Available online at www.sciencedirect.com
ScienceDirect
European Journal of Soil Biology 43 (2007) S176–S183
EUROPEAN JOURNAL OF SOIL BIOLOGY
http://www.elsevier.com/locate/ejsobi

Original article

Earthworm induced mineral weathering: Preliminary results

Daniel Carpenter [a,*], Mark E. Hodson [a], Paul Eggleton [b], Caroline Kirk [c]

[a] *Department of Soil Science, University of Reading, RG6 6DW, UK*
[b] *Soil Biodiversity Group, Department of Entomology, The Natural History Museum, London SW7 5BD, UK*
[c] *Department of Mineralogy, The Natural History Museum, London SW7 5BD, UK*

Available online 4 October 2007

Abstract

The role of earthworms in mineral weathering was investigated. The minerals anorthite, biotite, olivine, smectite and kaolinite were mixed with a sterilized manure substrate. Two treatments were used: minerals with earthworms and minerals without earthworms. The earthworms were established in mesocosms and left to process the substrates for 1, 2, 4 and 6 months. Four sacrificial replicates were used per time period. Changes in mineralogy were analysed using X-ray diffraction. Weathering of anorthite, biotite, smectite and kaolinite appears to be accelerated by the earthworms. There was evidence for the transformation of smectite to illite and the formation of a new mineral phase from kaolinite. Olivine appears not to be weathered by earthworms. Different minerals also appear to weather at different rates.

Keywords: Mineral weathering; Earthworms; X-ray diffraction

1. Introduction

Mineral weathering is a biogeochemical process, in which organisms play a significant role [1,2]. Bacteria [2–4], fungi [5–7], lichens [8,9] and plants [10–12] have all been shown to increase rates of mineral weathering, when compared with rates of inorganic mineral weathering. Mineral weathering in soils releases essential plant nutrients, such as K, Ca and P. The weathering of minerals can also increase the cation exchange capacity (CEC) and water holding capacity of soils through the formation of clay minerals and oxyhydroxides [13].

Most species of earthworm pass soil through their guts, though some species, such as *Eisenia fetida*, feed on organic matter with little or no soil content. Earthworms are divided into ecotypes based on where in the soil profile they feed, the stage of decomposition of the organic matter on which they feed and physiological characteristics, such as pigmentation. Different ecotypes pass different amounts of the mineral soil through their guts. Endogeic species (e.g. *Allolobophora chlorotica*) have the highest proportion of mineral soil in their guts, while epigeic species (e.g. *Dendrobaena* species) have the lowest. Anecic species (e.g. *Lumbricus terrestris*) are intermediate, passing soil though their guts when tunneling to create burrows, but feeding on litter at the soil surface [14].

There is evidence that other invertebrate species can induce mineral weathering. McIlroy et al. [15] have shown that the marine Annelid, *Arenicola marina*, accelerated the weathering of chlorite and muscovite, compared with controls. A new mineral phase was

* Corresponding author. Fax: +44 (0) 118 378 6660.
E-mail address: daniel.carpenter@reading.ac.uk (D. Carpenter).

1164-5563/$ - see front matter
doi:10.1016/j.ejsobi.2007.08.053

also detected that was not present in the controls. Soil-feeding termites perform some similar ecological functions to earthworms and they too have been shown to increase the weathering rates of some soil minerals. Jouquet et al. [16] showed that termites expanded clay layers and reduced the surface charge of these clays.

Suzuki et al. [17] fed quartz and feldspar grains to the earthworm *Eisenia foetida*. They were able to show experimentally that the earthworms have an influence on the physical weathering of mineral grains. The ingested grains in the earthworm casts were finer and rounder than the non-ingested grains.

The susceptibility of primary minerals to chemical weathering is described by Goldich [18]. Mineral susceptibility to weathering is related to mineral stability under current environmental temperatures and pressures. The least stable are more susceptible to weathering. Olivine is the least stable of the primary minerals used in this experiment and as such it would be expected to weather readily. Broadly speaking, anorthite has a similar susceptibility to weathering as olivine and so the weathering rates of these two minerals are expected to be similar. Goldich placed biotite midway down the stability series and as such it would be expected to weather quite readily. However, biotite weathers to vermiculite very readily and this may occur before the weathering of plagioclase feldspars, such as anorthite [19]. Smectite, a clay mineral, is a weathering product of primary micas. It is stable in some soil environments but in others it is expected to weather readily. Kaolinite is a clay mineral which is the ultimate weathering product for many primary minerals. It is generally highly stable in soils and therefore it is not expected to weather. The aim of these experiments was to investigate whether the weathering of minerals was accelerated by passing them through the earthworm gut. The current paper reports on X-ray diffraction results that are indicative of chemical weathering.

2. Materials and methods

2.1. Materials

A suite of primary silicate minerals that are expected to weather readily was chosen for the experiment. Anorthite, biotite and olivine were obtained from Ward's Geology, USA, crushed and sieved to obtain grains of between 63 and 150 μm, for all three minerals. Minerals were separated magnetically to obtain a monomineralic sample where necessary and washed ultrasonically. This grain size (smaller than that used by Suzuki et al. [17]) exposes a larger surface area (per mass of mineral) for chemical weathering and thereby increases the chances for weathering to occur. The minerals smectite and kaolinite were also used. These are clay minerals found commonly in soils. The kaolinite is well crystallised, from Washington County, Georgia, USA, obtained from the Source Clay Repository of the University of Missouri-Columbia. Kaolinite is the weathering product of many primary minerals. It is stable in highly weathered soils and was chosen as a control mineral, because it was not expected to weather. The smectite was a commercially available montmorillonite "Surrey Powder". Smectite is an intermediate stage in the weathering of micas. It can be stable in soil environments and is also formed by precipitation from solution or by alteration of other minerals.

Earthworms were kept in horse manure obtained from Burnham Beeches, Berkshire, UK, to which the minerals described were added. The animals that produce this manure are not given any antibiotics or other medication, so the manure is free of contamination. X-ray diffraction of the manure showed that it contained quartz. The manure was dried at 70 °C, ground to pass through a 2 mm sieve, and then rehydrated. Horse manure was used both as a food source and so that the mineralogy of the substrates could be kept simple.

The earthworm, *Eisenia veneta*, an epigeic species, was obtained from Blade's Biological, UK. *E. veneta* was chosen because it definitely passes soil through its gut [14] (unlike *E. fetida*, which feeds almost exclusively on soil-free organic matter) and because it could be obtained commercially. The earthworms were depurated in Petri dishes lined with moist filter paper for 36 h, prior to being added to the experimental substrates.

2.2. Experiment design

Two different treatments were used:

- mineral with earthworms and
- mineral, no earthworms.

Three grams of mineral were mixed with 7 g of manure and placed in a Petri dish lined with a Whatman No. 1 filter paper. In the treatment with no mineral, 7 g of manure were used. Water holding capacity was determined experimentally and the manure/mineral mix was hydrated to 75% of its water holding capacity. The earthworm treatments comprised four earthworms per Petri dish. Mortality was uncommon throughout the duration of the experiment, but when it occurred, the individuals were replaced so as to maintain four