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An update on the GOE to the Permian atmospheric oxygen levels by direct analysis

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Numerous attempts have been made to estimate the atmospheric oxygen levels in deep time as there are major implications for the evolution of life. Whether oxygen drove animal life or if animal life drove oxygen remains debated. Most attempts to estimate atmospheric oxygen in deep time have applied redox-sensitive element or stable isotope studies but none have been calibrated and most have sampled materials that were separated from the atmosphere. Very few studies have validated their approach using the Modern environment whereas the halite approach has been tested against Modern halite from across the globe.

We use a direct analytical method based on halite-hosted fluid inclusion gases measured by mass spectrometry. Halite grows at the brine-atmosphere interface and rafts of cumulate halite are able to sample the atmosphere. In addition, by examining fluid inclusions using microthermometry, one can measure the temperature at the brine-atmosphere interface to constrain environmental conditions. We back up the gas analysis and microthermometry by applying a rigorous screening protocol that includes: petrography, trace element and REE analysis, $^{40}Ar/^{36}Ar$ isotopes, and Sr isotope analysis. Below is a table of the atmospheric oxygen levels measured using the halite fluid inclusion and ooids.

Sequence	Age	O_2 measured
Boomplaas Fmn	2.65 Ga	2%
Onega Fmn	2.0 Ga	14%
Sibley Group	1.45 Ga	3%
Browne Fmn	830 Ma	11%
Salt Range Fmn	Ediacaran	17%
Ouldburra Fmn	Cambrian	12%
Carribuddy Fmn	End Ordovician	16%
Salina Fmn	Silurian 430-420 Ma	16%
Hutchinson Fmn	Permian 280-271 Ma	16%
Guadalupian	Permian 273-259 Ma	10%
	Modern	21%

Table 1. Atmospheric oxygen levels for several halite sequences and one ooid unit, determined by fluid inclusion gas analysis by mass spectrometry.

The atmospheric oxygen levels have fluctuated considerably over the past 2 billion years. Unfortunately, there has not been a continuous halite record and there are some major gaps during the Proterozoic. These gaps are being addressed by analyzing ooids as they are only formed in the shallow marine environment and by applying Henry's Law constants, the atmospheric oxygen level can be calculated.