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Biogeochemistry of isotopes in soil environments: theory and application

L.C. Nordt [a,*], E.F. Kelly [b], T.W. Boutton [c], O.A. Chadwick [d]

[a] *Department of Geology, Baylor University, Waco, TX 76798, USA*
[b] *Department of Agronomy, Colorado State University, Fort Collins, CO 80523, USA*
[c] *Department of Rangeland Ecology and Management, Texas A&M University, College Station, TX 77843, USA*
[d] *Department of Geography, University of California, Santa Barbara, CA 93106, USA*

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Scientific disciplines make significant theoretical advances when new and innovative techniques emerge. For example, pedology has been enhanced by the recognition that soils consist of weathered mineralogical and organic components supporting plant and animal life, that soils form as a function of independent soil-forming factors (climate, biota, parent material, topography, time), and that some soil processes can be quantified by mass balance calculations. Further progress in pedology will inevitably come from increased quantification and modeling of soil forming processes. We believe that the use of natural isotopic tracers provides a powerful technique that will fulfil this need and take pedology into the 21st century.

Understanding the biogeochemistry of different isotopic systems in soils can increase our ability to unravel complex biotic and abiotic interrelationships by resolving patterns and processes at appropriate spatial and temporal scales. Isotopes can heighten our understanding not only of soils, but of the entire earth–atmosphere–biosphere system. Isotopic ratios in nature integrate and record information regarding processes that form key components of soils, rates of these processes, and the environmental conditions prevailing at the time the components were formed. Hence, isotopic indicators recovered from soils can be used to study topics as diverse as: the origin of soil constituents, including those created by anthropogenic processes; organic matter turnover rates; nutrient

* Corresponding author. Fax: + 1 254 710 2673.

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cycling; carbonate pedogenesis; formation of clay minerals; landscape evolution; soil–atmosphere gas exchange; vegetation history; and climate change.

With these concepts in mind, we saw the need to organize a symposium to encourage dialogue regarding the latest theories and applications of isotopes in soil systems. The symposium was held at the national Soil Science Society of America meetings in Seattle, Washington in 1994. The collection of papers in this special issue emanated from the symposium, and also includes the latest theories and applications that have developed since 1994. As a consequence, the title of this special issue is *Biogeochemistry of Isotopes in Soil Environments: Theory and Application.* As noted by the background of the contributing authors, this work facilitates much needed interdisciplinary exchange of information among pedologists, geologists, and ecologists.

This compilation of papers for *Geoderma* is divided into four isotopic categories, each of which begins with a theoretical discussion and is followed by examples of applications. These isotopic categories are: organic carbon, carbonate carbon and oxygen, strontium, and hydrogen and oxygen.

Organic carbon. The first paper, by Boutton et al., discusses carbon isotope ratios of plants with different photosynthetic pathways and how these ratios assist in interpreting ecosystem structure and function. A case study is then presented from a subtropical savanna showing grass–woody plant dynamics during the last few hundred years. Bernoux et al. follow with an analysis of vegetation change in the tropical rain forest of the Amazon using carbon isotopes. They tested organic matter decay models against their empirical isotopic data set to determine which models had the most predictive power for estimating organic matter turnover rates. Kelly et al. use isotopes in soil organic matter and phytoliths of paleosols to infer paleoenvironmental conditions during the Holocene in the North American Great Plains. They quantified variations in the proportion of C-4 grasses that appeared to relate to changes in climate.

Carbonate carbon and oxygen. Amundson et al. begin this section by modeling the production, diffusion and isotopic composition of CO_2 and O_2 in the soil atmosphere. By modeling C-13 and C-14 contents of both atmospheric and organic soil components, they also show the possibilities and limitations of quantifying the contributions of these isotopic species to the global carbon cycle. Nordt et al. apply a stable carbon isotope diffusion model to a soil chronosequence in the Southern Great Plains to partition pedogenic and lithogenic carbonates. Results show pedogenic and total carbonate loss during the course of 15,000 years of pedogenesis. Next, Monger et al. use stable carbon and oxygen isotopes of pedogenic carbonate in the Southwestern U.S. for late Quaternary vegetation and climate reconstruction. Strong correlations were observed among isotopic, pollen, and pack-rat midden records demonstrating that soils respond to changes in climate.

Strontium. Strontium isotopes have received less attention in pedology research than carbon and oxygen; however, they have been used in biogeochemical research as a way to determine nutrient provenance in ecosystems. As demonstrated by Stewart et al. (theory) and Capo et al. (application) strontium isotopes are also sensitive geochemical tracers in soils. For soil profile samples from New Mexico and Hawaii, these isotopes allowed quantification of rates of chemical weathering, interpretation of pedogenic pathways, and identification of nutrient fluxes in vegetation.

Hydrogen and oxygen. Last, is a treatment of the theory and application of hydrogen and oxygen isotopes to soil water and to the genesis of soil clays. Savin and Hsieh present data showing that clay minerals inherit hydrogen and oxygen isotopic signatures during their formation, which can be used to infer environmental conditions at the time of clay formation. Hsieh et al. follow with two papers on hydrogen and oxygen isotopes of soil water. The first is a methodological paper revealing how the oxygen isotopic composition of soil water can be measured with an in-situ equilibration method, which avoids isotopic fractionation associated with extracting water from soils prior to isotopic analysis. This method is then applied to a study area in Hawaii for partitioning and quantifying evaporation and transpiration losses of soil water.

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