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Sedimentary evidence of deglacial megafloods in the northern Gulf of Mexico (Pigmy Basin)

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ABSTRACT

Cored sediments from the Pigmy Basin, northern Gulf of Mexico, were analyzed in order to better constrain late deglacial and early Holocene paleoenvironmental and sedimentary changes in response to North American climate evolution. Mineralogical and geochemical proxies indicate the succession of two sedimentary regimes: dominantly detrital during the deglaciation (15–12.9 cal ka BP) whereas biogenic contribution relatively increased later on during the Younger Dryas and early Holocene (12.9 and 10 cal ka BP). Geochemical data reveal that the deglacial record mainly reflects variations of terrigenous supply via the Mississippi River rather than modifications of redox conditions in the basin. Specific variations of almost all the parameters measured in this paper are synchronous with the main deglacial meltwater episode (Meltwater Spike) described or modeled in previous marine or continental studies. During this episode, most parameters display "stair-step-like" – pattern variations highlighting three successive steps within the main meltwater flow. Variations in grain-size and clay mineral assemblage recorded in the Pigmy Basin indicate that the erosional regime was very strong on land during the first part of the Meltwater Spike, and then milder, inducing more subtle modifications in the sedimentary regime in this part of the Gulf. Specific geochemical and mineralogical signatures (notably, clay minerals and trace metal geochemistry) pinpoint a dominant origin from NW North America for detrital particles reflecting meltwater outflow from the south-western Laurentide Ice Sheet (LIS) margin during the most intense freshwater discharge. The observed decrease of the sedimentation rate from about 200 to 25 cm/ka at ca 12.9 ka evidenced a drastic decrease of erosional processes during late phase of discharge, consistently with the hypotheses of major reduction of meltwater flow. The major modification at 12.9 cal ka BP is interpreted to result from both modifications of the main Mississippi fluvial regime due to eastward and northward rerouting of meltwater flow at the onset of the Younger Dryas, and the increase of sea-surface temperature linked to insolation. Finally, slight grain-size modifications suggest that some freshwater discharges may have episodically reached the Gulf of Mexico after the Younger Dryas reflecting possible small adjustments of the postglacial hydrological regime.

1. Introduction

It has long been known that the hydrological features of the Gulf of Mexico (GOM) were strongly impacted by the inputs of meltwater from the Laurentide Ice Sheet (LIS) during the last glacial cycle and subsequent deglaciation, since the Mississippi/Missouri watershed represented the main drainage system for the southern LIS meltwater (Kennett and Shackleton, 1975; Leventer et al., 1982; Joyce et al., 1993; Aharon, 2003; Flower et al., 2004). Deglacial meltwater episodes have been extensively documented in the GOM using hydrological proxies (Kennett and Shackleton, 1975; Emiliani et al., 1978; Leventer et al., 1982; Broecker et al., 1989; Flower and Kennett, 1990; Spero and Williams, 1990; Marchitto and Wei, 1995; Aharon, 2003; Flower et al., 2004). Modeling estimates indicate that the water discharge through the Mississippi River has varied by a factor of 5 during the Lateglacial (Teller, 1990), reflecting both the melting history of the LIS and also possible modifications in meltwater drainage pathways. Paleogeographic and ice sheet-volume reconstructions suggest that some of the ice lobe-extent

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fluctuations during deglaciation resulted in rapid switches of the meltwater flows pathways from the Mississippi River drainage towards the eastern drainage systems, triggering episodic cooling and warming in the North Atlantic region (Licciardi et al., 1999; Clark et al., 2001).

On the other hand, the detrital sedimentary record (including organic matter sources) of these meltwater discharges within the GOM has been studied in different works, for example in: (a) Orca Basin (Marchitto and Wei, 1995; Brown and Kennett, 1998; Meckler et al., 2008; Sionneau et al., 2008, in revision); (b) Pigmy Basin (Jasper and Gagosian, 1989a, b, 1990; Jasper and Hayes, 1993); and (c) Bryant Canyon (Tripsanas et al., 2007). An important aspect to extract of these studies is that the mineralogy, geochemistry and nature of the terrigenous components transported by the Mississippi River toward the GOM during the meltwater discharges are characteristics of the drainage areas, where the bedrock/soils contain both different clay mineral assemblages (Brown and Kennett, 1998; Sionneau et al., 2008, in revision) and geochemical signatures (Gustavsson et al., 2001). Indeed the mineralogical nature of sediments directly depends on the petrographic characteristics of their source areas (e.g., Bout-Roumazeilles et al., 1999; Sionneau et al., 2008) and they are useful to reconstruct the variability of detrital provenance through time if their main sources are well identified and constrained.

The northern GOM (Fig. 1a) is composed of small intraslope basins (e.g., Pigmy, Orca, La Salle basins) where sedimentation is mainly controlled by terrigenous supply from the Mississippi River and may record specific detrital discharges associated with the LIS melting history (Bout-Roumazeilles and Trentesaux, 2007). In this paper, we report on sedimentological and geochemical variations in terrigenous inputs in core MD02-2553 from the Pigmy Basin in the GOM during the last deglaciation. We chose the Pigmy Basin because it is located at some distance from the Mississippi Delta system. Thus, it collects continuously a smoothed and averaged terrigenous supply from North America and avoids local perturbations linked to the Louisiana slope depositional processes (Aharon, 2003, 2006). Using multiproxy analyses (grain-size, clay mineralogy, magnetic susceptibility, elemental analysis, inorganic geochemistry) on the deglacial terrigenous record of the Pigmy Basin, we aim to determine in detail the timing of continental erosion and sedimentary provenance of the main meltwater discharges, in order to: (1) document the different melting phases of the southern edge of the LIS; and (2) better constrain the history of meltwater input and its terrigenous transfers into the GOM.

2. Pigmy Basin – geological framework

The Pigmy Basin is located on the Louisiana continental slope, about 250 km southwest of the present-day Mississippi Delta, in the northern GOM. The basin is approximately 20 km-long, 7 km-wide, with average depth of 2300 m (Fig. 1b). The structure and bathymetry of the slope are controlled mainly by salt tectonics (Bouma, 1981), with salt domes protruding several hundred meters about the interdiapiric sea floor (Fig. 1b). The Pigmy Basin is defined as a former channel dammed by diapirs, with infilling by bottom transport. Thus sedimentation in the basin is mainly hemipelagic and is strongly linked to the Mississippi River detrital supply (Bouma and Coleman, 1986).

Studies from the Deep-Sea Drilling Project site 619 (Leg 96, Pigmy Basin, Fig. 1b) revealed that the Holocene section displays some intervals nearly devoid of foraminifera. These observations suggest high dilution of the faunal content by rapid influx of terrigenous sediments (Schroeder, 1983; Kohl et al., 1985). Sedimentation rates are higher during glacial isotopic stages (200–300 cm/ka) than during interglacial stages and substages (71–92 cm/ka) because of both increased physical erosion onshore and low sea level characterizing glacial periods. Coleman (1988) evidenced some variability in sediment accumulation during the Holocene, probably resulting from the migration of the main Mississippi River Delta.

Previous studies on the Pigmy Basin revealed glacial–interglacial variability in both the clay composition and terrigenous organic supply (e.g., Tieh et al., 1983; Jasper and Gagosian, 1989a, b, 1990; Jasper and Hayes, 1993). These observations suggest that this major mineral or/and organic terrigenous supply linked to meltwater discharge from the LIS during the deglaciation may have imprinted the Pigmy Basin sedimentary record.

3. Materials and methods

3.1. Materials

The samples were taken from the 10.3 m long core MD02-2553 (Calypso Square). The core was collected in the Pigmy Basin (27°11.01 N, 91°25.00 W) close to DSDP Site 619 (Leg 96, Bouma et al., 1986) during the 2002 Paleoceanography of the Atlantic and Geochemistry (PAGE) cruise of the research vessel Marion Dufresne, as part of the International Marine Past Global Changes Study (IMAGES) program (Fig. 1b). The sediment is mainly composed of massive or faintly laminated greenish gray to dark greenish gray silty to clayey mud throughout the core (Fig. 1c). Slight bioturbation is observed in the sediments. The uppermost 155 cm of the core are composed of sandy to silty clay with foraminifers and coccoliths, whereas the lower part is made up with clays showing foraminifers that become scarce below 400 cm. Dark microlaminations (mm- to cm-scale) are observed between 625–655, 880–946, and 981–1030 cm (Fig. 1c). A homogeneous interval is observed between 655 and 860 cm of the core. Five distinct upward grading, foraminifer-rich, sandy layers interpreted as small turbidites (Meckler, 2006) occurring in the core (298–300, 399–400, 594–596, 614–615, and 974–984 cm). These small turbidites were removed from our calculations because they do correspond to instantaneous processes and will distort the stratigraphic distribution of the proxies (age model).

For this study, the core was evenly sampled every 5 cm between 354 and 1029 cm (yielding a total of 139 samples); this interval corresponds to the deglacial section of the core (see Section 3.2 below). Aliquots of the homogenized sediment samples were rinsed five times to remove salt, dried (40 °C for 48 h) and ground for magnetic susceptibility and geochemical analysis.

3.2. Age model

The chronology of the core MD02-2553 is determined from seven accelerator mass spectrometry (AMS) ^{14}C dates on foraminifera on the studied interval (354–1029 cm) (Table 1; gray dots in Fig. 2). The younger five dates were measured on mixed planktic foraminifers at the CAMS, Lawrence Livermore National Laboratory, USA (Poore et al., in press). The other dates were measured on monospecific *Globigerinoides ruber* (both pink and white varieties) at the Poznan Radiocarbon Laboratory, Poland. All ages were converted into calendar years with the CALIB software (Stuiver and Reimer, 1993, version 5.0.2; http://calib.qub.ac.uk/calib), using the calibration curve Marine04 (Hughen et al., 2004). All AMS ^{14}C ages were corrected using a constant reservoir age of 400 years ($\Delta R = 0$) because it provides consistency with both modern values (Bard, 1988) and with previous paleoceanographic studies from the GOM (e.g., Flower et al., 2004; Meckler et al., 2008; Nürnberg et al., 2008). Reservoir age modifications in the tropical Atlantic Ocean during Late Pleistocene and Holocene are still a matter of debate (Stocker