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Outgassing of slightly-carbon-rich rocky exoplanets

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The search for atmospheres on rocky exoplanets has focused on thick, Venus-like CO_2 atmospheres. On planets cool enough to have solid crusts, this CO_2 would be supplied through partial melting of the mantle. Whether a planet's volcanic gas is oxidising (carbon as CO_2) or reducing (carbon as CO or CH_4) is inherited from redox conditions in the interior. Mantle oxygen fugacity is often presumed to be buffered by Fe^{2+}-Fe^{3+} equilibria. Yet carbon itself is also a powerful redox agent, given that it exchanges 4 electrons: a fact which has led to the suggestion that the oxygen fugacity of Earth's upper mantle is in part controlled by graphite-carbonate equilibria during melting [1,2], even though Earth is carbon-poor. Hence carbon redox processes would become increasingly important for exoplanets with slightly more carbon in their mantles. Indeed, a number of known rocky exoplanets could have formed enriched in refractory carbon [3]. We present a simple carbon outgassing model that captures the transition from iron-dominated to carbon-dominated redox buffering, applicable to silicate exoplanets. In this model, carbon-iron redox coupling results in characteristic melt oxygen fugacities which are more reducing than those at Earth's mid-ocean ridges. We estimate the speciation of carbon in exoplanetary volcanic gas depending on bulk mantle C/Fe^{3+}, with implications for the prevalence of Venus-like volcanic atmospheres. The scenarios we model exemplify that higher interior volatile budgets do not necessarily lead to higher outgassing rates.

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[2] Stagno, Ojwang, McCammon & Frost (2013), *Nature* 493, 84–88.

[3] Bergin, Kempton, Hirschmann, Bastelberger, Teal, Blake, Ciesla & Li (2023), *The Astrophysical Journal* 949, L17.