Palaeogeography, Palaeoclimatology, Palaeoecology 274 (2009) 54–63

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

# Heterozoan carbonates in oligotrophic tropical waters: The Attard member of the lower coralline limestone formation (Upper Oligocene, Malta)

Marco Brandano [a,b,*], Virgilio Frezza [a], Laura Tomassetti [a], Marco Cuffaro [b]

[a] Dipartimento di Scienze della Terra, Università di Roma "La Sapienza", P. Aldo Moro 5, I-00185 Roma, Italy
[b] IGAG-CNR, P. Aldo Moro 5, I-00185, Roma, Italy and ISMAR-CNR, Via Gobetti 101, I-40129, Bologna, Italy

ARTICLE INFO

Article history:
Received 21 April 2008
Received in revised form 8 December 2008
Accepted 23 December 2008

*Keywords:*
Heterozoan carbonates
Carbonate ramp
Biofacies
Trophism
Oligocene

ABSTRACT

Photozoan and heterozoan skeletal assemblages are controlled by their trophic requirements (i.e. light-based photosynthesis versus other sources) and temperature. Photozoan associations tend to dominate tropical and subtropical waters, whereas heterozoan carbonate systems tend to occur in cooler waters and in localised areas that are affected by nutrient-rich upwelling or terrestrial runoff. Because of the wide climatic spectrum in which heterozoan carbonates are found, their interpretation is often problematic. We present a high-resolution analysis of the Attard Member of the Lower Coralline Limestone Formation (Upper Oligocene, Malta). The biotic associations and palaeolatitudinal reconstructions suggest that carbonate sedimentation took place in tropical waters under oligotrophic conditions. An important factor controlling the spread of heterozoan assemblages in the Late Oligocene of Malta seems to be related to the palaeoecology and evolution of zooxanthellate. The limited capacity of corals to thrive in high-light conditions and to form a wave-resistant reef promoted the diffusion of heterozoan assemblages.

## 1. Introduction

The environmental conditions that control biogenic sediment formation on carbonate platforms are determined by ocean circulation, which affects water temperature (Lees and Buller, 1972; James, 1997), seawater composition and carbonate saturation state (Hallock, 1996; Stanley and Hardie, 1998), and nutrient availability (Hallock and Schlager, 1986; Birkeland, 1987; Carannante et al., 1988; Hallock, 1988, 2001; Mutti and Hallock, 2003). In turn, the biotic community determines accumulation rates and facies distribution, thus controlling platform geometry (Pomar, 2001a). James (1997) introduced the terms photozoan and heterozoan to relate skeletal assemblages to their trophic requirements (i.e. light-based photosynthesis versus other sources) and temperature. Photozoan associations tend to dominate tropical and subtropical waters, whereas heterozoan carbonate systems tend to occur in cooler waters (temperate to polar latitudes) and in lower-latitude settings affected by nutrient-rich waters resulting from upwelling or terrestrial runoff (Lees and Buller, 1972; Carannante et al., 1988; James, 1997; Mutti and Hallock, 2003; Pomar et al., 2004). Because heterozoan carbonates can be found across a wide climatic spectrum (Carannante et al., 1988; Henrich et al., 1995; James, 1997) their interpretation is often problematic. This is shown, for example, by the different reconstructions proposed for various Oligocene and Miocene carbonates of the Mediterranean area (Pomar et al., 2004; Braga et al., 2006). Recently, the role of trophic conditions has been stressed by Mutti and Hallock (2003), Pomar et al. (2004), and Wilson and Vecsei (2005). According to the model of Hallock and Schlager (1986), excess nutrient input may terminate accumulation on a chlorozoan (photozoan) carbonate platform or cause a shift towards heterozoan carbonate production (Pomar, 2001b; Brandano and Corda, 2002; Mutti and Hallock, 2003; Pomar et al., 2004).

Our detailed analysis of the stratigraphy, sedimentology and biofacies of the Attard Member of the Lower Coralline Limestone Formation (Upper Oligocene of Malta) shows that it was deposited on a carbonate ramp dominated by heterozoan and, subordinately, photozoan skeletal assemblages. The biotic associations and palaeolatitudinal reconstructions suggest that carbonate sedimentation took place in tropical waters under oligotrophic conditions, a typical environment for photozoan assemblages. The dominance of heterozoan assemblages under such conditions add a further complication to the interpretation of ancient carbonates dominated by this skeletal association. The aim of this work is to highlight the role of the different factors controlling the spread of heterozoan assemblages in the late Oligocene of Malta.

## 2. Geological setting

The Maltese Islands and the Iblea Plateu of Sicily were part of a geographically extensive carbonate ramp located on the distal segment of the Late Oligocene (Chattian) to Miocene African

---

* Corresponding author. Dipartimento di Scienze della Terra, Università degli Studi di Roma, "La Sapienza", P.le Aldo Moro 5, I-00185 Roma, Italy. Tel.: +39 06 49694240; fax: +39 06 4454729.
*E-mail address:* marco.brandano@uniroma1.it (M. Brandano).

0031-0182/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.palaeo.2008.12.018

continental margin. The characteristics of the Late Oligocene Maltese carbonate sequences have been summarised by Buxton and Pedley (1989) and in Pedley (1998). The sedimentary succession that outcrops on the Maltese Islands consists of four major lithostratigraphic units (Fig. 1A) (Pedley, 1978, 1993; Carbone et al., 1987; Knoerich and Mutti, 2003). The lowermost outcropping unit, the Lower Coralline Limestone Formation (Chattian), consists of rudstones and packstones with skeletal fragments typical of heterozoan carbonates (*sensu* James, 1997). This lithostratigraphic unit is overlain by the Globigerina Limestone Formation (Aquitanian–Langhian), which in turn is followed by hemipelagic clay to marlstones of the Blue Clay Formation (Serravallian to lower Tortonian). This latter formation is unconformably overlain by the shallow-water Upper Coralline Limestone Formation (Tortonian to Messinian). Our work focuses on the Attard Member of the Lower Coralline Limestone Formation (Fig. 1B). This formation was subdivided into four lithological members by Pedley (1978, 1987). The first member (Maghlaq) represents sedimentation in a sheltered lagoon. Progressive submergence resulted in colonisation by rhodolithic algae of the Attard Member, which is overlain by intertidal, cross-bedded units of the Xlendi Member. Subsequent renewed subsidence led to the accumulation of the Il Mara Member.

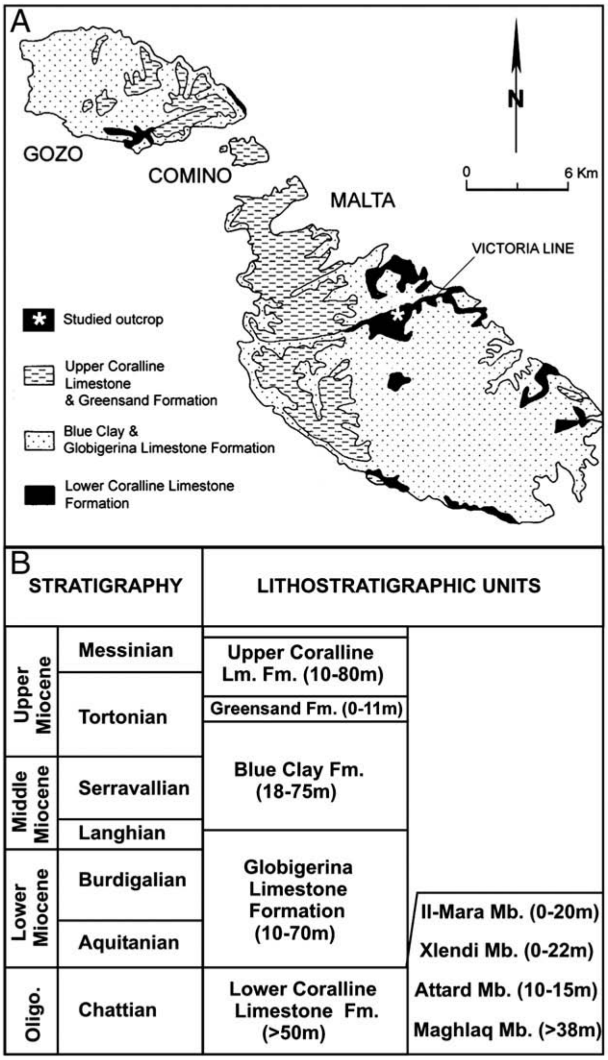

**Fig. 1.** A: Geological map of the Maltese Islands showing the lithostratigraphic units (modified from Pedley, 1987). The grey star indicates the investigated outcrop. B: Overview of the lithostratigraphy and age of the units outcropping on the Maltese Islands (modified from Pedley, 1978).

## 3. Methods

Field observations were complemented with the petrographic examination of 126 thin sections for textural characterization and identification of skeletal components. Ecological factors such as water depth, nutrient input, and reworking rates were determined by using coralline algal and foraminiferal assemblages. In particular, test shape variations (based on thickness to diameter ratios — $T/D$) of the large benthic foraminifer (LBF) *Amphistegina* were used to constrain the bathymetry of the depositional setting, according to the model proposed by Mateu-Vicens et al. (2005). Based on the studies by Beavington-Penney et al. (2004) on the abrasion of macrospheric nummulitids as indicators of transport processes, the preservation level of LBF tests was used to reconstruct taphonomic processes related to sediment transport within the ramp. Assessments are referred to as “Beavington–Penney Taphonomic Scale” numbers (i.e. BPTS#).

The interpretation of nutrient flux was based on the integration of biotic and sedimentological characteristics. Present-day studies (Birkeland, 1987; Hallock, 1987; Brasier, 1995) have shown that organism diversity and abundance can be related to trophic resource levels at the time of deposition. Changes in the trophic resource continuum from nutrient-poor, relatively oligotrophic conditions to nutrient-rich, relatively eutrophic states affect the turbidity of the water column and the characteristics of the substrate (Hallock, 1987; Wood, 1993).

For the palaeolatitudinal reconstruction we computed the past plate motions of the Maltese Islands using palaeomagnetic data from Schettino and Scotese (2005). We assumed a negligible relative motion between the Iblea–Malta Plateau block and the North-African plate over a 33 Ma time interval (Oligocene to Recent); this means that our reconstruction is based on rigid body rotations of Africa relative to the palaeomagnetic reference frame. We focused on Malta's past geographical position at different characteristic times, incorporating plate movements relative to Anomaly 13, Anomaly 6, and Anomaly 5, at $t = 33.1$ Ma, $t = 20.1$ Ma, and $t = 10.9$ Ma, respectively (Schettino and Scotese, 2005), and current plate kinematics at time $t = 3.2$ Ma (DeMets et al., 1994).

## 4. Depositional model of the Attard member

Stratigraphic and sedimentologic analysis of our detailed biofacies geometry shows that the depositional profile is consistent with a homoclinal ramp (Fig. 2A) (*sensu* Read, 1982, 1985). Although we use the terminology proposed by Burchette and Wright (1992) to subdivide the carbonate ramp facies, the criteria used here to characterize the various parts of the ramp follow those proposed by Pomar (2001a).

The inner ramp facies consists of cross-bedded porcellaneous foraminiferal grainstones to packstones (Table 1; Figs. 2B and 3A). The grain size ranges from medium to coarse sand. This facies contains relatively well sorted and highly abraded biogenic components. Other important components include rounded and micritised bioclasts of articulate, non-articulate coralline algal debris and LBF. Compound cross-bedding is characteristic of this lithofacies; it consists of planar to trough cross-bedding, with 10–20 cm thick individual units that show local concave-downward curvature and dips that average from 4–5° (up to 10°). Internal cross-laminae within these individual units dip 10–20° towards the E–NE. These units are stacked in 2 to 3 m thick, sub-horizontal, larger-scale, cross-bedded units. This facies was deposited in a very-shallow-water setting, as indicated by the occurrence of abundant porcellaneous foraminifera together with abraded fragments of articulated coralline red algae; articulated species generally occur from the intertidal to the subtidal zone, although they reach their maximum abundance in water that is less than 10 m deep (Wray, 1977). This bathymetry is in agreement with the *Amphistegina* test morphology ($T/D$ values), which indicates a water depth from 6 to 14 m.