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Uptake kinetics of the microbial populations with different redox pathways in the sulfuretum of Saanich Inlet*

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Abstract: The uptake kinetics of amino acids by natural microbial populations in the redox gradient of sulfuretum of Saanich Inlet, British Columbia, Canada, were studied based on Michaelis-Menten kinetics. Models of the kinetics were statistically generalized with reference to the anoxic-hypoxic-oxygenic environments of outermost sulfuretum layer. The classification of waters in this study were anoxic without dissolved oxygen, hypoxic with dissolved oxygen between 0.006 and 0.456 mgO_2 and oxygenic higher than 0.5 mgO_2, on the basis of redox range where the metabolism of each natural microbial population functions anaerobically, microaerophilically or aerobically. The kinetics in the anoxic environment were shown to be less efficient than those in the hypoxic environment. The actual function in the uptake kinetics took place only a few times inefficient in the order of microaerophilic, anaerobic and aerobic microorganisms, although the maximum attainable activities of the kinetic models in both hypoxic and anoxic environments were one order of magnitude lower than those in the oxygenic environment.

1. Introduction

In relation to redox condition of the marine environment, the predominant habitat segregation of marine organisms has been shown as; anaeobes in anoxic region between 0 and 0.01 PDL (O_2 of the present dissolved level), microaerophiles in hypoxic region between 0.01 and 0.1 PDL, and aerobes in oxygenic region between 0.1 and 1 PDL (SEKI, 1991; 1993). At all these conditions, except in anoxic region of the eutrophic environment, readily available organic nutrients are maintained in a steady-state equilibrium (HUTCHINSON, 1970; SEKI,1982) usually below 20 $\mu g l^{-1}$. Because of these low nutrient concentrations, marine microorganisms are chiefly responsible for the assimilation and decomposition of these organic debris in the marine environment (e.g., ZOBELL, 1946; PARSONS et al., 1977; SOROKIN, 1978; RHEINHEIMER, 1980; SEKI, 1982;1992).

The first step in the microbial function of purifying the environment can be performed through the assimilation of organic matter into microbial cells. This assimilation has usually been described using Michaelis-Menten enzyme kinetics, as originally been shown by PARSONS and STRICKLAND (1962), as

$$\frac{Vt}{V} = \frac{Sn}{Kt+Sn} \qquad \cdots\cdots\cdots\cdots\cdots\cdots (1)$$

where Vt is the rate of microbial assimilation, and V is its maximum. Kt is the transport constant of microbial assimilation, that is similar to the Michaelis constant and is defined as the substrate concentration when the rate Vt is half of the maximum rate V. Sn is the nutrient concentration in the environment of microbial cells.

Once the nutrient substrate passes through the cell membrane of a microorganism, it can be oxidized efficiently through a series of biochemical pathways. The rate of microbial decompostion of organic matter is, therefore, regulated by the rate of microbial uptake.

The uptake kinetics model of each microbial group utilizing terminal electron acceptor differently were determined at optimal condition of the anoxic, hypoxic or oxygenic environment inside outermost sulfuretum layer of Saanich Inlet, with reference to evolutionary aspect of the microbial energetics.

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Table 1. Statistical difference (F test) of each parameter value comprising microbial uptake kinetics in different redox conditions in the deep water of Saanich Inlet, B. C., Canada.

Tt	Sn	Kt	V	Vt
Between oxygenic and hypoxic environments				
58.14＊＊	22.74＊＊	83.23＊＊	15.97＊＊	64.71＊＊
$F_{0.01\ (1:78)}=6.97$ (degree of freedom: 1, 78)				
Between hypoxic and anoxic environments				
0.06	0.53	2.22	1.43	0.89
$FF_{0.05\ (1:58)}=4.01$ (degree of freedom: 1, 58)				

＊＊highly significant

2. Methods

The waters in the sulfuretum of Saanich Inlet has been shown as mesotrophic (Seki *et al.*, 1984). In these waters with various redox characteristics, the kinetic models of nutrient uptake by natural microbial communities were taken. Each kinetic model was analyzed with special reference to the catabolic characteristics of microbial population, using original data Seki (1882) and Seki *et al.* (1984).

3. Results and Discussion

The statistical differences between parameter values comprising the microbial uptake kinetics of amino acids in different redox environments are analyzed in Table 1. All the parameter values of uptake kinetics in the anoxic and hypoxic environments were not statistically different, whereas those in these environments and the oxygenic environment were statistically different at highly significant levels.

The uptake kinetics of amino acids by the natural microbial communities were statistically generalized (Figure 1) in each redox type of sulfuretum water by the following formulae:

(1) In the anoxic waters, the kinetic model could be expressed as,

$$\frac{Vt}{0.028} = \frac{Sn}{33 + Sn} \quad \cdots\cdots\cdots\cdots\cdots (2)$$

In this relationship, the actual microbial uptake took place in a concentration range of amino acids of $2.7 \pm 0.7\ \mu g l^{-1}$, with 95% confidence limits. The actual uptake rate took place in the range of $0.0023 \pm 0.0011\ \mu g l^{-1} hr^{-1}$ with 95% confidence limits. Therefore, the microbial uptake in situ could function at the level between 6 and 13% of the maximum attainable rate estimated from its Michaelis-Menten kinetics, with a moderately large transport constant of the natural microbial population (Seki, 1992). This model is representing energetically

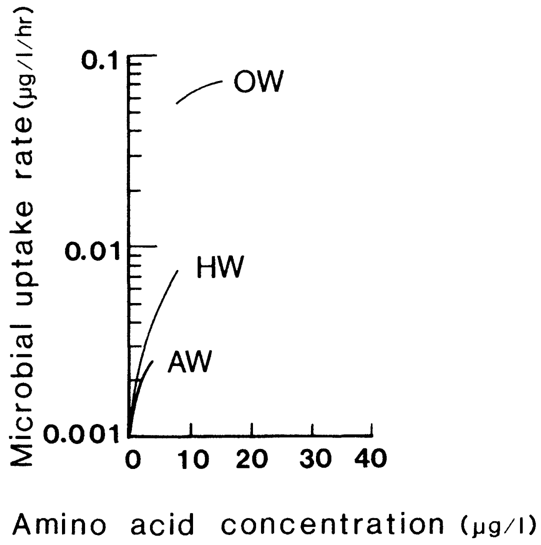

Fig. 1. Range of the generalized model of Michaelis-Menten kinetics for the assimilation of amino acids by the natural microbial communities (95% confidence limits) in the sulfuretum of Saanich Inlet.
AW: in anoxic waters
HW: in hypoxic waters
OW: in oxygenic waters

the nature of a moderately slow geochemical cycling in the marine anoxically mesotrophic waters.

(2) In the hypoxic waters, the kinetic model could be expressed as,

$$\frac{Vt}{0.048} = \frac{Sn}{40 + Sn} \quad \cdots\cdots\cdots\cdots\cdots (3)$$

In this relationship, the actual microbial uptake took place in a concentration range of amino acids of $2.9 \pm 5.1\ \mu g l^{-1}$, with 95% confidence limits. The actual uptake rate took place in the range of $0.0045 \pm 0.0026\ \mu g l^{-1} hr^{-1}$ with 95% confidence limits. Thus the microbial uptake in situ could have functioned at the level between 6 and 9% of the maximum attainable rate estimated from its Michaelis-Menten kinetics, with a moderately large transport constant of the natural microbial population (SEKI, 1992). This model is energetically well representing the nature of another moderately slow geochemical cycling in the marine hypoxically mesotrophic waters.

(3) In the oxygenic waters, the kinetic model could be expressed as,

$$\frac{Vt}{0.12} = \frac{Sn}{8.9 + Sn} \quad \cdots\cdots\cdots\cdots\cdots\cdots (4)$$

In this relationship, the actual microbial uptake took place in a concentration range of amino acids of $11.6 \pm 3.7\ \mu g l^{-1}$, with 95% confidence limits. The actual uptake rate took place in the range of $0.054 \pm 0.013\ \mu g l^{-1} hr^{-1}$ with 95% confidence limits. Thus the microbial uptake in situ could have functioned at the level between 41 and 53% of the maximum attainable rate estimated from its Michaelis-Menten kinetics, with a moderately small transport constant of the natural microbial population (SEKI, 1992). This model is energetically well representing the nature of the fastest geochemical cycling in the marine oxygenic mesotrophic waters.

Models of the microbial uptake kinetics show that those in the anoxic and hypoxic environments were similar statistically, but the most inefficient nature of microbial uptake was evident in the anoxic environment. These kinetics models show that these uptake efficiencies were one order of magnitude less than that in the oxygenic environment. Thus, with the function of in situ substrate concentration in the ambient water, the actual in situ uptake took place greater by the natural microbial population of aerobic, microaerophilic and anaerobic microorganisms, in that order. From the energetic point of view amongst these metabolic groups, the difference in free energy yeild efficiencies must be reasonable, as those efficiencies in fermentation, anaerobic and aerobic respiration are 25, 26 and 39 % for the procaryotic microorganisms. The best efficiency in the redox pathways of a microbial group must have ruled the theoretically appropriate order of the in situ predominancy of anaerobic, microaerophilic and aerobic microorganisms in the anoxic, hypoxic and oxygenic environments of Saanich Inlet, respectively.

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サニッチ入江の硫黄生態系における異なる電子伝達系を持つ微生物群集の栄養摂取様式

関　文威

要旨：カナダ国ブリテッシュコロンビア州に位置するサニッチ入江には大規模な硫黄生態系が存在し，その周囲に顕著な酸化還元電位の環境傾斜が形成される。この環境傾斜における嫌気状態（$<0.006\ mgO_2\ l^{-1}$）―貧酸素状態（$0.006-0.456\ mgO_2\ l^{-1}$）―好気状態（$>0.456\ mgO_2\ l^{-1}$）の各環境帯部分に優占して生息している微生物群集は，異なる電子伝達経路を用いて代謝経路を行って入る。発酵経路，微好気性呼吸経路，呼吸経路を用いた代謝効率と理論的に対応して，栄養摂取も行われていることが明らかになった。