The catalytic effect of bound extracellular polymeric substances excreted by anaerobic microorganisms on Ca-Mg carbonate precipitation: Implications for the “dolomite problem”

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ABSTRACT

Because of its rare occurrence in modern sediments, as well as the difficulty in synthesizing it under low-temperature conditions in the laboratory, the origin of sedimentary dolomite has remained a long-standing enigma, often referred to as the “dolomite problem.” Recently, anaerobic microorganisms, such as sulfate-reducing bacteria and methanogens, have been recognized for mediating dolomite precipitation. However, the exact role of microorganisms in dolomite crystallization is still under debate and the possible involvement of anaerobic fermenting bacteria has not been studied. In this study, we characterized the effect of purified non-metabolizing biomass and bound extracellular polymeric substances (EPS) of a natural consortium of anaerobic microorganisms dominated by fermenting bacteria and sulfate-reducing bacteria on Ca-Mg carbonate precipitation. This natural consortium was enriched from sediments of Deep Springs Lake, California, where dolomite is still precipitating. Our data show that disordered dolomite, a precursor of some sedimentary stoichiometric ordered dolomite, can be precipitated in calcite-seeded Ca-Mg carbonate solutions containing purified non-metabolizing consortium biomass. Bound EPS extracted from the consortium culture were shown to be the active component that triggered the crystallization of disordered dolomite. Further experiments show that purified non-metabolizing biomass from pure cultures of both anaerobic fermenting and sulfate-reducing bacteria closely related to those organisms present in the consortium could also catalyze the precipitation of disordered dolomite. This study contributes to the understanding of the “dolomite problem” by revealing (1) the catalytic effect of bound EPS on Ca-Mg carbonate crystallization and (2) the possible involvement of anaerobic fermenting bacteria in sedimentary dolomite formation, which has not been reported previously.

Keywords: Disordered dolomite, dolomite problem, sulfate-reducing bacteria, fermenting bacteria, non-metabolizing biomass, bound EPS

INTRODUCTION

The formation mechanism of dolomite has long been a controversy, commonly referred to as the “dolomite problem” (Hardie 1987; Machel and Mountjoy 1986; Mazzullo 2000; Warren 2000; Zenger et al. 1980). Dolomite is rare in Holocene and modern sediments, yet abundant in older rocks. According to thermodynamics, aqueous solutions supersaturated with respect to dolomite, such as seawater, certain lake waters, many groundwaters, and hypersaline waters are theoretically capable of precipitating dolomite as cement or dolomitizing limestone; however, such cases are rare in modern carbonate environments (Hardie 1987). Moreover, extensive attempts to synthesize dolomite inorganiclly under Earth-surface conditions have been unsuccessful (Land 1998).

The observation of dolomite occurrence within some anoxic, organic-rich sediments as a result of anaerobic microorganisms has provided a new biogeochemical approach to solving the “dolomite problem” (Baker and Burns 1985; Bontognali et al. 2010; Compton 1988; Mazzullo 2000; Roberts et al. 2004; Vasconcelos and McKenzie 1997; Wright 1999). Following this observation, laboratory syntheses of Ca-Mg carbonates in live cultures of sulfate-reducing bacteria (SRB) or methanogens have been conducted to study the effect of microorganisms on carbonate precipitation, and Ca-Mg-phosphates and aragonite were mis-identified as dolomite (Deng et al. 2010; Kenward et al. 2009; Van Lith et al. 2003b; Vasconcelos et al. 1995; Warthmann et al. 2000; Wright and Wacey 2005). However, the possible involvement of anaerobic fermenting bacteria in sedimentary dolomite formation has been largely ignored. Fermenting bacteria play a critical role in the cycling of some organic compounds in an ecosystem or a biofilm. For example, SRB depend on some products of fermenting bacteria that they can respire to CO2 (Jørgensen 2000). Considering the importance of fermenting bacteria in anoxic environments, the role of fermenting bacteria in dolomite formation warrants more attention.

In addition, despite several studies on microbe-related dolomite precipitation, the exact role of microbes is still not clear. The