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Integrated loessite-paleokarst depositional system, early Pennsylvanian Molas Formation, Paradox Basin, southwestern Colorado, U.S.A.

James E. Evans *, Jason M. Reed [1]

Department of Geology, Bowling Green State University, Bowling Green, Ohio 43403, USA

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Abstract

Mississippian paleokarst served as a dust trap for the oldest known Paleozoic loessite in North America. The early Pennsylvanian Molas Formation consists of *loessite facies* (sorted, angular, coarse-grained quartz siltstone), *infiltration facies* (loess redeposited as cave sediments within paleokarst features of the underlying Mississippian Leadville Limestone), *colluvium facies* (loess infiltrated into colluvium surrounding paleokarst towers) and *fluvial facies* (siltstone-rich, fluvial channel and floodplain deposits with paleosols). The depositional system evolved from an initial phase of infiltration and colluvium facies that were spatially and temporally related to the paleokarst surface, to loessite facies that mantled the paleotopography, and to fluvial facies that were intercalated with marine-deltaic rocks of the overlying Pennsylvanian Hermosa Formation. This sequence is interpreted as a response to the modification of the dust-trapping ability of the paleokarst surface. Loess was initially eroded from the surface, transported and redeposited in the subsurface by the karst paleohydrologic system, maintaining the dust-trapping ability of the paleotopographic surface. Later, the paleotopographic surface was buried when loess accumulation rates exceeded the transport capacity of the karst paleohydrologic system. These changes could have occurred because of (1) increased dust input rates in western Pangaea, (2) rising base levels and/or (3) porosity loss due to deposition within paleokarst passageways.

Keywords: Loessite; Paleokarst; Terra rossa; Paleohydrology; Paleoclimatology

1. Introduction

Significant accumulations of silt-sized eolian sediment (dust or loess) require a source area, transport mechanism (prevailing winds of sufficient energy) and depositional mechanism (Tsoar and Pye, 1987). Traditionally, glaciated areas have been considered the major source of loess (Pye, 1987), but recent studies have shown that modern deserts provide significant dust loadings to surrounding areas (e.g., Nettleton and Chadwick, 1996). In modern deserts, production of significant amounts of loess is dependent on seasonal runoff, the concentration of weathering detritus (including silt) in dry washes or wadis, and then remobilization by wind (Yaalon and Ganor, 1973). The most effective dust transport mechanisms are high latitude frontal systems or low latitude monsoonal-influenced circulation systems (Soreghan, 1992).

* Corresponding author. Tel.: +1 419 372 2414; fax: +1 419 372 7205.
E-mail addresses: evansje@bgsu.edu (J.E. Evans), Jason.Reed@epa.state.oh.us (J.M. Reed).
[1] Present address: Ohio Environmental Protection Agency, 3232 Alum Creek Drive, Columbus, OH 43207, USA. Tel.: +1 614 728 3873.

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Because particles >20 μm are transported within the lowest few 10 s of meters of the atmospheric boundary layer, dust trapping is enhanced by topography, such as deposition in the lee of topographic features (Tsoar and Pye, 1987). Other effective dust traps are moisture and vegetation (Cegla, 1969), and infiltration into porous sediments (Pye, 1987), talus (Goossens, 1995) or rock fractures (Villa et al., 1995). After deposition, eolian silt may be remobilized by wind or surface water erosion, and also because of the high permeability of silt, subsurface erosion by groundwater piping or sapping can be a major mechanism of sediment redistribution (Bal and Buursink, 1976).

In western North America, late Mississippian (Visean or Meramecian) sea level fall (Ross and Ross, 1985; Veevers and Powell, 1987) exposed an extensive carbonate shelf sequence to a range of humid tropical to subtropical weathering conditions. Over the ensuing 34 m.y., a broad paleokarst plain developed, with >50 m paleorelief and an extensive network of subsurface paleocaves, sinkholes and fissures (DeVoto, 1980; Sando, 1988; Palmer and Palmer, 1995).

This paper focuses on how this late Mississippian paleokarst surface served as a dust trap for early Pennsylvanian loess. The presence of loess in the cave sediments and overlying the paleokarst surface documents significant paleoclimatic change between more humid conditions of the late Mississippian, and the increasing aridity and seasonality of the late Pennsylvanian–Permian megamonsoonal paleoclimate of western Pangaea. In addition, this study highlights the complex relationship between the dust-trapping ability of the paleokarst surface and the accumulation of the eolian sediments. To be specific, the maintenance of the dust-trapping system was dependent upon the ability of the karst paleohydrological system to erode, transport and redeposit the eolian sediment. Once the accumulation rates of loess exceeded the transport capacity of the paleohydrologic system, the depositional system infilled paleocave passages, buried the karst paleotopography, and transitioned upwards to a fluvial and marine-deltaic depositional system.

2. Background

2.1. Late Mississippian paleokarst

The Mississippian Leadville Limestone is found in the Paradox Basin, San Juan Basin, San Juan Mountains, Maroon Trough and Central Colorado Mineral Belt (Armstrong et al., 1992). In the study area in southwestern Colorado (Fig. 1), paleokarst features in the Leadville Limestone include tower karst (kegelkarst) with approximately 25 m relief (Maslyn, 1977), solution valleys (poljes) with 100–200 m relief (DeVoto, 1988), paleo-sinkholes (dolines), sediment-filled joints and fractures (grikes) and breccias (DeVoto, 1988; Hall, 1990). This paper also reports phreatic tubes, "breakout domes" (e.g., Loucks, 1999), surficial erosion surfaces (rillenkarren), probable solution pans (kamenitzas) and mosaic and crackle breccias (Fig. 2). Previous studies reported that speleothems are rare in the Central Colorado Mineral Belt (DeVoto, 1988; Tschauder et al., 1990). In contrast, our work has found that flowstone sheets, dripstones, stalagmites and cave pearls can be locally common in the study area. The history of paleokarst in the Leadville Limestone is complicated by an earlier episode of intraformational surficial karst several meters thick, overprinted by later events (DeVoto, 1988; Hall, 1990), several episodes of pre- and post-karst dolomitization (Beaty, 1985; Horton and DeVoto, 1990; Hall, 1990), late Paleozoic and Laramide (Cretaceous–Paleogene) hydrothermal alteration (Hall, 1990; Landis and Tschauder, 1990; Symons et al., 2000), and modern karst (Teller and Welder, 1983).

2.2. Red siliciclastic sediment

There are red siliciclastic sediments (previously described as shale, claystone or silty claystone) both within the Leadville Limestone and overlying it. The overlying unit was labeled the Molas Formation (Cross et al., 1904) and was interpreted as a terra rossa (residual) paleosol that was reworked upwards (Merrill and Winar, 1958). The Molas Formation is considered early Pennsylvanian (Bashkirian–Moscovian or Morrowan–early Desmoinesian) in age and varies from 0 to 30 m thick throughout the study area (Merrill and Winar, 1958; Armstrong et al., 1992). Revisions of the age and stratigraphy of the Molas Formation are given in Fig. 3 and discussed later in this paper.

Problems with the terra rossa interpretation were evident even to those who proposed it. There is <1% insoluble residue in the Leadville Limestone, requiring dissolution of >1500 m of carbonate to account for the thickness of terra rossa (Merrill and Winar, 1958). Compositional mismatches between the insoluble residue and red siliciclastic sediment were noted but explained as diagenetic (Merrill and Winar, 1958). The terra rossa explanation does not agree with observations that the Molas Formation can also be found overlying non-carbonate rocks (Baars, 1966). Merrill and Winar (1958) noted that significant accumulation of insoluble residue in pore spaces would have reduced flow rates necessary to form karst features. These and other related problems with the terra rossa explanation have been discussed elsewhere (Evans, 2002).

Based upon the dominance of quartz silt with hematitic kaolinite grain-coatings, we propose that the