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Terra Rossa catenas in Wisconsin, USA

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ABSTRACT

The soils in the unglaciated part of Wisconsin have a loess cover over sedimentary rock, mostly dolostone of Ordovician age. The dolostone has weathered and produced layers of red clay or *Terra Rossa*. We have sampled 144 pedons of 16 catenas with different slope aspects and curvatures in a 70 km^2 area. Half of all the pedons had a red clay subsoil (mostly 5YR 3/4) and had on average over 40% clay. The mean thickness of the loess above the red clay was 50 cm but it ranged from 7 to 130 cm. The thickness of the red clay ranged from 4 cm to 60 cm with an average thickness of 25 cm. The red clay was found in every part of the landscape except the valley bottoms: it was present in soils on summits, shoulders, backslopes, and footslopes. The red clay is only found over dolostone, but not present on all dolostone ridges. It was concluded that there is large variation in the *Terra Rossa* soilscapes of Wisconsin and this variation can only partly be explained by topography.

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1. Introduction

Terra Rossa is a term given to reddish, clay-rich soil occurring on hard carbonate bedrock (Durn, 2003) and the first reference to these characteristic soils dates back to 1848 (Joffe, 1936). The red color is due to the formation of hematite and these soils generally have mixed clay mineralogies (Boero and Schwertmann, 1989). They are often found in areas with Mediterranean climates (Spain, France, Italy, Portugal, Greece, Bulgaria, Romania, Croatia, Slovenia, Turkey, Israel, and Jordan), but have also been described in Australia, Bermuda, China, Indonesia, Ireland, Jamaica, Japan, Mexico, Russia and the Tibetan Plateau among others (Bautista et al., 2011; Feng and Zhu, 2009; Glazovskaya and Parfenova, 1974; Herwitz et al., 1996; Maejima et al., 2005; Mee et al., 2004; Mella and Mermut, 2010; Muhs and Budahn, 2009; Smith and McAlister, 1995).

The origin of *Terra Rossa* has been widely debated (Joffe, 1936) but the classic theory is that these soils are formed *in situ* from carbonate dissolution and the weathering of insoluble material. The carbonates are dissolve by chemical weathering until only insoluble components remain, which become the parent material for the soil (Foster et al., 2004; Gal, 1966; Mella and Mermut, 2010; Moresi and Mongelli, 1988). Large amounts of carbonate weathering may be needed and the input of aeolian particles has been found to comprise considerable parts of *Terra Rossa* soils in the Mediterranean regions (Yaalon, 1997), parts of Australia (Mee et al., 2004), Greece (Macleod, 1980) and in Croatia (Wroblewski et al., 2010).

In the USA, *Terra Rossa* soils have been described in several states: Texas (Cooke et al., 2007; Rabenhorst and Wilding, 1986), Illinois (Ballagh and Runge, 1970), Maryland (Bourgault and Rabenhorst, 2011), Indiana (Olson et al., 1980; Shunk et al., 2009) and Wisconsin (Frolking, 1978; Knox et al., 1990; Stiles and Stensvold, 2008). Studies of *Terra Rossa* in Wisconsin have reported a wide range of depths at which it occurs and a range of thicknesses of the red clay. In part such differences are due to large spatial heterogeneity caused by irregular weathering of the limestone followed by soil erosion and other landscape processes (Frolking et al., 1983). Detailed knowledge about the clay subsoil is of importance as the clay acts as a cap over the limestone and influences water and solute movement through the landscape.

This study focuses on *Terra Rossa* catenas in parts of the unglaciated regions or Driftless Area of Wisconsin, USA. The objectives of our research were to assess where such soils occur in the landscape, at what depth the clay is found, and its thickness. We hypothesized that the catena approach is a useful concept for studying the *Terra Rossa* as soils along a hillslope are related through physical processes, explicitly linking the landscape and the soil (Brown and Olson, 1950; Brown and Thorp, 1942; Dan and Yaalon, 1971; Swanson, 1985). Soil sampling along catenas has been done in several recent studies (e.g. Odgers et al., 2008), but to our knowledge the catena concept has not been applied to study the *Terra Rossa* in the Driftless Area of Wisconsin. In our study, a total of 144 pedons was sampled of 16 catenas.

2. Materials and methods

2.1. The study area

The Driftless Area of Wisconsin is a region of stream-dissected uplands in the southwest part with an area of about 41,000 km^2 (Hole, 1976). It has not been glaciated within the Quaternary period.

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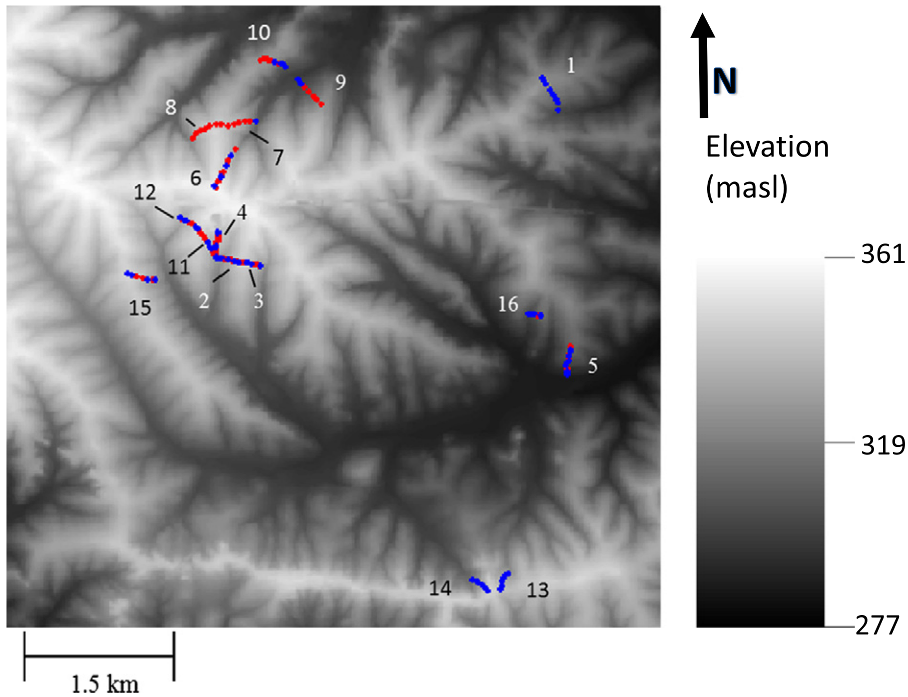

Fig. 1. Location of the 16 catenas and 144 pedons. Red dots indicate the presence of *Terra Rossa* (red clay), blue dots indicate the absence. DEM image (10 m resolution) of the study area near Verona, Wisconsin.

The unglaciated area extends into Minnesota, Iowa, and Illinois, but the greatest extent is found in Wisconsin. The study was conducted in a 70 km^2 area near Verona in Dane County, South central Wisconsin (Evans and Hartemink, 2014). The land use of the study area is primarily agriculture, with maize, soya and alfalfa as the most common field crops. The present climate of the Driftless Area is characterized by warm, moist summers and cold, drier winters. The mean annual precipitation is 857 mm, and for July, the wettest month, the precipitation averages 104 mm and the driest month, January, averages 20.8 mm. The mean annual temperature is 7.3 °C, while the warmest month, July, averages 21.7 °C, and January the coldest month averages −9.7 °C.

The bedrock underlying the Driftless Area of Wisconsin consists of nearly horizontal beds of sedimentary rocks, primarily sandstone and dolostone of Ordovician age, with some shale. The dolostone generally forms the ridges with the less resistant sandstone and shale occurring on the slopes and underneath the valley fill (Slater and McSweeney, 1992). The insoluble content of the dolostone is about 8 to 10% (Frolking, 1978).

In the Driftless Area, loess covers much of the landscape. The loess is from large outwash plains of the glaciers and rivers that would dry up or shrink seasonally and deposit some of their load (Hole, 1976). The prevailing wind direction was from the west, as it is today, and so the depth of the loess is the thickest, up to several meters, and the coarsest near the Mississippi in the west of the state, and thins to only a few centimeters in the east. The Driftless Area was affected by a periglacial climate and erosional processes during the last ice age that ended about 12,000 years ago. The periglacial conditions caused mass wasting and hillslope erosion due to solifluction and sheet wash and these processes reduced the depth of loess on side slopes. Much of the colluvial material was removed by alluvial activity and transported downstream after the glaciers receded. The dissected nature of the Driftless Area is attributed to erosion activity during the Pleistocene epoch.

2.2. Soil sampling and analysis

We have made 144 pedon observations along 16 catenas in June–August 2012 (Fig. 1). Catenas were selected based on slope and aspect, and the sampling interval between pedons was determined by the length of the catena and the elevation difference between the top and bottom sampling points. At each sampling point, information was collected on landscape and soil properties, including the presence of red clay, the depth of the red clay, and the thickness of the loess and the solum. The observations were made using a 7 cm Edelman auger. The average depth of the solum was 46 cm (±25 cm); where the clay was found the thickness was on average 23 cm (±14 cm) (Evans and Hartemink, 2014). Samples were taken from each soil horizon and color was determined by standard Munsell color chart.

Table 1
Characteristics of the 16 sampled catenas in a 70 km^2 area of the Driftless Area of Wisconsin, USA. Mean thickness of red clay layer in cm (±1 standard deviation).

Catena	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Number of pedons	8	13	10	17	13	9	8	5	7	10	11	9	6	6	7	5
Number of pedons with *Terra Rossa*	0	7	6	12	5	5	7	5	5	6	6	4	0	0	3	1
Aspect	SE	W	E	S	S	NE	E	W	NW	W	SE	W/NW	N/NW	NW	E	W
Avg. slope (%)	7	11	11	8	6	9	12	11	8	13	8	10	9	17	9	10
Elevation difference (m)	22	20	29	18	23	30	36	18	28	24	22	14	11	28	22	11
Length (m)	320	185	185	250	270	370	320	210	330	240	290	200	150	170	280	130
Sampling pedon interval (m)	30	15	20	20	30	50	50	50	45	15 to 30	40	20	30	30	50	30
Thickness of red clay (cm ± SD)	0	21 ± 15	27 ± 14	21 ± 13	11 ± 6	27 ± 18	19 ± 4	40 ± 14	15 ± 5	17 ± 17	41 ± 19	29 ± 20	0	0	28 ± 16	35