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ScienceDirect
Geoderma 142 (2007) 104 – 111
GEODERMA
www.elsevier.com/locate/geoderma

Isotopic variability in large carbonate nodules in Vertisols: Implications for climate and ecosystem assessments

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Received 4 February 2006; received in revised form 27 April 2007; accepted 5 August 2007
Available online 14 September 2007

Abstract

Vertisols occurring in the Coastal Prairie of Texas preserve distinctive patterns of carbon isotopic values with depth for both soil organic matter as well as pedogenic carbonate. These isotopic values may be used to reconstruct past climate and ecosystems (C3 *versus* C4 vegetation). Some soils contain large carbonate nodules (>2 cm diameter) that exhibit $\delta^{13}C$ isotopic gradients of up to 2–3‰ across the nodule and have an internal structure that resembles concentric growth rings. These isotopic gradients are used to potentially track relative nodule movement in soil profiles. Some nodules possibly move within and even across microenvironments displaced by several centimeters. The isotopic gradients of the nodules may also track climate and ecosystem changes associated with relative changes in soil depth caused by soil movement. In order to make accurate climate and ecosystem interpretations, soil organic matter and pedogenic carbonate should be demonstrated to have formed in isotopic equilibrium at their respective soil depth.

Keywords: Vertisols; Stable isotopes; Carbonate nodules; Climate; Ecosystem

1. Introduction

Vertisols constitute 2.4% of the Earth's land surface (Dudal and Eswaran, 1988). These clay-rich soils (>30% clay) consist predominantly of fine, smectitic clays and experience intense shrink/swell processes, which are attributed to seasonal periods of wetting and drying or to seasonal soil-moisture deficit (Soil Survey Staff, 1998). Studies of Vertisols indicate that there are differences in intensities of shrink/swell movement between (and within) gilgai microhigh and microlow pedons (Wilding et al., 1991; Coulombe et al., 1996). In addition, Vertisols maintain parallel, yet distinctive geochemical and isotopic profiles with depth within each soil microenvironment (*i.e.*, Vertisol microhigh and microlow) (Wilding and Coulombe, 1996; Driese et al., 2000).

Both modern soils and paleosols provide important climate information. The depth of the Bk horizon in Vertisols is useful for assessing climate information such as mean annual precipitation (MAP) (Nordt et al., 2006). The Bk horizon in microhigh pedons occurs at shallower depths than in microlows (Lynn and Williams, 1992; Nordt et al., 2006). Soil within gilgai microhighs is more susceptible to chemical translocation of solutes than are soils forming in gilgai microlow environments (Lynn and Williams, 1992; Driese et al., 2000; Nordt et al., 2004). The significance of climate interpretations derived from depth-to-carbonate (DTC) measurements from Vertisol microhigh pedons depends on whether: (1) the Bk horizons present in the microhigh and microlow pedons formed as a result of the same pedogenic processes, or (2) the DTC of the Bk horizon in the microhigh pedon is largely the result of pedoturbation of carbonate along master slickenside surfaces. The Bk horizon of the microhigh may contain both small (<1 cm diameter) carbonate nodules formed *in situ*, as well as larger carbonate

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doi:10.1016/j.geoderma.2007.08.007

nodules that may have experienced systematic pedoturbation from other depths in the soil profile. We hypothesize that because of the mechanical (shrink/swell) nature of Vertisols during pedogenesis, some larger pedogenic carbonate nodules may have been translocated along master stress cutanes, or slickensides, to their current positions within soil profiles, rather than having been precipitated in equilibrium with soil organic matter (SOM) and precipitation. This study examines micromorphologic and stable isotopic evidence for pedoturbation of pedogenic carbonate nodules in two Vertisol microhigh pedons from the Lake Charles series in the Coast Prairie of Texas, USA. Pedoturbation is evaluated using carbon isotope transects measured across four large (2 to 3.5 cm diameter) carbonate nodules. These nodules show carbon isotope gradients, as measured from each nodule, which suggest aggradational growth by precipitation of carbonate coupled with physical movement along master slickenside planes. Both the carbon isotopic composition of soil organic matter and soil carbonate may record clues to the previous climate and ecosystem (*e.g.*, Amundson et al., 1989; Cerling et al., 1989; Kelly et al., 1991; Nordt et al., 1994; Mora et al., 1996; Boutton et al., 1998; Driese et al., 2005). Carbon isotope micro-analytical transects of large carbonate nodules in Vertisols may track ecosystem and climate changes as each nodule was formed and possibly pedoturbated within the soil profile, and help to constrain the origin of carbonate within gilgai environments. The results have important implications for studies of paleoclimate and paleoenvironment using depth-to-carbonate (DTC), and on models for development of morphological characteristics of paleosols (or paleoVertisols).

2. Study area

Soil carbonate generally forms in regions of arid to subhumid climate conditions (Cerling, 1984), such as those existing today within the Coast Prairie region of Texas (Nordt et al., 2004; Driese et al., 2005). This study examines two modern Vertisol pedons in the Coastal Prairie region of Texas from the Lake Charles soil series, from Wharton County (pedon 481) and Harris County (pedon 201) (Fig. 1). The parent material for the Lake Charles Vertisols consists largely of red, calcareous, alluvial to deltaic deposits of the Beaumont Formation (Late Pleistocene), which was derived from weathered Permo-Triassic and Cretaceous rocks in the Brazos headwater region and is relatively uniform and clay-rich (Bernard and LeBlanc 1965). The soils developed on an exposed Late Pleistocene terrace during sea-level low-stand (Bernard and LeBlanc, 1965). The maximum age for the Lake Charles Vertisols is constrained by the youngest facies of the parent Beaumont Formation which is estimated to be between ~35 kyr BP (Birdseye and Aronow, 1991) and 70 kyr BP (Durbin et al., 1997). The landscape is characterized by a continuously flat and relatively uniform topography. Seasonally distributed mean annual precipitation across the study area ranges from 112 cm/yr in Wharton County (pedon 481) to 132 cm/yr in Harris County (pedon 201). Mean annual temperature for Wharton County (481) is 21.0 °C (annual range 25.2 °C to 16.8 °C) and for Harris County (201) is 20.6 °C (annual range 25.8 °C to 15.4 °C) (http://www.ncdc.noaa.gov/).

3. Materials and methods

At both sites, soil pits 2 to 3.5 m deep were excavated by backhoe to expose a soil topographic profile that contained both a gilgai microhigh and microlow. Bulk soil samples were systematically collected in the field at 10 cm intervals through a microhigh and laterally adjacent microlow, and pedogenic carbonate was collected as part of the bulk soil samples. Soil descriptions were made using standard field methods including characterization of horizons/subhorizons, soil color, soil texture,

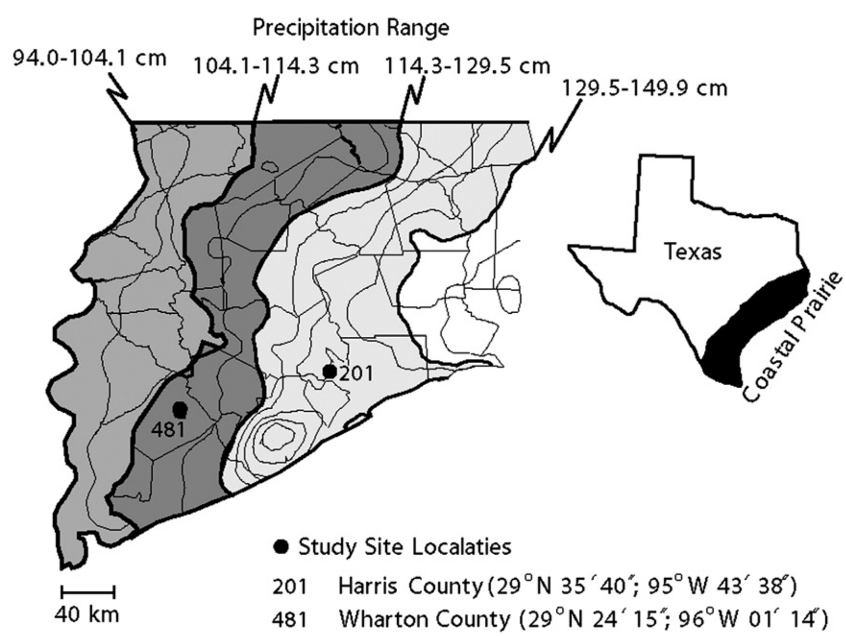

Fig. 1. Map showing the locations of study sites in the Coast Prairie of Texas. Precipitation contours define range of annual rainfall in centimeters (IAEA/WMO, 1998).