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Atmospheric trigger for Early Carboniferous carbonate mud mounds?

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Extensive development of carbonate mud mounds on shallow marine shelves in the Early Carboniferous, ~340 Myr ago, coincided with increases in calcified cyanobacteria and dasycladalean algae. These three, at first sight disparate, developments can tentatively be linked to changes in atmospheric CO_2 and O_2 levels that influenced photosynthetically induced calcification.

In extant algae and cyanobacteria, carbon-concentrating mechanisms pump CO_2 into cells to maintain photosynthesis. Carbon-concentrating mechanisms are triggered by low levels of atmospheric CO_2 and high levels of O_2. The need for carbon-concentrating mechanisms very likely arises from inefficiency of RUBISCO, the primary carbon fixing enzyme [1, 2]. RUBISCO's ability to bind CO_2 is limited because it can also bind O_2. When this occurs, oxygenase activity competitively inhibits carbon fixation, resulting in loss of CO_2 from the cell by photorespiration.

Carbon-concentrating mechanisms ameliorate this obstacle to photosynthesis by improving carbon uptake and concentrating CO_2 in the cell [2, 3]. Carbon-concentrating mechanisms import CO_2 and HCO3- into the cell. A side effect is extracellular increase in pH that favours sheath calcification in cyanobacteria [7]. A similar side effect can be inferred for dasycladalean calcification and for the precipitation of numerous small $CaCO_3$ crystals in the water column (whitings) adjacent to cyanobacterial picoplankton cells.

It has been speculated that, at some point following the appearance of RUBISCO in the Archaean, declining atmospheric CO_2 and increasing O_2 levels led photoautotrophs to develop carbon-concentrating mechanisms [3]. Adopting this approach, it has been proposed [4] that cyanobacterial carbon-concentrating mechanisms developed ~400-300 Myr ago in response to marked fall in CO_2 [5] and rise in O_2 [6].

The marine Palaeozoic records of calcified benthic cyanobacteria [8] and dasycladalean algae [9] show that both these groups increased in abundance and/or diversity in the Early Carboniferous. It is proposed here that these increases reflect enhanced calcification due to induction of carbon-concentratingmechanisms in these groups in response to atmospheric fall in CO_2 and increase in O_2. It is also proposed that, at the same time, cyanobacterial picoplankton also acquired carbon-concentrating mechanisms and that this led to whiting precipitation in nutrient-rich shelf seas where these plankton bloomed.

Extensive whiting precipitation would result in accumulation of large quantities of mud-grade carbonate on shelf sea-floors, facilitating mud mound formation. It is possible that the enhanced calcification of benthic cyanobacteria and dasycladaleans also contributed to mud mound deposition. Weaker calcification in dasycladaleans prior to the Carboniferous could account for their relatively poor record as calcified fossils in the Early and Mid-Palaeozoic.

Thus, the following sequence of geobiological events is suggested here to account for the widespread development of Early Carboniferous carbonate mud mounds: (i) Substantial decreases in atmospheric CO_2 levels and increases in O_2 levels occurred in the Early Carboniferous. (ii) These changes stimulated acquisition of carbon-concentrating mechanisms in cyanobacterial picoplankton that (iii) raised pH adjacent to the cells, promoting extensive precipitation of small $CaCO_3$ crystals in the water column in the vicinity of the cells. (iv) This whiting precipitation resulted in widespread and thick accumulations of carbonate mud on marine shelves.

At the same time, induction of carbon-concentrating mechanisms in benthic cyanobacteria and dasycladalean algae also stimulated calcification in these groups.

The processes responsible for the localization of the fine-grained whiting sediment into discrete mud mounds remain to be elucidated.

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