Planetary oxidation and the biogeochemistry of exoplanets

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Atmospheric oxygen is considered a fundamental prerequisite for the evolution of complex organisms with high metabolic demands. On Earth, this requirement can only be met by aerobic respiration. The main source of oxygen on Earth is biological, originating as a by-product of oxygenic photosynthesis. However, geological and planetary factors are important in controlling the relative abundance of oxygen in the atmosphere.

Over geological timescales, planetary oxidation is controlled by two mechanisms: the burial of organic carbon [1] and hydrogen escape from the upper atmosphere [2]. The relative importance of these processes varies significantly over time; hydrogen escape was an important oxidising mechanism during the early evolution of the planetary atmosphere, but represents only a limited source of oxidising power today when compared to the burial of organic carbon.

However, it seems that the 'default' state of the planetary atmosphere is reducing [3], and the oxidising atmosphere of the Earth is unusual. The homeostasis of atmospheric oxygen is perhaps the most obvious example of biogeochemical coupling on the Earth. Is the co-evolution of oxygen and biosphere likely to be a fundamental characteristic of habitable, life-bearing planets?

Planetary characteristics undoubtedly exhibit a fundamental control over these oxidising processes, but our understanding of these factors remains limited. Planet mass may play a particularly important role in controlling hydrogen escape for example, and an upper and lower mass limit must exist beyond which this mechanism fails or operates too slowly or too rapidly to contribute any lasting geochemical signal. Biology is the primary controlling factor in regards to carbon burial, representing the main pathway for organic carbon fixation. However, geological recycling processes enable the burial of organic carbon, and the rate and duration of these mechanisms are sensitively dependent on a number of planetary variables.

Modern biogeochemical models (eg: COPSE [4]) can resolve the rise of oxygen in acceptable agreement with geochemical proxies, but are difficult to apply to planets other than the Earth. Preliminary results from a simplified version of this model return estimates for 'oxygenation time' that vary over several orders of magnitude when forced by either hydrogen escape or carbon burial alone. It is hoped that this model can begin to reconcile these two fundamental processes over time, but also resolve potential oxygen fluxes operating on extrasolar planets, with extensive application to the search for habitable extrasolar planets as well as the emerging field of astrobiology.

[1]Hayes and Waldbauer (2006) *Phil. Trans. R. Soc. B* **361** 931-950 [2] Catling et al. (2001) *Science* **293** 839-843 [3] Kasting et al. (1993) *Journal of Geology* **101** 245-257 [4] Bergman et al. (2004) *American Journal of Science* **304** 397-437

Origin of silicic magmas in the primitive, intra-oceanic Tongan arc

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The origin of felsic magmas (> 60% SiO_2) in intra-oceanic arc settings is a matter of much current debate. In essence, two very different processes are currently invoked: fractional crystallization of basaltic magma and partial melting of lower crustal amphibolites. Importantly, the physical conditions, such as pressure, melt reactions, rates of melting and fluid dynamics of melt extraction differ markedly between the two mechanisms. Concurrently, a number of sophisticated numerical models of lower crustal amphibolite melting have been developed over the past decade. Such models are becoming widely invoked so there is a need for their applicability to be tested. Fonualei is unusual amongst subaerial volcanos in the Tonga arc because it has erupted dacitic vesicular lavas, tuffs and phreomagmatic deposits for the last 165 years and makes for an excellent natural laboratory. All of the products are crystal-poor and formed from relatively low viscosity magmas inferred to have had temperatures of 1100-1000 ºC, 2-4 wt. % H_2O and oxygen fugacities 1-2 log units above the QFM buffer.

Major and trace element data, along with Sr-Nd-Pb and U-Th-Ra isotope data, are used to assess competing models for the origin of the dacites. Positive correlations between Sc and Zr and Sr rule out evolution by closed-system crystal fractionation and an origin by direct partial melting of amphibolite cannot reproduce the data either. Instead, we develop a model in which the dacites reflect mixing between two dacitic magmas, both products of fractional crystallization of basaltic-andesite magma. Mixing was efficient because the two magmas had similar temperatures around 1000 ºC. This is inferred to have occurred around 6 km depth beneath the volcano and the relative proportion of the fractionation-derived dacite has increased over the 165 year eruption period implying crystal fractionation and mixing may all have occurred on a similar timescale. U-Th-Ra disequilibria in the basaltic-andesite and andesite indicate that the magmas parental to the fractionation produced dacite had fluids added to their mantle source regions less than 8 kyr ago.