Dolomite as a Biomineral and Possible Implications

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The addition of biological factors to the study of geological problems opens numerous possibilities to perform experiments to simulate natural conditions related to specific time periods relevant to Earth history. Hence, it becomes a major goal and challenge for geochemists to define equations and parameters, which may be retained as biogeochemical signals preserved as bioproducts in the rock record. The simulation of natural conditions from modern environments in laboratories using bacteria culture experiments opens the possibility to define specific metabolisms involved in mineral precipitation, which may help to decipher ancient environmental conditions. This interdisciplinary approach linking Earth and Life sciences has become one of the most energizing frontiers in modern natural sciences. The introduction of new conceptual and advanced technological breakthroughs in both biosciences and geosciences has allowed scientists to attack problems that were previously thought to be unanswerable. Indeed, some of these problems are the fusion of biological and geological processes, such as the genesis of Precambrian banded iron formations, which now can be linked with microbial metabolisms.

Despite two decades of low-temperature experimental research into the Dolomite Problem, the factors controlling its formation remain controversial. The debate concerning its biotic versus abiotic nature has led to the formulation of working hypotheses uniting geochemistry and biological cycles. Nadson (1928; Fig. 1) recognized an association between microbes and geological processes linked with carbonate formation. Furthermore, he postulated that microbes serve as geologic agents, which control geochemical reactions. For example, he proposed that the bacterial reduction of sulfate contributes to the precipitation of carbonates, as follows:

$$CaSO_4 + CH_3COOH \ ^{TM}\ CaCO_3 + H_2S + H_2O + CO_2$$

or

$$CaMg(SO_4)_2 + 2CH_3COOH \ ^{TM}\ CaMg(CO_3)_2 + 2H_2S + 2H_2O + 2CO_2.$$

Georgii Adamovich Nadson (1867 - 1940)

***Fig. 1.** Georgii Adamovich Nadson was a Soviet biologist, "one of the pioneers of radioecology in Russia". In 1930, he founded the Laboratory of Microbiology of the Russian Academy of Sciences (which in 1934 was transferred from Leningrad to Moscow and later transformed into the Institute of Microbiology). He was director of the institute until 1937. Ulvella nadsonii, a species of algae, is named for him. (Wikipedia: http:// en.wikipedia.org/wiki/ Georgii_Nadson)*

In addition, Nadson stated that “Understanding the essential role played by this bacterial phenomenon may be the solution to the Dolomite Problem and the problems of the Mg cycle in the ocean.” His observations, first published in 1903 and republished in 1928, were never widely considered in the study of carbonates, but they have been recently revived to explain the dolomite phenomenon.

During the last 15 years, the Earth System Science approach has been applied to provide clues to solve the Dolomite Problem. This research combined field studies and laboratory culture experiments. In an initial microbial dolomite study, Vasconcelos et al. (1995) were able to precipitate dolomite at low temperatures in the presence of sulfate–reducing bacteria (SRB) isolated from Lagoa Vermelha, Brazil (Vasconcelos & McKenzie, 1997). These studies led to the formulation of the microbial model for dolomite formation, in which SRB play an important role to overcome the kinetic factors inhibiting precipitation. Subsequently, Warthmann et al. (2000) and Warthmann et al. (2005) tested the microbial model and isolated a new species of halotolerent SRB bacterium, which mediates dolomite formation. Other modern natural environments, under both anoxic and oxic conditions, have been investigated and provide new evidence to expand our understanding of the microbial processes associated with dolomite formation (Sanchez et al., 2008). Although previous experiments related dolomite precipitation to anoxic conditions, it is commonly found in environments with aerobic characteristics, which have now been tested in laboratory experiments. All of these studies indicate that diverse microbial metabolisms are able to control oxidation/reduction conditions and promote dolomite precipitation. Distinct microbial communities can cross a geochemical barrier leading to bimineralization processes. To summarise, laboratory experiments provide convincing evidence that a biological factor is essential for dolomite formation at low temperatures under Earth’s surface conditions.

Dolomite is a Biomineral.

For nucleation and growth to occur, biomineral formation requires a localized zone that achieves and maintains sufficient super saturation (Weiner & Dove, 2003). Biominerals meet the criteria for being true minerals, but they can also possess other characteristics that distinguish them from their abiotic crystal habit. Bio-originated minerals have non-conventional structures, which associate them with microbial metabolisms. For example, in Figure 2, modern dolomite crystals from Lagoa Vermelha are compared with dumbbells forms

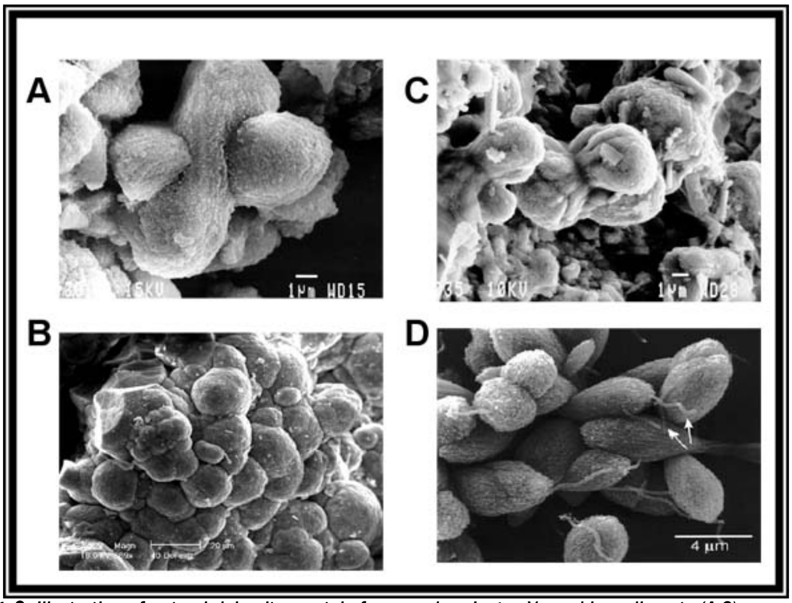

Fig. 2. Illustration of natural dolomite crystals from modern Lagoa Vermehla sediments (A,C) compared with experimental dolomite crystals produced in anaerobic SRB cultures (B,D).

produced in experimental dolomites. Precipitation of such spherical and dumbbell forms occurs via bacterial mediation.

There is now much evidence to designate dolomite as a biomineral. However, one of the major enduring questions is, Do microbes act as nucleation sites?. The Dolomite Microbial Model (Fig. 3) states that the cell wall acts as a nucleation site for precipitation. Recently, Bontognali et al. (2008) observed using confocal laser scanning microscopy (CLSM) that extracellular polymeric substances (EPS) secreted by the microbes play a key role in the mineralization process. Nanobacteria-like particles represent the early stage of carbonate nucleation within the EPS. The crystallization process continues and the globules grow detached from the cell wall. As a result of this mechanism, the microbes remain mobile, which excludes the possibility that they become entombed within the mineral (Fig. 4).

In conclusion, the study of dolomite precipitation at low temperatures has produced actualistic evidence that dolomite is also a biomineral. Therefore, we must include the microbial factor in the geochemical equation to solve the outstanding Dolomite Problem. In the future, it will now be essential to apply microbial experiments to better understand mineral nucleation processes.

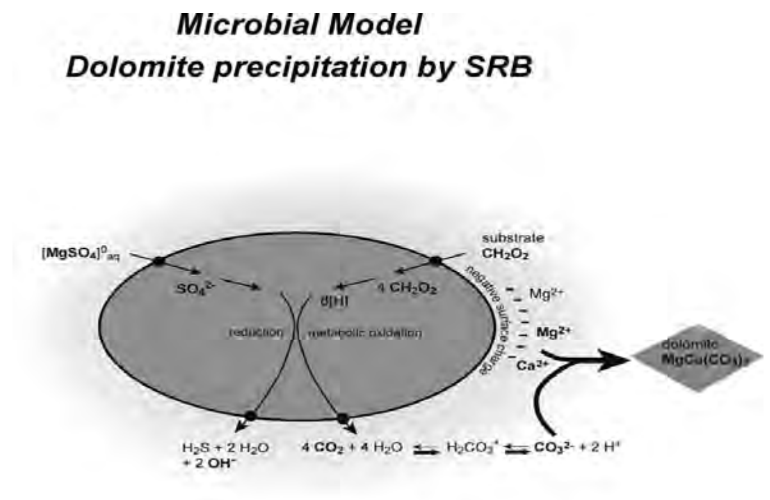

Fig. 3. Illustration of Microbial Model for dolomite formation by SRB.

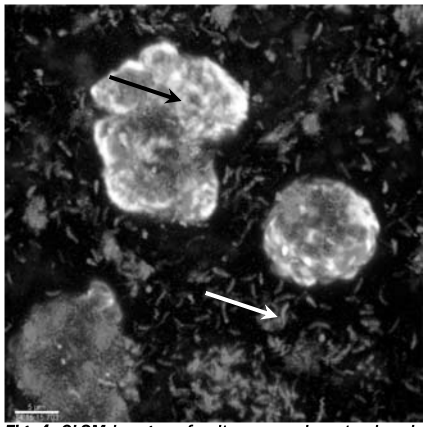

Fig. 4. CLSM images of culture experiment, wherein mineral globules (black arrow) are enveloped within EPS (grey mass) surrounded by bacteria (white arrow).

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