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Research paper

Organic-walled dinoflagellate cyst distribution in the Gulf of Mexico

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ABSTRACT

In order to document the distribution of organic-walled dinoflagellate cysts (dinocysts) and their relationship with sea-surface parameters (temperature, salinity, primary productivity), palynological analyses were performed on 44 surface sediment samples from the Gulf of Mexico (17°N to 29°N). Samples display low to moderate concentrations with values ranging from 78 to 3576 dinocysts·g^{-1} dry weight sediment. Assemblages are dominated by either *Brigantedinium* spp. or *Polysphaeridium zoharyi* along with the phototrophic taxa *Spiniferites* spp. and *Operculodinium* spp. Redundancy analyses (RDA) identified the distance to the coast and/or water depth and annual temperature as being the most important factors that control cyst distribution in the Gulf of Mexico. The first two axes explain respectively 44.7% and 20% of the total variance. The inshore to offshore trend in cyst distribution emphasized by the RDA involves changes in associations of species with the presence of *Impagidinium* spp. in more oceanic assemblages and higher representation of *P. zoharyi* nearshore. This latter species, produced by the potentially toxic dinoflagellate *Pyrodinium bahamense*, reaches very high abundances notably on the west Florida shelf and in the Mexican lagoons. Additionally, *Melitasphaeridium choanophorum*, which was considered to have gone extinct by the end of the Pleistocene, appears as a modern component of marine sediment from the north and southwestern Gulf. Our results thus demonstrate a biostratigraphical range extending to the present, at least in the study area. This palynological investigation highlights the importance of the Gulf of Mexico as potential refuge for late Cenozoic species thought to be extinct.

1. Introduction

A worldwide increase in harmful algal blooms (HABs), including toxic events, has been observed during the past decade (Anderson, 1989; Smayda, 1990; Hallegraeff, 1993; Anderson et al., 2002; Glibert et al., 2005a,b). This tendency of harmful phytoplankton to form blooms is highly influenced by the community composition, local hydrography (stratification, circulation patterns) and diverse environmental parameters such as nutrient concentrations, temperature, salinity and turbidity, which may be altered by human activity (i.e., cultural eutrophication, pollution, climate changes) (Burkholder, 1998; Anderson et al., 2002; Smayda, 2002; Peperzak, 2003; Glibert and Burkholder, 2006; Heisler et al., 2008). In the Gulf of Mexico, recurrent HABs are an issue as they may result in significant economic losses (Anderson et al., 2000). In this region, at least 40 species of toxic or potentially toxic algae are known to occur. These include harmful dinoflagellate species such as *Ceratium* sp., *Heterocapsa* sp., *Protoperidinium* sp., *Karlodinium* sp., *Takamaya* sp., *Dinophysis* sp., *Peridinium quinquecorne*, *Prorocentrum* sp., *Pyrodinium* sp. and *Scrippsiella* sp. (Licea et al., 2002; Sierra-Beltrán et al., 2005). Of all these taxa, the toxic dinoflagellate *Karenia brevis* – previously known as *Gymnodinium breve* – has the greatest impact on marine wildlife, human health, fisheries and tourism (Davis, 1948; Van Dolah, 2000; Magaña et al., 2003; Steidinger, 2009).

Because many dinoflagellates produce resting cysts that settle in bottom sediment for a variable time period (Wall and Dale, 1968; Dale, 1983; Taylor, 1987), interactions between the benthic and pelagic environments play a key role in HAB dynamics. Most dinoflagellate cyst taxa are composed of a complex carbohydrate-based polymer ("dinosporin") (Versteegh et al., 2012) and some taxa are composed of calcareous material (Matsuoka and Fukuyo, 2000). They represent a dormant stage related to sexual reproduction that also ensures the survival of dinoflagellates through unfavorable environmental conditions (Itakura et al., 1997). Cysts related to sexual reproduction may survive for decades and even centuries in bottom sediments (Lundholm et al., 2011; Ribeiro et al., 2011). When conditions are suitable, the germination of cysts occurs and the upward migration of cells may contribute significantly to the initiation of blooms (Anderson, 1998; Garcés et al., 2002; Anderson and Rengefors, 2006; Hense, 2010). The seed banks in sediment can therefore initiate blooms and have an important influence on their composition and magnitude. Additionally, species abundance and composition in assemblages from recent sediment offer a (fragmentary) picture of the organic primary production in a given area and may be helpful to document past productivity (Radi and de Vernal, 2008) along with living population diversity and dynamics in regions affected by harmful blooms (Anderson et al., 2005).

In middle to high latitudes of the Northern Hemisphere, numerous studies have shown close relationships between the assemblages of

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organic-walled dinoflagellate cysts (dinocysts) and the environmental conditions in the upper water column (e.g., Wall et al., 1977; Marret, 1994; Matthiessen, 1995; de Vernal et al., 1997; Zonneveld, 1997; Rochon et al., 1999; de Vernal et al., 2001, 2005; de Vernal and Marret, 2007; Pospelova et al., 2008; Radi and de Vernal, 2008; Bonnet et al., 2012). Dinocysts have thus been largely used for reconstructions of past sea-surface conditions such as temperature, salinity, sea-ice cover and productivity (e.g., Turon, 1978; Turon and Londeix, 1988; Harland and Howe, 1995; de Vernal et al., 2000; Hillaire-Marcel et al., 2001; Warny et al., 2003; Solignac et al., 2004). These studies rely on the development of extensive datasets of the modern distribution of cysts and corresponding environmental conditions. However, to date, the distribution of dinocyst assemblages from tropical Atlantic areas remains poorly documented despite important taxonomic diversity and their significance in terms of economic and health issues. Only few studies have documented dinocyst Quaternary assemblages from the Gulf of Mexico (e.g., Wall, 1967; Wall et al., 1977; Edwards, 1986; Wrenn, 1988; Edwards and Willard, 2001; van Soelen et al., 2010). Here, we present the results of palynological analyses undertaken on 44 surface sediment samples from selected areas of the Gulf of Mexico, all affected to a varying degree by harmful algal blooms. Since a few of these harmful species are known to produce fossilizable cysts, the goals of the study are 1) to provide an accurate picture of the cyst distribution in recent sediments with focus on the occurrence of potentially toxic species and their relationship with modern hydrographic parameters, and 2) to develop a regional dinocyst database that could be used for paleoenvironmental and paleoceanographical reconstructions.

2. Regional setting

It is believed that the Gulf of Mexico formed as a semi-enclosed back-arc basin in the Middle to Late Jurassic during a short-lived extensional phase (Stern and Dickinson, 2010). The surface circulation in the central portion of the Gulf is dominated by the Loop Current, its rings and a permanent anticyclonic gyre (Nowlin and McLellan, 1967; Cochrane, 1972; Elliot, 1979; Cherubin et al., 2006). Surface waters enter into the Gulf through the Yucatán channel and exit through the Florida Strait (Elliott, 1982; Blumberg and Mellor, 1985; Hofmann and Worley, 1986; Oey et al., 2005; Jochens and DiMarco, 2008; Auladell et al., 2010) (Fig. 1). The latitudinal and longitudinal extensions of the Yucatán Current into the northeastern Gulf are seasonally variable and may lead to the shedding of mesoscale rings that gain velocity through

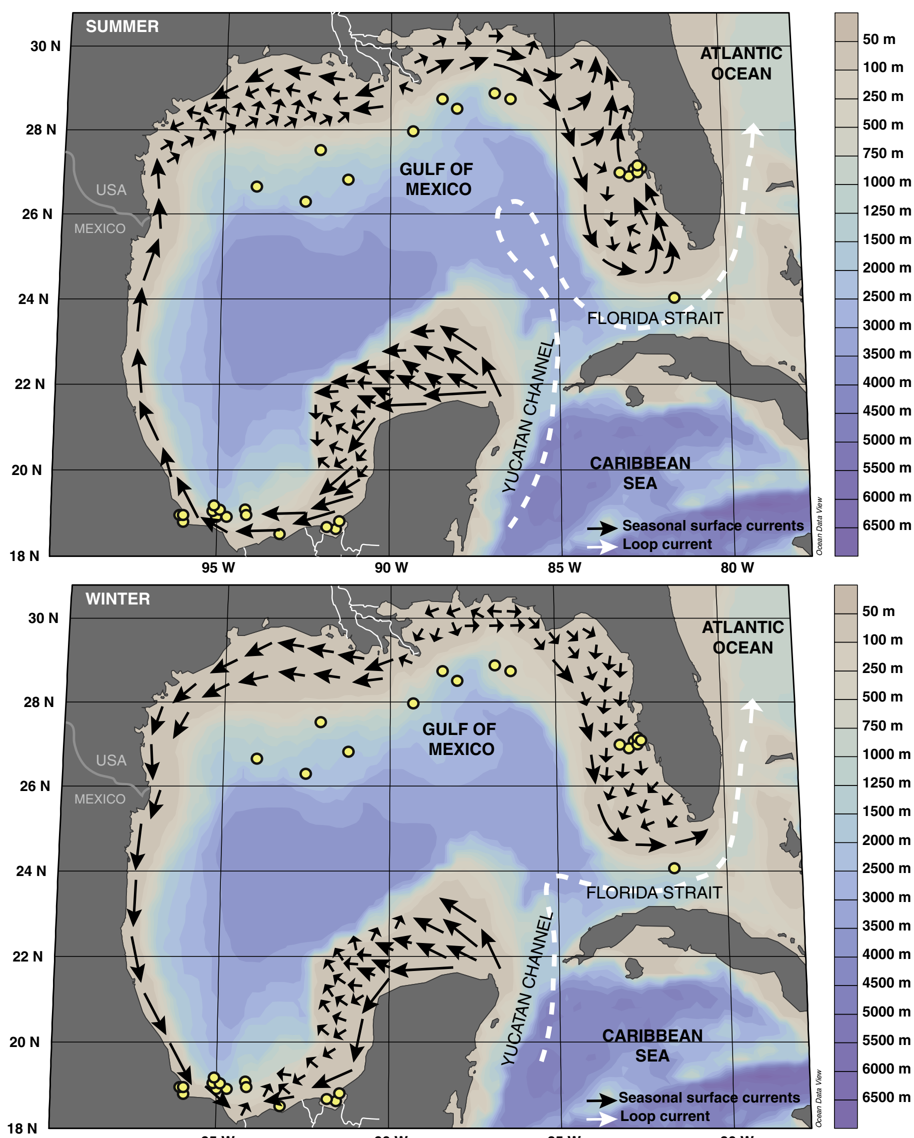

Fig. 1. Simplified map of seasonal surface currents along the shelves of the Gulf of Mexico. Modified from Zavala-Hidalgo et al. (2003); western shelves and Yang et al. (1999); Florida coast.