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Biocalcification throughout Phanerozoic time: Effects of the Mg/Ca ratio of seawater

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Oscillations in the Mg/Ca ratio of seawater, driven by changes in spreading rates along mid-ocean ridges, have governed the mineralogy of nonskeletal marine carbonate precipitates throughout earth history. Low-Mg calcite has formed in seawater with Mg/Ca ratios of <1 ("calcite seas"), high-Mg calcite has formed in seawater with Mg/Ca ratios >1, and both high-Mg calcite and aragonite have formed with Mg/Ca ratios >2 ("aragonite seas"). The carbonate mineralogy of major reef-building and sediment-producing organisms has paralleled that of nonskeletal precipitates throughout Phanerozoic time.

Experiments in which (Mg+Ca) of artificial seawater is held constant but Mg/Ca is varied show the Mg content of calcite grown by calcareous nannoplankton, coralline algae, and various animal groups to be strongly correlated with the Mg/Ca ratio of seawater, as it is in nonskeletal calcite. Fractionation varies among species, but ones that produce high-Mg calcite today produce low-Mg calcite in "Cretaceous" seawater. Additional experiments have revealed effects of seawater chemistry on productivity. Secretion of calcium carbonate facilitates growth of algae by releasing CO_2 that is available for photosynthsis. Thus, *Halimeda,* a major producer of aragonite sediment, secreted less aragonite and grew less rapidly when grown in seawater with an Mg/Ca ratio of 2.5 instead of 5.2 (the modern ratio). Similarly, exponential rates of population growth for calcite-secreting nannoplankton increased markedly in cultures as the ambient Mg/Ca ratio was reduced (and Ca elevated). Experiments in which either the Mg/Ca ratio or the absolute concentration of Ca was held constant while the other was varied showed that both of these chemical traits influenced population growth rates.

Formation of massive chalk deposits by calcareous nannoplankton in Late Cretaceous time can be attributed to the Mg/Ca ratio and Ca concentration in the ocean, which were at an all-time low and high, respectively. Productivity of most extant calcareous nannoplankton species appears to be limited by the high Mg/Ca ratio and low Ca concentration in the modern ocean. Being unable to bloom when nitrogen, phosphorus, and iron are plentiful, most modern species have been relegated to a low-nutrient refugium in the subtropical-tropical zone.

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Relative impact of biologically versus physiochemically dominated modes of mineralization on the Earth's environment

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Taxonomic groups forming biominerals that have had the largest impact on the earth's environment may have common styles of mineralization processes. Lowenstam recognized that organisms utilize two principal modes in biomineralization: "biologically-dominated" and "physiochemically-dominated" mineralization. The most prolific mineralizing taxa are: (1) reef framework builders, (2) reef sediment formers, (3) pelagic carbonate formers, and (4) planktonic mineralizers associated with upwelling. Taxa that have had the least impact on the earth's environment are mobile organisms with non-massive, often exceptionally strong skeletons. The prolifically mineralizing taxa (1?–4) have modes of mineralization dominated by physiochemical mineralization processes. The least prolific mineralizers have modes of mineralization dominated by biologically-controlled processes. Taxa that are (1) reef framework builders such as scleractinian corals and rudistid bivalves show a physiochemically-dominated mode of mineralization. Green algae, the most important (2) reef sediment formers in modern reef systems, show a physiochemically-dominated mode of mineralization. Modern coocolithophoridae, the most abundant modern contributors to (3) pelagic realm deep sea carbonates above the calcium carbonate compensation depth, have a mode of mineralization dominated by physiochemical processes. Modern diatoms dominate the biological production of minerals in upwelling environments (4), and demonstrate a physiochemically-dominated mode of mineralization. Endosymbiotic relationships between plants and carbonate producing animals are present amongst physiochemically-dominated mineralizers.