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Scale Analysis of Non-Local Sink for H_2S

Strictly speaking, Equation 6 in Kump et al. (2005) is inappropriate for characterizing regional euxinia created by intense local upwelling, as the problem becomes 2- or 3-dimensional. However, the following analysis demonstrates that the inclusion of lateral transport is unimportant for this problem.

To include the non-local sink for H_2S requires an additional term in equation 6 that accounts for horizontal eddy diffusion (D_h, $m^2 \cdot yr^{-1}$) (cf. the treatment of worm burrow irrigation by Boudreau, 1997). D_h is scale-dependent (Okubo, 1971); here we have chosen L=1000 km, which gives $D_h \approx 3x10^{10}$ $m^2 \cdot yr$. We can then express horizontal diffusion in terms of a horizontal piston velocity $\left(\frac{D_h}{L}\right)$. If the flux is radially symmetric, then the horizontal flux of H_2S from the upwelling region is through a cross-sectional area of $2\pi LZ$, where Z is the surface layer thickness, and the vertical upwelling flux of H_2S from below and the in-mixing flux of O_2 from above are through a cross-sectional area πL^2. Thus, we multiply the maximum horizontal diffusive flux $\left(\frac{D_h}{L} \cdot \rho_{oce} \cdot [H_2S]_{deep}\right)$, when $[H_2S]_{surf} = [H_2S]_{deep}$, by the ratio of these areas $\left(\frac{Z}{L}\right)$ and insert this flux into equation 6. This leads to the following revised steady-state expression for the critical ratio above which the surface layer becomes euxinic given the conditions applied to equation 6:

$$\left(\frac{[H_2S]_{deep}}{P_{O_{2,atm}}}\right)_{crit} = \frac{k \cdot K_H}{2 \cdot \left(u - 2 \cdot \frac{D_h}{L} \cdot \frac{Z}{L}\right)} =$$

$$= \frac{1000(m \cdot yr^{-1}) \cdot \; 10^{-3} \; mol \cdot kg^{-1} \cdot bar^{-1}}{2 \; \cdot \; \left(100 \; m \cdot yr^{-1} - 2 \cdot \frac{3x10^{10} m^2 \cdot yr^{-1}}{10^6 m} \cdot \frac{10^2 m}{10^6 m}\right)} = 0.005 \; \frac{mol}{kg \cdot bar}.$$

For an atmospheric pO_2 of 0.21 bar, the critical $[H_2S]_{deep}$ is 1 $mmol \cdot kg^{-1}$, virtually identical to that obtained by using equation 6 with the appropriate upwelling velocity. In other words, lateral transport is not an important consideration for this problem.

References

Boudreau, B. P., 1997, Diagenetic Models and their Implementation: Berlin, Springer, 414 p.
Okubo, A., 1971, Oceanic diffusion diagrams: Deep-Sea Research, v. 18, p. 789-802.