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Sulphate reduction in oxic and sub-oxic North-East Atlantic sediments

(Porcupine Abyssal Plain; Rockall Trough; Malin Shelf; sulphate-reducing bacteria; titration alkalinity; low-M_r organic acids)

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1. SUMMARY

Oxic and sub-oxic N.-E. Atlantic sediments were examined for sulphate-reducing activity. Oxygen and/or nitrate reduction are probably the dominant mineralisation processes in the abyssal plain sediment studied. A low rate of sulphate reduction (0.1 nmol SO_4^{2-}/ml/day) was recorded in the surface 5 cm of the continental slope sediment, together with the presence of a range of sulphate-reducing bacteria (SRB). A higher activity of sulphate reduction (2.2 nmol SO_4^{2-}/ml/day) occurred in the continental shelf sediment which led to a small decrease in pore water sulphate and an increase in titration alkalinity. This sediment contained approx. 10^2–10^3 acetate, lactate and propionate oxidising SRB/ml. No low-M_r organic acids were detected in these sediments. However, amendment with 75 μM acetate stimulated sulphate-reducing activity in the shelf sediment.

2. INTRODUCTION

The use of sulphate as terminal electron acceptor by the sulphate-reducing bacteria (SRB) is the predominant means of anaerobic oxidation in sulphate-rich marine sediments, and is of key importance in the oceanic sulphur cycle [1]. SRB activity in coastal and deep sea sediments is concentrated in areas of reduced sediment [2,3] consistent with the requirement of SRB for a reduced environment ($E_h \triangleq -100$ mV) prior to growth [4]. Relatively little is known about the distribution and activities of SRB in areas where their presence is not immediately manifest. Much of the sea bed is underlain by oxic sediment due to the low flux of comparatively refractory organic material into the sediment [5]. However, dissimilatory sulphate reduction can occur within reduced microsites (e.g., faecal pellets, organic aggregates) in an otherwise oxic environment [6].

This paper reports on sulphate reduction in one sub-oxic and 2 oxic sediments in the North-East

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Atlantic. Sampling stations were located on the Porcupine Abyssal Plain (A1, depth 4920 m, oxic), on the continental slope of the Rockall Trough (A2, depth 2880 m, oxic) and on the Malin Shelf (A3, depth 158 m, sub-oxic). The sediment at A1 and A2 consisted of carbonate ooze, whilst that at A3 was green sand. All three sediments had redox potentials $> +300$ mV in the surface 4 cm.

3. MATERIALS AND METHODS

Undisturbed sediment samples were collected with the S.M.B.A. multiple corer [7]. Sediment cores were sliced, squeezed and homogenised in air as they were not anoxic. However, all microbiological procedures were performed under a stream of oxygen-free nitrogen [8]. Sediment interstitial water was extracted using a diaphragm-type squeezer [9] at a N_2 pressure of 138 kPa.

Sulphate was determined gravimetrically on 5-ml aliquots of pore water by $BaSO_4$ precipitation [10]. Titration alkalinity was determined by titration with standardised HCl [11]. Low-M_r organic acids (acetate, propionate, butyrate, valerate) were assayed by direct injection gas-liquid chromatography, using a Pye Unicam 204 series gas chromatograph equipped with a flame ionisation detector. A 2 m $\times$ 4 mm glass column filled with FFAP (Pye Unicam Ltd.) was used at a temperature of 120°C, with an argon carrier gas flow of 20 ml/min. The detector and injector were maintained at 180°C. Filtered pore water samples were stored frozen and thawed immediately prior to analysis. Direct injection of the pore water into the top of the column resulted in problems of ghosting due to adsorption to accumulated sea salt in the top of the column. This was minimised by the injection of acidified distilled water and distilled water between each sample, and by the periodic removal and repacking of the top of the column. The detection limit of the method was approx. 1 mM, determined on filtered seawater samples.

SRB were enumerated in medium E of Postgate [4] with 20 mM acetate, lactate or propionate as the growth substrates. 1 ml/l Trace element solution 2 of Pfennig et al. [12] was added to the medium and potentially toxic thioglycollate [12] was replaced by 1 g/l sodium ascorbate. The sulphate concentration in the medium was 30 mM. Inoculated agar shake tubes were incubated at 30°C for up to 4 weeks, with black colonies being recorded as SRB.

Sulphate reduction rates were determined by incubation with 20 μCi carrier-free $^{35}SO_4^{2-}$ (Amersham International, Bucks.) in slurries [13] of 5 ml wet sediment and 10 ml deoxygenated 0.4 M NaCl, with either no substrate addition or with 75 μM sodium acetate. Sulphate reduction, after 24 h of incubation at 4°C, was terminated by the addition of 5 ml 0.75 M cadmium acetate. ^{35}S-sulphide distillation was as described by Jørgensen and Fenchel [2] but with 1.5 M NaOH as the primary trapping agent (S^{2-}-trapping efficiency 95%). The radioactivity of the trapped sulphide was measured by counting aliquots of each trap in 'Dimilume-30' (Packard Instruments Ltd., U.K.) with quench correction by the internal standard method, using [^{35}S]dioctyl sulphide (Amersham International).

4. RESULTS AND DISCUSSION

At stations A1, on the abyssal Atlantic plain, and A2, on the continental shelf, there was no depletion of sulphate with increasing sediment depth, and only small increases in titration alkalinity (Table 1). This suggested that mineralisation of organic matter was occurring by way of oxidation by oxygen or nitrate. Both sediments have the potential for dissimilatory nitrate reduction [14]. Sulphate reduction was not detected in A1 sediment, whilst a very low rate (0.1 nmol SO_4^{2-}/ml/day) was measured in the A2 slope sediment. It was not clear whether this activity occurred at the in situ pressure [15], although the presence of SRB (Table 2) indicated the potential for mineralisation via sulphate reduction. The organic carbon content of these carbonate oozes is approx. 0.23%, and is probably recalcitrant. Previous research on deep-sea sediments has concluded that the negligible sulphate reduction activity is due to the very low levels of organic matter present [16,17].

At station A3, sulphate decreased with depth as

Table 1

Sulphate and titration alkalinity profiles in N.-E. Atlantic sediments

Sediment depth (cm)	Site A1		Site A2		Site A3	
	SO_4^{2-} (mM)	TA (meq/l)	SO_4^{2-} (mM)	TA (meq/l)	SO_4^{2-} (mM)	TA (meq/l)
OSW [a]	27.2	3.21	26.3	2.65	26.7	3.36
0–2	27.1	3.52	26.4	2.73	25.4	3.37
2–4	27.1	3.51	26.3	2.75	25.4	3.38
4–6	27.2	3.63	26.3	2.77	24.7	3.40
6–8	27.0	3.84	26.2	2.81	24.6	3.43
8–10	27.3	3.88	26.3	2.89	23.9	4.61
10–12	27.1	4.18	26.2	2 88	23.2	5.08
12–14	27.1	4.31	26 1	2 89	22.1	5.37
14–16	27.2	4.42	26.2	2.87	nd [b]	nd
16–18	27.1	4.61	26 1	2.88	nd	nd
18–20	27.2	4.53	26.1	2.88	nd	nd

[a] Overlying seawater.
[b] Not determined.

titration alkalinity increased (Table 1). This was consistent with the oxidation of organic matter by sulphate reduction [18,19] and reflected the higher measured rates of sulphate reduction (Table 2). Due to its shallower depth, A3 sediment is likely to be subjected to a higher sedimentation rate of organic material than that from sites A1 or A2 [5]. For example, the organic carbon content of A3 sediment was approx. 1.3%, and the sulphate reduction rate over the surface 5 cm was 20 times that of the A2 slope sediment. These data support the observation that whilst the total area of the continental shelf is only 50% that of the slope, shelf sediments reduce more sulphate on an annual basis, due to their higher activity [1,20].

The importance of sulphate reduction in the terminal oxidation of organic matter in shelf sediments is dependent on the ability of SRB to oxidise acetate to CO_2 [1,21]. Previous studies have recovered only lactate-oxidising SRB from coastal sediments (e.g., [22,23]), which were most probably *Desulfovibrio* spp. These SRB incompletely oxidise organic matter to the level of acetate [4], which would result in the accumulation of acetate in the sediment. However, no acetate was detected in A3 shelf sediment samples (see below). In A3 sediment, acetate, lactate and propionate-oxidising SRB were recovered in approximately equal numbers (Table 2), indicating that this sediment possessed a sulphate-reducing flora capable of oxidising a diverse range of organic compounds through to CO_2 [12,21,24]. The addition of 75 μM acetate to this sediment resulted in a 17% stimulation in the sulphate reduction rate of the surface 5 cm, and an 81% stimulation at a depth of 5–10 cm.

No low-M_r organic acids were detected by the direct injection GLC technique and this was in agreement with the hypothesis that higher dissolved pools of these compounds are present in sediments containing larger amounts of organic matter [25]. Acetate is often below the limits of detection in such sulphate-rich, unpolluted sedi-

Table 2

Sulphate reduction rates and occurrence of acetate, lactate and propionate-oxidising SRB in N.-E. Atlantic sediments

Sample	Sulphate reduction rate (nmol SO_4^{2-}/ml/d)	SRB/ml [a]		
		Acetate-oxidising	Lactate-oxidising	Propionate-oxidising
A1 0–5 cm	–	–	–	–
A2 0–5 cm	0.1	+	+	+
A3 0–5 cm	2.2	3.0×10^2	5.0×10^3	3.0×10^2
A3 5–10 cm	0.4	3.0×10^2	4.0×10^2	2.0×10^2

[a] –, Not detected; +, present.

ments as are encountered in the N.-E. Atlantic [26]. Recent kinetics experiments with marine SRB have shown, however, that SRB are good scavengers of acetate [27] and can outcompete fermentative bacteria for substrates such as ethanol [28]. This suggests that sulphate reduction in this low-carbon sediment was occurring via the rapid turnover of very low concentrations of substrate.

In conclusion, these data show the wide metabolic potential of marine SRB and demonstrate the potential for sulphate reduction in micro-environments within oxic sediments, subject to the limitations of the methods used (e.g., pressure changes, disturbance of sediments).

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