Available online at www.sciencedirect.com
ScienceDirect
Catena 68 (2006) 59 – 69
CATENA
www.elsevier.com/locate/catena

Clay illuviation and calcium carbonate accumulation along a precipitation gradient in Kansas

H. Gunal [a,*], M.D. Ransom [b]

[a] Gaziosmanpasa University, Agricultural Faculty, Soil Science Department Tasliciftlik, Tokat-60250, Turkey
[b] Department of Agronomy, Kansas State University, Manhattan, KS 66506-5501, USA

Received 9 November 2004; received in revised form 10 April 2006; accepted 20 April 2006

Abstract

One of the significant features of loess-derived soils in Kansas is the occurrence of clay-rich subsurface horizons above a layer enriched with pedogenic carbonates. In order to examine the extent of clay increase and pedogenic carbonate enrichment in a precipitation gradient, ten soil profiles from three different precipitation regions were studied using micromorphological and mineralogical techniques. The precipitation gradient was divided into three groups: 400–550 mm, 550–750 mm, and 750–1100 mm regions. The objectives were to (1) understand the cause of clay orientation in clay-rich horizons (2) investigate the reasons for the clay increase, and (3) observe the interaction of clay and pedogenic carbonate accumulation features along a precipitation gradient in Kansas. Although clay films were identified in the field for soils in the 400–550 mm regions, illuvial clay films were not observed in thin section analysis. The clay accumulations mostly occurred as grain coatings. The rest of the clay accumulations observed were very thin, striated, and mostly associated with voids. The argillic horizons had a granostriated b-fabric, which indicates stress orientation of micromass caused by high shrink–swell activity. Thick and continuous illuvial coatings were observed in the buried horizons of paleosols. In the other two regions where precipitation exceeds 550 mm, illuvial clay coatings with strong orientation were observed along with thin and striated stress-oriented clay. Both types of clay orientations exceeded 1% of the cross-sectional area for the thin section. Although illuvial clay features and pedogenic carbonates were observed in all soils at approximately the same depth, complete obliteration of clay coatings was not observed in these horizons. In-situ weathering of biotite was one of the reasons for the clay increase in all soil profiles. In all soils studied, the clay increase and cause of clay orientation cannot be attributed to a single genetic process or event. Both illuviation and shrink–swell activity were involved in the orientation of clay. Although orientation of clay and pedogenic carbonates were observed in all soils at approximately the same depth, the decomposition of clay coatings was not observed in these horizons.

Keywords: Illuviation; Stress; Pedogenic carbonate; Argillic horizon; Micromorphology; Climate

1. Introduction

In Kansas, climate is perhaps the most diverse of the five factors of soil formation named by Jenny (1941). Kansas climate differs from that of most other states in terms of a regular gradation of precipitation from east to west across the state. The mean annual temperature is uniform, but precipitation is around 400 mm on the west and almost 1100 mm on the eastern border of Kansas (Goodin et al., 1995). This provides an opportunity to study the influence of modern climate on soil genesis; especially clay illuviation and pedogenic carbonate accumulation, while isolating the other factors of soil formation. Jenny and Leonard (1934) showed that isolating the other soil forming factors while studying the effects of precipitation is possible only in some regions of U.S.A., and Kansas is one of these regions.

Along this transect, the soils have been classified (Soil Survey Staff, 1999) as Ustolls in the west (Howando, 1978; Fraser, 1990; Ransom and Bidwell, 1990; Ricks Presley et al., 2004) and Udolls in the east (Wehmueller, 1996; Glaze,

* Corresponding author. Tel.: +90 356 2521616; fax: +90 356 2521488.
E-mail addresses: hgunal@gop.edu.tr, hgu3248@yahoo.com (H. Gunal).

0341-8162/$ - see front matter
doi:10.1016/j.catena.2006.04.027

1998). Loess is the major parent material of soils found in Kansas. There are three important loess units in Kansas: Loveland, Peoria (Wisconsin age), and Bignell (Holocene age). Loveland is an older, pre-Wisconsin, loess that is often buried beneath Peoria loess. Peoria loess is the most exposed loess unit. Bignell loess is discontinuous and restricted to central and western Kansas. Bignell loess is younger than Peoria loess, and it may be a product of reworked Peoria loess at some localities. If Bignell and Peoria loess occur in the same soil profile, they can be distinguished only by the presence of the Brady paleosol (Welch and Hale, 1987), which developed within the Peoria loess and was later covered by the Bignell loess (Johnson et al., 1993). The Brady paleosol formed during the Holocene. Johnson et al. (1993) reported the age of the Brady paleosol as 9820 ± 110 and 8850 ± 140 years for two locations in central Kansas.

Organic matter, clay type and content, color, presence and absence of calcium carbonate and more soluble salts, and depth of leaching in soils are closely associated with the climate (Birkeland, 1999). The nature of clay minerals in soils is easily affected by soil forming processes. Clay illuviation is also one of the most important pedogenic processes for the Kansas soils. Soils with argillic horizons cover most of the land area of Kansas. In contrast, pedogenic carbonate accumulation primarily occurs in soils in central and western Kansas where the climate is semi-arid.

Although soils in western Kansas are usually classified with an argillic horizon based on a significant clay increase in the B horizon, clay coatings may not be evident in field examination of many soils (Ransom et al., 1997). Theoretically, the increase in clay content should be due to illuviation in order to be classified as an argillic horizon (Soil Survey Staff, 1999). Clay skins or films on ped faces or on the walls of voids imply the translocation and subsequent accumulation of clay. Such features result in argillic horizon formation (Gile and Grossman, 1968; Brewer, 1976; McKeague, 1983). However, in some cases an increase in clay with depth in the profile may be due to the in-situ weathering of mica, feldspar, or some other minerals as indicated by many researchers (Smeck et al., 1981; McKeague, 1983; Ransom and Bidwell, 1990).

The translocation from upper horizons and shrink–swell activity (stress) are the different pedogenic processes causing clay orientation. Brewer (1976) described illuvial clay coatings as the coatings of translocated clay minerals on the natural surfaces in soil materials. The shrink–swell activity results from in-situ modification of orientation of clay minerals on the natural surface as a result of micromass separation. Both processes results in clay orientation on natural surfaces, but the mechanism of formation is different for each process. According to Soil Taxonomy (Soil Survey Staff, 1999), argillic horizons should be formed by illuviation not by stress. Therefore, distinguishing stress-oriented clay from illuvial-oriented clay is important for soil classification.

The accumulation of pedogenic calcium carbonates is an important pedogenic process for arid and semi-arid regions (Sobecki and Wilding, 1983), and horizons enriched with pedogenic calcium carbonate are often the most prominent features in such soils (Gile et al., 1966). The depth of calcium carbonate leaching and the extent of calcium carbonate precipitation in the profile are functions of the original carbonate content, water chemistry (pH), partial pressure of CO_2 and cumulative quantity of infiltrating water (Allen and Whiteside, 1954). Arkley (1963) observed a strong relationship between the depth to a horizon containing carbonates and water holding capacity as well as precipitation.

The source of the calcium carbonate in the soil profile can be lateral movement of carbonate-rich waters (Rabenhorst and Wilding, 1986), eolian dust addition (Gile et al., 1966; Nettleton et al., 1990; Ransom and Bidwell, 1990), weathering of carbonate-rich materials (Monger et al., 1991), local redistribution of carbonate-rich water from lower topographic positions to the drier higher positions via capillary movement (Sobecki and Wilding, 1983; Knuteson et al., 1989), or climatic factors as explained by Arkley (1963).

Theoretically, the pedogenic processes of clay illuviation and calcium carbonate accumulations should be contradictory to each other, since large quantities of Ca^{2+} tend to cause clay flocculation and reduce illuviation. However, these pedogenic features may be observed in the same soil at approximately the same depth (Gile and Grossman, 1968; Aguilar et al., 1983; Ransom and Bidwell, 1990; Fraser, 1990; Pal et al., 2003). The presence of both accumulation of calcium carbonate and oriented clay in the same horizon implies a complex history of carbonate leaching, deposition of secondary calcite, and clay illuviation (Smith and Wilding, 1972; Khormali et al., 2003). Gile and Grossman (1968), Aguilar et al. (1983), and Pal et al. (2003) observed obliteration of clay films in some parts of the argillic horizon because of pedogenic carbonate accumulation, especially for those clay coatings that occurred on the surfaces of sand grains and pebbles. Pal et al. (2003) reported that poorly-oriented clay platelets are often found associated with $CaCO_3$ grains. However, Ransom and Bidwell (1990) did not observe any evidence of disruption of clay skins in horizons where secondary carbonate was accumulating. They reported that the clay coatings were intact.

The purposes of this study were to (1) understand the cause of clay orientation in clay-rich horizons (2) investigate the reasons for the clay increase, and (3) observe the interaction of clay and pedogenic carbonate accumulation features of soils formed in loess parent materials along a precipitation gradient in Kansas.

2. Materials and methods

Ten pedons along a precipitation gradient from west to east were studied (Fig. 1). The selection of individual soils