

Isotopic Studies of Yucca Mountain Soil Fluids and Carbonate Pedogenesis

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ABSTRACT

Secondary carbonates occurring within the soils, faults, and subsurface fractures of Yucca Mountain contain some of the best available records of paleoclimate and paleohydrology for the potential radioactive waste repository site. This article discusses conceptual and analytical advances being made with regard to the interpretation of stable isotope data from pedogenic carbonates, specifically related to the ^{13}C content of soil CO_2 , CaCO_3 precipitation mechanisms, and isotopic fractionations between parent fluids and precipitating carbonates.

The ^{13}C content of soil carbon dioxide from Yucca Mountain and vicinity shows most of the usual patterns expected in such contexts: decreasing ^{13}C content with depth (due mainly to increased importance of respired CO_2), decreasing ^{13}C with altitude (partially due to relatively more C-3 vegetation), and reduced ^{13}C during spring (due again to higher rates of respiration, and reduced gas permeability of wet soils.) These patterns exist within the domain of a noisy data set; soil and vegetational heterogeneities, weather, and other factors apparently contribute to isotopic variability in the system.

Several soil calcification mechanisms appear to be important, involving characteristic physical and chemical environments and isotopic fractionations. When CO_2 loss from thin soil solutions is an important driving factor, carbonates may contain excess heavy isotopes, compared to equilibrium precipitation with soil fluids. When root calcification serves as a proton generator for plant absorption of soil nutrients, heavy isotope deficiencies are likely. Successive cycles of dissolution and reprecipitation mix and redistribute pedogenic carbonates, and tend to isotopically homogenize and equilibrate pedogenic carbonates with soil fluids.

1. INTRODUCTION

The shallow soils of Yucca Mountain and vicinity form a skin over the landscape, through which gases and liquids pass before crossing from the atmosphere to the deep unsaturated zone, or vice versa. This skin is far from passive; soil processes, including interactions between meteoric precipitation and soil minerals and biota, determine the chemical and isotopic properties of fluids at the air-land interface. Soil fluids tend to retain their properties as they penetrate deeper

into the unsaturated zone, and hydrogenic minerals precipitated along the way likewise reflect the soil genesis of parent fluids^{1,2,3,4}. Soil fluids are therefore key to understanding the origins and movements of subsurface fluids, and for interpreting the isotopic compositions of hydrogenic minerals (mainly calcite, opal, and clays) deposited from those fluids.

Climatic change adds an important temporal dimension to the problem. The abundance and isotopic composition of meteoric waters has changed over time. So have the species composition and densities of vegetation, which affect surface water balance, the isotopic composition of soil fluids, and weathering rates. Soil and subsurface carbonates record these changes, providing useful mineral repositories of climatic information at Yucca Mountain.

Faults in and around Yucca Mountain accumulate particularly impressive carbonate and silica infillings because of their effects on surface and subsurface hydrology. Understanding how these carbonates form and attain their structural, chemical, and isotopic properties therefore illuminates important aspects of fault hydrology. As dating procedures for the carbonates become better developed, the tectonic history of the mountain may also become clearer.

A. Carbon-13 in Soil Gas Carbon Dioxide

Soil gas sampling sites in the vicinity of Yucca Mountain are shown in Figure 1. Seven sites span more than 1 km of elevation, encompassing substrates ranging from desert colluvium to volcanic tuff, and vegetation types ranging from desert scrub to pinon-juniper forest. Steel sampling tubes were forced into the soils to depths ranging from 10 cm to 3 m, usually limited by rocks in the soils. Deeper samples were also obtained using gas sampling tubes previously installed at the USGS low-level waste research facility near Beatty, and from a caisson facility in Jackass Flats. Samples from near the crest of Yucca Mountain were obtained from shallow holes drilled into the volcanic tuffs.

Separate gas samples were generally withdrawn by syringe for analysis of CO_2 concentrations (by portable infrared gas analyzer) and pumped into mylar balloons, for later extraction of CO_2 for isotopic analysis. In-line desiccant traps were used during collection of some balloon samples, but had little effect on the $\delta^{13}\text{C}$ or $\delta^{18}\text{O}$ values of

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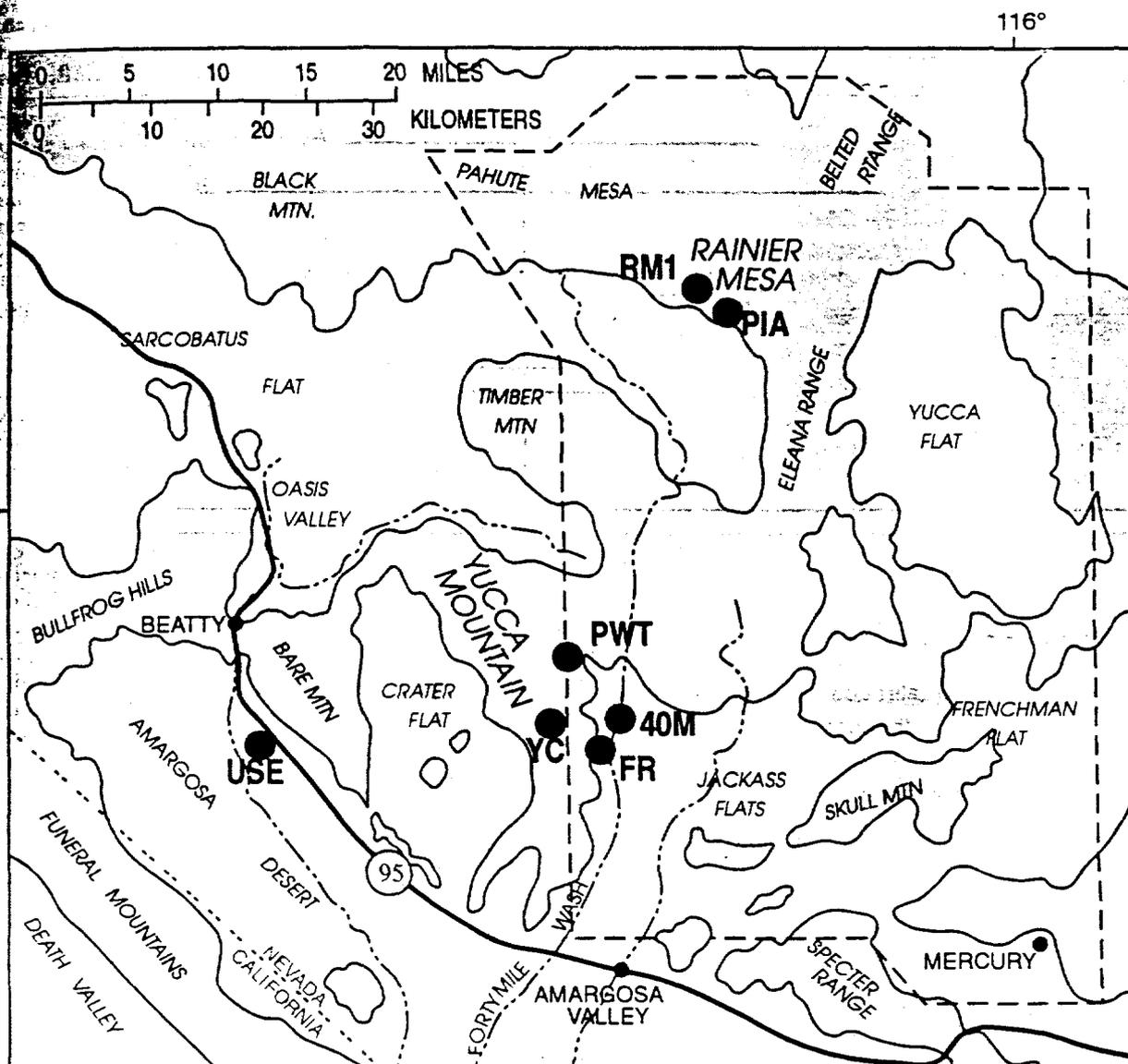


Figure 1. Soil gas sampling sites in the vicinity of Yucca Mountain. USE = U.S. Ecology; YC = Yucca Crest; FR = Fran Ridge; 40M = Fortymile Wash; PWT = Pagany Wash; PIA = roadcut on side of Rainier Mesa; and RM1 = top of Rainier Mesa.

extracted CO_2 . Soil samples for analysis of soil moisture, of the H and O isotopic composition of soil water, and $\delta^{13}\text{C}$ of associated organic and inorganic soil carbon, were also collected by auger, and frozen for later analysis.

Extraction of CO_2 for isotopic analysis was accomplished by cryogenic trapping in the laboratory. Replicate extractions from single balloons made within a few days typically agreed within mass spectrometric precision for both $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ (about 0.05‰^a), and replicate balloons typically agreed within 0.2‰ . Some isotopic drift has

^a $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values are reported as the ‰ (parts per thousand) deviations of the unknowns from the isotopic compositions of the International Standards PDB (for C) and SMOW (for O).

however been noted over periods of several months, presumably reflecting CO_2 leakage through the mylar balloons or their septa. Other limitations on the data stem from the creation of flow fields within the soils during sampling, and from spatial heterogeneities related to nearby vegetation, animal burrows, etc. For samples collected between March and September 1993, soil gas $\delta^{13}\text{C}$ ranges from about -22 to -8‰ PDB, with the following trends (Fig. 2):

1) Soil gas $\delta^{13}\text{C}$ decreases with depth within the top meter, while CO_2 concentrations increase. These observations are consistent with larger contributions of isotopically light CO_2 from soil respiration, deeper within the soils. About half of the depth-dependent variation often occurs within the top 10 cm, while the $\delta^{13}\text{C}$ minimum or asymp-

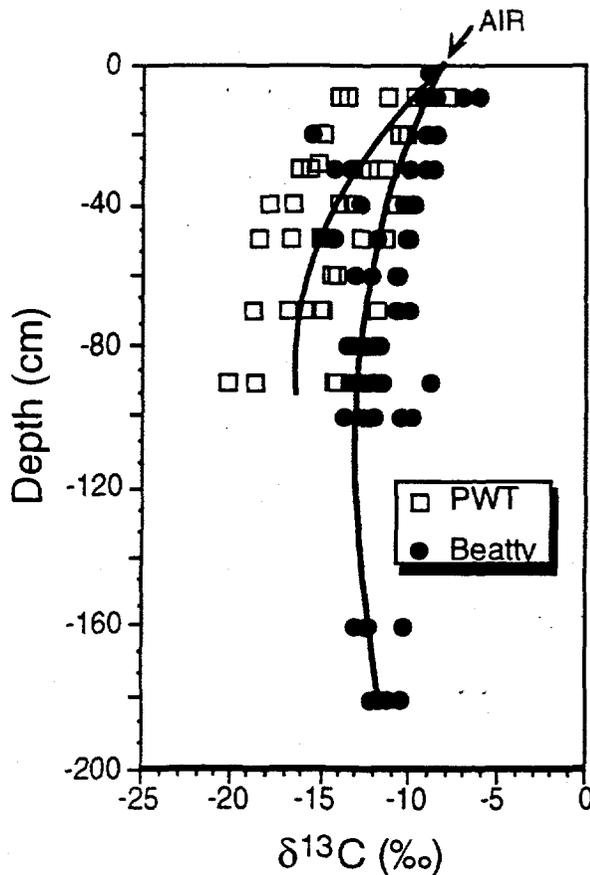


Figure 2. Carbon-13 content of soil gas carbon dioxide from vertical profiles at two sites in the Yucca Mountain region, March-September 1993. The PWT site (open squares), near the head of Pagany Wash, is the highest soil gas sampling site on Yucca Mountain. The USE site near Beatty (filled circles) is located in the Amargosa Desert southwest of Yucca Mountain.

tote usually occurs at about the depth (30 to 50 cm) where plant roots appear to be concentrated.

2) Most sites show a seasonal progression from isotopically light (low $\delta^{13}\text{C}$) in the spring to isotopically heavy in late summer. Soil gas CO_2 concentrations are likewise highest during the spring. The $\delta^{13}\text{C}$ minimum occurs earlier in the year at the more arid low elevation sites than at high elevation sites. These seasonal patterns reflect higher rates of soil respiration during spring, when soils are moist and warm. Summertime desiccation also increases soil porosity and allows faster escape of respired CO_2 , further lowering CO_2 concentrations and increasing downward penetration of isotopically heavier atmospheric CO_2 .

3) Moister, high elevation soils have higher CO_2 concentrations and lower $\delta^{13}\text{C}$, consistent with large contributions from respired CO_2 , and isotopically light CO_2 derived from C-3 plants. Soil gas CO_2 from the highest sites (PWT,

on North Yucca Mountain, Yucca Crest near UZ-6, and RM-1 and PIA on Rainier Mesa) contain about 10‰ lower $\delta^{13}\text{C}$ than the low elevation sites (such as USE, near Beatty).

At least as interesting as these trends are the large isotopic variations observed at individual sites. This is especially pronounced within the stream-terrace alluvium sampled at Fortymile Wash, where seasonal isotopic variations at a single depth sometimes span nearly the entire isotopic range observed at all sites, for all depths and seasons. Shallow holes drilled into tuffs on Yucca Crest also illustrate this variability (Fig. 3). Factors controlling the range of $\delta^{13}\text{C}$ at a particular site are currently under investigation.

B. Isotopic Mixtures.

Soil CO_2 derives from two main sources: atmospheric CO_2 and CO_2 respired by plant roots and soil organisms. Each has a characteristic carbon isotopic composition. Atmospheric CO_2 has a $\delta^{13}\text{C}$ of about -8.5‰, down somewhat from the pre-industrial value of about -6.5‰ which prevailed during the time most existing recent soil carbonates precipitated. Respired CO_2 resembles surrounding vegetation, which ranges from about -27 to -12‰, depending on the local mix of C-3 and C-4 plants, respectively. This in turn correlates with altitude and other factors. Carbonate-rich dusts derived largely from Paleozoic limestones and playa sediments supply much of the calcium in soil carbonates, but their contributions to carbon are minor compared to atmospheric and respired CO_2 .

Carbonates precipitated in isotopic equilibrium with soil CO_2 should be about 8‰ increased in $\delta^{13}\text{C}$, depending to some extent on temperature. Based on the data presented above, this defines a contemporary equilibrium range around -14 to +0‰. The lower values apply to high elevation sites and deeper than 50 cm in the soil column, and the heavier values apply where atmospheric CO_2 contributes most of the carbon to the mixture. Atmospheric CO_2 was about 2‰ heavier before the industrial revolution, and considering the uncertainties in environmental temperatures at the time of soil calcification, and in the associated equilibrium isotope fractionation factors, it is reasonable to extend the range for equilibrium pedogenic carbonates to about +3‰. Most carbonates from the Yucca Mountain region fall within this range^{1,3,5}, and equilibrium models shed considerable light on their genesis^{5,6,7}.

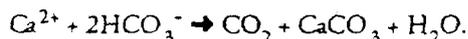
Carbonate $\delta^{13}\text{C}$ values as high as +5‰ are occasionally observed however, and are hard to fit into this scheme. Conversely, careful sampling of distinctive carbonate morphotypes at trenches 14, 14c, 5a, and at Busted Butte h revealed the existence of anomalously light carbonate "pellets", ooids, and layers near the bottom of the B soil horizon³. Although it is not clear what the isotopic compositions of soil gases were at the time of precipitation, such carbonates appear to be lighter than would be expected from equilibrium precipitation from contemporary soil CO_2 , and stretch the credibility of arguments based on isotopically light paleo- CO_2 .

The existence of anomalously heavy and light carbon isopes in carbonates, and their association with distinctive carbonate morphologies, suggests that such carbonates precipitate in isotopically distinctive microenvironments and/or precipitate under non-equilibrium conditions. What follows is a framework for interpreting these phenomena.

C. Calcification Mechanisms and Isotopic Consequences

Calcification is a two-step process. First, calcium bicarbonate rich solutions form. In the climatic context of Yucca Mountain, this is likely to occur mainly during early spring, when soils are wet, plants are active, and soil respiration generates high CO₂ partial pressures in the soils. Conditions then change to encourage CaCO₃ precipitation. Soil dewatering during late spring and summer has been considered to be the dominant process driving pedogenic calcification⁵; other physical processes contributing to CaCO₃ supersaturations within bulk soils include temperature increases and loss of CO₂ from soil waters. Biological processes also appear to be important.

Soil CO₂ concentrations vary among sites near Yucca Mountain from less than atmospheric (currently about 350 ppm) to more than 40,000 ppm. The subatmospheric values were observed transiently during cold, wet periods, and probably resulted from wetting of alkaline soils to form solutions which temporarily absorbed CO₂. High soil CO₂ values result from respiration by soil organisms (including plant roots), and are most pronounced within the root zone, in spring, at higher elevations. Most of this CO₂ is lost as soils dry out in the summer. CO₂ loss from soil fluids (evasion) should induce CaCO₃ precipitation in a manner analogous to what frequently occurs during travertine and speleothem deposition, as represented by the reaction



CO₂ evasion probably contributes to calcification mainly during late spring and summer, as soils dry out and become more permeable to exchange with atmosphere, and as soil respiration diminishes in response to desiccation. Degassing contributes to calcification in the deep unsaturated zone as well; CO₂ concentrations below the soils within the unsaturated zone are lower than many soil CO₂ concentrations, allowing downward percolating fluids to lose CO₂ and precipitate CaCO₃.

When CO₂ evasion from solution causes CaCO₃ supersaturation and precipitation, some interesting disequilibrium isotopic fractionations can occur^{8,9,10,11}. These disequilibrium effects commonly enrich the precipitate by several ‰. There are at least two components to these enrichments.

First, molecules bearing ¹³C suffer a kinetic disadvantage during HCO₃⁻ dehydroxylation and H₂CO₃ dehydration. In thin, alkaline solutions, such as those that occur on wet soil particles in Yucca Mountain region, the ¹³C depleted CO₂ so formed can partially escape from solution before fully equilibrating with HCO₃⁻. This leads to ¹³C-enriched

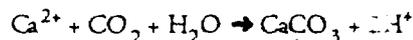
HCO₃⁻, and isotopically heavy carbonate precipitates. A similar kinetic isotope fractionation can affect oxygen isotopes.

Second, CO₂ evasion sets up Rayleigh-type isotope separations, even in the absence of kinetic disequilibria during CO₂ generation, since CO₂ at equilibrium at ambient surface temperatures is lowered in δ¹³C by about 7-8‰ compared to HCO₃⁻. Consequently, as CO₂ evasion progresses, the remaining HCO₃⁻ becomes progressively heavier, sometimes leading to large ¹³C enrichments¹². If kinetic fractionations during HCO₃⁻ → CO₂ reactions (as above) are added to the picture, larger ¹³C enrichments in precipitating carbonates result.

The association of soil calcification with plant roots has possible relevance to occurrences of isotopically light carbonates. Calcified roots are ubiquitous around Yucca Mountain, forming particularly impressive fossil gardens within fault zones, as for example where the Paintbrush fault crosses the sand ramps of Busted Butte, and along the Ghost Dance and Solitario Canyon faults. Well-preserved calcified roots also occur in paleodischarge deposits, as near the southern end of Crater Flat and Ash Meadows, and in cracks within non-welded volcanic tuffs throughout the region. Calcified rootlets and apparent fungal products also occur widely within massive pedogenic carbonates^{3,13}. The abundance and diversity of such features suggests that roots and fungi contribute to soil calcification in many settings which are not as clear and which have not been closely examined.

Root calcification involves several components. Transpiration draws water toward the root, concentrating ions there and encouraging calcification. Roots also produce conduits for downward water flow from the surface. Finally, roots often exhibit external pH banding¹⁴, i.e. zones around the roots, usually near the root tips, which are more acidic or alkaline than surrounding soil fluids. The acidic zones apparently contribute to the solubilization and uptake of elements such as P, Fe, and Mn from the soils. The roots obtain protons for acid secretion either from soil fluids some distance away, creating external alkaline zones which may become calcified, or from the intracellular (vacuolar) precipitation of carbonates and oxalates:

CaCO₃ precipitation:



Oxalate precipitation:



Root calcification is particularly likely in alkaline and calcareous soils, since more protons are required to titrate soil bases and free the acid soluble nutrients. The vacuoles of root cells sometimes become completely filled with oxalates or carbonates¹⁵ creating microscopically recognizable soil fossils. The regions of proton extrusion distant to the root tip are also likely to become silicified, as is often observed in desert soils. Microbes may also metabolize plant oxalates to

carbonates.

The physiology of root calcification appears to be similar to that described for aquatic plants^{16,17} in which case molecular CO_2 provides much of the carbon for calcification. CaC_2O_4 deposition probably involves a mechanism similar to that previously described for calcium salts of other anions lacking uncharged forms (analogous to CO_2) at physiological pH. If so, oxalate reaches the calcification site through an anion exchange process which is absent in CaCO_3 precipitating systems¹⁸, accounting for the fact that CaCO_3 and CaC_2O_4 do not normally occur together in the same calcified cell^{15,4}.

Calcification associated with pH banding by plant roots may display nonequilibrium isotope fractionations that are opposite in character to those discussed above, i.e. lighter than isotopic equilibrium, analogous to those observed in many other biological carbonates^{19,20}. Applying that model, CO_2 diffuses across the calcifying membrane into adjacent alkaline solutions, ionizes, and precipitates as CaCO_3 . C^{13}O_2 molecules are kinetically disadvantaged especially during CO_2 hydroxylation, resulting in ^{13}C depletions in precipitating CaCO_3 . ^{18}O kinetic fractionations usually accompany the ^{13}C effects, often giving rise to positive correlations between $\delta^{13}\text{C}$ and ^{18}O . $\delta^{13}\text{C}$ decreases of over 10‰, and ^{18}O decreases of about 4‰ are possible.

Numerous published reports^{3,21} contain data suggestive of the presence of such kinetic ^{13}C depletions in pedogenic carbonates. Unpublished data by Jaillard is particularly impressive. The isotopic composition of soil CO_2 is poorly constrained in most cases however, and other processes could influence the isotopic composition of precipitating carbonates in the general manner observed. Continuing investigations will attempt to pin down roles played by such mechanisms in determining the isotopic compositions of soil and UZ carbonates.

The probability that isotopic disequilibrium will exist during some of the more probable forms of carbonate precipitation at Yucca Mountain raises the obvious question of why equilibrium models appear to have worked rather well. Part of the answer undoubtedly rests in the fact that we have only demanded rather general and low resolution models up to this point. Probably more important however, is the fact that soil carbonate deposits represent the accumulated products of repeated cycles of precipitation and dissolution, and these cycles encourage homogenization and equilibration of the carbonates. This complex genesis is of course part of the reason why isotopic dating of soil carbonates is complicated^{22,23}.

References:

1. WHELAN, J.F., D.T. VANIMAN, J.S. STUCKLESS, and R.J. MOSCATI, "Paleoclimatic and paleohydrologic records from secondary calcite: Yucca Mountain, Nevada", in IHRLWM Proc., ASCE and ANS, 5th Internat. Conf., Las Vegas, Nevada, (this volume) (1994).
2. STUCKLESS, J.S., Z.E. PETERMAN, and D.R. MUHS, "U and Sr isotopes in ground water and calcite, Yucca Mountain, Nevada: Evidence against upwelling water", *Science*, 254, 551-554 (1991).
3. VANIMAN, D.T. and J.F. WHELAN, "Inferences of paleoenvironment from chemical and stable isotope studies of calcretes and fracture calcites", in IHRLWM Proc., ASCE and ANS, 5th Internat. Conf., Las Vegas, Nevada, (this volume) (1994).
4. PETERMAN, Z.E., J.S. STUCKLESS, B.D. MARSHALL, S.A. MAHAN, and K.A. FUTA, "Strontium isotope geochemistry of calcite fillings in deep core, Yucca Mountain, Nevada - a progress report", in IHRLWM Proc., ASCE and ANS, 3rd Internat. Conf., Las Vegas, Nevada, 1582-1586 (1992).
5. QUADE, J., T.E. CERLING, and J.R. BOWMAN, "Systematic variations in the carbon and oxygen isotopic composition of pedogenic carbonate along elevation transects in the Southern Great Basin, United States", *Geol. Soc. Amer. Bull.*, 101, 464-475 (1989).
6. WOOD, W.W. and M.J. PETRAITIS, "Origin and distribution of carbon dioxide in the unsaturated zone of the southern high plains of Texas", *Water Res. Res.*, 20, 1193-1208.
7. CERLING, T.E., "Carbon dioxide in the atmosphere: Evidence from Cenozoic and Mesozoic paleosols", *Am. J. Sci.*, 291, 377-400 (1991).
8. GONFIANTINI, R., C. PANICHI, and E. TONGIORGI, "Isotopic disequilibrium in travertine deposition", *Earth Plan. Sci. Lett.*, 5, 55-58 (1968).
9. FRIEDMAN, I., "Some investigations of the deposition of travertine from hot springs -- I. The isotopic chemistry of a travertine-depositing spring. *Geochim. Cosmochim. Acta*, 34, 1303-1315 (1970).
10. HENDY, C.H., "The isotopic geochemistry of speleothems -- I. The calculation of the effects of different modes of formation on the isotopic composition of speleothems and their applicability as paleoclimatic indicators", *Geochim. Cosmochim. Acta*, 35: 801-824 (1971).
11. MICHAELIS, J., E. USDOWSKI, and G. MENSCHERL, "Partitioning of ^{13}C and ^{12}C on the degassing of CO_2 and the precipitation of calcite -- Rayleigh-type fractionation and a kinetic model", *Am. J. Sci.*, 285, 318-327 (1985).
12. STILLER, M., J.S. ROUNICK, and S. SHASTA, "Extreme carbon-isotope enrichments in evaporating brines", *Nature*, 316, 434-435 (1985).
13. MARSHALL, B.D., Z.E. PETERMAN, K. FUTA, J.S.

- STUCKLESS, S.A. MAHAN, J.S. DOWNEY, and D. GUTENTAG, "Origin of carbonate deposits in the vicinity of Yucca Mountain, Nevada: Preliminary results of strontium-isotope analyses", in IHRLWM Proc., Proc. ANS, Las Vegas, Nevada, v. 2, 921-923 (1990).
- RAVEN, J.A. "Terrestrial rhizophytes and H⁺ currents circulating over at least a millimetre: an obligate relationship?", *New Phytologist*, 117: 177185 (1991).
- JAILLARD, B., A. GUYON, and A.F. MAURIN, "Structure and composition of calcified roots, and their identification in calcareous soils", *Geoderma*, 50: 197-210 (1991).
- MCCONNAUGHEY, T.A. and R.H. FALK, "Calcium-proton exchange during algal calcification", *Biol. Bull.*, 180, 185-195 (1991)
- MCCONNAUGHEY, T., "Calcification in *Chara corallina*: CO₂ hydroxylation generates protons for bicarbonate assimilation", *Limnol. Oceanogr.*, 36, 619-628 (1991).
- MCCONNAUGHEY, T., "Biomineralization mechanisms", p 57-73 in *Origin, Evolution, and Modern Aspects of Biomineralization in Plants and Animals* (ed. R. E. Crick), Plenum, New York, 1989.
- MCCONNAUGHEY, T. "¹³C and ¹⁸O isotopic disequilibrium in biological carbonates. 1. Patterns. *Geochim. Cosmochim. Acta*, 53, 151-162, (1989)
- MCCONNAUGHEY, T. "¹³C and ¹⁸O isotopic disequilibrium in biological carbonates. 2. In vitro simulation of kinetic isotope effects", *Geochim. Cosmochim. Acta*, 53, 163-171 (1989)
- CERLING, T.E. and R.L. HAY, "An isotopic study of paleosol carbonates from Olduvai Gorge", *Quat. Res.*, 25, 63-74 (1986).
- AMUNDSON, R.G., O.A. CHADWICK, J.M. SOWERS, and H.E. DONER, "The stable isotope chemistry of pedogenic carbonates at Kyle Canyon, Nevada. *Soil Sci. Soc. Am. J.*, 53, 201-210 (1989).
- PENDELL, E.G., J.W. HARDEN, S.E. TRUMBORE, and O.A. CHADWICK, "Isotopic approach to soil-carbonate dynamics: Implications for paleoclimatic interpretations. ???

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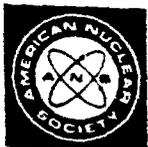
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