A Review on the Role of Reactive Iron Phases in the Stabilization of Organic Carbon in Sediments

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Abstract

There is a continual rivers influx of dissolved organic carbon (DOC; 0.25×10^{15} g yr^{-1}) and particulate organic carbon (POC; 0.15×10^{15} g yr^{-1}) from continents to the ocean and this constitutes a significant flux of carbon (C) and a major pathway that marine ecosystem sequester C. Once in the ocean, complex abiotic and biotic processes affect the residence time of these C, wherein some of these processes result in the immediate release of these C into the atmosphere, whereas others can effectively stabilize organic carbon (OC) in sediments for decadal or millennial scale. Uncertainty remains, however, the underlying mechanisms of OC stabilizations and preservations in sediments, which cast shadows in predicting the response of OC in sediments to climate change. This paper reviews the long-term stabilization (e.g. co-precipitation, direct chelation, sorption, etc.) of OC in sediments and discusses the sorptive interaction of OC with mineral phases. We argue that iron (Fe), which is derived from dust, coastal and shallow sediments exerted significant control over OC stabilization in sediments ('rusty sink') and thus, contributing to the global cycles of C. Lastly, protecting the remaining natural mangrove vegetation could reduce sediments and OC losses from these areas and thus, will increase the resilience of OC to the anticipated more extreme hydrological events.

Introduction

Understanding how ecosystem store or release carbon (C) is one of ecology's greatest challenges in the 21st century. Of the 5 global C pools (i.e. pedologic, biotic, fossil fuel and atmospheric pools), the oceanic pool which is estimated at 38,000 Pg (1 Pg = 1 billion metric tons) is 5 times higher than the four C pools combine (Lal, 2008). About 96% of this C is deposited in the deep layer (inorganic C and is a very stable form of C), while about 670 Pg is located in the surface layer and about 1,000 Pg are in the organic form. The atmospheric pool is connected to the ocean pool which absorbs (sink) 92.3 Pg C yr^{-1} and releases (source) 90 Pg C yr^{-1} resulting in a net positive balance of 2.3 Pg C yr^{-1}. However, complex abiotic and biotic processes affect the residence time of these C, wherein some of these processes result in the immediate release of these C into the atmosphere, whereas others can effectively stabilize OC in sediments for decadal or millennial scale. To enhance understanding of the effects of climate change on the ocean carbon cycle and its implications, we must improve our limited knowledge of OC preservation in sediments. Despite several decades of research, our understanding of the mechanisms by which OC is stabilized and sequestered in aquatic sediments remains far from complete. The objective of this paper is to review the available information on the role of reactive iron phases in the stabilization of organic carbon in sediments.

Relationship between sedimentation rate & OC accumulation rate

Continental margin has high OC content net primary productivity (NPP), which is influenced by the river-derived nutrients and sedimentation rates are also high. The widely cited preservation rate for OC in marine sediments is a value of 0.13×10^{15} g C yr^{-1} and about 86% of the total OC preservation occurs in deltas, shelves and upper slopes near river mouths (Hedges & Keil, 1995). However, the rate of burial of OC depends strongly on the sedimentation rate and that OC accumulation rate in marine sediments doubles with each 1.6 fold increase of the sedimentation rate (Müller & Suess, 1979). The OC accumulation rates are lowest in the pelagic sediments of the Central Pacific but higher in the rapidly deposited sediments of the Baltic Sea and the upper continental slope of Peruvian margin. Clearly, greater preservation of OC in near-shore environments are likely to be due to the greater NPP in these regions, rapid burial and somewhat less efficient decomposition under anoxic conditions (Müller & Suess, 1979).

Surface area control of OC accumulation

The long-term persistence of OC in marine aluminosilicate sediments is enhanced by its association with mineral surfaces (Mayer, 1994). The association of OC with the mineral surface area leads to a hypothesis that OC is protected by its location inside pores, too small to allow functioning of the hydrolytic enzymes necessary for organic matter decay (e.g. Mayer, 1994; Hedges & Keil, 1995). Because of this, the control of OC preservation of the mineral surface area indicates that it is the availability of surface area, not the supply of OC that limits the extent the OC preservation.

Sorptive preservation of labile organic matter

More than 90% of the labile organic matter preserved in marine sediments is intimately associated with the mineral surfaces that slow remineralization rates by up to five orders of magnitude (Keil et al., 1994). The sorptive protection accounts for the enigmatic preservation of intrinsically labile molecules in marine deposits and link the preservation of OC in marine sediments to the deposition of mineral surfaces (Keil et al., 1994).

Preservation of organic matter promoted by iron

It has been known that the biogeochemical cycles of iron and OC are “strongly interlinked” (Lalonde et al., 2014). This interlinked is evidenced by the positive correlation of the amount of OC and reactive iron and that on average more than 20% of the OC in aquatic sediments from a wide range of depositional environment, which vary in salinity, proximity to land, water depth, OC content is associated with reactive iron. The OC bound to iron is metastable over geological timescales and thus serve as an efficient ‘rusty sink’ for OC (Lalonde et al., 2014), thus contributing to the long-term storage of OC and contributing to the global cycles of C.

Conclusion and Outlook

Iron, which is derived from dust, coastal and shallow sediments exerted significant control over OC stabilization in sediments (‘rusty sink’) and thus, contributing to the global cycles of C. To enhance understanding of the effects of climate change on the ocean carbon cycle and its implications, we must improve our limited knowledge of OC preservation in sediments.

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Citation: Navarrete, I.A., G. Dicen, M.C.A. Garcia, K.M.I. Castro, E.J. Sta. Maria and S.G. Salmo III, 2015. A Review on the Role of Reactive Iron Phases in the Stabilization of Organic Carbon in Sediments. Paper presented at the 13th National Symposium in Marine Science held in General Santos City on 22-24 October 2015.