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Contribution of mineral tunneling to total feldspar weathering

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Abstract

In this study, we quantified the contribution of mineral tunneling by fungi to weathering of feldspars and ecosystem influx of K and Ca. We studied the surface soils of 11 podzols across a Lake Michigan sand dune chronosequence with soil ages between 450 and 5000 years. Weathering by tunneling was quantified in thin sections by image analysis. Total mineral weathering was quantified by comparing the mineralogy of the surface soil with the underlying parent material. Mineralogy was characterized using X-ray fluorescence spectroscopy (XRFS), followed by a normative mineralogical calculation. Tunnels were observed only in soils older than 1650 years. Throughout the chronosequence the contribution of tunneling to mineral weathering in the upper mineral soil, expressed as tunnel volume divided by volume of weathered feldspar, was less then 1%. Contribution of tunneling to Na/Ca-feldspar weathering was higher than the contribution of tunneling to K-feldspar weathering. Feldspar tunneling equals an average ecosystem influx of 0.4 g ha^{-1} $year^{-1}$ for K and 0.2 g ha^{-1} $year^{-1}$ for Ca over 5000 years of soil development. Intensity of mineral tunneling, determined as fraction weathered feldspars, was higher than in a previously described North Swedish podzol chronosequence. The presented data suggest that the contribution of tunneling to weathering becomes more important in older soils, but remains low.
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1. Introduction

In 1997, tunnel-like features were discovered in feldspar grains of podzol E horizons. Formation of these tunnels was attributed to mineral dissolution by organic anions exuded at the tips of fungal, presumably ectomycorrhizal, hyphae (Jongmans et al., 1997). By feldspar tunneling, fungi would contribute to feldspar weathering, and consequently to ecosystem influx of dissolved calcium (Ca) and potassium (K). Feldspar weathering is an important source of Ca and K in most ecosystems (Likens et al., 1994, 1998). Our aim was to quantify the contribution of fungal tunneling to feldspar weathering and to ecosystem

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influx of Ca and K at different stages of soil formation.

The quantitative significance of fungal weathering in soil formation and ecosystem functioning has seldom been established (Sterflinger, 2000), although biological activity as catalyst in the dissolution of silicate minerals was recognized a long time ago (Boyle and Voight, 1973; De Turk, 1919; Haley, 1923; Henderson and Duff, 1963; Lewis and Eisenmenger, 1948). Van Breemen et al. (2000) assumed that as much as half of the weathering of a Swedish podzol E horizon was due to fungal tunneling. Indeed, results from isotope analyses suggest that apatite weathering by ectomycorrhizal trees represents the main source of calcium for these trees (Blum et al., 2002).

On the other hand, Sverdrup et al. (2002) argue that mycorrhizal weathering, and in fact any biotically driven weathering, is quantitatively unimportant. They base this idea on (a) agreement between the temperature dependency of the rate of weathering by H_2O and H^+ and that observed in two mountain toposequences over a temperature gradient, using the Arrhenius equation and (b) comparison of results of the profile model (which assumes weathering in the bulk soil solution only) with weathering rates derived from element depletion measurements. The two "biotic" weathering agents, CO_2 and organic acids, gave temperature dependencies that deviated strongly from those calculated from the toposequence data. We consider that approach too simplistic. If weathering would involve H_2O and H^+ only, the process would stop soon by depletion of H^+ and buildup of OH^- alkalinity. So, proton donors are required for continued weathering. In most unpolluted soils, the main proton donors are CO_2 and organic acids, derived from tree roots with or without mycorrhizal fungi, and the decomposer food web. This is reflected by bicarbonate as the major anion accompanying weathering-derived cations in the worlds' rivers.

Measurements of fungal contribution to mineral weathering have often been hampered by the impossibility to distinguish fungal weathering from other types of weathering. Fungal tunnels can be identified visually and distinguished from other weathering phenomena (Hoffland et al. 2002). This identification allows measurement of tunnel volumes and assessment of the impact of fungal tunneling activity on weathering. It must be noted that fungal tunneling represents only a part of fungal weathering. It is likely that the contribution of fungi to mineral surface weathering is more important than their contribution by tunneling. Many minerals in the surface soil are completely covered by fungal hyphae (Van Breemen et al. 2000). In this study, we determine and discuss the contribution of fungal tunneling in different stages of soil formation in a sand dune chronosequence in Michigan.

2. Study area

2.1. The soil chronosequence

We did our research in a Lake Michigan sand dune chronosequence, west of Naubinway, on the northern shore of Lake Michigan (46°04′ N, 85°32′ E) (Petty et al., 1996). Seventy-five dune ridges, approximately 10–30 m wide and several kilometers long, lay parallel to the Lake Michigan shoreline. Ridges were deposited at intervals of around 75 years. The oldest dune is 5400 years old. This regular dune formation is caused by postglacial isostatic rebound and changes in the level of Lake Michigan, caused by climatic oscillations (Barrett 2001; Delcourt et al. 1996).

Soil age estimation is based on tree-ring data and a dated shipwreck (second dune ridge) for the youngest three dune ridges. Soil age estimation for older dune ridges is based on radiocarbon dates of basal sediment cores from swales between the ridges (Petty et al. 1996).

2.2. Profile descriptions

The soils on the top of the crests are moderately well drained, with only short periods with wet conditions within the rooting depth during snowmelt in spring. The soil temperature regime is frigid and the moisture regime is udic (Soil Survey Staff, 1998). The soils are undergoing the process of podzolization. Barrett (2001) classified the young soils as Typic Udipsamments and soils 3300 years or older as Spodic Udipsamments (Soil Survey Staff 1998). Roots dominantly occur in the O, E and upper B

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