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An enigmatic kilometer-scale concentration of small mytilids (Late Miocene, Guadalquivir Basin, S Spain)

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ABSTRACT

Upper Miocene heterozoan carbonates crop out extensively in a NE–SW-trending belt (42 km long and 1.5–8 km wide) along the so-called El Alcor topographic high, from Carmona to Dos Hermanas (Seville, S Spain). These carbonates formed at the southern active margin of the Guadalquivir Basin, the foreland basin of the Betic Cordillera. They change to marls basinward (NE) and to sands landward (SE and SW). Therefore, carbonate production was constrained to a limited area in an otherwise siliciclastic shelf. The carbonates (up to 40 m thick) overlie a gradually coarsening-upward succession of marls followed by silts and sandstones. The carbonate sequence can be divided into three subunits corresponding, from bottom to top, to lowstand, transgressive, and highstand system tract deposits. The lower subunit, exhibiting extensive trough cross-bedding, is interpreted as a shallow-water bar deposit. The intermediate subunit onlaps underlying sediments and was deposited in deeper, low-turbulence conditions. The upper subunit deposits accumulated in a well-oxygenated outer platform based on benthic foraminiferal assemblages. The presence of hummocky and swaley cross-stratification in these latter deposits suggests that they were affected by storms. Pervasive fluid-escape structures are also observed throughout the carbonates.

The three subunits consist of bioclastic packstones to rudstones made up of abundant fragments of small mytilids. Isotopic data from serpulid polychaete *Ditrupa* tubes show ^{13}C-depleted values (up to −16.1‰), whereas $\delta^{18}O$ yields normal marine values. Additional isotopic data on shells of scallops, oysters, and small mussels, as well as bulk sediment, show diagenetic alterations. Based on actualistic examples of massive concentrations of mussels, the nearly monospecific composition of the El Alcor deposits, together with negative $\delta^{13}C$ values of *Ditrupa* tubes, indicates that cold seeps presumably promoted carbonate formation. However, the absence of typical features of cold-seep deposits, such as authigenic carbonates mediated by anaerobic bacterial activity and the typical chemosynthetic shelly organisms, makes the large carbonate body of El Alcor an unusual cold-seep deposit.

1. Introduction

Light, temperature, and nutrients are thought to be the major factors controlling associations of benthic organisms that produce carbonate particles in marine environments and therefore types of carbonate sediments (e.g. James, 1997; Mutti and Hallock, 2003). Photozoan carbonates form only in well-illuminated, warm shallow-water settings, whereas heterozoan carbonates, produced mainly by light-independent organisms, can accumulate in a wide range of water temperatures and depths (James, 1997; Schlager, 2003). Known heterozoan carbonates are made up of skeletal particles of heterotrophic invertebrates, including in some cases coralline red algae.

Bivalves are among the most abundant components in the heterozoan carbonates. Of these, mussels (Bivalvia: Mytilidae) are able to produce dense concentrations (the so-called mussel beds, mussel aggregations, mussel reefs, mussel bioherms) in different mid- and high-latitude aquatic ecosystems (e.g. Bertness and Grosholz, 1985; Commito and Dankers, 2001; Gutiérrez et al., 2003), leading to massive carbonate accumulations. Based on data of biomass production of *Mytilus edulis* from western Sweden (Loo and Rosenberg, 1983) and the Wadden Sea (Asmus, 1987), Steuber (2000) estimated a carbonate production rate ranging from 2 to 6.5 kg per m^2 and year. In soft-bottom marine settings, kilometer-scale mussel beds can be found in a very wide range of water depths, from marshes and subtidal settings to deep abyssal planes. In very shallow waters, crowded concentrations of the blue mussel (*M. edulis*) in tidal flats and subtidal settings are well known (Dittmann, 1990; Commito and Dankers, 2001; Commito et al., 2006; Folmer et al.,

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2014). Additionally, dense aggregations of the ribbed mussel (*Geukensia demissa*) have been described in the seaside margin of salt marshes from the western North Atlantic (Bertness, 1984; Bertness and Grosholz, 1985; Franz, 1993, 1996, 2001). In subtidal conditions, from a few meters deep down to ~100 m, the horse mussel (*Modiolus modiolus*) forms elongated accumulations (bioherms/reefs) in the Northern Atlantic (Magorrian and Service, 1998; Wildish et al., 1998, 2009; Lindenbaum et al., 2008; Elsäßer et al., 2013; Gormley et al., 2013). Finally, chemosynthetic mytilids can also be major colonizers in hydrothermal vents and cold-seep areas (Paull et al., 1992; Aharon, 1994; Pichler and Dix, 1996; Sibuet and Olu, 1998; Schlager, 2003; Conti and Fontana, 2005; Levin, 2005; Campbell, 2006; Roberts et al., 2010; Taviani, 2010).

Massive accumulations of mussels form a kilometer-scale carbonate body along the so-called El Alcor area (Seville, SW Spain) (Fig. 1). These carbonates consist of rudstones-packstones of mussel fragments and are completely surrounded by siliciclastics. They extend along the outer fringe of a terrigenous Late Miocene ramp on the active margin of the Atlantic-linked Guadalquivir Basin (S Spain). We describe these enigmatic heterozoan carbonates, studying the nature of the major carbonate producer and analyzing stable isotopes of the carbonates in order to decipher the paleoenvironmental context in which they formed. Comparisons with present-day massive accumulations of mytilids, together with geochemical results and taphonomic observations, suggest that the El Alcor carbonates might most likely represent unusual cold-seep deposits.

2. Location and geologic setting

The studied deposits crop out in a SW–NE trending belt 42 km along the so-called El Alcor, a topographic high extending from southwest of Dos Hermanas to Carmona (Seville, SW Spain) (Fig. 1). The width of the carbonate belt increases southwestward: 1.5 km in Carmona, about 3.5 km in Alcalá de Guadaira, and up to 8 km in Dos Hermanas (Fig. 1). These carbonates change laterally to marls to the north-northwest (basinward) and to sands to the southeast, and southwest (landward) (Viguier, 1974).

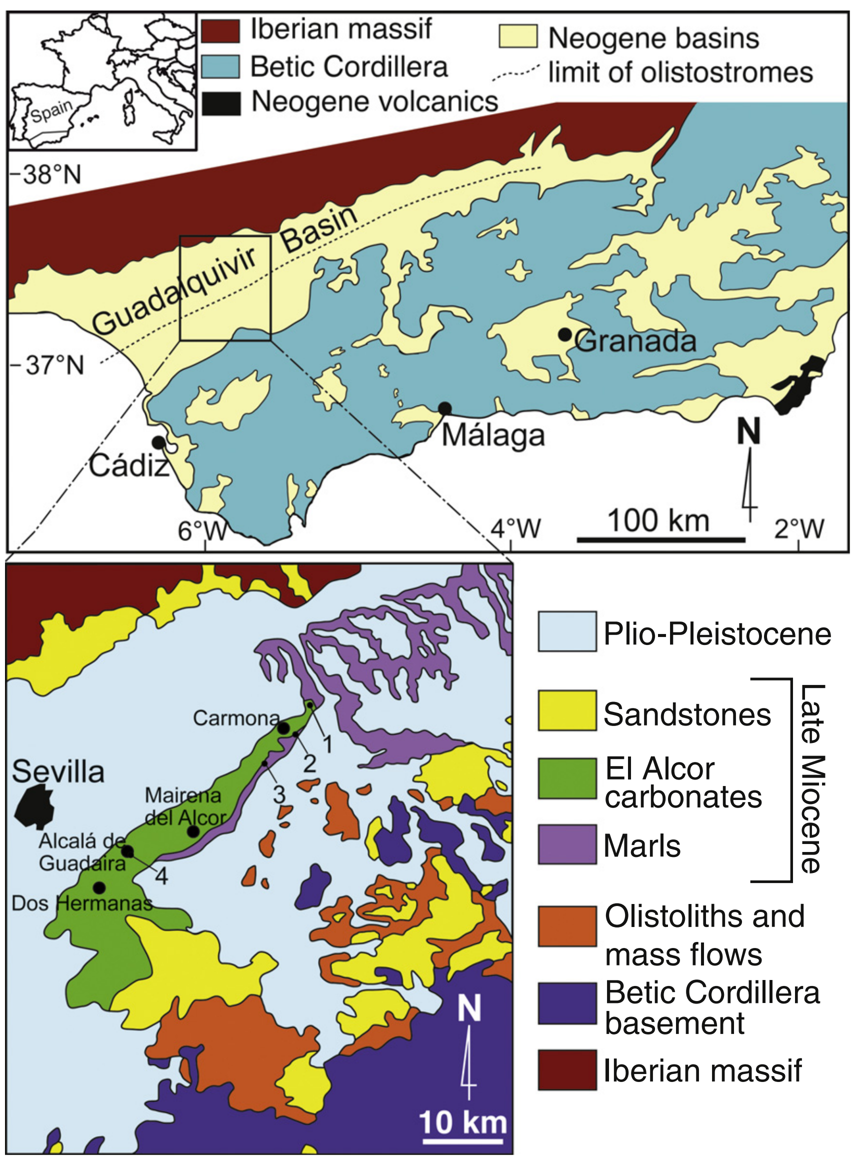

Fig. 1. Simplified geological sketch of the Betic Cordillera and geological map of the study area. Numbers indicate the location of the four studied stratigraphic sections: 1 — Carmona Quarry, 2 — Carmona Antena, 3 — Carmona Fútbol, 4 — Alcalá de Guadaira.