A thermodynamic model for microbial diversity in a range of geochemical settings

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Introduction

Collection of metagenomic data from geochemically well-characterized locations has led to quantitative accounts of the changes in diversity of communities along temperature and other geochemical gradients. The diversity is often assessed by counting the numbers of phylogenetically distinct sequences of a certain gene, for example 16S rRNA. The forces that control the numbers of microbial species that can coexist in particular environments remain obscure.

Hypothesis

We hypothesize that the diversity of microbial species is linked to the diversity of biomolecules in metastable assemblages, the compositions of which can be calculated using thermodynamics and geochemical constraints.

Results

We identified 24 phylogenetically distinct sequences of model proteins associated with two carbon metabolisms (12 Ribulose-1,5 bisphosphate carboxylase/oxygenase and 12 Acetyl-coenzyme A carboxylase) in thermophilic and mesophilic organisms. The compositions of metastable assemblages of these proteins were calculated as a function of oxygen fugacity, of temperature, and of temperature with oxygen fugacity corresponding to the quartz-fayalite-magnetite and hematite-magnetite buffers. Proteins whose predicted abundances were at least one-one hundredth of the total protein concentration in the system were counted as contributing to the overall diversity. At a temperature of 25°C, the predicted diversity goes from one at extremely high oxygen fugacity, jumps to a maximum of 23 at logarithm of oxygen fugacity from -72 to -75 (equivalent to logarithm of activity of aqueous H_2 from -8.6 to -7.2), and steadily decreases to four at the lowest oxygen fugacities considered. A similar trend is seen with increasing temperature at constant oxygen fugacity.

Conclusions

Thermodynamic predictions of biomolecular diversity provide a background for understanding the trends in microbial diversity, which in nature can maximize at the intersection of two environments. These results and comparisons suggest that temperature and the buffering effects of mineral assemblages on oxidation state or other chemical variables are essential in defining the composition of a community.

A possible long-term record of Mg isotopic composition in seawater from ferromanganese nodules in the South Pacific

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Mg stable isotope ratios can now be measured to a precision that resolves differences amongst terrestrial and oceanic reservoirs. The budget for Mg in the oceans is controlled mostly by the input from rivers and groundwater and the output from oceanic hydrothermal vents, marine carbonates, and exchange reactions with clays. A long-term record of stable Mg isotope variations in seawater would provide an improved understanding of these fluxes, which control the Mg composition of the oceans through geologic time.

We have measured Mg stable isotope variations in ferromanganese nodules recovered from depths of ca. 4 km off the east coast of New Zealand. The nodules were dated by ^{10}Be methods and are up to 15 Myr in age. Mg isotope ratios were measured by MC-ICPMS after chemical purification of Mg from all other elements including the large amounts of Mn and Ni present in this material. The results show that a 0.2‰ isotopic fractionation may exist between Mg in the nodule and seawater, but this is small compared to the 1.2‰ variation in δ^{26}Mg of the nodule. In addition, a significant negative correlation exists between δ^{26}Mg in the nodule material and the ^{87}Sr/^{86}Sr composition of seawater over the last 8 Myr. This correlation suggests that the stable Mg isotope composition of the ocean and ^{87}Sr/^{86}Sr are being influenced, at least in part, by similar processes.

We speculate that the evolution of δ^{26}Mg in the nodule and by inference in seawater through to the present day reflects one or a combination of: (a) increasing continental input to the oceans by rivers, which have isotopically light Mg, (b) decreasing deposition of marine carbonate, which has isotopically light Mg and, (c) a decrease in hydrothermal activity, which has a yet unknown fractionation of Mg isotopes in seawater.