Nitrogen biogeochemical cycling in ferruginous Lake Pavin

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Over geological timescales, the Earth's oceans were affected by several periods of total or partial anoxia. The timing, causes and consequences of ocean oxygenation are intimately linked to paleo- N cycling. Studies on modern analogues are essential for interpreting biogeochemical signals recorded in ancient sediments. Lake Pavin (French Massif Central) is permanently stratified with anoxic Fe-rich deep waters (from 60 to 92m depth) overlain by oxic shallow waters (from 0 to 60m depth) and can be regarded as an analogue for the ocean during periods of redox stratification with ferruginous deep waters. Such ferruginous conditions were prevalent during the Precambrian and may also have been important during Phanerozoic Ocean Anoxic Events (OAEs). In order to determine if the primary N isotope signatures are preserved or modified in this type of environment, we analyzed bulk N isotope compositions in 6 sediment cores from different depths in Lake Pavin: in the oxic zone (31.5, 26.8 and 19.5m depth), at the oxic-anoxic boundary (60m depth), at the peak of H_2S production from SO_4^{2-} reduction (65m depth) and at the bottom of the lake (90m depth). Complementary analyses of sediment traps set up at 4 different depths in the water column (25, 56, 67 and 88m depth) provide a reference frame for organic matter deposited in the sediments and allow us to test diagenetic N evolution in the water column. For the traps and cores of the anoxic layer, the N isotope composition is not significantly affected by diagenetic processes with $\delta^{15}N_{tot}$ values around -1 ‰. Such unusually low $\delta^{15}N$ values suggest a dominance of N_2-fixers in the water column, which is expected in a stratified system where nitrate is strongly depleted by denitrification at the redox boundary and N_2 is the major source of N for organisms living in the photic zone. For each core of the oxic layer, $\delta^{15}N_{tot}$ increases with depth within the sediment, from values as low as -3.3 ‰ up to +0.3 ‰. These variations are not compatible with purely oxic diagenesis but require a migration of the sediment oxycline through time, possibly due to an increase in the organic matter flux associated with eutrophication in Lake Pavin.

Stretching, Coalescence and Mixing in Porous Media

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We study mixing in heterogeneous permeability fields, whose structural disorder varies from weak to strong. We propose a unified framework to quantify the overall concentration distribution predicting its shape and rate of deformation as it progresses towards uniformity in the medium. The concentration field is represented by a set of stretched lamellae whose rate of diffusive smoothing is locally enhanced by kinematic stretching. Overlap between the lamellae is enforced by confinement of the scalar line support within the dispersion area. Based on these elementary processes, we derive analytical expressions for the concentration distribution, resulting from the interplay between stretching, diffusion and random overlaps, holding for all field heterogeneities, residence times, and Peclet numbers. We discuss consequences for effective chemical reaction kinetics in heterogeneous media.