Relationships Between Microbial Distributions and the Anaerobic Decomposition of Organic Matter in Surface Sediments of Long Island Sound, USA

R. C. Aller and J. Y. Yingst

1 Department of the Geophysical Sciences, The University of Chicago; 5734 South Ellis Avenue, Chicago, Illinois 60637, USA
2 Department of Biology, Wayne State University; Detroit, Michigan 48202, USA

Abstract

Relative rates of the anaerobic decomposition of organic matter in the upper 10 cm of sediment from two stations in central Long Island Sound, USA, were compared. Sediment samples from discrete depth intervals were incubated anoxically and changes in SO$_4^-$, NH$_4^+$, bacterial numbers, extractable adenosine triphosphate (ATP), organic matter, and organic carbon were measured as a function of time and temperature. At both stations (~15 and ~34 m water-depths, respectively), the calculated rates of SO$_4^-$ reduction and NH$_4^+$ production decreased exponentially (approximately) with depth below the sediment-water interface. Over the same depth interval, ATP concentrations dropped by a factor of 6 to 7 and bacterial numbers were lower by a factor of 2 to 3. These decreases in SO$_4^-$ reduction, NH$_4^+$ production, bacterial numbers, and ATP, reflect a change in the physiological state of microbial populations with depth in the sediment and are consistent with the conclusions that the quantity of easily utilizable organic matter changes rapidly below the sediment surface and that food limitation controls the basic depth distribution of microbial activity. The average rates of SO$_4^-$ reduction, ~29 to 39 mM year$^{-1}$ (22°C), in the top 10 cm are similar at both stations studied here, as well as at an additional station from a previous study. In contrast, average NH$_4^+$ production differs by a factor of ~2 at the two stations, reflecting differences in the C:N ratio of the organic matter supplied to the sediment surface and differences in particle reworking by macrofauna at each site. The apparent activation energy of SO$_4^-$ reduction was 19 ± 1 kcal mole$^{-1}$ and that of NH$_4^+$ production, 18 ± 3 kcal mole$^{-1}$. The overall quantity of carbon required to support the calculated average SO$_4^-$ reduction rate in the top 10 cm is 23 g C m$^{-2}$ year$^{-1}$ and represents ~36% of all the carbon available to the benthos annually and ~11% of the net primary production in the water column. Directly measured fluxes of NH$_4^+$ from sediments to overlying water at both stations agree well with those predicted from production rates obtained by the incubation techniques.

Introduction

Knowledge of the rates and types of microbial metabolic activities in bottom sediments is required for understanding chemical and biological properties of sedimentary deposits and their overlying waters (Berner, 1976a; Pamatmat, 1977; Smith, 1978). In this report, we examine microbial activity associated with the decomposition of organic matter in sediments from Long Island Sound, an estuary along the northeast coast of North America. We have concentrated on estimating potential rates of SO$_4^-$ reduction and NH$_4^+$ production as a function of vertical position of the samples within the deposits at two locations in the estuary. These rates are compared with direct counts of bacteria and the quantity of extractable ATP in the same samples and then used to help interpret relative chemical characteristics and bacterial distributions of the deposits.

Other investigators have used various techniques to measure microbial metabolic activities in sediments. These techniques include: (1) incubation of sediment and direct measurement of the consumption rates of naturally occurring electron acceptors (or donors), and the associated production of metabolites (e.g. Hargrave, 1972; Pamatmat and Skjoldal, 1974; Wieser and Zech, 1976; Christensen and Packard, 1977; Olanczuk-Neyman and Vosjan, 1977; (4), direct determination of heat production during metabolism (Pamatmat, 1977).
In the present work, we have used a combination of the incubation techniques to directly measure rates of $\text{SO}_4^{2-}$ reduction and $\text{NH}_4^+$ production, and the ATP assay method to monitor changes in microbial biomass and activity during decomposition.

**Study Area**

Sediment samples were obtained from two stations in Long Island Sound (Fig. 1). These stations, NWC and DEEP, lie in the central basin of the Sound under ~15 and ~34 m of water, respectively. A third shallow-water station (FOAM) from an earlier study is also shown in Fig. 1; data from this station are presented later for comparison purposes. Detailed physical, chemical, and biological descriptions of these stations are given elsewhere (Aller, 1977; McCall, 1977; Rhoads et al., 1977; Rhoads et al., 1978; Yingst, 1978; Benninger et al., 1979).

NWC sediment consists of $>75\%$ silt-clay-sized material and, except in distinct layers, $<10\%$ CaCO$_3$. A well defined color stratigraphy determined by the relative abundance of Fe-oxides and sulfides is present. The surface few centimeters are commonly yellow-brown, followed by a black layer of several centimeters thickness, which itself is underlain by a grey layer many decimeters thick. This station is inhabited by a predominantly mobile deposit-feeding infauna, characterized by the protobranch bivalves *Yoldia limatula* and *Nucula annulata* and the polychaete *Nephtys incisa*.

Sediment at DEEP is also $>75\%$ silt-clay, but CaCO$_3$ is generally $<3\%$. The surface few millimeters of this area are yellow-brown and are underlain by a zone of mottled yellow-black-grey sediment several decimeters thick. Sediment below ~30 cm is usually grey in color, reflecting the dominance of pyrite. The infauna is represented by relatively deep-burrowing sediment-deposit-feeding polychaetes such as the flabelligerid *Pherusa affinis* and the maldanid *Clymenella* sp. Other macrobenthos, present at both NWC and DEEP, include the burrowing anemone *Ceriantheopsis americanus*, the suspension or surface deposit-feeding polychaete *Spiochaetopterus oculata*, and the suspension-feeding bivalves *Mulinia lateralis* and *Pitar morrhua*na. The infauna at both stations are important in redistributing reactive organic particles within the deposits.

Salinity ranges from about 24 to 28%o throughout the year. Temperature oscillates annually between 2 °C and 22 °C, and follows a roughly sinusoidal time distribution. Lowest temperatures are found in February-March and highest in August-September (Riley, 1956a).