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Geobiology of microbial carbonates: metazoan and seawater saturation state influences on secular trends during the Phanerozoic

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Abstract

Microbial carbonates are long-ranging, essentially bacterial, aquatic sediments. Their calcification is dependent on ambient water chemistry and their growth is influenced by competition with other organisms, such as metazoans. In this paper, these relationships are examined by comparing the geological record of microbial carbonates with metazoan history and secular variations in CaCO₃ saturation state of seawater. Marine abundance data show that microbial carbonates episodically declined during the Phanerozoic Eon (past 545 Myr) from a peak 500 Myr ago. This abundance trend is generally inverse to that of marine metazoan taxonomic diversity, supporting the view that metazoan competition has progressively limited the formation of microbial carbonates. Lack of empirical values concerning variables such as seawater ionic composition, atmospheric partial pressure of CO₂, and pH currently restricts calculation of CaCO₃ saturation state for the Phanerozoic as a whole to the use of modeled values. These data, together with palaeotemperature data from oxygen isotope analyses, allow calculation of seawater CaCO₃ saturation trends. Microbial carbonate abundance shows broad positive correspondence with calculated seawater saturation state for CaCO₃ minerals during the interval 150–545 Myr ago, consistent with the likelihood that seawater chemistry has influenced the calcification and therefore accretion and preservation of microbial carbonates. These comparisons suggest that both metazoan influence and seawater saturation state have combined to determine the broad pattern of marine microbial carbonate abundance throughout much of the Phanerozoic. In contrast, for the major part of the Precambrian it would seem reasonable to expect that seawater saturation state, together with microbial evolution, was the principal factor determining microbial carbonate development. Interrelationships such as these, with feedbacks influencing organisms, sediments, and the environment, are central to geobiology.

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1. Introduction

Throughout the 545 Myr of the Phanerozoic Eon, marine organisms have extensively used the calcium carbonate minerals aragonite and calcite to create organic skeletons. From much earlier times additional deposits have resulted from algal and bacterial processes, such as photosynthesis and sulphate reduction, that promote carbonate precipitation in microenvironments adjacent to cells. In marine environments over geological timescales these processes of CaCO₃ biomineralization have had great significance for the fossil record. They have also contributed to the generation of large quantities of carbonate sediment. The resulting long-lived accumulations of limestones and dolostones constitute important sedimentary records in oceanic and crustal rocks. This carbon reservoir, dependent upon the presence of a hydrosphere on Earth, is much larger than that in modern biomass and fossil fuels (Rubey, 1951; Holland, 1978; Stumm and Morgan, 1996). Such large-scale sequestration of CO₂ in carbonate rocks dominates the long-term carbon cycle and is therefore likely to have been a key influence on Earth's climate (Walker et al., 1981; Berner et al., 1983; Kasting and Catling, 2003). It follows that the relationship between water chemistry and biomineralization in aquatic organisms is a major research area for geobiology at the interface between palaeobiology and carbonate sedimentology, with broad implications for Earth's surface environment.

Microbial carbonates have particular relevance in this field for two reasons. Firstly, microbial carbonates are very long ranging, with probably the longest geological record and most extensive facies distribution of any biogenic sediment (Riding, 2000). Secondly, microbial carbonates are very susceptible to environmental influence, both for the growth of the micro-organisms that localize them and for the precipitation processes that determine their sedimentary accretion and geological preservation. One of the most widely appreciated features of the secular distribution of microbial carbonates is the suggestion that they have declined in abundance from a peak in the Proterozoic. Phanerozoic stromatolite decline was noted by Fischer (1965) and Cloud and Semikhatov (1969) but recognition of its longer term pattern, and possible link to metazoan competition, resulted from

study of gastropod grazing on the Bahama Banks (Garrett, 1970) coupled with compilation of late Proterozoic reduction in stromatolite diversity (Awramik, 1971). Nonetheless, decline in microbial carbonates has also long been linked to changes in calcification (Fischer, 1965; Monty, 1973, 1977; Serebryakov and Semikhatov, 1974; Gebelein, 1976; Grotzinger, 1990), ultimately related to seawater chemistry.

Here we examine the Phanerozoic distribution of microbial carbonates in general and consider to what extent it may be possible to relate their secular abundance to competition with metazoans and to changes in seawater chemistry. This enquiry necessarily involves a number of assumptions, e.g., that metazoan diversity may be a proxy for metazoan abundance and, therefore, competition in its broadest sense, and also that currently available modeled estimates of Phanerozoic atmospheric and seawater composition may provide a window into changes in past seawater saturation state. Not the least aim of this study is to encourage further work that will lead to more robust information on which these interpretations can be based. Our approach to these questions is therefore essentially to compare secular variation in microbial carbonate abundance, metazoan abundance, and seawater saturation state for the Phanerozoic.

2. Microbial carbonates

Microbial carbonates can be regarded mainly as products of bacterial, and also algal, processes that promote the precipitation of CaCO₃ minerals such as aragonite and calcite, and trap sedimentary particles. Some microbial carbonates are difficult to confidently recognize in ancient carbonate sediments even though they are likely to have been volumetrically important. These may include micritic particles precipitated in the water column by pelagic microbes (Thompson, 2000) and those produced by the disintegration on the seafloor of calcified bacteria such as *Girvanella* (Pratt, 2001). In contrast, benthic microbial carbonates (Burne and Moore, 1987) produced by calcified microbial mats and biofilms are much more readily recognizable. These deposits include forms such as stromatolites and thrombolites

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