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Research paper

Ancient upwelling record in a phosphate hardground (Tortonian of Menorca, Balearic Islands, Spain)

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A B S T R A C T

The Tortonian sedimentary succession of Menorca Island (Balears, Spain) includes two stratigraphic sequences: the lower Tortonian distally-steepened carbonate ramp and the coral reef complex of late Tortonian-early Messinian age. The boundary between the two sequences corresponds to *Heterostegina*-rich sediments in the western part of Menorca, and to a phosphatic hardground in the eastern part of the island. In the field, the hardground is represented by a dark-brown layer and a rough surface on top of the Tortonian Ramp deposits. Dark phosphate precipitates infill cracks and borings in the underlying limestone to a depth of up to 50 cm. The phosphatic hardground is overlain by planktonic rich wackestone to packstone, which penetrates downward into the fissures, borings, and vugs. This deposit is characterized also by grains of reworked phosphate, glauconite grains, small benthic foraminifers and is followed by tabular beds of bioclastic packstone to wackestone with abundant thin crusts of coralline algae.

Based on the *Amphistegina* tests shapes and red algal assemblage of sediments below and above the hardground, and the lateral correlation with *Heterostegina* deposits, the bathymetry for the development of the phosphatization is estimated less than 100 m. The limited localization of the phosphatic hardground at the eastern side of the ramp indicates that a dynamic upwelling of deeper and nutrient-enriched waters favored development of a phosphatic hardground. This upwelling episode is representative of the paleoceanographic settings induced by the climate conditions of the Mediterranean area during the Tortonian.

1. Introduction

The extensive carbonate platform successions in the Mediterranean area characteristic for the middle to late Miocene (Esteban, 1996; Pedley, 1998; Pomar, 2001; Pomar et al., 2002), are in many instances interrupted by hardgrounds, some of which show high concentrations of phosphate (Carannante, 1982; Pedley and Bennett, 1985; Mutti and Bernoulli, 2003; Föllmi et al., 2008, 2015; Föllmi, 2016). These hardgrounds may divide the thick shallow-water carbonate deposits alternating between red-algal and coral dominated ecosystems (Pomar, 2001; Föllmi et al., 2015). The reason for the formation of these pronounced breaks in carbonate sedimentation has been discussed controversially. Their presence has been linked to deepening phases or paleoceanographic changes or simply changes in humid-dry climate conditions. In any case there is a general agreement that they developed during periods of general climate warming (Pomar, 2001; Pomar et al., 2002; Föllmi et al., 2015). It is thought that the geodynamic evolution of the Mediterranean area during the Miocene led to important and pronounced palaeogeographic and related paleoceanographic changes that turned the system into a highly sensitive sensor of climatic change (John et al., 2003; Kocksis et al., 2008; Brandano et al., 2010). The Tethys Ocean was subdivided by the orogenetic evolution of the different belts (Alpine,

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Betic, Apennine, and Dinarid belts), and the Indopacific seaway was closed following the collision of the Eurasian and Arabian plates (Carminati et al., 2010). With this the global paleogeography and current circulation changed in a way that strongly increased the climatic sensitivity in that the resulting circulation pattern responded rapidly to climatic changes – (Bethoux and Gentili, 1999; Sierro et al., 2003).

The present-day Mediterranean is characterized by a negative water balance, where evaporation exceeds precipitation plus run-off, inducing an anti-estuarine circulation, which involves an inflow of Atlantic surface waters and an outflow of more saline and thus denser Mediterranean water (Bethoux et al., 1999). Similar circulation patterns occurred during the late Miocene (Kouwenhoven and van der Zwaan, 2006). In this context, deep water would reach the surface by topographic upwelling before returning to the Atlantic. Under humid conditions as inferred by sedimentological records an estuarine circulation developed, with an inflow of deeper, nutrient-rich Atlantic waters and an outflow of surface Mediterranean water (Rohling, 1994; Meijer and Tuenter, 2007).

In upwelling areas, sediments with high authigenic phosphorus contents are produced (Jarvis, 1980; Parrish, 1990; Föllmi et al., 2008). In some cases, sea-level rise has been interpreted to increase the influence of the upwelling on shelves, favouring phosphorite accumulation by sediment starvation (Simone and Carannante, 1988; Allouc, 1990; Mutti and Bernoulli, 2003). During the Miocene, phosphorite deposition occurred at a global scale, and three main episodes of phosphogenesis are distinguished. They occurred in the late Oligocene to early Miocene, in the middle to late Miocene (Föllmi et al., 2008 and references therein), and during Tortonian. The last episode has been documented in California (Monterey Formation), in Florida, and on the western shelf of South Africa (Riggs and Sheldon, 1990) and recently in the Mediterranean (Föllmi et al., 2015).

Adding to the complexity, the Mediterranean experienced episodes of increased precipitation in the Miocene that are also thought to have been the result of palaeogeographic changes (Böhme et al., 2008). When the Central America isthmus narrowed, the restricted exchange of water masses between the tropical Atlantic and Pacific oceans led to an increase of the northward transport of heat in the water masses. This setting promoted warm conditions and consequently higher evaporation in the North Atlantic domain, which is the preponderant source of European precipitation, causing so-called washhouse events.

This paper discusses the origin of a phosphatic hardground that marks the contact between the lower Tortonian red-algal dominated mesotrophic ramp and the overlying late Tortonian to early Messinian oligotrophic Coral Reef Complex on Menorca (Balearic Islands). This hardground is situated in a critical position in the Mediterranean, namely in the western Mediterranean where the outflow of the water during an estuarine circulation meets the topographic hindrance of the Balearic Promontory. This situation makes the study area a sensitive gauge of circulation change in the Mediterranean.

Lastly a substantial point in interpreting shallow water carbonate successions is the evolution from ramp to rimmed shelf (Read, 1985). A classic example is represented by the western margin of the Great Bahama Bank evidencing a clear change from a Miocene ramp to a Pliocene rimmed shelf (Betzler et al., 1999; Westphal et al., 1999). Generally the high rate of carbonate production localized along the incipient shelf edge, commonly associated with reefal biota, which is coupled with sediment starving in the basin, increases the relief and steepens the margin of the carbonate platform. Such changes are referred to climate or oceanographic changes inducing a switch in the type of shallow-water carbonate factory from bioclastic production to a shallow-water, photozoan reef dominated production (Bosence, 2005). The investigated example offer the possibility to analyse the factors triggering the rapid end of the bioclastic dominated factory and producing a suitable substrate for the photozoan reef building factory.

2. Study area

The island of Menorca belongs to the Balearic archipelago (Fig. 1A, B), which is the emergent part of the Balearic Promontory, the NE prolongation of the external zones of the Betic Range (Fontboté et al., 1990). During the late Miocene, prograding carbonate platforms developed in the shallow waters on the promontory around emergent palaeo-islands (Pomar et al., 1996). On southern Menorca, carbonate rocks of the upper Miocene platform-system unconformably onlap onto the Palaeozoic to lower Cenozoic basement of the Tramuntana palaeo-island (Fig. 1B).

These upper Miocene carbonate rocks are composed of two stratigraphic sequences (Fig. 1C): (1) The lower Tortonian distally-steepened carbonate ramp (also termed Lower Bar Unit); (2) The coral reef complex. According to Bizon et al. (1973) the foraminiferal assemblages of the ramp succession provide evidences of deposition lasted all the N16 zone. This zone corresponds to the M13a zone (*N. acostaensis* LOSZ) of Berggren and Pearson (2005), that according to Wade et al. (2011) falls in the interval 9.93 Ma and-8.58 Ma. The foraminiferal association of the coral reef complex are indicative of the N17 zone. This biostratigraphic datum is in agreement with the age obtained for volcanoclastic levels of the reef complex succession (See Pomar et al., 2012; and reference therein).

The lower Tortonian carbonate ramp is, from the shore to the open sea, composed of fan deltas and shoreface deposits passing into an inner-ramp, dominated by deposits related to seagrass meadows (Pomar et al., 2002; Mateu-Vicens et al., 2008). Basinward on the middle ramp, subaqueous dunes are represented by cross-bedded grainstones with abundant fragments of red algae, echinoids, bryozoans and molluscs (Pomar, 2001; Pomar et al., 2002; Asprion et al., 2009). Further basinward, a rhodolithic rudstone to floatstone forms the steepened slope. On the lower slope, the rhodolithic clinobeds intercalate with turbiditic and debris-flow deposits. They interfinger with outer ramp sediments composed of laminated wackestones to grainstones rich in planktonic foraminifers. The overlying upper Tortonian to early Messinian reef complex results well-known from Mallorca but is only poorly preserved on Menorca. It is composed of coral-reef deposits with red algal-dominated sediment in off-reef and open shelf settings.

The transition from the lower Tortonian ramp to the upper Tortonian to Messinian reef complex is thought to have been induced by a change from a humid to an arid climate and thus to be controlled by photic conditions (through a change in the turbidity of the water column) and trophic regime rather than by temperature (Pomar et al., 2004). In this context the temperature appears to have been somewhat higher during the deposition of the lower Tortonian red algae-dominated ramp than during the formation of the coral reef system (Pomar et al., 2004).

The boundary between the two depositional sequences is represented by *Heterostegina*-rich sediments in the western part of Menorca, and by a phosphatic hardground in the eastern part of the island (Obrador et al., 1992). The outcrops of the hardground along the rocky shoreline around the village of S'Algar (Fig. 2) are the object of the present study.