Geoderma 154 (2010) 438–446

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Mineralogy of loess and volcanic ash eolian mantles in Pacific Northwest (USA) landscapes

P.A. McDaniel [a,*], K.W. Hipple [b,1]

[a] Soil & Land Resources Division, Box 442339, University of Idaho, Moscow, ID 83844-2339, USA
[b] USDA-NRCS-NSSC, Federal Building, Room 152, Mail Stop 36, 100 Centennial Mall North, Lincoln, NE 68508-3866, USA

ARTICLE INFO

Article history:
Received 16 August 2008
Received in revised form 18 December 2008
Accepted 23 December 2008
Available online 30 January 2009

Keywords:
Mineralogy
Tephra
Loess
Mollisols
Andisols
Bioclimatic gradient

ABSTRACT

Eolian mantles consisting of Quaternary loess, Holocene volcanic ash, and mixtures of the two are prominent features of most landscapes in the inland Pacific Northwest region of the USA. Soils of the loess-mantled Palouse region of eastern Washington and northern Idaho exhibit regional mineralogical trends related to mean annual precipitation and age. Clay content increases and $CaCO_3$ decreases from areas of lower to higher precipitation. Clay mica is the dominant clay mineral in soils formed in the youngest loess (ca.<15 ka). In the next older loess paleosol (ca. 40 ka), vermiculite is dominant, indicating a time-dependent mica-to-vermiculite weathering sequence. Smectite and kaolin also occur to a lesser extent in soils of the region. This mineralogical signature provides a useful tool in identifying paleosols and interpreting the complex pedogenesis occurring in local Palouse landscapes. More recently, Holocene volcanic ash has influenced many mid- and high-elevation forested soils. Relatively thick mantles of volcanic ash from the cataclysmic eruption of Mount Mazama 7600 years ago have undergone slight-to-moderate weathering, giving rise to Andisols (Andosols). Environmental conditions generally promote development of allophanic properties across the region, with allophane and ferrihydrite being dominant mineral components. Non-allophanic mineralogy is much less extensive in ash mantles of the region, but is favored in two pedogenic environments — E horizons of podzolized soils and horizons supporting vigorous growth of bracken fern.

1. Introduction

Eolian mantles represent relatively uniform parent materials distributed across landscapes. As such, they provide a unique context for mineralogical investigations at various spatial and temporal scales. At scales of 10s or 100s of kilometers, eolian mantles may span regional bioclimatic gradients, making it possible to observe mineralogical trends associated with broad climate and vegetation patterns. At a more local scale (up to 10s or 100s of meters), mineralogical differences in a once-uniform surface mantle reflect the effects of various soil-forming processes operating within hillslopes and pedons. Additionally, eolian mantles resulting from temporally defined events such as volcanic eruptions often provide a precise time frame in which to evaluate pedogenesis. Thus, mineralogical characteristics of eolian mantles provide important information about the nature and magnitude of pedogenic processes that have been active in soils, and this information can, in turn, be used to develop models of pedogenesis. In the Inland Pacific Northwest region of the USA, the two most extensive eolian mantles consist of Quaternary loess and Holocene volcanic ash (Busacca 1989; McDaniel et al., 2005).

1.1. Loess deposits

There are ca. 50,000 km^2 of late-Pleistocene/Holocene-age loess deposits in southeastern Washington, northeastern Oregon, and northern Idaho (McDonald and Busacca, 1992; Sweeney et al., 2007). In the eastern portion of the region referred to as the Palouse, loess covers ~10,000 km^2 and has been deposited episodically throughout the Pleistocene and early Holocene (Fig. 1) (Busacca, 1989). A major source of Palouse loess was Eureka Flat, Washington, where sediments derived from glacial outburst flood sediments were suspended and carried in a northeasterly direction by prevailing winds (Sweeney et al., 2007).

Two loess pedostratigraphic units, L1 and L2, have been recognized and correlated across the Palouse region (e.g. McDonald and Busacca, 1992; Kemp et al., 1998; Sweeney et al., 2007). The L1 unit has an approximate age of 0–15 ka and the approximate age of L2 is 15–70 ka (Sweeney et al., 2007). Luminescence ages indicate a period of relatively low dust accumulation across the Columbia Plateau between ca. 15 and 35 ka (Sweeney et al., 2004). This likely represents a period of maximum soil formation in the upper L2 loess, which would have been followed by the accumulation and subsequent soil formation in the L1 loess.

* Corresponding author. Tel.: +1 208 885 7012.
E-mail addresses: paulm@uidaho.edu (P.A. McDaniel), karl.hipple@lin.usda.gov (K.W. Hipple).
[1] Tel.: +1 402 437 5351.

0016-7061/$ – see front matter
doi:10.1016/j.geoderma.2008.12.023

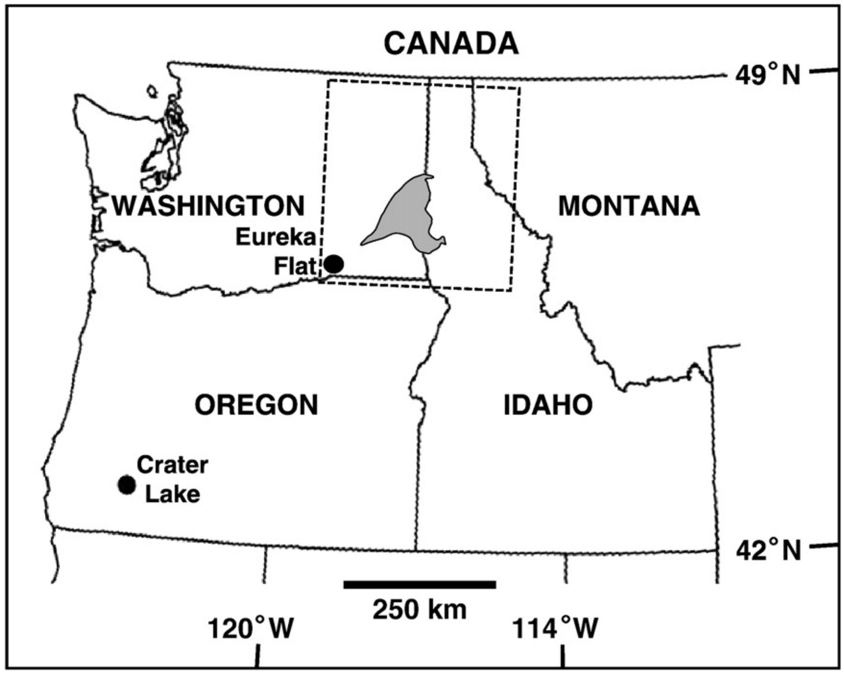

Fig. 1. General location map of the Pacific Northwest USA. Inset box with dashed line indicates general area of loess and volcanic ash mantles focused upon in this paper. Gray-shaded area is the core Palouse region; Crater Lake and Eureka Flat are sources of Mazama tephra and Palouse loess, respectively.

Lotspeich and Smith (1953) provided the first detailed mineralogical descriptions of major soils of the Palouse region. They found very fine sand and clay fractions sampled to approximately 3–4 m exhibiting gross mineralogical uniformity, suggesting little difference with depth; quartz and feldspar consistently dominated the sand and silt fractions. Little difference was seen in clay fractions either with depth or among soils; illite was the dominant clay mineral and traces of montmorillonite also reported (Lotspeich and Smith, 1953).

Despite forming in what might appear to be a relatively homogenous blanket of loess, soils of these landscapes can exhibit markedly different profile characteristics. Some of these differences and the pedogenic processes responsible for them are described by Lotspeich and Smith (1953), Rieger and Smith (1955), Busacca (1989), and Kemp et al. (1998). Landscape-scale models have been developed to aid in detailed mapping of the Palouse region of eastern Washington and northern Idaho (Donaldson, 1980; Barker, 1981). As an example, three different soils are mapped on a typical Palouse hill landform: Palouse soils occupy backslopes and have a thick (pachic) mollic epipedon overlying a cambic horizon; Naff soils have a relatively thin mollic epipedon overlying an argillic horizon; and Thatuna soils have an albic E horizon overlying a dense argillic horizon, and occupy steep, north-facing slopes that receive extra moisture from snow accumulation (Donaldson, 1980; Barker, 1981). Some of the mineralogical and landscape relationships associated with these soils will be examined in this paper.

1.2. Volcanic ash

An estimated 116 km^3 of tephra blanketed the Pacific Northwest region following the cataclysmic eruption of Mount Mazama (now Crater Lake) ca. 7600 years ago (Fig. 1) (Bacon, 1983; Zdanowicz et al., 1999). Because of the magnitude of this eruption and the large geographic extent of the ash fall, Mazama ash today mantles many landscapes of the Pacific Northwest region. Since deposition, it has undergone considerable redistribution. Today, Andisols (Andosols in WRB) are found primarily in mid- to high-elevation forested areas where forest canopy and litter layers have helped protected the ash from erosion and maintained a relatively thick mantle (McDaniel et al., 2005). At lower elevations, volcanic ash does not exist as a discrete mantle but is extensively mixed with other soil parent materials (Busacca et al., 2001; McDaniel et al., 2005). It is erratically found as relatively unweathered buried lenses of varying thicknesses in soils of depositional landscape positions. Many of these soils are classified as vitrandic, andic, vitrixerandic, and vitritorrandic subgroups in Soil Taxonomy, reflecting the reduced influence of tephra weathering products on soil properties (McDaniel et al., 2005; Soil Survey Staff, 2008).

Mazama tephra has a felsic composition, consisting of glass, plagioclase, hypersthene, hornblende, augite, and fluorite (Sarna-Wojcicki et al., 1983). Silicon and Al dominate the chemical composition of Mazama glass, together accounting for >87% of the mass when expressed on an oxide basis (McDaniel et al., 1997). Quantities of colloidal material present in soil horizons formed in Mazama ash mantles are typically small, suggesting relatively little weathering has taken place. Nevertheless, these horizons exhibit andic properties in the form of elevated levels of acid ammonium oxalate-extractable Si and Al, high P retention, and low bulk density. As such, the presence of Mazama ash mantles at least 30–36 cm in thickness results in the classification of these soils as Andisols (Soil Survey Staff, 2008) or Andosols (IUSS Working Group WRB, 2006).

In this paper we examine some of the mineralogical aspects of these two important eolian mantles in both regional and local-landscape contexts. Specific objectives include: (i) identifying major mineral components of soils formed in loess and volcanic ash; and (ii) examining some of the relationships between these minerals and their regional and local pedogenic settings.

2. Materials and methods

This study focuses on a broad geographical area of the inland Pacific Northwest region of the USA in which landscapes are mantled by loess or volcanic ash (Fig. 1). Mineralogical, physical, and chemical data from representative pedons of the region were obtained from various sources (Table 1). Some data were obtained from the United States Department of Agriculture — Natural Resources Conservation Service (USDA-NRCS) National Soil Survey Laboratory characterization database. Pedons contained in this database are sampled for