'Dark' oxygen - Revelation with Doubts!

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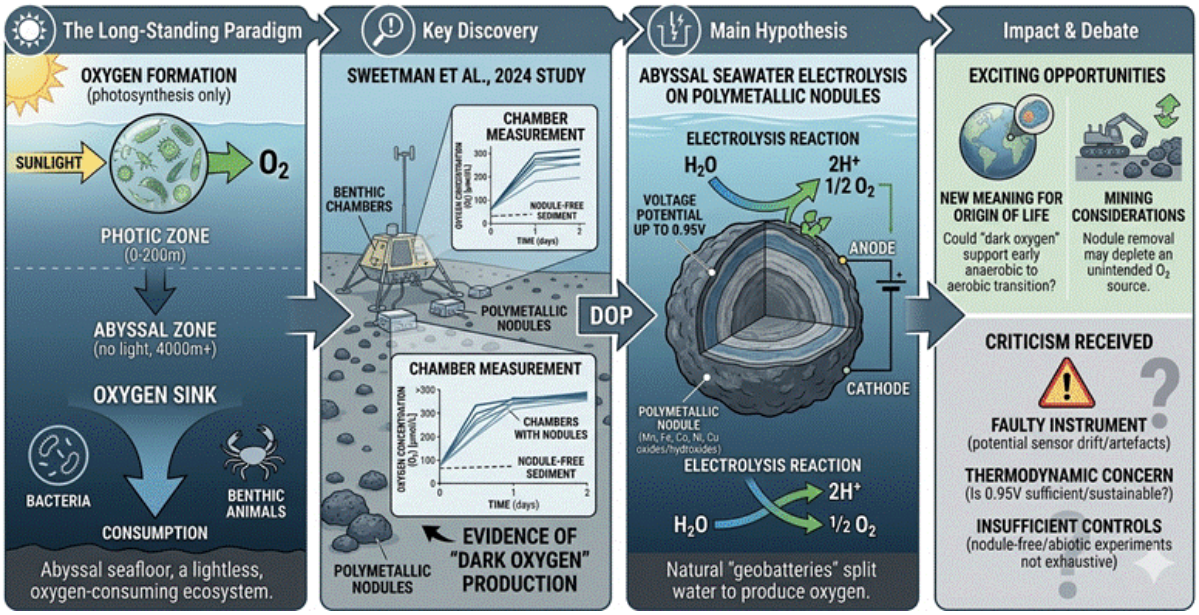
ABSTRACT



Graphical Abstract: Dark Oxygen Production (DOP) at the abyssal seafloor (Sweetman *et al.*, 2024, *Nature Geoscience*) (Image credits-Gemini.ai)

The recent breakthrough discovery with the suggested hypothesis of Dark Oxygen Production (DOP) led by Andrew Sweetman at the Scottish Association for Marine Science, United Kingdom in 2024 has sparked a debate amongst many science enthusiasts and specialists, leading to many critiques and arguments. Like every coin has two sides, this 'new'

mechanism of dark oxygen production also unfolds at two fronts-one of exciting possibilities and other of careful skepticism. The new discovery has raised serious doubts or concerns about their observations. This article presents these observations about dark oxygen production.

INTRODUCTION:

Ever since we have started studying biological systems and earth sciences, 'photosynthesis' has always been known as the one and only natural mechanism of oxygen production. It was proposed by Dutch-British biologist Jan Ingenhousz in 1779, in which green plants utilise light to fix carbon dioxide from nature for their energy production and simultaneously release oxygen molecules as by-product due to splitting of water molecules. This extremely simple process that occurs in chloroplasts contributes to roughly 50-80% of the global oxygen source. Oxygen is a vital molecule that serves as survival fuel for many organisms as it helps in cellular respiration. The chemical equation of aerobic respiration: $C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + ATPs$, represents the oxidation of glucose, in which cells use oxygen to break down glucose, thereby producing carbon dioxide, water and energy (ATP). So, the major proportion of oxygen in atmospheric air on Earth is produced through photosynthesis, however, there are other modes of *light dependent pathways* for oxygen production like ultraviolet driven photolysis of water in the upper atmosphere. Also, there are *light-independent pathways* involved in 'dark' oxygen production, namely microbial and abiotic chemical reactions. The latter include decomposition of hydrogen peroxide and radiolysis of water, while the former include chlorite and nitric oxide dismutation and proposed mechanism of water lysis by methanobactins. However, these processes produce very small amounts of oxygen in the atmosphere in comparison to oxygenic photosynthesis carried out by plants, algae and cyanobacteria.

Recently, Scottish scientists have reported another source of oxygen production from the 'dark' corridors of the sea floor. They reported the presence of oxygen on the surface of polymetallic nodules at the south Pacific Ocean bed. This important study carried out by Sweetman *et al*., 2024 and published in *Nature Geoscience* has gained attention as well critique worldwide. The hypothesis of the study suggests that seawater electrolysis on the deep-sea floor embedded with polymetallic nodules is leading to dark oxygen production. So, in other words, the polymetallic nodules (rich in metals like manganese, nickel, cobalt, and copper) have been hypothesized as 'geo-batteries' or natural batteries which are producing 'dark' oxygen, i.e., oxygen being produced in the dark sea floor (~ below 200 m) rather than on Earth's surface in presence of light by photosynthesis. The study used a sophisticated instrument called a *benthic chamber* with *in situ oxygen sensors* (optodes) to measure the levels of oxygen from the sea floor. Also, the classical chemical method of Winkler titrations was also used to estimate the dissolved oxygen concentrations in water. They reported values of 1.7–18 mmol O_2 m^{-2} d^{-1} of oxygen produced, indicating net oxygen production per square meter of seafloor per day. They found positive oxygen flux, meaning that the oxygen levels were increasing rather than the expected decrease due to consumption of O_2 by animals and microbes across the abyssal seafloor in the

Pacific Ocean. They also measured the electric potential of up to 0.95 V on nodule surfaces. Interestingly, such polymetallic nodules have also been reported in an Indian sea exploration program called *Samudrayaan Project*, in which over 100 kg of cobalt-rich polymetallic nodules were collected from 1173m depth in the Andaman Sea under Deep Ocean Mission in August, 2025.

The recent report published in reputed Nature Geoscience has sparked debates in scientific community. One of the important critiques is based on the 'faulty' instrument used to measure oxygen concentration. The benthic chambers can easily trap air bubbles under the sea floor, leading to false positive readings. Some reports claim that oxygen may also have been detected in the control set of experiments, i.e., without the polymetallic nodules. In fact, some critics argue that no adequate negative control experiments were performed to confirm the absence of oxygen production in the incubations of sediment and seawater without nodules (Downes *et al*., 2025). Further, the proposed mechanism of electrolysis raises thermodynamic concerns because at least a voltage of ~1.23 V is required to split water molecules into hydrogen and oxygen, however, the study detected voltage potential up to 0.95 V on nodule surfaces. The DOP claimed by the study also needs to be reproduced by other research groups in order to validate their key findings. In contrast, earlier studies for investigating DOP using similar benthic chambers in nodule rich regions have also been done, the earliest one being carried out by Smith *et al* in 1983. Subsequently, 4 independent studies were also done but they never reported the dark oxygen production from abyssal sea floor (Downes *et al*., 2025).

Despite the growing criticism for this revelation of the discovery of dark oxygen production from sea floor, the study opens exciting new frontiers of scientific research in the field of astrobiology and biogeochemistry and will help in understanding microbial diversity in deep sea ecosystems. Also, it provides alternative hypotheses for the origin of life as well as creates new questions for the researchers to explore and to revisit the Great Oxygenation Event (GOE), which links oxygen production through photosynthesis around 2.4 billion years ago. To conclude, the shocking revelation of dark oxygen production amidst the growing doubts reflects how scientific research progresses with each answer paving way for more questions for better understanding. So, future studies will shed light and provide substantial evidence either in favor or against the hypothesized 'dark' oxygen production on nodule rich sea floor.

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