



Elemental translocation and loss from three highly weathered soil–bedrock profiles in the southeastern United States

Neung-Hwan Oh¹, Daniel D. Richter*

Nicholas School of the Environment and Earth Sciences, Duke University, Durham, NC 27708, United States

Available online 25 December 2004

Abstract

Chemical weathering of soils and rocks during pedogenesis is significant because it provides many essential elements for life and because it is coupled with the rise and fall of atmospheric CO₂. We used geochemical mass-balance equations to quantify the net result of pedogenic weathering, i.e. elemental loss and gain, in three residual soil–bedrock profiles on the Piedmont of North Carolina. Soils are located on interfluves and derived directly from the bedrock below: a Kanhapludult (Tarrus series) from phyllite, a Kanhapludult (Cecil series) from granitic gneiss, and a Hapludalf (Enon series) from diabase.

Bulk density ratios of soils and bedrock as well as elemental concentrations referenced to Zr, Ti, Y, and V were used to estimate strain and open-system mass-transport functions through the soil profiles. Estimated strains of the three soils indicated substantial volumetric changes during C horizon and saprolite formation. Overall, desilication was the most predominant pedogenic process removing chemical elements from the three soils. Losses of Si were about 50% of total elemental molar losses in the 8.5-m deep Tarrus profile, 75% of total losses in the 3.8-m deep Cecil profile, and 39% of total losses in the 4-m deep Enon profile. Base cations were also lost in great amounts following desilication. Losses of base cations accounted for about 50% of the total elemental losses in the Tarrus, 20% of the total losses in the Cecil, and 37% of the total losses in the Enon profiles. The specific base cations lost in greatest amounts differed among the three soils and depended on bedrock mineralogy. Sodium and Mg accounted for 24% and 16% of total elemental loss from Tarrus profiles, Na and K accounted for 14% and 4% of total elemental loss from Cecil profiles, and Ca and Mg accounted for 19% and 12% of total elemental loss from Enon profiles.

The vertical pattern of loss of base cations was not always gradual from surface soil horizons to saprolite to bedrock. For example, almost 100% of Ca in the bedrock had been lost from throughout the upper 4.5-m deep Cecil and 8-m deep Tarrus profiles. Aluminum and iron were lost from A and E horizons but were accumulated in B and C horizons due to translocation as well as secondary clay and sesquioxide formation at depth. Physical and chemical data from all three soils and geologic

* Corresponding author. Tel.: +1 919 613 8031; fax: +1 919 684 8741.

E-mail addresses: neung-hwan.oh@yale.edu (N.-H. Oh), drichter@duke.edu (D.D. Richter).

¹ Current address: School of Forestry and Environmental Studies, Yale University, New Haven, CT 06511, United States. Tel.: +1 203 432 3657; fax: +1 203 432 7394.

substrata indicate that the entire regolith profile (A through C horizons or solum plus saprolite) is formed by pedogenic processes of elemental inputs, transformations, translocations, and removals.

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Keywords: Chemical weathering; Strain; Desilication; Saprolite; Ultisol; Alfisol

1. Introduction

Soil C horizons, including saprolites, have traditionally not been considered to be pedogenically formed. The often voluminous C-horizon materials have not been described as being an integral part of the soil but are referred to as residuum, parent material, over-burden regolith, or merely an obstacle for the study of bedrock by pedologists and geologists alike (Calvert et al., 1980a). Although the biological activity of the C horizon is much less than that of the O, A, and B horizons, biological activity, climate, topography, and geologic material are all important factors in C horizon formation. On this basis, Richter and Markewitz (1995, 2001) considered C horizons, including saprolite, as an integral part of the soil profile. Studies of C horizons have been motivated by interests in water quality management (e.g. controls on water chemistry and the fate of pollutants), plant management (e.g. deep rooting and plant productivity), and global biogeochemistry (e.g. weathering link to atmospheric CO₂).

As soil concepts have broadened, soil scientists have shown much more interest in C horizons. Ruxton and Berry (1957) studied weathering of granite in a 60-m-deep soil profile in Hong Kong, and Eswaran and Bin (1978a,b) investigated physicochemistry and mineralogy of a 19-m deep soil derived from granite in Malaysia. Both studies demonstrated the potentially enormous volumes of saprolite that can develop in tropical climates. Stolt et al. (1992) examined associations of landscape position and saprolite formation in gneissic rocks in Virginia and demonstrated greater thickness of saprolites on geomorphically stable summits compared with backslopes and footslopes. Calvert et al. (1980a,b) studied a whole soil–saprolite–granitic gneiss profile from a quarry in the Piedmont of North Carolina demonstrating that desilication and leaching of base cations were some of the most important processes in pedogenesis. O'Brien

and Buol (1984) demonstrated that reduced saturated hydraulic conductivity at the interface between Bt and saprolite horizons shielded underlying saprolite from extensive vertical leaching. Rice et al. (1985a,b) investigated soil genesis and the association of iron oxide with aluminosilicate clays from gabbro and metagabbro rocks containing large amounts of ferromagnesian minerals in the Piedmont. Buol and Weed (1991) summarized saprolite–soil transformation in the Piedmont and Mountains of North Carolina emphasizing dependence of weathering on rock type and mineralogy.

Many of the above studies quantified patterns of elemental concentrations throughout soil–bedrock profiles and estimated elemental loss or gain during chemical weathering assuming isovolumetric weathering in the saprolite, i.e. in which the volume of rock is conserved during weathering process. Although there may be many cases in which isovolumetric weathering occurs during saprolite formation (Velbel, 1990), the isovolumetric-weathering assumption may not be applicable to all saprolites and needs more thorough investigation (Chadwick et al., 1990). To better estimate elemental gain and loss from weathering, immobile index elements such as Zr or Ti are used as well as elemental concentration ratio of saprolite and parent bedrock due to potential volume change during soil formation (Chadwick et al., 1990).

Volumetric and mass changes during soil formation were evaluated by applying a mass conservation equation (Brimhall et al., 1988, 1991a,b; Chadwick et al., 1990). Although the mass conservation equation has been used in soils of Africa, Australia, and the western U.S., it has not been widely applied to the soils in southeastern North America. The general objective of this study is to estimate volume change and elemental loss during soil formation in three Piedmont soils derived from contrasting bedrocks: metamorphic phyllite, felsic igneous granitic gneiss, and mafic igneous diabase.

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