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Late Pleistocene-Holocene variability in the southern Gulf of Mexico surface waters based on planktonic foraminiferal assemblages

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ABSTRACT

Planktonic foraminiferal assemblages are used as proxies of surface ocean variations, as documented in five marine sediment cores from the Bay of Campeche (BoC), Gulf of Mexico (GoM), spanning the last 34,000 cal yrs BP. This paper seeks to better understand the regional history by studying cores taken in the poorly studied Southern GoM. Multivariate factor analyses calculated five assemblages at millennial to glacial–interglacial scales. During the last glacial period, including the Last Glacial Maximum (LGM), the assemblage contained *G. inflata*, and *T. sacculifer* which suggests the presence of colder and less saline waters than younger times; although during the LGM, saltier waters and weaker ocean circulation may have occurred. During the deglaciation, the deep-dweller *G. crassaformis* suggest a reorganization of deep-thermocline waters and the establishment of transitional conditions, where mild to warm waters entered the Gulf. During the early to mid-Holocene, the tolerant tropical species *G. ruber* pink suggests salinity variations and warmer conditions than the previous interval. During the late-Holocene, only warm species comprise the assemblage, where the group *G. menardii* and *G. truncatulinoindes* suggest warm and stratified conditions, with an oxygen decrease in the thermocline, and rather high salinity levels linked to reduced moisture exported from the Pacific due to the progressively more influential ENSO-like conditions. Prominently, all the assemblages include the species *G. ruber* white chromotype, suggesting that the environmental conditions are continuously favorable to this abundant species. These scenarios show agreement to previous reconstructions in northern and western GoM, the Caribbean, as well as paleoclimate on land, which are mostly regulated by the position of the ITCZ, changes in the expansion of the Atlantic Warm Pool, the tropical circulation, and teleconnections with nearby regions.

1. Introduction

In Quaternary paleoceanographic studies of the Gulf of Mexico, the use of planktonic foraminifera as environmental proxies and biostratigraphic tools has been successfully employed over several decades. They show clear latitudinal and vertical distribution patterns in the surface water column, determined by their species-specific environmental adaptations and intervals of optimum conditions (Bé and Tolderlund, 1971; Kennett and Huddlestun, 1972a, 1972b; Hemleben et al., 1989). Thus a long practice of reconstructions of Sea Surface Temperature (SST), Sea Surface Salinity (SSS), geochemistry, and circulation patterns have used them to document detailed relationships between faunal distributions and hydrography (e.g., Bé and Hamlin, 1967; Brunner and Cooley, 1976; Brunner, 1982; Schmuker and Schiebel, 2002; Martinez et al., 2007; Nürnberg et al., 2008; Steph et al., 2009; Wejnert et al., 2013; Them Ii et al., 2015).

The surface circulation in the Gulf of Mexico (GoM) is known to be a key element of the climate in the North Atlantic and the Atlantic Meridional Overturning Circulation (AMOC), as it conveys heat and salt from low to high latitudes via the Gulf Stream. Therefore, the corresponding oceanographic variations at different timescales are of major interest for regional studies (Martin et al., 1990; Brown et al., 1999; Poore et al., 2003; Oey et al., 2005; Sturges et al., 2005; Zavala-Hidalgo et al., 2006). However, there are still few available records to resolve uninterruptedly the last glacial to Holocene interval. Previous studies are mostly limited to the Holocene (Brown et al., 1999; Schmuker and Schiebel, 2002; Poore et al., 2003; Poore et al., 2009), the last glacial termination period (Kennett et al., 1985; Flower et al., 2004), the Last Glacial Maximum (LGM) event (Lynch-Stieglitz et al., 1999), or they reconstruct several glacial-interglacial cycles (Kennett

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and Huddlestun, 1972b; Martinez et al., 2007). Likewise, there is a limited number of studies in the southern part of the GoM (i.e., the Bay of Campeche, Mexico) in comparison to the north (i.e., the Gulf Coast of the United States). Consequently, interpretations on a basin scale typically utilize the northernmost GoM as the representative region of the patterns of change. Hence through identifying the local variability, we can establish clearer connections and understanding of the mechanisms controlling the GoM variability.

In this tropical region, the meridional migration of the ITCZ exerts a key control on the seasonal hydrologic cycle and the circulation from the Caribbean Sea to the Gulf of Mexico. On a seasonal scale, the climate in the modern SE Mexico and the Bay of Campeche (BoC) shows two distinct phases (e.g., Saha, 2009). (1) A warm and wet season in the late summer and early fall (i.e., when the ITCZ is located farthest to the north); and (2) a cool and dry season during boreal winter (i.e., when the ITCZ migrates south). However, it remains unclear how the oceanography and the climate operate on millennial to sub-millennial timescales.

Previous studies have linked North Atlantic cooling to a southward migration in the mean position of the ITCZ on orbital, millennial and sub-millennial timescales (Haug et al., 2001; Chiang et al., 2003; Them Ii et al., 2015). The former is supported by modeling studies showing that a southward ITCZ displacement could be linked to periods of reduced AMOC and Northern Hemisphere (NH) cooling (Schiller et al., 1997; Vellinga and Wood, 2002; Hawkins et al., 2011), resulting in reduced rainfall in northern South America and a wetter tropical climate farther south (Peterson et al., 2000; Peterson and Haug, 2006). However, during periods of reduced AMOC the high latitudes cooled, but the tropical western and south Atlantic warmed, as the northward heat transport diminished (Manabe and Stouffer, 1997; Ruhlemann et al., 1999; Seidov and Maslin, 2001). Hence, since the GoM has a close connection with the Caribbean warm pool, it represents a key location to identify the transference of salt and heat to the North Atlantic by tracking variations in the GoM Current System (i.e., Yucatan Current – the Loop Current – the Florida Current).

Additionally, remote teleconnections linked to the El Niño Southern Oscillation (ENSO) have been studied in the tropical Atlantic, showing at least two mechanisms of influence. The first mechanism is established through the anomalous Walker circulation setup by a convection rearrangement over the eastern tropical Pacific (Chiang et al., 2000; Saravanan and Chang, 2000). The second mechanism is related to the meridional SST gradient over the tropical Atlantic and its effect on the positioning of the ITCZ and rainfall (Enfield and Mayer, 1997; Giannini et al., 2001). Hence, by identifying changes in the BoC hydrographic conditions, we could link climatic teleconnections between the GoM and the eastern tropical Pacific region on millennial timescales (Koutavas et al., 2006; Conroy et al., 2008; Zhang et al., 2014).

The main goals of this paper are: (1) To analyze a continuous record of planktonic foraminifera from the BoC to determine their abundances and distribution over the past 34 kyr BP. (2) To use the species assemblages as proxies of surface ocean conditions to reconstruct the BoC oceanographic scenarios in parallel to existing GoM records. (3) To identify the controlling mechanisms of climatic variations in southern Mexico on different time-scales based on comparisons with nearby regions.

2. Regional settings

The Gulf of Mexico is an oceanic basin located on the SE margin of North America that covers an area of 1,550,000 km^2. It is connected to the Atlantic Ocean by the Strait of Florida and to the Caribbean Sea by the Yucatan Channel (INEGI, 2014). The climate in southern Mexico and the BoC vary from tropical to subtropical (Köppen, 1936) and from tropical wet and dry climate to tropical wet climate (Köppen, 1936; Peel et al., 2007). During the winter, the region is influenced by strong cold north-easterly winds called *Nortes*. During summer and early autumn, the region is an important hurricane passageway, where meteorological and oceanographic conditions are conducive to develop annual tropical cyclones from June to November (http://www.nhc.noaa.gov/). Precipitation variations in the BoC result from the seasonal migration of the ITCZ, creating drier conditions during boreal winter and rainy conditions during boreal summer (Saha, 2009). Consequently, water discharge and sediment yield from the local rivers seasonally increase during boreal summer. Conversely, the southerly position of the ITCZ during winter is associated with stronger northeast trade winds that favor a large influx of South Atlantic water and a stronger Caribbean Current (CC) flowing towards the GoM (Müller-Karger et al., 1991; Muller-Karger and Castro, 1994) (see Fig. 1).

In the GoM open waters, the average salinity is comparable to that of the North Atlantic (~36.0–36.3). Salinity, however, varies greatly during the year along coastal waters, particularly near the outflow of the delta region of the Mississippi River. During periods when the volume of the Mississippi River is larger, SSS can be as low as 14.0–20.0, occurring as far as 30 to 50 km offshore (e.g., Morey et al., 2003). In the BoC, the two main rivers are the Grijalva-Usumacinta and the Coatzacoalcos (mean annual drainage of 115,535 and 28,679 hm^3/year, respectively (CONABIO, 1998; INEGI, 2014)). Near the coast SSS reach values as lower as 32.0–33.5; showing a mean summer average of SSS = 36.5–37.0 and a mean winter average of SSS = 35.0–36.0 (NASA Aquarius project, 2015).

Sea surface temperatures in winter vary between 18 °C in the northern GoM and 23.5 °C along the southern coast. In the summer, surface temperatures of about 30–32 °C are commonly registered (MODIS-Aqua, 2014). Bottom-water temperatures of about 6 °C have been recorded near the northern part of the Yucatan Channel (Badan et al., 2005; Zavala-Hidalgo et al., 2006).

In the GoM, the surface circulation is characterized by two semi-permanent flows. (1) The Loop Current (LC) in the eastern part, being the main source of the Gulf Stream in the North Atlantic and the principal current moving waters through the Gulf; and (2) an anticyclonic gyre that moves on the western side of the basin (Behringer et al., 1977). To the southeast, events of upwelling occur off Yucatan Peninsula, and the Campeche Bank, as well as water from the Caribbean entering through the Yucatan Channel, flowing clockwise via the Straits of Florida (Salas-de-León et al., 1992; Sturges et al., 2005; Zavala-Hidalgo et al., 2006). In the south-western part of the GoM, a less persistent pattern exists because currents are relatively weak, varying appreciably in intensity with season and location. There is extreme variability in both current direction and speed on the continental shelf and the coastal waters of the GoM. Currents are subjected to seasonal and annual variations produced not only by major circulation patterns but also by changes in the prevailing wind direction (DiMarco et al., 2005; Oey et al., 2005; Sturges et al., 2005). In the south, although the LC and their current eddies (called Loop Current Eddies) greatly influence the general circulation, a semi-permanent cyclonic gyre domains over the BoC. This eddy brings nutrients to the surface from the thermocline subsurface waters (Müller-Karger et al., 1991; Monreal-Gómez et al., 1992; Salas-de-León et al., 1992; Zavala-Hidalgo et al., 2006).

The ocean circulation of the upper water column of the Gulf of Mexico consists of western Atlantic waters entering over the Antilles passages into the Caribbean (Johns et al., 2002). These water masses contribute to the west-flowing of the CC that derives from the North and South Equatorial Currents during boreal winter and summer, respectively. Conversely, the influx of North Atlantic water (i.e., the Sargasso Sea) is large during boreal summer, thus increasing the sea-surface salinity in the western Caribbean. When the CC passes north of the Guajira Peninsula, Colombia, it continues into the north-western Caribbean to eventually feed the Yucatan Current (Johns et al., 2002; Sturges et al., 2005) and finally the Gulf of Mexico.