AMELIORATION OF MINE TAILINGS WITH LOCAL PEAT SOILS IN SOUTHERN CANADIAN SHIELD*

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ABSTRACT

Many Canadian mine tailings contain iron sulphides, which are oxidized by microorganisms. This causes extensive acid leaching and consequently contamination of the environment. It is known that, if the tailings are flooded, there is insufficient oxygen dissolved in the water for this oxidation to take place. This method is currently being considered for the prevention of oxidation in certain sites. However it is impractical to flood many old tailings, so we suggest that a self-sustaining anaerobic cover of peat bog will both prevent acid leaching and reclaim old tailings dumps with a natural environment. Part of the methane produced by degradation of biomass is trapped in the peat and prevents both the penetration of oxygen and the movement of water in the tailings.

INTRODUCTION

For a century mining has been one of Canada's major industries, and during this time a vast amount of waste rock, deposited as mill tailings, has accumulated around the mine sites. Many of these tailings have been left unattended for years, and in a considerable number of cases this waste contains iron sulphides such as pyrite and pyrrhotite, which are used by microorganisms, notably *Thiobacillus ferrooxidans*, as an energy source for growth. This use results in a run-off from the tailings, which is both extremely acidic and also contains soluble sulphate salts of any remaining heavy metals (Moneco 1984). The increasingly stringent regulations for effluents released into the environment require that this acid leaching and heavy metal contamination be controlled.

The US Bureau of Mines was already looking in 1918 for a method to treat acid drainage from coal mines (Tracy 1918); and by 1930 it was realised that exclusion of oxygen prevented this acid formation and the precipitation of iron (Leitch & Yant 1930); but already acid mine drainage threatened to be a problem of national importance as coal resources were increasingly developed. Even at

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this date the process of oxidation was being questioned, as it seemed to be too rapid to be solely due to chemical reactions, and it was suggested that it might be caused by organisms similar to <u>Thiobacillus thiooxidans</u> (Carpenter & Herndon 1933).

However it was not until 1947 that microorganisms were generally recognized as the cause of the breakdown of pyritic minerals to sulphuric acid (Colmer & Hinkle 1947). Pyrite is found in association both with coal and metal ores, but the generation of acid in tailings of metal mines was not perceived as a problem until after 1960 when several uranium mines were shut down for economic reasons (Hester 1984).

TAILINGS

There are some 500 million tons of acid tailings in Canada covering an area of 9,000ha (Moneco 1984) (Figure 1). The problem is thus vast, especially when it is realized that many of these tailings have been deposited on porous ground because the initial aim was to drain the tails of their liquid, as it was thought to be easier to reclaim the dried material. In addition, the old dams which once held back the tailings slurry, are now broken and incompetent. However, in spite of the length of time since the problem was first understood, no efficient and economic method has yet been found to manage acid leaching.

Iron sulphides, such as pyrite, are formed in sediments by active microbial sulphate reduction. The microorganisms convert the sulphur to hydrogen sulphide, about 90% of which diffuses up to the oxic zone, while the rest is precipitated by iron to form mackinawite initially, which is converted to greigite and then pyrite (Figure 2). Pyrrhotite is formed when pyrite is subjected to higher temperatures. The sulphur is thus continuously cycled through the sediment, and over time, pyrite is concentrated. It is these pyritic and pyrrhotitic formations that have the potential to cause soil acidity when brought into the oxic zone as they provide a growth substrate for chemolithic sulphur oxidizing microorganisms, notably <u>Thiobacillus ferrooxidans</u>.

These organisms are able to derive energy from the oxidation of ferrous iron and inorganic sulphur. The sulphur is oxidized to sulphate (Figure 2) and thus forms sulphuric acid, while the ferrous iron is further oxidized to ferric iron which, either alone or in combination with sulphate, is involved in the indirect attack on sulphide minerals (Lundgren & Silver 1980).

Since the oxidation of iron sulphide is a very inefficient method of obtaining energy the bacteria require a good supply of oxygen (Kuenen & Tuovinen 1981). The depth of an oxidation layer is dependant upon the availability of oxygen for the bacteria, and is controlled by the permeability of the tailings, which regulates the penetration of air or oxygenated water. Oxygen is consumed in

Figure 1. Pouring tailings slurry at Kidd Creek Mine, Timmins.

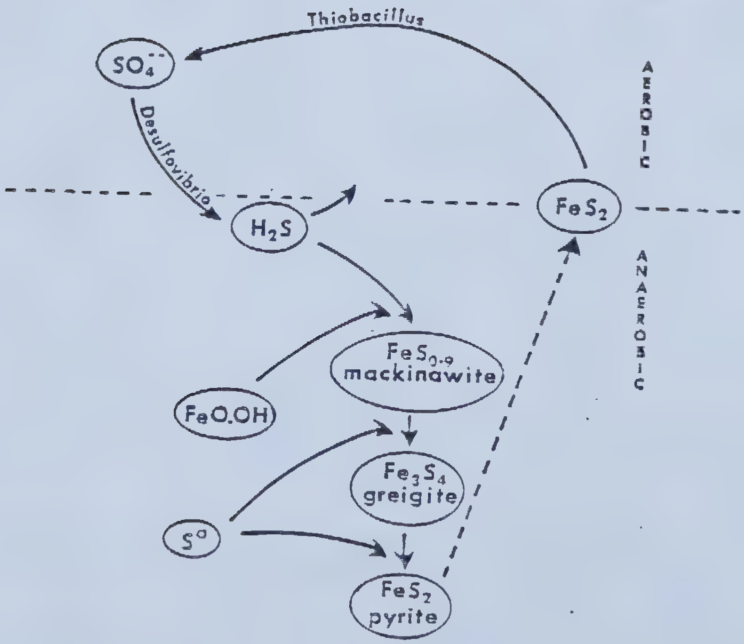

Figure 2. The Sulphur Cycle.

the top layer until the concentration is inadequate to support the generation of ferric ions. With oxygen depleted, ferric ion is then rapidly reduced by pyrite to the ferrous state. Iron hydroxides and/or oxides are then formed and precipitated to form a well defined hardpan, with fresh, unaltered tailings below (Boorman & Watson 1976). This zoning was recently confirmed by Petruk & Pinard (1986) in the Waite Amulet tailings: where there is a high concentration of sulphides in the base, there is a sharp change in concentration at the water table, and there are essentially no sulphides near the surface.

PEAT SOILS

Thus, to eliminate acid leaching oxygen must be prevented from reaching the pyritic tailings. This can be accomplished by flooding, as there is insufficient oxygen dissolved in the water to allow these organisms to grow (Moneco 1984). However, where flooding is not feasible, we suggest that an anaerobic environment can be induced by covering the tailings with a layer of muskeg peat bog.

Muskeg bogs cover about 12% of the land area of Canada, and contain peat more than 60cm thick. They are found in cool, wet environments in mid-Temperate latitudes and are common in the Canadian Shield where many of the mines are located. These wetland bogs have been accumulating throughout the northern Temperate Zone, where there is adequate precipitation, since the ice retreated 5,000 to 10,000 years ago.

Peat itself is formed from the partial degradation of plant biomass. Plants consist of three interlinking polymers of cellulose, hemicellulose and lignin (Brown 1985). Cellulose is the main degradable constituent, and normally, in aerobic terrestrial soils, it is rapidly degraded to carbon dioxide. But in waterlogged soils a consortium of bacteria reduce the cellulose to methane, and this anaerobic degradation is much slower. Impressive accumulations of peat occur when there is an imbalance between the slow degradation of plant biomass in an anaerobic environment, and the faster rate of deposition of the plants detritus (Kurbatov 1968).

We have investigated thirty different bogs from the mining areas of Noranda, Timmins, Sudbury and Elliot Lake. These bogs were characterized by physical, chemical and biological methods to find their suitablility for methane production.

Peat will thus produce an anaerobic milieu through the synthesis of methane by the bog microorganisms. Once the bog is established on top of the tailings, the normal succession of plant growth, death, and partial decomposition should take place and create a self-sustaining bog, which will be viable indefinitely in cool, wet climates, and therefore require no further expenditure.

SPHAGNUM

The most important bog plant is sphagnum. This moss is a bryophyte which typically grows at a pH of around 3, and is ombrotrophic, that is it only requires nutrients from rain or its own detritus. The genus Sphagnum has remarkabie powers of water retention due to the large water storage cells which form much of the bulk of the leaves and stems. This produces a raised water table due to the high water-holding capacity and low hydraulic conductivity.

In regions where there is a high rainfall and a moisture-laden atmosphere, there may be sufficient humidity to cause waterlogging and peat formation even outside drainage basins. Where these conditions are extreme peat may even accumulate over the sloping hill sides as well as on flat surfaces, covering the landscape with a thick 'blanket bog'. In drier climates, bogs which are dependant upon precipitation can still develop, mainly in valley bottoms. Such mires are called 'raised or domed bogs' for they typically grow in convex shapes (Godwin 1978).

PRODUCTION OF METHANE

The microorganisms of the anaerobic degradation chain bring about the complete conversion of cellulose to methane and carbon dioxide (Morris 1975). There are two interrelated processes: first the cellulose carbon is oxidized to carbon dioxide and other small carbon compounds, while at the same time hydrogen is produced; and secondly this hydrogen is oxidized to water, and the carbon dioxide is reduced to methane (Figure 3). If sulphate is present

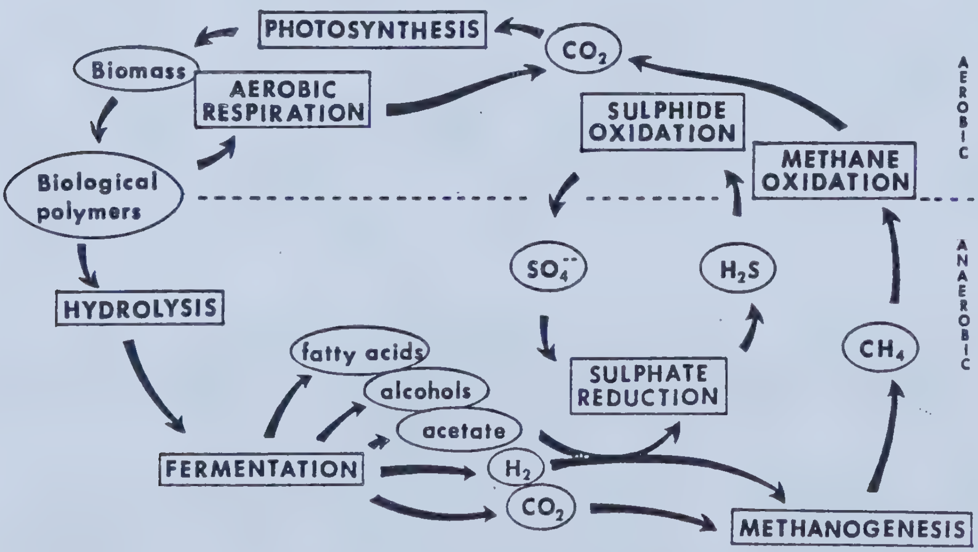

Figure 3. Metabolic pathways in peat.

other bacteria can also act as hydrogen-consumers and reduce sulphate to hydrogen sulphide.

The production of methane from bogs has been know for a long time from the will-o'-the-wisp (ignited marsh gas) that is produced under certain weather conditions. Surprisingly there seems to be little data on size or flux of peatland methane pools (Armentano & Menges 1986), which may be due to the difficulty of measuring the methane. Late last summer we developed, refined and tested a system for measuring methane <u>in situ</u> (Dinel et al 1987). In several bogs near Ottawa the concentration of the methane, and the ratio of methane to carbon dioxide was found to increase with depth.

This methane is trapped in the peat, especially in deeper layers where it is usually saturated to levels beyond that found at normal temperature and pressure. This supersaturation is mainly due to the hydrostatic pressure of the overlying water, similar to that found in lake sediments. Since methane is less dense than air, when a cavity is created or methane-saturated water interfaces with air at the fringe of a bog, methane will be outgassed and driven to the surface through the pore cavities which already contain water. Bubbles of methane may block these spaces when there is not enough energy to push the gas through constrictions. This blocking prevents not only the penetration of any oxygen but also the movement of water and its attendant dissolved minerals (Mathur & Lévesque 1985).

In the past methane production has generally been estimated through laboratory incubation of peat samples from various depths, or from measurement of methane released from the surface. Our initial results show that this does not give the complete picture, since the methane is trapped within the peat. In a small basin bog in the Gatineau we have obtained samples of interstitial gases and water from deep layers where up to 60% by volume was methane. Due to the acid environment of bogs the bacteria produce methane very slowly so it would seem that this methane had been accumulating for tens of years, if not millenia.

While placing the muskeg on the tailings it will be necessary to expose the anaerobic layers to the atmosphere. Initially we did not know whether this would destroy the obligately anaerobic methanogens but preliminary results suggest that, if the peat is kept wet, the anaerobic degradation chain can generally be reestablished so long as there is sufficient cellulose substrate to be degraded into methane.

RECLAIMATION

When tailings do not contain much pyritic rock, it is possible to revegetate them successfully. But the vegetation on old sulphide tailings dumps, such as those of Waite Amulet near Noranda and

Figure 4. Acid leaching at Waite Amulet, Noranda.

Figure 5. Pumping water on to organic cover of pyrrhotite tailings, at Falconbridge Nickel Mines, Ontario.

Nickel Rim near Sudbury, which have been revegetated with heavy expenditure on lime and fertilizer, is very fragile. The acid seepage continues (Figure 4) and slowly percolates up into the covering vegetation and kills not only the plants but also the soil microorganisms. So, although revegetation which allows oxygen penetration may seem at first to be successful, it is actually only a temporary cosmetic measure, because it has little or no effect on the acid leaching and the long term reclamation of tailings dumps, for, as the acidity reasserts itself, the phytotoxic heavy metals are more easily taken up by the plants and cause vegetation die-off. It should be noted however that, unlike mineral soil microorganisms which are very susceptible to metal toxification, peat microorganisms are protected by the ability of peat humus to chelate metal ions (Mathur & Farnham 1985).

A start has been made by Falconbridge Nickel Mines, Ontario to saturate and cover a pyrrhotite tailings dump with organic matter in order to build up an anaerobic soil layer (Figure 5). There are two problems to establishing a peat cover on tailings: one is the actual application of the organic soil, and the other is raising the water table to maintain anaerobiosis during the establishment of the soil.

Most of the old tailings have been drained of the water from the original slurry long ago and both this drainage and later rainfall have caused internal channelling, so that any water applied quickly runs through. This rapid flowthrough does not occur in bogs; the water saturation of the bog, and the gas pressure of the methane prevents penetration, and rain runs off the surface. If we can establish a raised bog on the tailings we hope that it will be able to maintain a raised water table, to ensure that the tailings remain anaerobic.

The establishment of a bog will initially require added organic matter, such as some type of cellulose, for the anaerobic microbiological degradation chain to use as substrate. Once the metabolic cycle has been set up (Figure 3), the slow degradation of the bog plants on death will maintain the bog indefinitely, so long as the rainfall remains adequate.

CONCLUSION

If a self-sustaining active peat cover can be established on tailings dumps it will prevent oxygen penetration by methane production in the peat; it will increase the level of the water table by the growth of sphagnum; and it will chelate many of the metal ions in the peat humus. It will also solve a perennial environmental problem of the Canadian mining industry caused by acid leaching.

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