

Internet Case Study #16:
Sulphide Oxidation and Metal Leaching
in Permafrost Areas of Greenland and Canada

by Kevin A. Morin and Nora. M. Hutt
Minesite Drainage Assessment Group (MDAG)

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Abstract

Regions of continuous permafrost in the High Arctic are sometimes assumed to be free of risk for acidic drainage and significant metal leaching. Such assumptions arise from the expectation that freezing conditions will halt oxidation and associated reactions. However, laboratory and field studies have shown for decades that significantly acidic drainage arises in the High Arctic. This Internet Case Study summarizes two recent studies to complement the findings of several others.

INTRODUCTION

Due to cold conditions, frozen soils, and annual-average temperatures below freezing, continuous-permafrost environments are often assumed to limit or preclude acid generation and metal leaching. However, laboratory testwork and field studies have shown for decades that such assumptions are wrong (Dawson and Morin, 1996) and that acidic drainage with elevated metal concentrations can appear each summer for millennia. This Internet Case Study summarizes below two recent studies, one in Greenland and one in Canada, that continue to demonstrate a conclusion published in 1977 that permafrost is no deterrent to acidic drainage.

NORTHERN GREENLAND

Elberling and Langdahl (1998) conducted field studies of a semi-massive to massive sulphide deposit at Citronen Fjord. This fjord is located on the northern end of Greenland at 83°N latitude. The deposit was roughly 1.5 by 0.4 km in area and included coloured gossans from prior natural oxidation. Previous laboratory studies by these authors on bacteria in the gossans revealed that the bacteria could increase the rate of pyrite oxidation by a factor of eight at 0°C. Bacterial populations were similar to those found in temperate climates, indicating High Arctic conditions do not limit bacterial populations and activity.

Field studies focussed on one of the major gossan areas measuring roughly 100 m by 200 m. Average annual temperature was -17°C and thaw occurred from late May until mid August.

Depths to permafrost in August ranged from 0.50-0.70 m in dry gossan soil to less than 0.10 m in near-saturated soil, with ground temperatures between 5 and 12°C in the upper 0.10 m. Solid samples and repetitive samples of porewater and runoff were chemically analyzed. Also, a chamber sealed into the soil was used to monitor the consumption (flux) of oxygen by the soil.

Solid-phase analyses showed that fresh sulphide-rich rock contained almost 30% S total sulphur, primarily as iron sulphide, whereas gossanous soil contained up to several % S with excess iron showing the past oxidation.

Oxygen consumption rates in dry soil were $9.7\text{-}39.7 \times 10^{-2}$ mol/m²/day, with an average of 19.8×10^{-2} , but were about 10 times less in the moist soil. These rates were less than a factor of 10 below those measured in dry tailings in Sudbury, Canada, indicating relative high oxidation rates can be found during summer months in the High Arctic.

Porewater analyses yielded pH values between 1 and 2, with iron concentrations up to 50,000 ppm, zinc up to 7000 ppm, lead up to 3 ppm, and nickel, cadmium, and copper up to 3 ppm. Surface runoff from reactive areas had pH below 3, whereas non-reactive areas released water with pH between 7 and 8.

NORTHERN CANADA

Physical, chemical, and biological studies of tailings and natural ore outcrop were conducted at the Nanisivik Minesite in Canada's high arctic with continuous permafrost (Elberling et al., 2000). Tailings at Nanisivik were deposited underwater within a tailings impoundment since 1976, but some tailings are now exposed and reacting. The tailings are generally 75-95% pyrite with the remainder composed mostly of dolomite and minor amounts of sphalerite and galena, with the typical total-metal analysis reporting 35-40% Fe, 0.3% Zn, and 0.1% Pb.

Elberling et al. (2000) established each of four study sites in one of three conditions: unsaturated 0.5-year-old tailings (two replicate study sites), unsaturated 6-year-old tailings (one study site), and nearly saturated 6-year-old tailings (one study site). Field studies involved pore-gas analysis, tailings-surface oxygen consumption, and porewater extraction. Tailings samples were collected from four sites to depths of 0.60 m, crossing the limit of oxidation, for laboratory testing including various static chemical analyses, thermal monitoring to estimate chemical and biological reaction rates, and bacterial enumeration. The depth of the active layer (thawed during summer months) was approximately 1.5 m and ranged in temperature from 4 to 13°C.

Pore-gas oxygen levels were determined by pumping less than 30 mL of pore gas from 4-cm depth intervals. At the unsaturated sites, oxygen fell from atmospheric levels (20.9%) to below detection (0.1%) at approximately 0.3 m, which coincided with the observed depth of oxidation. At the saturated site, oxygen was below detection below 0.02 m.

Tailings-surface oxygen consumption was measured by sealing a chamber into the tailings

and monitoring falling oxygen levels within the chamber. The unsaturated sites showed similar oxygen consumption [around 0.40 moles/(m² day)], with no significant difference between the 6-year-old and 0.5-year-old sites. The oxygen consumption at the saturated site roughly 100 times less.

Porewater samples were obtained from suction probes installed at depths of 0.10, 0.20, 0.30, 0.40, and 0.80 m. For all sites below a depth of 30 cm, pH was 6.8-7.9, aqueous sulphate was generally 1000-4000 mg/L (units not provided by Elberling et al., but presumed to be mg/L), thiosulphate was generally 1-5 mg/L, and the highest polythionate (tetrathionate, S₄O₆²⁻) was generally 10-1000 mg/L. In general, sulphate comprised 98% of aqueous sulphur species, and concentrations of polythionates increased with depth. However, at the unsaturated 0.5-year-old site, concentrations of sulphur species decreased with depth. The highest aqueous concentrations of elemental sulphur were found at the base of the oxidized zone. Metal concentrations below 30 cm averaged 35 mg/L for zinc, 0.05 mg/L for lead, and 0.004 mg/L for cadmium.

At depths from surface to 30 cm, pH fluctuated widely. After rainfall, pH and aqueous concentrations were similar to those below 30 cm (previous paragraph). However, after a four-week dry period, pH fell as low 2.3 and metals reached maximums of 250 mg/L for zinc, 1.1 mg/L for lead, 0.6 mg/L for cadmium, and 29,340 mg/L for sulphate.

Thirty-nine tailings-solids samples were collected across 2-cm intervals, every 5 cm, to depths of 0.6 m. At unsaturated locations, this crossed the base of oxidation at roughly 0.3 m depth. Special precautions were taken to avoid oxidation and bacterial contamination during and after sampling. These samples were well-sorted fine sand, and pyrite content was 15-40% in the oxidation zone and 80% in the unoxidized zone.

Chemical and biological oxidation rates were estimated by heat production under controlled conditions, with the chemical rate determined after bacteria were apparently terminated after two-hour exposure of 4 or 15 g of sample to chloroform. Heat production was converted to oxidation rates and oxygen consumption using 1546 kJ/mole for biological pyrite oxidation, which could then be compared to the field oxygen-consumption measurements. The rates, combined with those of other studies (Figure 1), show general consistency, with rates at 0°C approximately 25% of those at 20°C. After chloroform treatment, rates were found to be 50-100% of the bacteria-based rates, with an average of 65%. This indicated the effect of bacteria was negligible to doubling the chemical rate, and the contribution did not correlate with depth or pH. The rates agreed well with the field measurements of oxygen consumption when converted to 1 m² of surficial tailings.

Bacterial enumeration included (Group 1:) strongly acidophilic, lithotrophic iron-and-sulphur-oxidizing bacteria (pH 1.8 and 4.5), (Group 2:) moderately acidophilic, lithotrophic thiosulphate oxidizing bacteria (pH 6.8), and (Group 3:) chemoorganotrophic microorganisms that were acidophilic (pH 2) and neutrophilic (pH 7). The maximum measured count for Group 1 was 10⁴ cells/g, whereas for the other Groups was 10⁶ cells/g.

No microorganisms were above the unspecified detection limits in the 0.5-year-old tailings and in the unoxidized zones of the unsaturated tailings. In the oxidized zones of unsaturated

tailings, Groups 1 and 2 were found in roughly two-thirds of the samples, and Group 3 was apparently found in all samples. All Groups were found in samples of natural ore outcrop and of spilled “unbuffered” tailings mixed with fine rock.

As in previous studies (e.g., Dawson and Morin, 1996), the authors conclude, “... a temperature decline will gradually limit the overall reactivity in mine tailings, but also that temperatures just below 0°C are no guarantee for neglectable rates of pyrite oxidation in well-drained pyritic tailings.”

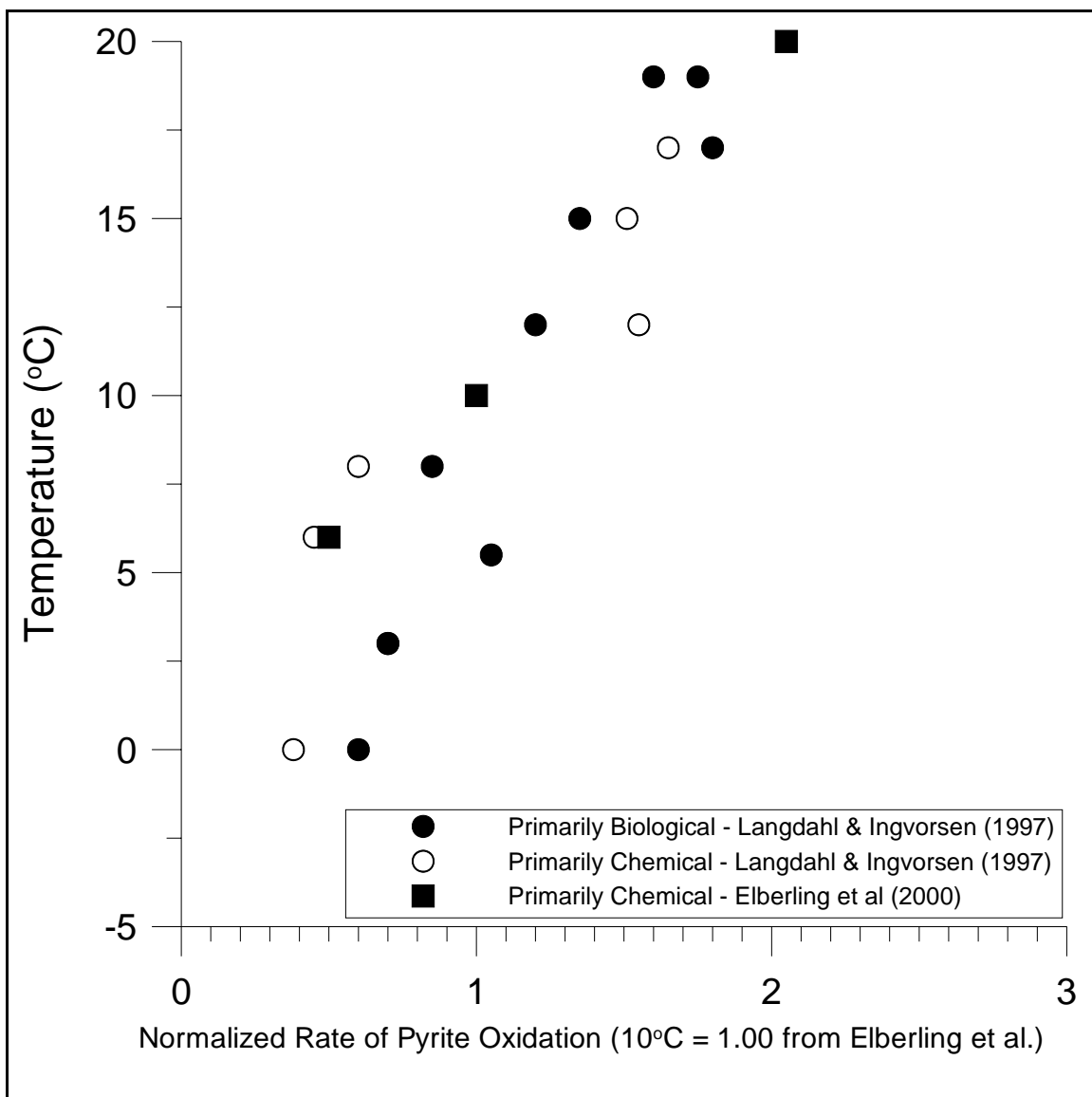


FIGURE 1. Compiled Rates of Pyrite Oxidation Normalized at Rate = 1.00 from Rate Reported for 10°C from Elberling et al. (2000).

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