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The Much Overrated Microbial Carbon Pump in the Oceans

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Abstract

The basic idea of the heralded microbial carbon pump (MCP) was that any recalcitrant dissolved organic matter (RDOM) that is not microbially degraded for extended periods effectively stores carbon in the oceans. This store, however, is only 2% of the dissolved inorganic carbon (DIC) pool. Further, the pumping efficiency of the DIC pool is 400-600 times larger than the pumping efficiency of the MCP. Due to its pivotal role in converting dissolved and particulate organic matter into RDOM but the very low carbon pumping efficiency, the MCP perhaps better reflects the Microbial Carbon Process rather than the microbial carbon "pump."

Keywords: Microbial carbon pump; Physical pump; Biological pump; Dissolved organic material; Ocean carbon sink; Carbon cycle; Hydrothermal vents; Recalcitrant dissolved organic matter

Abbreviations: AABW: Antarctic Bottom Water; AAIW: Antarctic Intermediate Water; DIC: Dissolved Inorganic Carbon; DOM: Dissolved Organic Matter; MCP: Microbial Carbon Pump; NADW: North Atlantic Deep Water; NPIW: North Pacific Intermediate Water; PDW: Pacific Deep Water; POM: Particulate Organic Matter; RDOM: Recalcitrant Dissolved Organic Matter

Opinion

The oceans cover 70.8% of the globe's surface and absorb 26.6% of the CO_2 released by human activities in 2019 [1]. As CO_2 is the major greenhouse gas, the more the oceans absorb it, and the longer the oceans keep it, the slower the Earth warms. It is thus of paramount importance in understanding the air-sea exchange of CO_2 and the carbon cycle in the oceans.

The oceans exchange 90GtC CO_2 with the atmosphere with net absorption of 2.5GtC anthropogenic CO_2 in 2019 [1]. Once CO_2 enters the surface ocean, it is traditionally considered to be transported downward by two major pathways, or the so-called "pumps." The physical or solubility pump works mainly by sinking the cold, CO_2-rich seawater in the polar and subpolar regions, thus storing CO_2 in the deep oceans for hundreds of years. Figure 1 shows, schematically, the sinking of major deep and bottom waters: the North Atlantic Deep Water (NADW) in the polar North Atlantic Ocean, the Antarctic Bottom Water (AABW) in the Antarctic region, the Antarctic Intermediate Water (AAIW) in the sub-Antarctic region, and the North Pacific Intermediate Water (NPIW) in the subpolar North Pacific Ocean.

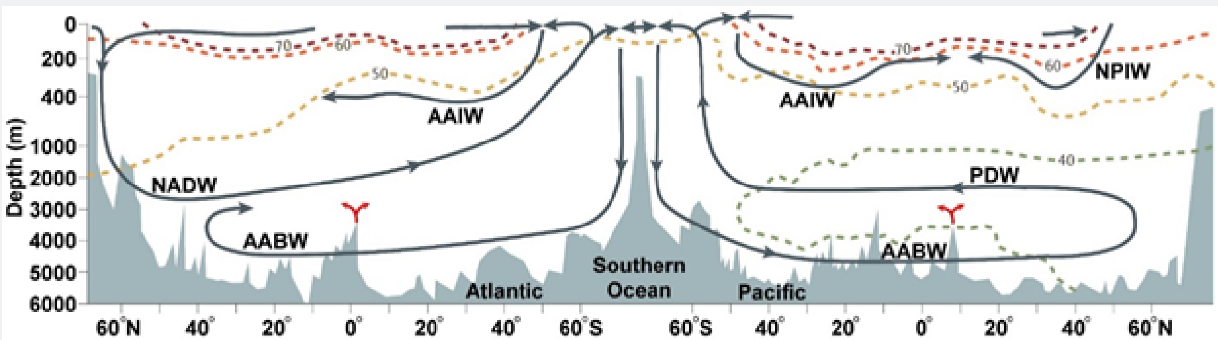

Figure 1: Schematic diagram of subsurface circulation and DOC distribution in the Atlantic and Pacific Oceans. Acronyms are spelled out in the text and red arrows denote hydrothermal vents and seeps (modified from 12,14,19).

The biological pump works everywhere in the oceans. In the surface euphoric layer, photosynthesis consumes CO_2 but produces particulate organic matter (POM) and dissolved organic matter (DOM). Subsequently, the POM sinks and decomposes into DOM almost entirely in the water column. The DOM also mixes downward by way of diffusion or advection. To summarize, the biological pump transports products of photosynthesis to the deep oceans.

It has been known for decades that microbes play an important role in converting POM to DOM [2]. This process has traditionally been considered part of the biological pump until Jiao et al. [3] coined the term "Microbial Carbon Pump (MCP)." The basic idea was that any DOM molecules that are not degraded for extended periods effectively store carbon. Indeed, most DOM in the deep oceans is relatively stable and is termed recalcitrant dissolved organic matter (RDOM). The mean apparent radiocarbon age of RDOM is 4,000 to 6,000 years [3,4], several times higher than the around 1,000yr turnover time of oceanic thermohaline circulation [5]. As a result, the RDOM plays a role in the long-term storage of atmospheric CO_2 by the ocean. Jiao et al. claimed, correctly, that if all RDOM were respired and the carbon released to the atmosphere, it would double the atmospheric CO_2 inventory. The MCP has garnered much attention recently [6-8], and it has been shown that its role might become more significant under future climate change conditions [9].

The MCP, unfortunately, might have been misnamed. It has been pointed out [10-14] that stable and ancient DOM is released from the seafloor, thus contributing a non-microbial source to RDOM. Figure 1 shows the DOM cross-sections in the Atlantic and Pacific Oceans, mainly based on the data of Hansell et al. [15]. Coastal oceans receive DOM from land and may have a DOM concentration as high as 100μM [16,17]. The open ocean surface water generally has a concentration just above 70μM, which gradually decreases to between 40 and 50μM in the deep Pacific and Atlantic Oceans. The lowest DOM of between 30 and 40μM in subsurface waters exists in the Pacific Deep Water (PDW), which is the return flow of the AABW in the Pacific Ocean and is the oldest water mass [5]. The RDOM in the Pacific Ocean is older than that in the Atlantic Ocean [4], and this is consistent with the notion that there is an input of RDOM from the seafloor.

Altogether the oceans contain 700GtC DOM [1]. Waters deeper than 1,000m contain 477GtC RDOM, but about 40% of the DOM in the surface ocean is labile or semi-labile [15]. Roughly, 610GtC DOM in the oceans is recalcitrant. Dividing this amount by the age of RDOM means that the pumping efficiency of the RDOM is merely 0.102 - 0.153GtC/yr. Legendre et al. [7] obtained an even lower value of 0.043GtC/yr.

As for the major pool of carbon in the oceans, the dissolved inorganic carbon (DIC) amounts to 38,000GtC [1]. The radiocarbon age for waters deeper than 1,500m is about 200-400yrs in the Atlantic Ocean and 600-1,000yrs in the Pacific Ocean [5]. Taking an average age of 600±200 yrs, the DIC flux is 63±12.6GtC/yr which is consistent with the net primary productivity of approximately 50GtC/yr [18]. That is, the DIC pump is 400-600 times larger than the MCP. If all DIC were released to the atmosphere, it would increase the atmospheric CO_2 inventory 50 times. On the other hand, if all RDOM were respired, it would become DIC and increase only 2% of the DIC inventory in the oceans.

The above is not to say that the microbial activities are not important; they are. It is just that calling the process of converting DOM to RDOM a "pump" may disservice the important roles microbes play. The microbes are indeed effective in respiring POM and DOM into DIC, but their pumping efficiency in converting DOM to RDOM is very low. Perhaps it is more proper to call the process of transferring labile DOM to RDOM with its long-term storage a Microbial Carbon Process but keeping the MCP acronym.

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