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Take a Deep Breath: The Influence of Earth's Deep Interior on the Emergence of an Aerobic Biosphere

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The emergence of Earth's aerobic biosphere is a central topic in the coevolutionary history of Earth and life. Beyond the fundamental relevance of this transition to Earth system science, it is necessary to understand the factors that shaped it to assess whether aerobic environments are likely to be common or rare on extrasolar "Earth-like" planets. This assessment has consequences for the strategies used to search for life on other worlds.

The past quarter century saw remarkable progress in reconstructing the timing of O_2 production and accumulation in Earth's atmosphere and oceans. While many mysteries remain, a large and growing body of evidence indicates that biological O_2 production began hundreds of millions of years before the Great Oxidation Event (GOE), ca. 2.4 Ga. Apparently, the evolution of oxygenic photosynthesis was a necessary, but not a sufficient, condition to account for the GOE.

Why didn't O_2 rise earlier? One intriguing possibility is that the oxygen fugacity of mantle-derived gases rose progressively through the Archean, due to secular redox evolution of the mantle. Evidence of secular mantle redox evolution has been reported, with the right pace and magnitude to account for a shift in atmospheric O_2 around the time of the GOE. Although the interpretation of this evidence is a focus of debate, it has stimulated investigation into the possible causes of secular mantle redox evolution. One suggestion is that slow mixing of an oxidized primordial bridgmanite layer at the core-mantle boundary oxidized the bulk mantle over a prolonged period of time. If so, the accumulation of O_2 at Earth's surface – and the emergence of an aerobic biosphere – depends crucially on mantle dynamics and hence on details of mantle chemistry and physics. These details may differ among nominally "Earth-like" planets, raising the intriguing possibility that there may be many worlds on which oxygenic photosynthesis evolves but an aerobic biosphere can never emerge.

In this presentation, we will review the literature summarized above, present new constraints from a 3D dynamical model on possible timescales of secular mantle redox evolution, and consider the implications for the prevalence of aerobic biospheres beyond our own.