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Composition, micromorphology and distribution of microartifacts in anthropogenic soils, Detroit, Michigan, USA

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ABSTRACT

The composition, micromorphology and distribution of microartifacts in anthropogenic soils were studied as part of a project that was evaluating the utility of geophysical surveying techniques for mapping vacant urban land. Petrographic criteria for the identification and classification of microartifacts (MAs) were generated using a set of 25 different types of reference artifacts of known origin, and then tested on a suite of 20 urban topsoils from sites in Detroit, Michigan representing three different land use types (residential demolition, undemolished residential, and industrial). Petrographic and X-ray diffraction analyses showed that reference MAs may be classified into five basic compositional types (carbonaceous, calcareous, siliceous, ferruginous and miscellaneous). Reference MAs were generally distinguishable using optical microscopy by color, luster, fracture and microtexture, and further differentiable using scanning electron microscopy and energy-dispersive X-ray spectroscopy. MAs were found in all of the anthropogenic soils studied, but in highly variable proportions (<15% to >80%). Coal-related wastes were the most common types of MAs, and included unspent coal, ash (microspheres, microagglomerate), cinders and burnt shale, probably representing a legacy from the coal-burning era (~1850–1936 AD). These were associated with MAs derived from waste building materials (brick, mortar, glass), and manufacturing wastes (iron-making slag, coked coal), in demolition and industrial site soils, respectively. Urban soils impacted by airborne deposition of fly ash were widespread, including conspicuous black (10YR2/1) topsoils at undemolished residential sites located near railroads and areas of heavy industrial activity. Coal combustion products and iron-smelting slag had distinctive compositions that included magnetite-bearing aluminosilicate glass. These results support our hypothesis that there are systematic relationships between soil geophysical properties, type and abundance of microartifacts, and land use history. Hence, it seems likely that magnetic susceptibility surveying and other geophysical methods will facilitate the mapping of soils in urbanized areas.

1. Introduction

The traditional method of mapping involves delineating soils based on landscape position, and profile characteristics ascertained with a hand auger or in a hand-dug pit. This approach is difficult to apply in heavily urbanized terrain because anthropogenic soils often contain rock-like artifacts (objects of anthropogenic origin) that are difficult to penetrate with a hand auger or a shovel (Howard and Olszewska, 2011; Howard et al., 2013a,b; Howard and Shuster, 2015). It is possible that the traditional method can be augmented by non-invasive, geophysical surveying using surface probes, but this approach has not yet been proven to be effective on urban soils. In a previous study, we found that the electrical conductivity (EC) and magnetic susceptibility (MS) signatures of soils were significantly impacted by different types of microartifacts (Howard and Orlicki, in press). We attributed these geophysical characteristics to compositional differences, but mineralogical data were sparse for many types of artifacts. We also found that the EC and MS signatures of soils were affected even when only a small quantity (<5–10 wt.%) of microartifacts was present. However, the nature and geographic distributions of microartifacts generally found in urban soils were poorly known.

The purpose of this study was to better constrain the compositions and distributions of microartifacts in urban soils, and their EC and MS characteristics. We tested the hypothesis that there are systematic relationships between soil geophysical properties, type and abundance of microartifacts, and land use history. If so, we expect to be able to map urban land more efficiently with geophysical methods using land use history as a guide to ascertaining the geographic distribution of microartifact assemblages. We anticipate being able to not only distinguish between anthropogenic and native soils in urbanized terrain, but also amongst different types of anthropogenic soils. In this study, we investigated anthropogenic soils derived from Alfisols in a cool, humid-temperate climate. The study area was Detroit, Michigan, which has a long history of industrialization. We first assembled a collection of reference artifacts, and determined the compositions of

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selected types using optical petrography and X-ray diffraction analysis. We used the reference materials to develop a set of micromorphological criteria for the identification of microartifacts. We then tested the method on urban soils associated with different land use types using optical and scanning electron microscopy, and energy-dispersive X-ray spectroscopy. In this paper, we synthesize compositional data to formulate an artifact classification system, and discuss the possible implications of microartifact assemblages and compositions for geophysical mapping. This study is timely, given that there is currently great interest in mapping urban soils.

2. Materials and methods

2.1. Terminology

In this paper, “anthropogenic particles” are artifacts of any size, whereas the terms “artifact” and “macroartifact” are used interchangeably for any object >2 mm in size that was produced, modified, or transported from its source by human activity (Dunnel and Stein, 1989; IUSS Working Group, 2006; Schoeneberger et al., 2012; Soil Survey Staff, 2014). “Microartifacts” are 0.25 to 2.0 mm in size (Dunnel and Stein, 1989; Rosen, 1991; Sherwood, 2001), and “microparticles” are <0.25 mm in size. “Charcoal” is charred wood produced by oxycombustion. Anthropogenic particles produced by iron smelting are called “ferruginous slag” and “glass slag”, whereas those produced by coal combustion are called “cinder” and “ash.” “Microspheres” are any type of spherical microparticle, “cenospheres” are hollow microspheres, and “pleurospheres” are hollow microspheres containing other smaller microspheres. “Concrete” refers to a lime-based material unless otherwise indicated. Human-altered material (HAM) is defined as parent material for a soil that has undergone in situ mixing or disturbance by humans. Human-transported material (HTM) is defined as parent material for a soil that has been moved horizontally onto a pedon from a source outside of that pedon by human activity, usually with the aid of earthmoving equipment (Soil Survey Staff, 2014). Hence, an anthropogenic soil is defined as a soil that has formed either in HAM or HTM.

2.2. Geologic setting

Detroit is located along the Detroit River adjacent to Windsor, Ontario, Canada (Fig. 1). The city lies on a glaciolacustrine lowland of late Wisconsinan age underlain by weakly stratified clayey diamicton and a discontinuous capping of sand or gravelly sand usually <1 m thick (Howard, 2010). The climate is mesic, with a mean annual temperature of 9 °C (49 °F), 99 cm yr^{-1} of precipitation, and a frost line at 107 cm depth. Native soils in Detroit are generally somewhat poorly drained Aqualfs developed in sandy (Metamora Series) or clayey diamicton (Blount Series) lacustrine sediments with a solum 70 to 75 cm thick (Larson, 1977). The Metamora soil (Udollic Ochraqualf) has a sandy loam epipedon over gleyed and mottled subsoil, containing a prominent lithologic discontinuity at variable depths, depending on thickness of the lacustrine sand capping. The Blount soil (Aeric Ochraqualf) has a loamy epipedon over gleyed and mottled, silty clay to clay subsoil. These native soils are characterized by leaching of carbonate from the solum, and conversion of clay-sized chlorite to vermiculite in A horizons (Howard and Olszewska, 2011; Howard et al., 2012).

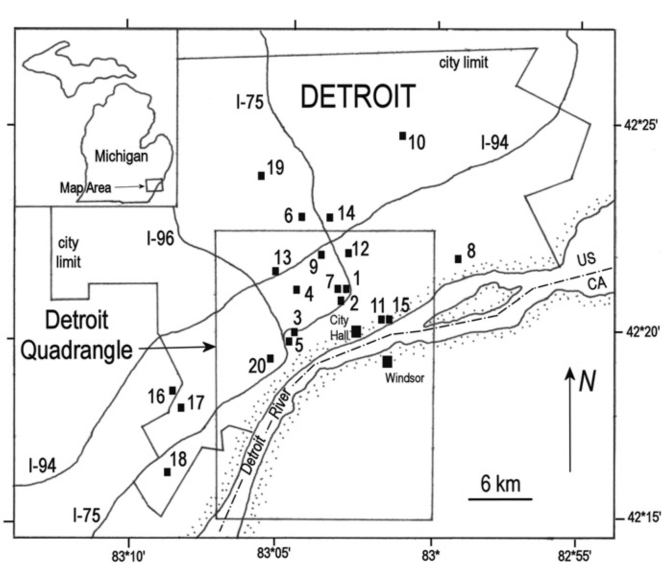

Fig. 1. Study area in the Detroit, Michigan 7.5 min topographic quadrangle, and surrounding areas, showing locations of anthropogenic soils sampled.

The land directly beneath Detroit is composed almost entirely of anthropogenic surficial deposits of mixed earthy fill in which artifacts are widespread. Weakly developed soil profiles have formed in these fill deposits locally where they lie beneath lots created by building demolition that have remained vacant for many decades (Howard and Olszewska, 2011; Howard et al., 2013a). The anthropogenic soils studied are classified primarily as Anthropic or Anthroportic Udorthents, according to Soil Taxonomy (Soil Survey Staff, 2014), or as Technosols using the World Reference Base (IUSS Working Group, 2006). Detroit is mostly residential land (including schools, churches and small commercial businesses). Residential land in the inner city is a mosaic of demolished and undemolished building sites underlain by deposits of HTM produced by multiple demolition cycles, and composed of material often dating from the 19th century. Residential land in the outer city is a similar mosaic, but undemolished buildings overlie relatively undisturbed native soils, and demolition site soils contain artifacts mainly from the 20th century. Small areas of Park Land and Cemetery Land are scattered throughout Detroit, and there are extensive areas of Industrial Land (current or former) concentrated along railroads, especially in the lower River Rouge basin near its confluence with the Detroit River.

2.3. Reference artifacts

The reference materials used in this study were anthropogenic particles of known origin obtained locally from demolition sites, derelict buildings awaiting demolition, and other miscellaneous sources (Table 1). Artifact compositions are based on compilations from the literature. If published data were not available, petrographic compositions were determined by transmitted light microscopic analysis of thin sections stained for calcite, or X-ray diffraction (XRD) analysis of finely ground samples using a Bruker Phaser II diffractometer equipped with a LYNXEYE detector. Reference materials were produced by sizing with a jaw crusher, and collecting the >2 mm, 0.25 to 2 mm (medium to very coarse sand) and 90 to 150 μm (very fine to fine sand) fractions by wet sieving. The petrographic features of microartifacts (0.25 to 2 mm) were characterized with a binocular microscope using the criteria explained in Supplementary Table 1. Microparticles of iron-smelting slag, coal, and coal-ash were collected by hand-picking under a binocular microscope, coated in gold, and analyzed by scanning electron

Table 1
Origin and types of anthropogenic particles examined in this study.

Origin	Type of anthropogenic particle
Coal-related wastes	Unspent coal, cinders, ash, burnt shale
Waste building materials	Wood (lumber), charcoal, asphaltic concrete, lime concrete, mortar, cinder block, lime brick, ceramic brick, other ceramics (pipe, tile, etc.), window glass, nails, drywall
Industrial wastes	Coked coal, glass slag, ferruginous slag
Archeological materials	Ceramic pottery sherds, bottle glass, bone