Sulfate respiration in extreme environments: A kinetic study

A. N. ROYCHOUDHURY

Department of Geological Sciences, University of Cape Town, Rondebosch, 7700, South Africa (roy@geology.uct.ac.za)

Measured sulfate reduction rates from hydrothermal springs at Yellowstone National Park, USA, varied between 2 and 600 nmol cm^{-3} d^{-1} with the majority of the rates remaining below 100 nmol cm^{-3} d^{-1}. Higher rates were associated with microbial mats. In general, the measured rates are comparable to modern environments where activity of sulfate reducers is limited due to substrate availability or competition from other microbes.

Results from incubation experiments performed at two sites (Obsidian Pool and Black Sediment Pool) suggest that the microbes were capable of utilizing only very simple organic molecules as electron donors. Their efficiency to respire decreased when the electron donor was changed from formate to acetate or lactate. Activation energy for sulfate reduction at the same two sites was 16 and 38 kJ mol^{-1} respectively. These values for activation energy are consistent with other microbially mediated processes. At another site (Mushroom Spring), the activation energy was found to be 131 kJ mol^{-1}. Surprisingly, however, this is the same site where comparably higher sulfate reduction rates were measured and the microbes preferred lactate to acetate or formate as electron donor.

K_s (half saturation constant), for sulfate reduction was determined at two sites (Black Sediment Pool and Mushroom Spring). Again Mushroom Spring provided the highest value for K_s (3.17 mM). At Black Sediment Pool the value of K_s (1.24 mM) was close to the one known for modern deep-sea sediment and was much higher than those determined in laboratory cultures or in sediments from other aquatic environments.

Their preference towards simple organic molecules suggests that microbes in some of these hydrothermal springs may be more primitive than other sulfate reducing bacteria, i.e., they may be archaea and not bacteria. However, a detailed phylogenetic classification of microbes present in the springs is required to confirm these claims.

It is clear that sulfate reduction is limited in these hydrothermal springs. Addition of organic acids did not increase the sulfate reduction rate, implying that organic carbon may not be the limiting factor. Rather, low sulfate concentration in the porewaters is the reason for the limitation. Measured porewater sulfate concentrations in these springs are much lower than the K_s values retrieved during these experiments.

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A critical review of CO_2 proxies and models

DANA L. ROYER

Department of Geology and Geophysics, Yale University, New Haven, Connecticut, USA (dana.royer@yale.edu)

In order to understand the operation of the carbon cycle in the geologic past, various proxies and geochemical models have been developed to reconstruct pre-Quaternary levels of atmospheric CO_2. The generation and use of these techniques have resulted in a recent proliferation of CO_2 data. Here, I evaluate the strengths and limitations of the major techniques.

Atmospheric CO_2 can be predicted from mass balance expressions that quantify carbon fluxes to and from the atmosphere. Some of the fluxes are poorly constrained, and so errors can be larger than ±1500 ppm for the early Paleozoic and other times of high CO_2. These models are powerful predictors of general Phanerozoic CO_2 patterns, however because of their typically coarse time resolutions (~10 m.y.) they cannot resolve short-term anomalies.

The $\delta^{13}C$ of pedogenic carbonates reflects the mixing of atmospheric and plant-derived soil carbon. Atmospheric CO_2 estimates are dependent on the $\delta^{13}C$ of co-existing organic matter, and so should be measured directly, not inferred from the marine carbonate record. Errors are moderately large (±500 to 1000 ppm), particularly in comparison to other methods for the Tertiary, but is applicable back to the Devonian.

The $\delta^{13}C$ of photosynthate in phytoplankton is partially dependent upon [CO_2]. Marine sediments therefore offer the potential for high resolution CO_2 reconstructions. Errors are reasonably well constrained (±25 to 100 ppm), however the effects of growth rate and O_2 concentrations are not fully understood. This proxy saturates at CO_2 levels >1000 ppm, and so is not appropriate for times of high CO_2.

The stomatal indices and stomatal ratios in the leaves of most vascular plants inversely respond to atmospheric CO_2. High resolution reconstructions (10^1-10^2 years) are possible. Errors are low with the stomatal index method (< ±50 ppm), however it saturates at CO_2 levels >500 ppm, and is species-specific, and so is not appropriate for pre-Cretaceous sediments. The stomatal ratio method is less quantitative, but can be applied back to the Devonian.

The $\delta^{11}B$ in marine carbonate shells is sensitive to seawater pH, which in turn reflects CO_2. It is the least constrained method discussed here, principally because it assumes that the $\delta^{11}B$ of the ocean has remained nearly constant. Some Quaternary studies do not support its use in the pre-Quaternary record.

With few exceptions, there is good agreement among the proxies and models for the Phanerozoic. Furthermore, periods of low inferred CO_2 correspond well with evidence for continental glaciations, while little such evidence exists for periods of high CO_2. CO_2 and global temperatures have been coupled for much of the Phanerozoic.