Questioning the Ferromanganese Nodule Dark Oxygen Production Hypothesis

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Sweetman et al.[1] proposed a dark oxygen production hypothesis for deep-sea ferromanganese nodules based on in situ benthic chamber measurements and ex situ incubation experiments. If correct, this hypothesis would affect estimates of global oxygen cycling, ecological baselines and the environmental assessment of polymetallic-nodule mining. We examined and recalculated the reported data and identified two issues that weaken this interpretation, particularly the attribution of oxygen production to polymetallic nodules.

Oxygen-increase rates in ex situ core incubations were miscalculated

The blank controls reported by Sweetman et al.[1] do not support their conclusion that external oxygen exchange was negligible. According to Sweetman et al.[1], oxygen in the shipboard blank increased from 39 to 69 μmol/L over about 5 h, and the corresponding area-normalized oxygen-increase rate was 0.14 mmol/m^2/d. We used these reported values to back-calculate the implied water-column height. The 30 μmol/L increase over 5 h corresponds to a volume-normalized rate of 144 mmol/m^3/d. Combining this value with the reported area-normalized rate gives an implied water-column height of only 0.99 mm. Such a shallow water column is physically implausible for the described core-tube setup. If the water-column heights reported for the experimental cores are used instead (10~38 cm; Source Data Extended Data Fig. 4), the

corresponding area-normalized rate would be 14.40~54.72 mmol/m^2/d. This is about three orders of magnitude higher than the value reported by Sweetman et al.[1] and exceeds the oxygen-increase rates in all 15 experimental treatments (Table 1).

The second blank control, performed in the laboratory, raises a similar concern. Sweetman et al.[1] reported that the original core tubes were filled with artificial seawater at an initial oxygen concentration of about 100 μmol/L. The tubes were then sealed and submerged for 48 h in seawater containing 228.12 μmol/L oxygen. However, the final oxygen concentration inside the tubes was not reported. Sweetman et al.[1] provided only an area-normalized oxygen-increase rate of 0.11 mmol/m^2/d. Assuming that the effective water-column height was the same for the shipboard and laboratory blanks, and that the reported laboratory-to-shipboard blank rate ratio (0.11/0.14) remained applicable, the inferred volume-normalized rate in the laboratory blank would be approximately 113 mmol/m^3/d (Table 1). Over the reported 48-h incubation, this rate would further imply an oxygen increase of approximately 226 μmol/L and a final concentration of approximately 326 μmol/L, exceeding the oxygen concentration of the surrounding seawater (Table 1). Taken together, these results indicate that the blank-control parameters reported by Sweetman et al. are neither quantitatively nor logically self-consistent.

These inconsistencies indicate that the potential contribution of external oxygen cannot be excluded from the ex situ core incubations on the basis of the reported blank controls. More fundamentally, this inability to exclude external oxygen intrusion raises

the question of whether the core tubes functioned as effectively closed systems. This is a central methodological problem, because it directly determines data quality and the credibility of the conclusions. Therefore, all experimental parameters underlying the blank-control calculations need to be disclosed to enable a rigorous assessment of the validity of the experimental results and conclusions reported by Sweetman et al. A further observation adds uncertainty, although it is secondary to the rate-calculation issue. Of the 19 experimental incubations, one was excluded because bubbles were observed after incubation. This could reflect redistribution of pore fluids or dissolved gases stored within sediments or nodules following changes in external physicochemical conditions. This observation indicates that sediments, nodules and overlying water should not be treated as a single system without further constraint, especially when small artefacts can strongly affect conclusions about oxygen production.

Transient oxygen increases in in situ benthic chamber experiments

Sweetman et al.[1] reported oxygen increases in 25 in situ benthic chambers, from an initial mean of 185.2 ± 2.9 μmol/L to maxima of 201~819 μmol/L over 47 h. Although the chambers were equipped with two one-way valves for venting, we suggest that retained oxygen-rich water or gas still affected the measurements and may have been the main cause of the oxygen increases observed in the in situ chambers. This interpretation is supported by a previously noted mismatch between chamber and

bottom-water oxygen concentrations. Initial oxygen concentrations in the chambers ranged from 161 to 246 μmol/L, whereas contemporaneous bottom-water oxygen concentrations in this region were only approximately 145~159 μmol/L[2]. These high and variable starting values indicate that the chamber water was not fully equilibrated with ambient bottom water at the start of incubation[2]. We further note that most chamber records do not show sustained oxygen increase. Oxygen concentrations commonly rose rapidly soon after monitoring began and then declined slowly. This variation pattern is especially clear in seven chambers (Figure 1), and it can be better explained by the release of a finite oxygen-rich reservoir introduced during deployment. At abyssal pressure, these residual reservoirs could form compressed oxygen-rich pools and diffuse into the chamber along a concentration gradient, causing a pulse-like, rapid and transient increase in oxygen concentration.

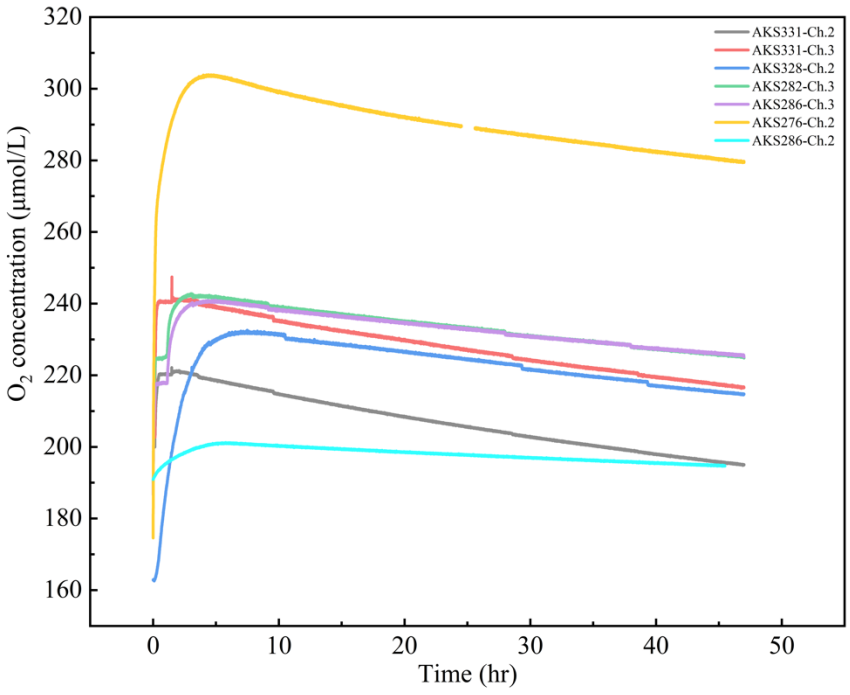

Figure 1. Transient oxygen increases in seven in situ benthic chambers. This figure was replotted

from the source data underlying Fig. 1 of Sweetman et al. (2024)[1], licensed under CC BY 4.0.

References

1 Sweetman, A. K. *et al.* Evidence of dark oxygen production at the abyssal seafloor. *Nature Geoscience* **17**, 737-739 (2024).

2 Downes, P. *et al.* Extraordinary claims require extraordinary evidence: evaluating nodule-associated dark oxygen production. *Frontiers in Marine Science* **12**, 1721853 (2025).

Author contributions

All authors contributed to the writing and editing and have approved the submitted version.

Competing interests

The authors declare no competing interests.

Table 1. Supplementary recalculation of oxygen-increase rates from the ex situ core incubation data reported by Sweetman et al.

Treatment	Replicate	Area of core (cm^2)	Height of water in core (cm)	Volume (ml)	T=0hr (O_2 concentration µmol/L)	T=48hr (O_2 concentration µmol/L)	T=5hr (O_2 concentration µmol/L)	Net oxygen increase (µmol/L)	Volume-normalized rate ($mmol/m^3/d$)	Area-normalized rate ($mmol/m^2/d$)
Control	A	70.88	37.00	2622.64	59.54	96.99		37.46	18.73	6.93
Control	B	70.88	33.00	2339.11	108.10	126.28		18.18	9.09	3.00
Control	C	70.88	35.00	2480.88	74.11	102.85		28.75	14.37	5.03
Bicarbonate	A	70.88	33.00	2339.11	129.63	149.71		20.08	10.04	3.31
Bicarbonate	B	70.88	33.00	2339.11	123.51	142.91		19.40	9.70	3.20
Bicarbonate	C	70.88	35.00	2480.88	108.10	132.14		24.04	12.02	4.21
Ammonium (10 micromol)	A	70.88	28.00	1984.70	96.06	125.11		29.05	14.52	4.07
Ammonium (10 micromol)	B	70.88	32.00	2268.23	141.88	158.14		16.26	8.13	2.60
Ammonium (10 micromol)	C	70.88	33.00	2339.11	147.58	155.56		7.99	3.99	1.32
Ammonium (50 micromol)	A	70.88	38.00	2693.52	104.93	128.39		23.46	11.73	4.46
Ammonium (50 micromol)	B	70.88	30.00	2126.47	59.12	85.75		26.63	13.32	3.99
Ammonium (50 micromol)	C	70.88	36.00	2551.76	138.92	158.61		19.69	9.84	3.54
Bicarbonate and ammonium (10 micromol)	A	70.88	33.00	2339.11	146.31	157.67		11.36	5.68	1.87
Bicarbonate and ammonium (10 micromol)	B	70.88	34.00	2409.99	142.72	152.52		9.80	4.90	1.67
Bicarbonate and ammonium (10 micromol)	C	70.88	35.00	2480.88	138.92	158.84		19.92	9.96	3.49
Mercury chloride	B	70.88	30.00	2126.47	107.46	134.71		27.25	13.63	4.09
Mercury chloride	C	70.88	27.00	1913.82	128.15	147.13		18.98	9.49	2.56
Nodules only	A	78.54	10.00	785.40	167.12	233.02		65.90	32.95	3.30
Average value										3.48
Shipboard blank			10~38 (inferred)		39 (reported)		69 (reported)	30 (calculated)	144 (calculated)	14.40~54.72 (inferred)
The laboratory blank					100 (reported)	326 (inferred)		226 (inferred)	113 (inferred)	

Note: Blue-shaded cells contain original data reported by Sweetman et al. Light-red-shaded cells show values recalculated. The average area-normalized rate for the 18 incubation experiments was recalculated as 3.48 $mmol/m^2/d$. This value is consistent with the mean reported by Sweetman et al., supporting the reliability of our recalculation.