Evidence for bacterially mediated P release from anoxic sediments

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In the classic Einsele-Mortimer model of anaerobic P release it was assumed that under anoxic conditions solid ferric (Fe^{3+}) minerals were reduced to ferrous ions (Fe^{2+}) with a co-release of P adsorbed to the ferric mineral. The released P could either be taken up by the biota or, could readsorb onto ferric oxyhydroxides particles (which were formed by the abiotic oxidation of ferrous iron). however, it is becoming evident that the anaerobic release of P from sediments is not simply an abiotic process but, can be the result (either directly or indirectly) of bacterial processes.

In particular, three anaerobic bacterial processes – sulphate reduction, dissimilatory iron reduction and poly-phosphate hydrolysis – can potentially lead to the release of P under anaerobic conditions: viz:-

Dissimilatory iron reduction

Iron reducing bacteria use iron(III) oxides and oxyhydroxides as the terminal electron acceptor for anaerobic respiration. In other words these bacteria facilitate the reduction of solid ferric minerals to dissolved ferrous ions. Any phosphate ions which are associated with the solid mineral surface (as in the Einsele-Mortimer model) will be released when the surface is reduced. It has been shown by Lovley *et al.* (1991) that Fe(III) reduction in sediments is almost entirely mediated by bacteria.

Sulphate reduction

Sulphate reducing bacteria use the sulphate ion (SO_4^{2-}) as the terminal electron acceptor for anaerobic respiration. The respiratory by-product of this reaction is sulphide. Sulphide is a strong enough reducing agent to facilitate the reduction of solid ferric minerals to dissolved ferrous ions with concurrent P release (e.g. see Boström *et al.*, 1988). This reaction is favoured by the insolubility of one of the reaction products – iron sulphide.

Poly-P hydrolysis

A number of authors have postulated that bacteria containing polyphosphates (poly-P) as P storage products can hydrolyse these compounds to ortho-phosphate under anaerobic conditions, releasing P (e.g. see Gächter and Meyer 1993) It has been suggested that under anaerobic conditions these bacteria take up low molecular weight fatty acids - particularly acetate. The acetate is metabolised in the synthesis of poly-β-hydroxybutyrate(PHB). Concurrently with PHB synthesis, poly-phosphate grannules are de-polymerized and phosphate ions are released from the cell (Wentzel *et al.*, 1986).

It is important to note that each of these three processes use the end products of fermentation (e.g. acetate or lactate but not glucose) as electron donors / carbon source under anaerobic conditions.

If these bacterial processes are indeed important in P release from sediments it is possible to formulate a number of predictions which can be tested experimentally viz:-

1. Most P release from the sediments occurs under anaerobic conditions, but not under aerobic conditions;

2. P release should not occur from sediments which have been sterilised, even if they are maintained under anaerobic conditions and/or have been augmented with organic acids.

3. Anaerobic P release should be enhanced if additional electron acceptors (e.g. sulphate) are added to the sediments.

4. Anaerobic P release should also be enhanced if an appropriate electron donor/carbon source (e.g. acetate) is added to the sediment but, other carbon sources (such as glucose) should not initially enhance P release.

In order to test these predictions, slurries of sediments taken from a number of locations were augmented either with a toxicant (formaldehyde), various carbon sources (including acetate and

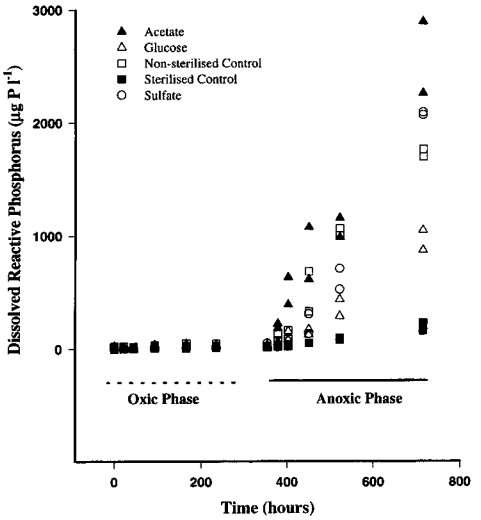

FIG. 1. Release of P from wetland sediments under oxic and anoxic conditions following selective chemical augmentation (after Baldwin *et al.*, 1997).

glucose) and/or an electron acceptor – sulphate (e.g. see Baldwin *et al.*, 1997; Mitchell and Baldwin, 1998). The sediments were maintained either under oxic or anoxic conditions by periodically bubbling the slurries with either air or an inert gas (N_2 or Ar); anaerobic slurries were maintained at 25°C in a Forma anaerobic chamber, aerobic sediments in a Clayson incubator. After a period of time the oxic status of the sediment slurries were reversed (oxic sediments were made anoxic and vice versa). The potential for P release was determined by measuring the amount of P in solution as a function of time.

Figure 1 shows the results of one such experiment on slurries of a sediment taken from a local wetland – Ryan's Billabong. From the figure it can be seen that little or no P was released into solution when the sediment slurry was maintained under oxic conditions; P was only released under anoxic conditions. Furthermore, very little P was released when the sediments were sterilised with formaldehyde relative to non-sterilised samples. P release was enhanced when the slurries were augmented with acetate or sulphate, but in fact net P release was reduced by the addition of glucose. (Anaerobic glycolysis leads to the conversion of ADP to ATP and hence is a net consumer of P. However, as noted above, the ultimate end-products of glucose fermentation (e.g. acetate) can subsequently be utilised by other bacteria leading to the release of P).

Taken together these data suggest that microbial processes are important in the anaerobic release of P from sediments. Data from other aquatic systems will be presented which re-enforces this proposition

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