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# Calcite and aragonite seas and the evolution of carbonate skeletons in animals

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Carbonate skeletons evolved *de novo* multiple times independently in animals. Their appearances are clustered in time such that aragonite skeletons tended to appear during intervals when seawater chemistry favored aragonite precipitation ("aragonite seas") and calcite skeletons during intervals favoring calcite precipitation ("calcite seas"). However, after skeletons evolved, skeletal mineralogy rarely changed, despite subsequent changes in seawater chemistry. Thus it appears that seawater chemistry initially played a primary role in determining mineralogy, but later did not. The reasons for this shift are not well understood. One possibility is that canalization of the genetic repertoire involved in controlled biomineralization made it difficult to respond to changing seawater chemistry, consistent with evidence for distinct genetic toolkits used to form calcitic and aragonitic elements. However, evidence suggests that rapid evolution of the biomineralization toolkit is commonplace [1] in which case switching mineralogies may not be all that difficult. Another possibility is that skeletons became increasingly resilient to changes in seawater chemistry as they adapted to other selective factors, such as predation and bioerosion (e.g. evolving thicker organic layers) [1]. A third possibility, favored here, is that, for many taxa, it did not matter whether their mineralogy matched seawater chemistry; their fitness was not affected much either way. In this view, the initial mineralizers did not actively select for a particular polymorph, but merely made use of whatever materials were at hand: calcite during calcite seas, and aragonite during aragonite seas. In other words, they were passive biomineralizers. They subsequently built secretory repertoires specific to shaping those polymorphs—evolving to become active biomineralizers—and thus did not switch mineralogies when seawater changed. However, they were not particularly disadvantaged as a result, consistent with studies suggesting that, for most carbonate mineralizing taxa, oscillations between aragonite and calcite seas seems to have had little impact on their success.

[1] Gold & Vermeij (2023), *Frontiers Physiology* 14, 1092321.