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Crustal oxidation experiments to test the plausibility of oxygen biosignature false positives

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The detection of molecular oxygen (O_2) is a key goal in the search for life beyond Earth [1]. But the detection of O_2 alone may not be a reliable biosignature, as abiotic O_2-rich atmospheres are a potentially common outcome of rocky exoplanet evolution [2]. Current and upcoming NASA telescopes (JWST, HWO) may be able to detect O_2 on terrestrial exoplanets, however, no O_2-rich atmospheres have been detected by JWST thus far.

Whether O_2 produced by H escape can accumulate on hot rocky planets depends on the rate of crustal oxidation, where Fe^{2+} in fresh crust is oxidized to Fe^{3+} without liquid water in the reaction [3]. Atmospheric oxygen can be removed from the atmosphere if it can react with crustal Fe^{2+}; e.g. $2FeO + 0.5O_2 \rightarrow Fe_2O_3$. However, the efficiency of crustal oxidation under hot, post-accretion conditions is unknown. Here, we conduct high-pressure, high-temperature experiments to constrain the kinetics of O_2 drawdown on hot rocky exoplanets to help predict the presence (or absence) of abiotic O_2 atmospheres.

We developed a novel high-pressure, high-temperature experimental system to simulate hot rocky exoplanet atmospheres under post-accretion conditions (Fig. 1). We test a range of temperatures and pressures (100-300 bar; 700-900 K) to represent early terrestrial planet surface conditions. Whole-rock samples are placed inside the chamber under an O_2-CO_2 gas mixture and held at high pressure-temperature conditions for several weeks. The altered samples will then be analyzed by an Electron Probe Microanalyzer to measure oxidative diffusion.

If crustal oxidation is found to be efficient at removing atmospheric O_2 from abiotic accumulation, future O_2 detections could be more reliably attributed to life. This would also help explain the absence of thick O_2 exoplanet atmospheres from JWST detections. If crustal oxidation is found to be an inefficient O_2 sink, then future detections alone cannot confidently be interpreted as a biosignature. In either scenario, this work will motivate advancements towards upcoming space telescopes and enable more robust characterizations of exoplanet atmospheres.

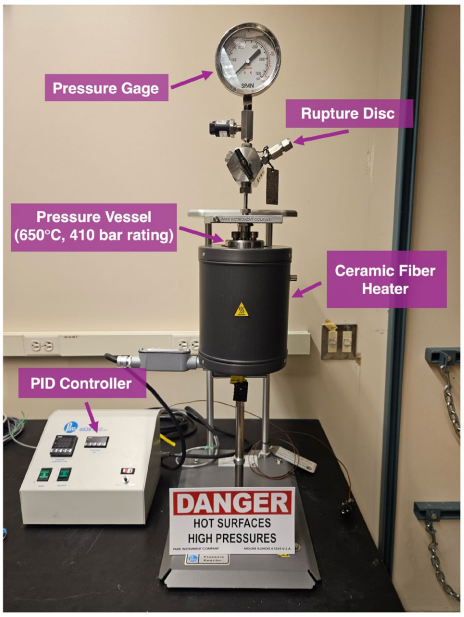

Figure 1: Experimental set-up for crustal oxidation experiments. Samples are placed in the 75-mL high-pressure, high-temperature vessel, where they are heated up to 900 K and pressurized up to 300 bar.

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[2] Luger, R., & Barnes, R. (2015), Astrobiology, 15
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