

Subglacial Microbiology and Chemical Weathering

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The rates of chemical weathering in glaciated terrain are similar to those in temperate locales with similar specific runoff and bedrock. A significant proportion of the weathering usually occurs beneath the glacier, in so-called "subglacial" environments. These were formerly thought to be abiotic. The reverse is now thought more likely. Viable and active microbes have been found in glacier runoff and basal ice in all glacial systems sampled to date, a detailed example of which follows. The debris-rich basal ice layers of a high Arctic (80°N) polythermal glacier contain metabolically diverse microbes which can be cultured at low temperatures (4°C or lower). These include aerobic chemoheterotrophs and anaerobic nitrate reducers, sulfate reducers and methanogens. Parallel cultures from debris-poor glacier ice showed no evidence of microbial activity. This suggests that microbes may be widespread at the base of the glacier where water is present and the basal sediments are not frozen. Particulate organic carbon (POC) concentrations in the debris-rich basal ice are 1 M C providing a carbon source readily available for metabolism. These concentrations are 10⁵ times greater than in the debris-poor glacier ice. The absence of microbial activity in the cultures from debris-poor glacier ice indicates a link between sediment concentration and/or POC concentration and microbial activity and argues against contamination of the samples during sampling and analysis. Hence, *in situ* oxidation/fermentation of organic carbon in basal sediments beneath the ice is a tenable process in high Arctic subglacial environments (Skidmore et al., submitted).

The presence of microbial populations and the drive towards anoxia in subglacial chemical weathering environments helps to explain a number of aspects of the geochemistry of waters sampled *in situ* from the glacier bed via boreholes at a glacier in the Alps, Haut Glacier d'Arolla, which is underlain largely by non-carbonate metamorphic rock (Tranter et al., 1997; submitted). The initial rock-water reactions in subglacial environments are carbonate hydrolysis, and sulphide oxidation coupled predominantly with carbonate dissolution. There is also ion exchange of divalent for monovalent ions. These subglacial environments are water full, and hence there is little opportunity for the ingress of atmospheric gases. Hence, the maximum amount of sulphide that can be oxidised is apparently set by the initial oxygen saturation of the meltwater that

descends from the surface to the glacier bed. This apparent upper limit is exceeded by many of the meltwaters. Further, the ratio of bicarbonate to sulphate is always higher than that which would arise from the coupling of sulphide oxidation to carbonate dissolution (i.e. >2:1). This suggests that sulphide oxidation is proceeding in an anoxic environment, utilising Fe(III) as an oxidising agent. The source of the Fe(III) and the sink for the Fe(II) set the number of protons that are generated by the sulphide oxidation, and hence the amount of carbonate that is dissolved. Several plausible reaction schemes can generate ratios of bicarbonate to sulphate that are >2:1. Hence, it is likely that subglacial chemical weathering preferentially dissolved trace carbonates from bedrock utilising acidity derived from sulphide oxidation in environments that become progressively anoxic.

The wider implication of these results is that microbial populations were likely to be active in the temperate based sectors of Pleistocene mid-latitude ice sheets, where water and organic carbon, in overridden soils and peat were present. CO₂ produced by the *in situ* activity of microbial populations may have been dissolved in subglacial meltwaters, providing a proton source for subglacial chemical weathering, or stored as gas in basal ice and subglacial sediments. Through time the subglacial chemical weathering environment would likely have become progressively anoxic. CO₂ and CH₄ concentrations produced from cultures of debris-rich basal ice (Skidmore et al., submitted) are similar to those from the basal ice from Dye 3 and GRIP ice cores from the Greenland ice sheet. This raises the possibility that the greenhouse gases in these ancient samples may partially be the product of *in situ* microbial activity at the base of the ice sheet. If this is the case, the retreating Pleistocene ice sheets might have been a source of methane to the atmosphere.

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