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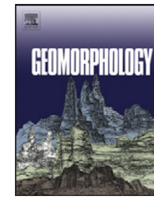

Clay mineralogical evidence of a bioclimatically-affected soil, Rouge River basin, South-Central Ontario, Canada

W.C. Mahaney

Quaternary Surveys, 26 Thornhill Ave., Thornhill, Ontario L4J1J4, Canada
Department of Geography, York University, 4700 Keele St., N. York, Ontario M3J1P3, Canada

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ABSTRACT

Holocene soils in drainage basins of South-Central Ontario, Canada, are generally Fluvisols (Entisols) in floodplains transitioning to Brunisols (Inceptisols), Luvisols (Alfisols) and Podzols (Spodosols) in older terraces and in the glaciated tableland. A single landslide sourced from the highest fluvial terrace in the Rouge basin, with a rubble drop of ~12 m emplaced a lobe-shaped mass of reworked stream gravel, glaciolacustrine sediment and till, emplaced approximately 6 m above mean water level at a height roughly equivalent to previously dated mid-Holocene terraces and soils. Clay mineralogy of the soil formed in this transported regolith produced the usual semi-detrital/pedogenic distribution of 1:1 (Si:Al = 1:1), 2:1 and 2:1:1 clay minerals as well as primary minerals consisting of plagioclase feldspar, quartz, mica and calcite. Unexpectedly, the presence of moderate amounts of Ca-smectite in the Bk and Ck horizons, relative to a clay-mineral depleted parent material (Cuk), argues for a soil hydrological change affecting the wetting depth in the deposit. The presence of the uncommon 'maidenhair fern' (*Adiantum pedantum*) in the mass wasted deposit, a plant capable of high evapotranspiration, is interpreted as producing a bioclimatic disruption limiting soil water penetration to near root depth (wetting depth), thus producing a clay mineral anomaly.

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1. Introduction

In local catchments of South-Central Ontario (Fig. 1A, B) the evolution of floodplain soils to terrace soils follows a progression from Ck/Cuk to Ahk/Ck/Cuk (Regosol) profiles in the floodplain to more complex soils in higher and older terraces developing either Ah/Bm/Bk/Ck/Cuk (Brunisol), Ah/Bt/Ck/Cuk (Luvisol), and occasionally under pine forest L/E/Bh/Ck/Cuk (Podzol) profiles which deepen with time. In the US taxonomic soil system (NSSC, 1995), Regosols in the Canadian system (CSSC, 1998) key out as Entisols, Brunisols as Inceptisols, Luvisols as Alfisols and Podzols as Spodosols. Entire profiles in the Rouge catchment reach ~1.0 m depth developing over ~11 ka which, given well-dated fluctuations of Glacial Lake Iroquois (Jackson et al., 2000; Mahaney et al., 2014), is the maximum age for any riverine profiles in the area. Aside from occasional ^{14}C dates on younger floodplain soils, the entire soil evolutionary sequence has been dated by relative dating (RD) methods including pebble/sand weathering characteristics, topographic position and soil stratigraphy (Mahaney and Sanmugadas, 1986; Mahaney and Hancock, 1993a,b; Mahaney et al., 2014). Changing profile morphology over time brings staged removal of calcite from soil epipedons over time, slow increase in concentrations of extractable cations and C/N ratios, increases in Fe_d/Fe_t (dithionite extractable/total Fe) (Mahaney and Sanmugadas, 1986; Mahaney and Hancock, 1993a) along with slow conversion of illite/mica to both chlorite and vermiculite. Randomly interstratified illite–smectite and occasional kaolinite and metahalloysite are not authigenic, the former is considered to be inherited from Ordovician shales, the latter from previous interglacial paleosols eroded by incoming ice during Wisconsinan-age ice advances (Mahaney and Ermuth, 1975; Mahaney et al., 2014). However, despite the high ratio of carbonates:silicates (approximately 80:20%) in fluvial sediment, chloritization of illite and slow genesis of vermiculite in middle to Early Holocene profiles (Mahaney and Sanmugadas, 1986) are documented in the basin. Clay mineral genesis is accompanied by degradation of plagioclase and mica, very minor decrease in quartz, and in horizons with lower pH, near complete removal of calcite.

Stratigraphically similar soils in several catchments of south-central Ontario contain randomly interstratified illite–smectite inherited from Ordovician shales but lack 'free' smectite in any quantity. Wetting depth in middle to Early Holocene fluvial soils in the region, estimated from root depth and thickness of B horizons (Mahaney and Sanmugadas, 1986), allows the throughput of soil moisture sufficient to remove smectite. Thus, the presence of moderate to large amounts of smectite in a soil stratigraphically similar to other Middle and Early Holocene soils in the basin with pedons lacking expandable clay minerals, invokes a means of explaining its genesis. Of all the soil forming factors (Birkeland, 1999)—climate, biota, topography, lithology and time—only biota and soil climate are the two variables that could

E-mail address: arkose@rogers.com.

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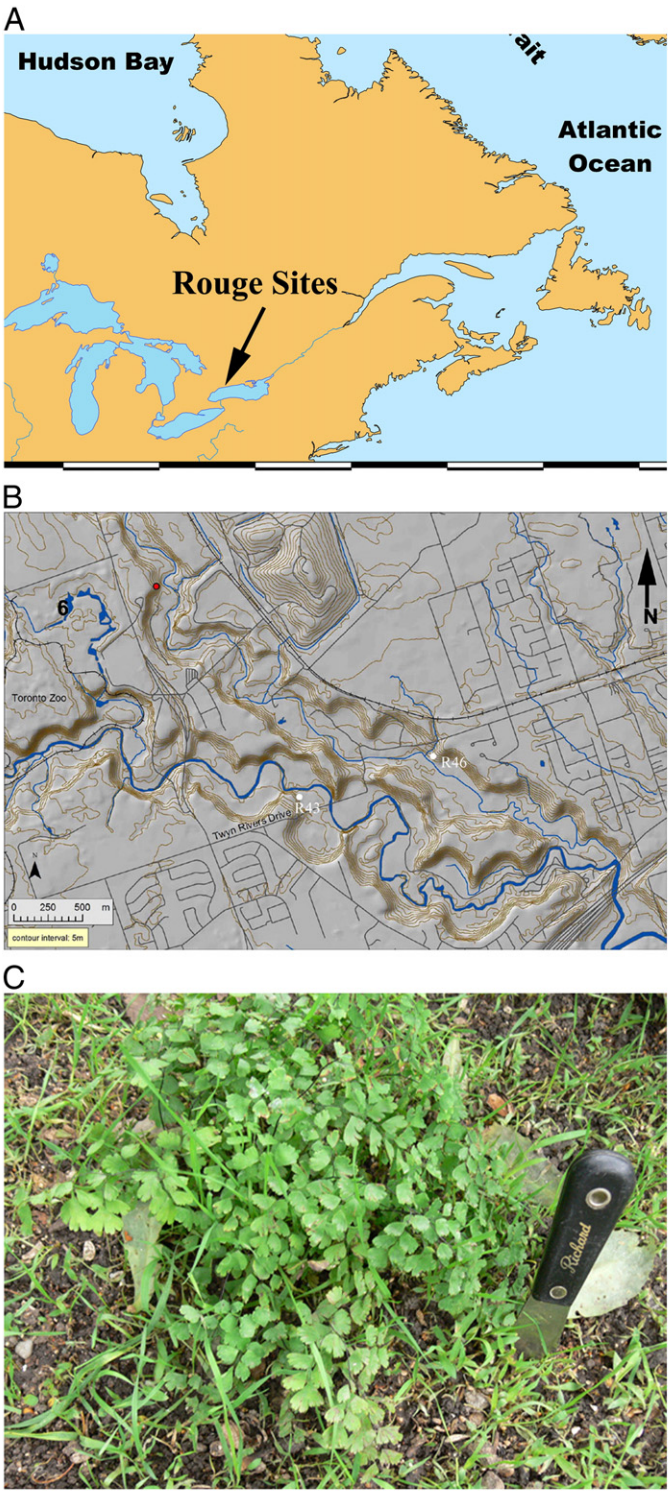

Fig. 1. A, location map of the field sites in southern Ontario based on GIS data (after Mahaney et al., 2014); b, Topography of the landslide (R43) and 8 m terrace section (R46) in the Rouge River Catchment; C, Maidenhair fern (*Adiantum pedantum*).

intervene to offset the throughput of meteoric water into the soil system. The only biotic element present on the landslide mass is the maidenhair fern (*Adiantum pedantum*) (Fig. 1C), an uncommon plant in the drainage, and a species preferring wet/shaded, coarse sandy habitat with a known positive effect on evapotranspiration (Jones, 1987; Paris and Windham, 1988; Cody and Britain, 1989). It is the relationship between the presence of this fern and the clay mineral composition of the resident soil (R43), compared with an equivalent pedological standard (R46), that is explored here. A regional study like this is important since it adds to the bioclimatic literature first introduced by Jenny (1941) and this may well be the first time in the literature that clay genesis has been shown to be related to fluctuating soil moisture regulating certain aspects of soil chemistry, in all likelihood caused by a hydrophilic fern, with possible applications elsewhere.

2. Regional geology and field area

The Rouge River and Little Rouge Creek basins of South-Central Ontario (Fig. 1B) drain across till-encrusted Ordovician shales of the Whitby formation, a gray to black noncalcareous shale (Liberty, 1955, 1964). Quaternary deposits mask most of the shale with most information derived from well logs and a prominent outcrop near Twyn Rivers Drive on Little Rouge Creek (Fig. 1B), 3 km north of Lake Ontario.

The mean annual temperature in the area is 7 °C, with extremes of −34 °C and 40 °C. Mean annual precipitation is 860 mm and mean annual actual evapotranspiration is 530 mm (Brown et al., 1968; Phillips and McCulloch, 1972) yielding a mean annual water surplus of 330 mm. Hence, the climate is humid with sufficient soil water available for leaching. Available soil moisture in the basin is unknown and can only be estimated from solution of carbonate in Ah/B horizon complexes, followed by precipitation of carbonate in C horizons, as an estimate that normal leaching is capable of throughput of moisture mostly to at least root depth (ca. 50 cm). In the R43 profile discussed here this depth is greatly reduced to, at most, a few cm— a response to the presence of a hydrophilic fern capable of reducing soil water to slow leaching allowing the genesis of Ca-smectite.

More recent data obtained from the Ministry of the Environment (1984) averaged from broad regions along the north shore of Lake Ontario provide mean climatic data as follows: mean annual precipitation (MAP)— 900 mm, mean evaportranspiration (AE) —550 mm, runoff— 250–300 mm, and snowfall —100–150 mm. These values are approximate and while similar to previously recorded climatic data, the latter increase in precipitation and evapotranspiration presumably reflects global warming.

The mean water surplus calculated at 330 mm is probably declining somewhat with recent warming but sufficient to provide soils at or beyond field capacity most of the year. The sandy to silt loam textures of the R43 and R46 profiles normally yield about ~5% water content.

3. Materials and methods

The R43 profile was excavated to expose fresh material. All samples were collected from a profile face cleaned back 10–15 cm. Soil descriptions follow guidelines set out by the Canada Soil Survey Committee (1998) and Birkeland (1999). Correlations with the US soil taxonomic system are made using the guidelines of the Soil Survey Staff (NSSC, 1995) for comparative purposes, for example, Ah = A, Bm = Bw. The Cu horizon relates to fresh, unconsolidated and unweathered (cf. 'u' material; Hodgson 1976). Therefore, soil description and stratigraphy presented here are similar to what was discussed in Mahaney and Sanmugadas (1986). Soil color assessments are based on Oyama and Takehara (1970) soil chips. At least 500 g samples were collected at the sites to allow for particle size, clay mineral, and chemical analyses. These were used for laboratory work including particle size analysis following procedures outlined by Day (1965), and chemical extractions outlined below. Samples were wet sieved to separate sands from clay and silt. The clay fraction was analyzed by hydrometer following a method described by Mahaney (1990). Soluble salts were measured by electrical conductivity (Bower and Wilcox, 1965) and pH by electrode in a 1:5 solution of distilled water. Calcium carbonate was determined by acid dissolution of carbonate and measurement of evolved CO_2 (Nelson, 1982). Organic carbon was measured following procedures of Walkley and Black (1934) using the Degtjareff method and total nitrogen by the Kjeldahl method (Bremner, 1965).

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