Understanding Remote Biosignatures Using Earth's Atmospheric Evolution as a Template

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Earth's atmosphere has evolved over time from a weakly reduced, CO_2-rich composition to today's predominately N_2-O_2 mixture. Understanding how Earth's atmosphere evolved may help us understand Earth-like exoplanets when spectroscopic observations of such planets become available. Hadean atmospheric composition is particularly uncertain, as there is only the sketchiest geological record from that time. High concentrations of CO_2 would be expected from impact degassing during accretion. CO may also have been relatively abundant. Once life evolved, both CO and H_2 would have been drawn down, likely leading to the production of CH_4. High concentrations (~1000 ppmv) of CH_4 could be expected up until the Great Oxidation Event (GOE) at ~2.4 Ga. Depending on the CH_4/CO_2 ratio, organic haze may also have been present. (Haze is predicted when $CH_4:CO_2 > 0.1$.) Following the GOE, O_2 concentrations should have risen, and CH_4 should have declined. Studies of Cr isotopes suggest that Proterozoic O_2 levels were no higher than 0.1% PAL (times the Present Atmospheric Level), although these low values are disputed by other authors. Understanding how abundant O_2 was during this time interval has implications for the evolution of complex life (which requires higher O_2 levels), and for the identification of 'false positives', i.e., abiotic O_2 concentrations that mimic those produced biotically. Some hypothetical abiotic planets, particularly those orbiting M stars, could conceivably develop O_2 concentrations exceeding 0.1% PAL.

One of the best indicators of past atmospheric O_2 concentrations is the presence, or absence, of mass-independent S-isotope signatures in ancient rocks. New work by C. E. Harman et al., discussed elsewhere in this meeting, suggests that the mechanism for producing this anomalous fractionation has been misunderstood. Sulfur chain formation, not SO_2 photolysis itself, is probably the dominant process. Understanding this process may lead to new insights into Archean atmospheric composition.