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Invited review article

Mississippi River subaqueous delta is entering a stage of retrogradation

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ABSTRACT

The subaqueous delta of the Mississippi River, the largest river system in the conterminous U.S., has entered a stage of retrogradation caused by multiple natural and anthropogenic activities. Since the 1950s, the suspended sediment load of the Mississippi River has decreased by ~50% due primarily to the construction of > 50,000 dams in the Mississippi basin. The impact of this decreased sediment load has been observed in subaerial environments, but the impact on sedimentation and geomorphology of the subaqueous delta front has yet to be examined. To identify historic trends in sedimentation patterns, we compiled bathymetric datasets, including historical charts, industry and academic surveys, and National Oceanic and Atmospheric Administration hydrographic data, collected between 1764 and 2009. The progradation rate (measured at the 10 m depth contour) of Southwest Pass, which receives 69% of the suspended sediment load reaching Head of Passes, has decreased from ~67 m/yr between 1874 and 1940 to ~26 m/yr between 1940 and 1979, with evidence of further deceleration from 1979 to 2009. At South Pass and Pass a Loutre, the delta front has entered the destructive phase, with the 10 m contour retreating at rates > 20 m/yr at both passes since 1979. Advancement of the delta front also decelerated in deeper water (in some areas out to ~180 m depth). Except locally, where mudflow lobes are advancing, deeper contours show a pattern of decreasing progradation rate between 1874–1940 and 1979–2005 time periods. Furthermore, based on differences measured between available bathymetric datasets, the sediment accumulation rate across the delta front decreased by ~73% for the same period. The retention rate of Mississippi River sediment on the delta front ranged from 67 to 81% for the time periods assessed, with total sediment load stored on the delta front equal to 317 ± 54 Mt/yr from 1874 to 1940, 145 ± 25 Mt/yr from 1940 to 1979, and 87 ± 15 Mt/yr from 1979 to 2005. We document for the first time that the Mississippi River delta front has entered a phase of retrogradation, which will likely be accelerated by future upstream activities that divert a portion of the sediment load to the upper delta for coastal protection and restoration projects. The decline of the subaqueous Mississippi River Delta has critical implications for biogeochemical cycling, subaqueous mass wasting, and sediment dispersal to the coastal ocean.

1. Introduction

Deltas are an important part of the source-to-sink pathway where terrestrial sediments are dispersed into the marine environment. Transport and deposition of sediment within and away from the delta are important for global carbon cycling, marine ecosystems, pollutant dispersal, and natural resources. Recent research on global deltas has shown that anthropogenic impacts to river systems are influencing patterns of sediment distribution at the river mouth (e.g., Bergillos et al., 2016; Blum and Roberts, 2009; Couvillion et al., 2011; Fan et al., 2006; Yang et al., 2017). Here, we examine changes in sedimentation patterns on the subaqueous Mississippi River delta, which is formed where the Mississippi River empties into the northern Gulf of Mexico (Fig. 1). The Mississippi River is ranked seventh in the world in both water discharge and suspended sediment load (Milliman and Meade, 1983; Meade, 1996) and the Mississippi River delta is one of the most

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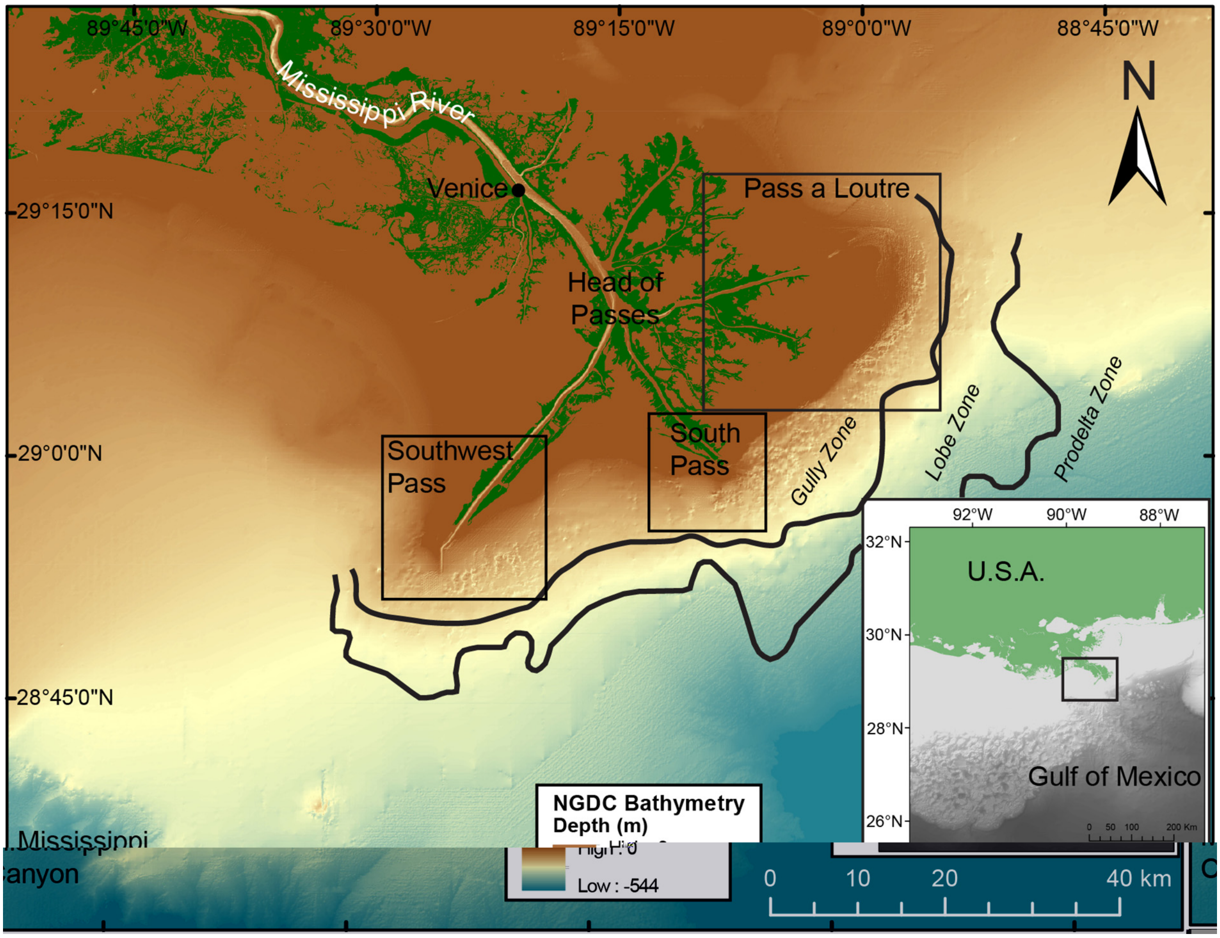

Fig. 1. Overview map of the Mississippi River delta showing major passes and offshore bathymetry (Love et al., 2012). Black lines represent the boundaries between the mudflow gully, mudflow lobe, and prodelta zones, which are labeled Gully Zone, Lobe Zone, and Prodelta Zone and italicized. Three small black boxes highlight the three major passes, which are the study areas in Fig. 4. Inset shows regional map with black box over delta location.

well studied and recognizable deltas in the world (Bentley et al., 2016).

Recent studies have shown extensive land loss (4877 km^2 between 1932 and 2010) in the subaerial deltaic plain of southern Louisiana (Couvillion et al., 2011), which has been mainly attributed to construction of flood-protection levees disconnecting the river from the deltaic plain and a decline in Mississippi River sediment load (Kesel, 1988; Keown et al., 1986). Wetland-loss rates are estimated at 50–100 km^2/yr (Gagliano et al., 1981), with 25% of the 1932 deltaic land area lost through 2010 (Couvillion et al., 2011). This poses a threat to communities along the north-central Gulf of Mexico coast, energy and navigation infrastructure, fisheries, commerce, and the extensive wetland ecosystem of the delta region (Twilley et al., 2016). Clearly, anthropogenic modifications to the Mississippi River are impacting the delta, but little is known about the extent of these impacts on the subaqueous portion of the delta. Furthermore, the subaqueous delta front is an area of extensive sediment instability (e.g. Coleman et al., 1980) and upstream modifications may affect submarine landslide activities due to changes in sedimentation rates and patterns of sediment consolidation.

In order to assess trends in sedimentation rates and patterns on the subaqueous delta front, we examined historic datasets and show that the delta is entering a stage of decelerated and negative growth. Sediment transport pathways transition from land to sea across deltas and understanding both the marine and terrestrial delta environments will provide insight into the processes that control delta sedimentation and morphology.

2. Background

Since post-Last Glacial Maximum sea-level rise decelerated ~7 ka (thousands of years before present, where present is 1950 CE), the Mississippi River has been building land off the southern Louisiana coast in a series of delta complexes, switching depo-center location due to upstream avulsions every ~1–1.5 k.y. (Frazier, 1967; Tornqvist et al., 1996; Blum and Roberts, 2012). Deposition on the currently active Plaquemine-Balize complex began ~1.2 ka (Tornqvist et al., 1996) and has deposited sediment > 100 m thick on the shelf (Coleman and Roberts, 1988; Kulp et al., 2002), building out almost to the shelf edge. The distinctive "birdfoot" shape of the modern active subaerial delta has been used as an end-member for fluvially dominated deltas, where the supply of sediment is high and there is relatively small influence of waves and tides (Galloway, 1975; Wright, 1985).

Sediment from the Mississippi River enters the Gulf of Mexico through multiple distributaries that comprise the "birdfoot" including, from west to east, Southwest Pass, South Pass, and Pass a Loutre (Fig. 1). The estimated annual sediment load from the Mississippi River is ~210 Million tons per year (Mt/yr) with ~80% of the total load represented by fine silt and clay in suspension (Milliman and Meade, 1983), but much of this sediment load is sequestered in the lower reaches of the river before entering the Gulf of Mexico. For example, during water years 2008–2010, only 19% of the total suspended sediment load of the river measured at Tarbert Landing reached the major passes entering the Gulf of Mexico (Allison et al., 2012). Sediment load is lost from the main Mississippi River channel through outlets and diversions between Baton Rouge and Head of Passes (e.g., Bonnet Carre