daily precipitation over the United States: Journal of
756 Climate, v. 20, no. 14, p. 3561-3579.

757 Higgins, R. W., Yao, Y., and Wang, X. L., 1997, Influence of the North American Monsoon
758 System on the U.S. Summer Precipitation Regime: Journal of Climate, v. 10, no. 10, p.
759 2600-2622.

760 Hill, D. F., Griffiths, S. D., Peltier, W. R., Horton, B. P., and Törnqvist, T. E., 2011, High-
761 resolution numerical modeling of tides in the western Atlantic, Gulf of Mexico, and
762 Caribbean Sea during the Holocene: Journal of Geophysical Research, v. 116, no. C10.

763 Humphrey, J. D., and Ferring, C. R., 1994, Stable Isotopic Evidence for Latest Pleistocene and
764 Holocene Climatic Change in North-Central Texas: Quaternary Research, v. 41, no. 2, p.
765 200-213.

766 Kilbourne, K. H., Quinn, T. M., Webb, R., Guilderson, T., Nyberg, J., and Winter, A., 2008,
767 Paleoclimate proxy perspective on Caribbean climate since the year 1751: Evidence of
768 cooler temperatures and multidecadal variability: Paleoceanography, v. 23, no. 3.

769 Land, L. S., Behrens, E. W., and Frishman, S. A., 1979, The ooids of Baffin Bay: Journal of
 770 Sedimentary Petrology, v. 49, no. 4, p. 1269 – 1278
 771 Livsey, D., and Simms, A. R., 2013, Holocene sea-level change derived from microbial mats:
 772 Geology.
 773 Livsey, D., Simms, A. R., Hangsterfer, A., Nisbet, R., and Dewitt, R., 2016, Drought modulated
 774 by North Atlantic Sea Surface Temperatures for the last 3,000 years in Southwest United
 775 States: Quaternary Science Reviews. v. 135, p. 54-64.
 776 Maddox, J., Anderson, J. B., Milliken, K. T., Rodriguez, A. B., Dellapenna, T. M., and Giosan,
 777 L., 2008, The Holocene evolution of the Matagorda and Lavaca estuary complex, Texas,
 778 USA: Geological Society of America Special Papers, v. 443, p. 105-119.
 779 Mann, M. E., Zhang, Z., Rutherford, S., Bradley, R. S., Hughes, M. K., Shindell, D., Ammann,
 780 C., Faluvegi, G., and Ni, F., 2009, Global signatures and dynamical origins of the Little
 781 Ice Age and Medieval Climate Anomaly: Science, v. 326, no. 5957, p. 1256-1260.
 782 Maxwell, J. T., Ortengren, J. T., Knapp, P. A., and Soulé, P. T., 2013, Tropical Cyclones and
 783 Drought Amelioration in the Gulf and Southeastern Coastal United States: Journal of
 784 Climate, v. 26, no. 21, p. 8440-8452.
 785 Milliken, K. T., Anderson, J. B., and Rodriguez, A. B., 2008a, A new composite Holocene sea-
 786 level curve for the northern Gulf of Mexico: Geological Society of America Special
 787 Papers, v. 443, p. 1-11.
 788 Milliken, K. T., Anderson, J. B., and Rodriguez, A. B., 2008b, Tracking the Holocene evolution
 789 of Sabine Lake through the interplay of eustasy, antecedent topography, and sediment
 790 supply variations, Texas and Louisiana, USA: Geological Society of America Special
 791 Papers, v. 443, p. 65-88.
 792 Milliken, K. T., Anderson, J. B., and Rodriguez, A. B., 2008c, Record of dramatic Holocene
 793 environmental changes linked to eustasy and climate change in Calcasieu Lake,
 794 Louisiana, USA: Geological Society of America Special Papers, v. 443, p. 43-
 795 63. Montero-Serrano, J. C., Bout-Roumazeilles, V., Sionneau, T., Tribovillard, N., Bory,
 796 A., Flower, B. P., Riboulleau, A., Martinez, P., and Billy, I., 2010, Changes in
 797 precipitation regimes over North America during the Holocene as recorded by
 798 mineralogy and geochemistry of Gulf of Mexico sediments: Global and Planetary
 799 Change, v. 74, no. 3-4, p. 132-143.

800 Morse, J. W., Cornwell, J. C., Arakaki, T., Lin, S., and Huerta-Diaz, M. A., 1992, Iron sulfide
801 and carbonate mineral diagenesis in Baffin Bay, Texas: *Journal of Sedimentary Research*,
802 v. 62, no. 4, p. 671-680.

803 Myoung, B., and Nielsen-Gammon, J. W., 2010, The Convective Instability Pathway to Warm
804 Season Drought in Texas. Part I: The Role of Convective Inhibition and Its Modulation
805 by Soil Moisture: *Journal of Climate*, v. 23, no. 17, p. 4461-4473.

806 NOAA, 1998, Baffin Bay, TX (G320) Bathymetric Digital Elevation Model (30 meter
807 resolution)
808 Derived From Source Hydrographic Survey Soundings Collected by NOAA, NOAA's Ocean
809 Service, Special Projects (SP): Silver Spring, MD.

810 Nordt, L. C., Boutton, T. W., Hallmark, C. T., and Waters, M. R., 1994, Late Quaternary
811 Vegetation and Climate Changes in Central Texas Based on the Isotopic Composition of
812 Organic Carbon: *Quaternary Research*, v. 41, no. 1, p. 109-120.

813 Nordt, L. C., Boutton, T. W., Jacob, J. S., and Mandel, R. D., 2002, C4 Plant Productivity and
814 Climate-CO2 Variations in South-Central Texas during the Late Quaternary: *Quaternary*
815 *Research*, v. 58, no. 2, p. 182-188.

816 Nurnberg, D., Ziegler, M., Karas, C., Tiedemann, R., and Schmidt, M. W., 2008, Interacting
817 Loop Current variability and Mississippi River discharge over the past 400 kyr: *Earth and*
818 *Planetary Science Letters*, v. 272, no. 1-2, p. 278-289.

819 Paine, J. G., 1993, Subsidence of the Texas Coast - Inferences from Historical and Late
820 Pleistocene Sea Levels: *Tectonophysics*, v. 222, no. 3-4, p. 445-458.

821 Parnell, A. C., and Gehrels, W. R., 2015, Using chronological models in late Holocene sea-level
822 reconstructions from saltmarsh sediments, *Handbook of Sea-Level Research*, John Wiley
823 & Sons, Ltd, p. 500-513.

824 Parnell, A. C., Haslett, J., Allen, J. R. M., Buck, C. E., and Huntley, B., 2008, A flexible
825 approach to assessing synchronicity of past events using Bayesian reconstructions of
826 sedimentation history: *Quaternary Science Reviews*, v. 27, no. 19-20, p. 1872-1885.

827 Poore, R. Z., Dowsett, H. J., Verardo, S., and Quinn, T. M., 2003, Millennial- to century-scale
828 variability in Gulf of Mexico Holocene climate records: *Paleoceanography*, v. 18, no. 2,
829 p. 1048.

- 830 Poppe, L. J., McMullen, K. Y., Williams, S. J., Crocker, J. M., and Doran, E. F., 2008, Estuarine
831 sediment transport by gravity-driven movement of the nepheloid layer, Long Island
832 Sound: *Geo-Marine Letters*, v. 28, no. 4, p. 245-254.
- 833 Reimer, P. J., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P. G., Bronk Ramsey, C., Buck, C.
834 E., Cheng, H., Edwards, R. L., Friedrich, M., Grootes, P. M., Guilderson, T. P.,
835 Haflidason, H., Hajdas, I., Hatté, C., Heaton, T. J., Hoffmann, D. L., Hogg, A. G.,
836 Hughen, K. A., Kaiser, K. F., Kromer, B., Manning, S. W., Niu, M., Reimer, R. W.,
837 Richards, D. A., Scott, E. M., Southon, J. R., Staff, R. A., Turney, C. S. M., and van der
838 Plicht, J., 2013, IntCal13 and Marine13 Radiocarbon Age Calibration Curves 0–50,000
839 Years cal BP: *Radiocarbon*; Vol 55, No 4 (2013).
- 840 Richey, J. N., Poore, R. Z., Flower, B. P., and Quinn, T. M., 2007, 1400 yr multiproxy record of
841 climate variability from the northern Gulf of Mexico: *Geology*, v. 35, no. 5, p. 423.
- 842 Rodriguez, A. B., Anderson, J. B., and Simms, A. R., 2005, Terrace inundation as an autocyclic
843 mechanism for parasequence formation: Galveston Estuary, Texas, USA: *Journal of*
844 *Sedimentary Research*, v. 75, no. 4, p. 608-620.
- 845 Rodriguez, A. B., Greene, D. L., Anderson, J. B., and Simms, A. R., 2008, Response of Mobile
846 Bay and eastern Mississippi Sound, Alabama, to changes in sediment accommodation
847 and accumulation: *Geological Society of America Special Papers*, v. 443, p. 13-29.
- 848 Rodriguez, A. B., Simms, A. R., and Anderson, J. B., 2010, Bay-head deltas across the northern
849 Gulf of Mexico back step in response to the 8.2ka cooling event: *Quaternary Science*
850 *Reviews*, v. 29, no. 27-28, p. 3983-3993.
- 851 Rusnak, G. A., 1960, Recent Sediments, Northwest Gulf of Mexico, Tulsa, OK, American
852 Association of Petroleum Geologists, Recent Sediments, Northwest Gulf of Mexico.
- 853 Shideler, G. L., 1984, Suspended sediment responses in a wind-dominated estuary of the Texas
854 Gulf Coast: *Journal of Sedimentary Research*, v. 54, no. 3, p. 731-745.
- 855 Simms, A. R., Anderson, J. B., DeWitt, R., Lambeck, K., and Purcell, A., 2013, Quantifying
856 rates of coastal subsidence since the last interglacial and the role of sediment loading:
857 *Global and Planetary Change*, v. 111, no. 0, p. 296-308.
- 858 Simms, A. R., Anderson, J. B., Rodriguez, A. B., and Taviani, M., 2008, Mechanisms controlling
859 environmental change within an estuary: Corpus Christi Bay, Texas, USA: *Geological*
860 *Society of America Special Papers*, v. 443, p. 121-146.

- Simms, A. R., Aryal, N., Miller, L., and Yokoyama, Y., 2010, The incised valley of Baffin Bay, Texas: a tale of two climates: *Sedimentology*, v. 57, no. 2, p. 642-669.
- Toomey, R. S., Blum, M. D., and Valastro, S., 1993, Late Quaternary climates and environments of the Edwards Plateau: *Global and Planetary Change*, v. 7, no. 4, p. 299-320.
- Törnqvist, T. E., González, J. L., Newsom, L. A., van der Borg, K., de Jong, A. F. M., and Kurnik, C. W., 2004, Deciphering Holocene sea-level history on the U.S. Gulf Coast: A high-resolution record from the Mississippi Delta: *Geological Society of America Bulletin*, v. 116, no. 7, p. 1026.
- Troiani, B. T., Simms, A. R., Dellapenna, T., Piper, E., and Yokoyama, Y., 2011, The importance of sea-level and climate change, including changing wind energy, on the evolution of a coastal estuary: Copano Bay, Texas: *Marine Geology*, v. 280, no. 1-4, p. 1-19.
- Weppner, K.N., Pierce, J.L., Betancourt, J.L., 2013. Holocene fire occurrence and alluvial responses at the leading edge of pinyon-juniper migration in the Northern Great Basin, USA. *Quaternary Research*, v. 80, no. 2, p. 143-157.
- Wong, C.I., Banner, J.L., and Musgrove, M.L., 2015, Holocene climate variability in Texas, USA: An integration of existing paleoclimate data and modeling with a new, high-resolution speleothem record: *Quaternary Science Reviews*, v. 127, p. 155-173.
- Zhu, J., and Liang, X.-Z., 2012, Impacts of the Bermuda High on Regional Climate and Ozone over the United States: *Journal of Climate*, v. 26, no. 3, p. 1018-1032.

FIGURE CAPTIONS

Figure 1 A. Map indicating regional location of Baffin Bay, Texas and studies that document Holocene-flooding surfaces. 1. Simms et al. (2008) 2. Maddox et al. (2008) 3. Anderson et al. (2008) 4. Milliken et al. (2008b) 5. Milliken et al. (2008c) 6. Rodriguez et al. (2008)

B. Map of Baffin Bay, Texas with location of cores used in this study indicated by yellow diamonds. **C.** Upper-bay study area with location of cores used in this study and position of seismic survey.

Figure 2 Holocene sea-level data from upper Baffin Bay (Livsey and Simms, 2013) with Bayesian regression of sea-level data computed using BCHRON (Parnell and Gehrels, 2015). Maximum and minimum ages of flooding surfaces (FS) marked by inundation of intertidal mud-flat deposits estimated by mean elevation of flooding surface and mean elevation plus modern water depth, respectively.

Figure 3 A. Core description and foraminifera assemblage data indicative of drier climate conditions for core BB07-01 from Buzas-Stephens et al., 2014. Timing of each flooding surface (FS), constrained by radiocarbon data and the RSL method described in the text, occurs within error of drying events indicated by foraminiferal assemblage changes; therefore, depths wherein foraminiferal assemblages indicate maximum dry conditions were correlated for each FS. **B.** BCHRON age model for core BB07-01 from which 95% error range for each depth was computed.

Figure 4 Accommodation changes with respect to mean sea level. Note linear increase in accommodation across the elevation ranges of each flooding surface.

Figure 5 A-G. Grid models utilized in this study to compute volumes shown in Figure 7. Grid models for B-G computed using elevations picked from core (black polygon symbols) and the seismic survey. **A.** Modern bathymetry grid computed from sounding data (NOAA, 1998). **B.** Flooding surface 5 grid. **C.** Flooding surface 4 grid. **D.** Flooding surface 3 grid. **E.** Flooding surface 2 grid. **F.** Flooding surface 1 grid. **G.** Pleistocene incised-valley grid.

Figure 6 A-B. 3D perspective view of Pleistocene incised-valley grid with high-resolution (A) and lower resolution lithology models (B). Red-square on inset map of A. indicates location of high-resolution lithology model. Black arrow in each inset map in A and B indicate location of viewer.

Figure 7 A. Total sediment accumulation changes **B-E.** Sediment accumulation changes for each grain-size category.

Figure 8 A-D. Field images of select depositional environments. Shovel for scale in A and B is 1.25 m tall. GPS for scale in D is 2 m tall. **E.** Core images of select sedimentary facies. Numerals by each core photo indicate sedimentary facies number (see Table 3 for sedimentary facies explanation). Dewatered Pleistocene (PI) sediment shown in bottom-right core image.

Figure 9 A. Portion of seismic survey with seismic facies (SF) identified in this study.

Figure 10 A. Select core descriptions utilized to make generalized dip profile for upper Baffin Bay. **B.** Generalized dip profile for Baffin Bay. FS identified in this study are correlated to FS identified in Simms et al. (2010) generalized dip profile. Asterisk in legend indicates surfaces taken from Simms et al (2010) and not sampled in this study. **C.** Generalized dip profile for upper Baffin Bay. Calibrated radiocarbon samples with 2σ age-ranges shown in white-font. Cores with core descriptions shown in A. have black labels. Cores with no description shown have grey labels. Not all core description shown to conserve space. **D.** Core photos showing FS identified in this study. Note FS2 in core AM10-05 and abrupt transition from facies assemblage 2 sedimentary facies 20 to facies assemblage 1 sedimentary facies 8.

Figure 11 A-H. Paleogeographic maps for times just before and after flooding surfaces 2 through 5 reconstructed from core facies interpretations. Paleogeographic maps for flooding surface 5 are not shown since only 8 cores sampled below this surface.

Figure 12 A. Seismic survey from upper Baffin Bay. See figure 1C for survey line location. **B.** Interpretation of seismic survey shown in A. with location of base of incised fill and five flooding surfaces. **C.** Color-shading of each parasequence (i.e. area between each interpreted surface in B) for viewing in RockWorks16® 3D viewer shown in figure 13.

Figure 13 3D perspective view of seismic survey from upper Baffin Bay with numbered flooding surface grids (FS) shown as light-blue planes. FS grids were interpolated from core contact elevations. FS grids that were closest in elevation to flooding surfaces identified in the seismic survey (FSs) were correlated.

Figure 14 A. Timing for each flooding surface identified in upper Baffin Bay using different methods discussed in the text. Minimum time constraint (shown as “All”) wherein flooding surface formed was selected using 95% error range from each method. Vertical-grey bars indicate range of timing wherein each FS formed. **B.** Composite mean sea-level curve for northern Gulf of Mexico with rates of sea level rise indicated (modified from Milliken et al., 2008). **C.** North Atlantic ice-rafted debris record (Bond et al., 2001) utilized, after Fensterer et al., 2013, as proxy for North Atlantic sea surface temperatures (SST). **D.** Mg/Ca ratio of planktonic foraminifera, a proxy for SST, from northern Gulf of Mexico utilized as a proxy for the mean position of the ITCZ after Monterro-Serrano et al., 2010. Data with diamond symbols from Richey et al., 2007 and data with triangular symbols from Nürnberg et al., 2008. **E-F.** Foraminifera assemblage data from core BB07-01 a proxy for estuarine salinity and hence precipitation (Buzas-stephens et al., 2014). **G.** Drought frequency derived from nearby playa Laguna Salada (Livsey et al., 2016). Timing of Medieval Climate Anomaly (MCA) and Little Ice Age (LIA; Mann et al., 2009), Roman Climate Anomaly (RCO; Weppner et al., 2013), and dune migration (DM; Foreman et al., 2009) discussed in text is shown in black bars.

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

Figure 11

Figure 12

Figure 13

Figure 14

Table 1

Table 1. Radiocarbon data

Lab code	Core and sample depth	Material	Age Error			Radiocarbon reservoir	Calibration curve ^b	Calibrated median age (yr BP)	2σ calibrated younger age (yr BP)	2σ calibrated older age (yr BP)	Reference
			¹⁴ C age ^a	(±1σ)	δ ¹³ C ^c						
UCS-115618	AM 10-37 54cm	Microbial mat	1730	30	NR	220 ± 100	MNH-TM	1550	1410	1691	This study
UCS-115617	AM10-33 134cm	Microbial mat	3225	40	NR	220 ± 100	MNH-TM	3307	3205	3408	This study
UCS-115619	AM 10-56 81 cm	Microbial mat	3605	40	NR	220 ± 100	MNH-TM	3818	3638	3998	This study
D-AMS 000511	AM12-01 329 cm	Chlorine Candelabra	4518	35	3.5	220	GM	4991	4701	5288	This study
D-AMS 000510	AM12-02 284 cm	Bulk organic carbon	4620	31	-15.8	220	GM	5410	5298	5493	This study
UCS-115616	AM10-01 385cm	Microbial mat	4910	25	NR	220 ± 100	MNH-TM	5544	5333	5960	This study
UCS-115620	AM 12-62 261cm	Microbial mat	5200	45	NR	220 ± 100	MNH-TM	5844	5689	6091	This study
D-AMS 000512	AM12-02 325 cm	Linear Pectinase	5888	28	-7.8	220	GM	6291	6026	6516	This study
D-AMS 000513	AM12-13 377 cm	Linear Pectinase	5853	25	5.5	220	GM	6570	6325	6815	This study
Beta-227548	BB07-02 105 cm	Anomaloecardia cuneiformis	790	40	NR	220	GM	548	334	710	Simms et al., 2010
Beta-227548	BB07-02 105 cm	Microbial mat	800	40	-10.7	220 ± 100	MNH-TM	678	358	781	Simms et al., 2010
MTC-08627	BB06-02 24 cm	Calocardiacalyptra texana	900	30	-0.30	220	GM	681	518	863	Simms et al., 2010
MTC-08628	BB06-02 70 cm	Rangia fasciata	2180	120	-0.30	220	GM	1878	1891	2334	Simms et al., 2010
MTC-12307	BB07-11 958 cm	Anomaloecardia cuneiformis	2730	190	1.07	220	GM	2602	2132	3203	Simms et al., 2010
MTC-08630	BB07-01 382 cm	Bivalve no identification	3540	75	-0.30	220	GM	3658	3502	3813	Simms et al., 2010
MTC-08730	BB06-02 262 cm	Anomaloecardia cuneiformis	4040	35	1.07	220	GM	4317	3995	4610	Simms et al., 2010
Beta-227549	BB06-02 308 cm	Charcoal	3900	40	-26.3	0	NHT	4411	4208	4520	Simms et al., 2010
MTC-08629	BB06-02 502 cm	Anomaloecardia cuneiformis	4250	35	1.07	220	GM	4608	4320	4891	Simms et al., 2010
MTC-12306	BB07-11 765 cm	Anomaloecardia cuneiformis	4380	65	1.07	220	GM	4761	4418	5112	Simms et al., 2010
MTC-08639	BB07-01 485 cm	Rangia fasciata	4570	80	-0.30	220	GM	5029	4698	5360	Simms et al., 2010
MTC-08904	BB07-01 667 cm	Anomaloecardia cuneiformis	4790	75	-0.30	220	GM	5248	4918	5598	Simms et al., 2010
Beta-227547	BB06-02 674 cm	Microbial mat	5040	40	-14.5	220 ± 100	MNH-TM	5684	5503	5965	Simms et al., 2010
MTC-08901	BB07-01 937 cm	Rangia fasciata	5430	80	1.07	220	GM	6037	5733	6391	Simms et al., 2010
MTC-12305	BB07-11 1245 cm	Tigridia sp.	5620	150	-0.30	220	GM	6211	5808	6635	Simms et al., 2010
MTC-08903	BB07-01 946 cm	Mulinia lateralis	5910	75	-0.82	220	GM	6527	6267	6815	Simms et al., 2010
MTC-09749	BB06-02 804 cm	Nuculana aculeata	6080	40	-0.30	220	GM	6694	6423	6942	Simms et al., 2010
MTC-12310	BB07-11 1543 cm	Mulinia lateralis	7190	80	-0.82	220	GM	7797	7570	8012	Simms et al., 2010
MTC-08902	BB07-01 1113 cm	Mulinia lateralis	7570	80	-0.82	220	GM	8218	7947	8430	Simms et al., 2010
MTC-12311	BB07-11 188 cm	Mulinia lateralis	8230	60	-0.82	220	GM	8911	8637	9118	Simms et al., 2010
MTC-12312	BB07-11 1727 cm	Bivalve no identification	8740	70	-0.30	220	GM	9523	9340	10011	Simms et al., 2010
CS-73348	BB07-01 1394 cm	Anomaloecardia cuneiformis	8440	50	NR	220	GM	9270	9004	9487	Rodriguez et al., 2010
CS-88859	AM11-02 16 cm	Microbial mat	475	35	-12.58	220 ± 100	MNH-TM	408	301	505	Livsey and Simms 2013
CS-88823	AM10-08 19 cm	Microbial mat	300	45	-12.84	220 ± 100	MNH-TM	460	369	544	Livsey and Simms 2013
CS-81858	AM10-07 24 cm	Microbial mat	540	30	-12.84	220 ± 100	MNH-TM	474	322	643	Livsey and Simms 2013
CS-88861	AM11-13 34 cm	Microbial mat	1280	25	-10.84	220 ± 100	MNH-TM	1394	962	1721	Livsey and Simms 2013
CS-81981	AM10-16 53 cm	Microbial mat	1400	20	-11.38	220 ± 100	MNH-TM	1237	1098	1325	Livsey and Simms 2013
CS-88860	AM 11-17 51 cm	Microbial mat	1470	30	-11.74	220 ± 100	MNH-TM	1399	1162	1596	Livsey and Simms 2013
CS-88732	AM11-68 34 cm	Microbial mat	1480	28	-12.42	220 ± 100	MNH-TM	1316	1185	1412	Livsey and Simms 2013
CS-88731	AM 11-16 58 cm	Microbial mat	1540	30	-12.03	220 ± 100	MNH-TM	1307	1275	1500	Livsey and Simms 2013
CS-88730	AM11-18 57 cm	Microbial mat	1550	25	-11.7	220 ± 100	MNH-TM	1364	1283	1507	Livsey and Simms 2013
CS-88862	AM 11-17 27 cm	Microbial mat	1540	65	-11.40	220 ± 100	MNH-TM	1365	1191	1538	Livsey and Simms 2013
CS-88729	AM 11-15 47 cm	Microbial mat	1580	25	-8.87	220 ± 100	MNH-TM	1374	1290	1512	Livsey and Simms 2013
CS-88728	AM10-19 47 cm	Microbial mat	1580	28	-11.32	220 ± 100	MNH-TM	1393	1298	1518	Livsey and Simms 2013
CS-79738	AM10-06 43 cm	Microbial mat	1600	40	-12.23	220 ± 100	MNH-TM	1417	1298	1540	Livsey and Simms 2013
CS-88876	AM11-10 60 cm	Microbial mat	1780	25	-13.2	220 ± 100	MNH-TM	1982	1818	1718	Livsey and Simms 2013
CS-81980	AM10-16 56 cm	Microbial mat	1950	25	-11.27	220 ± 100	MNH-TM	1811	1635	1949	Livsey and Simms 2013
CS-88727	AM10-16 141 cm	Microbial mat	2650	35	-14.13	220 ± 100	MNH-TM	2562	2370	2716	Livsey and Simms 2013
CS-88874	AM11-20 116 cm	Microbial mat	2600	35	-12.58	220 ± 100	MNH-TM	2609	2415	2750	Livsey and Simms 2013
CS-88836	AM10-17 136 cm	Microbial mat	2620	30	-11.72	220 ± 100	MNH-TM	2648	2438	2774	Livsey and Simms 2013
CS-88894	AM10-33 118 cm	Microbial mat	2730	40	-12.21	220 ± 100	MNH-TM	2776	2545	2945	Livsey and Simms 2013
CS-88835	AM10-52 287 cm	Microbial mat	4900	30	-13.85	220 ± 100	MNH-TM	5024	4862	5205	Livsey and Simms 2013
CS-88875	AM09-05 10' 62 cm	Microbial mat	4540	30	-14.87	220 ± 100	MNH-TM	5102	4904	5284	Livsey and Simms 2013
CS-88837	AM10-20 20' 15 cm	Microbial mat	4750	30	-12.32	220 ± 100	MNH-TM	5334	5089	5472	Livsey and Simms 2013

^a The ¹⁴C dates of all radiocarbon samples measured by accelerator mass spectrometry (AMS)
^b Ages calibrated/calibrated using the following calibration curves of CALIB 7.1 (Reimer et al., 2013):
global marine (GM), northern hemisphere terrestrial (NHT), and mixed northern hemisphere marine curve (MNH-TM)
^c Annotated
NR: Not reported. For samples in this study if fractionation occurred during sample graphitization or the AMS measurement, δ13C were not reported from laboratory

Table 2

Table 2. Ages used to constrain timing of flooding surfaces

Flooding surface	Method	Calibrated 2 σ younger age (yr BP)	Calibrated 2 σ older age (yr BP)	Radiocarbon sample for younger age	Radiocarbon sample for older age	Median age (yr BP)	Range (yrs)
FS5	Radiocarbon	962	1325	AM11-13 34 cm	AM10-18 53 cm	1144	363
FS5	BB07-01 BCHRON age-model	284	2523			1404	2239
FS5	RSL	650	1130			890	480
FS5	All	962	1130			1046	168
FS4	Radiocarbon	1633	2716	AM10-16 58 cm	AM10-18 141 cm	2175	1083
FS4	BB07-01 BCHRON age-model	1593	3294			2444	1701
FS4	RSL	2060	2630			2445	770
FS4	All	2060	2716			2388	656
FS3	Radiocarbon	2545	3973	AM10-33 116 cm	BB07-01 262 cm	3259	1428
FS3	BB07-01 BCHRON age-model*	3030	4439			3735	1409
FS3	RSL	2960	3750			3355	790
FS3	All	3030	3750			3390	720
FS2	Radiocarbon	4894	5268	AM09-05 16' 62 cm	AM12-01 229 cm	5081	374
FS2	BB07-01 BCHRON age-model	4549	5174			4861	625
FS2	All	4894	5174			5034	280
FS1	Radiocarbon	5733	6516	BB07-01 837 cm	AM12-02 235 cm	6123	786

*Flooding surface occurred within core break age-range
taken from top and bottom depths of missing section in BB07-01

Table 3

Table 3. Sedimentary facies

Sedimentary facies #	Facies assemblage #	Depositional environment	Description
1	1	Floodplain	Light greenish-grey clay with plant fragments, darker-clay lamina, and few distinct sedimentary structures or fauna
2	1	Modern creek-channel deposits	Massive brownish-grey, poorly sorted fine sand with some plant fragments and gravel
3	1	Tidal-influenced channel sand deposits♦	Light grey to blue muddy sand with massive bedding and flaser lamination
4	1	Mud flat	Interbedded and interlaminated light-blue, blue, and green muds with white 1-3mm thick carbonate-clay interlaminae and microbial mats
5	1	Supratidal mud flat♦	Mottled tan to brown sandy mud with sand filled burrows and occasional root casts
6	1	Pro mud flat♦	Mottled light blue and green clay with abundant plant fragments and lenticular bedding. Shell fragments ≤ 2 cm are occasionally found
7	1	Valley-margin sand♦	Bioturbated muddy light blue to grey medium sand with few shell fragments
8	1	Upper-bay/bay margin	Bioturbated dark greenish-grey muddy sand with several sand laminae
9	1	Upper-bay mud♦	Blue and light blue mottled mud with fine sand-filled burrows and few shell fragments
10	1	Erosive bayfloor lag♦	Structureless shelly sandy blue to gray clay
11	1	Open-bay or distal upper-bay	Homogenous black to greenish-grey clayey silt/silt with occasional faint laminae
12	1	Open bay	Well laminated and interbedded blue, greenish-grey, and light grey white interbedded mud
13	1	Nephroid mud♦	Black, very soft, homogenous, mud
14	1	Shelly-spit or fetch-limited barrier island	Grey-tan shelly fine sand or shell hash
15	1	Back-spit lagoon♦	Green mud with lenticular and continuous, sharp-based, fine-sandy laminae, abundant plant fragments, and shell-hash and sand-filled burrows
16	1	Serpulid worm-tube reef	Randomly oriented serpulid worm tubes ~ 1 cm in diameter
17	2	Wet upper bay	Structureless green and dark-grey muds with sand-filled burrows, plant fragments, and diverse array of molluscan fauna
18	2	Seagrass flat♦	Structureless dark-green muds with a high abundance of plant fragments, and diverse array of molluscan fauna
19	2	Fluvial floodplain	Dark bluish-grey sandy mud with plant fragments
20	2	Bayhead-delta mouth bar	Structureless muddy medium blueish-grey sand with little to abundant shell fragments and plant material

♦ Additional sedimentary facies identified in cores from this study