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Micromorphological and physico-chemical analyses of cultural layers in the urban soil of a medieval city — A case study from Krakow, Poland

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ABSTRACT

This study assessed the impact of human activity on the properties of urban soils and the formation of cultural layers (CLs) over several hundred years by examining the micromorphological, physical and chemical features of those soils. The study relied on a soil profile exposed during archaeological excavations carried out in the Main Market Square (MMS) of Krakow, Poland, in 2007. Two parts of the profile were distinguished. The upper section of the soil profile was composed of 13 cultural layers, while the base layer was composed of macroscopically unchanged natural soil. CLs with similar soil textures clearly differed from the natural horizons (NHs), exhibiting higher organic carbon (C_{org}), total nitrogen (Nt), $CaCO_3$ and available phosphorus (P_{Ol}) levels. The ranges of CL C_{org}, N_t, $CaCO_3$ and P_{Ol} levels are 14.3–118 $g \cdot kg^{-1}$, 1.1–10.6 $g \cdot kg^{-1}$, 10.5–79.0 $g \cdot kg^{-1}$ and 163–510 $mg \cdot kg^{-1}$, respectively, while NH levels are 0.39–5.5 $g \cdot kg^{-1}$, 0.13–0.54 $g \cdot kg^{-1}$, 1.2–2.5 $g \cdot kg^{-1}$ and 50.1–214 $mg \cdot kg^{-1}$, respectively. CLs were characterised by lower pH values compared to NHs. An A horizon Development Index (ADI) was used to assess the degree of advancement of pedogenesis in the different layers. Additionally, correlation coefficients between ADI and the P_{Ol} content, as well as between ADI and the C_{org} content, were calculated.

A micromorphological assessment revealed differences between the structural makeups, voids and $c/f_{5\ \mu m}$-related distributions of CLs and NHs. A greater number of artefacts were found in CLs compared to NHs, including fragments of bones, ash and black carbon (BC). The presence of artefacts decreased gradually in the buried soil horizons, giving way to BC, which is the most stable organic compound found in soil. The study also demonstrated the role of CL in the storage of organic carbon stocks in urban soils.

1. Introduction

Urban soils are formed through the transformation of natural soil cover under specific conditions and are the result of human activity (Lehmann, 2006; Golyeva et al., 2014). Over the centuries, the settlement process and human activities have changed the properties of many natural soils. Cultural layers (CLs) above the first natural horizon (NH) (Mažeika et al., 2009; Shaw et al., 2010; Golyeva et al., 2014) or between NHs (Dolgikh and Alexandrovskiy, 2010) are an indicator of anthropogenic impacts on the soil environment. CLs typically occur when the natural soil profile is covered by alien material.

CLs provide a record of the evolution of the urban landscape. In addition, the study of CLs in urban soils allows to explicate their pedogenesis over a specified period of time (Alexandrovskaya and Alexandrovskiy, 2005; Dolgikh and Alexandrovskiy, 2010). Studies of the soil material originating from CL also allow the reconstruction of anthropogenically influenced soil formation histories, an analysis of the degree of interaction between humans and the soil environment and an assessment of the degree of soil contamination and changes induced by human activity (Vasenev et al., 2013). Under urban conditions, CLs are characterised by varying levels of thickness; the deepest deposits can reach up to several metres. The depth of a CL is closely related to the type of human activity conducted and the period of settlement at a specific site, as well as the degree of OM stabilization (Howard et al., 2013).

Compared to naturally originating horizons, CLs are usually characterised by considerable carbon and nitrogen enrichment (Alexandrovskaya and Alexandrovskiy, 2005; Lorenz and Kandeler, 2005; Golyeva et al., 2014), as well as the higher C/N ratio (Alexandrovskaya and Alexandrovskiy, 2005).

The organic carbon content in urban soils usually varies spatially and within each profile (Lorenz and Kandeler, 2005). The presence and share of carbon in CL is a measure and expression of the impact of human activity (Pawlikowski and Such, 2009; Sándor and Szabó, 2014). Urban soils are usually characterised by the visible presence of charred organic carbon (black carbon, BC). BC is defined as the incorporation of incompletely combusted biomass or fossil fuels into the soil (Schmidt and Noack, 2000; Liu et al., 2011; Brodowski et al., 2005; Lorenz et al., 2010; Ghosh et al., 2012; Heitkötter and Marschner,

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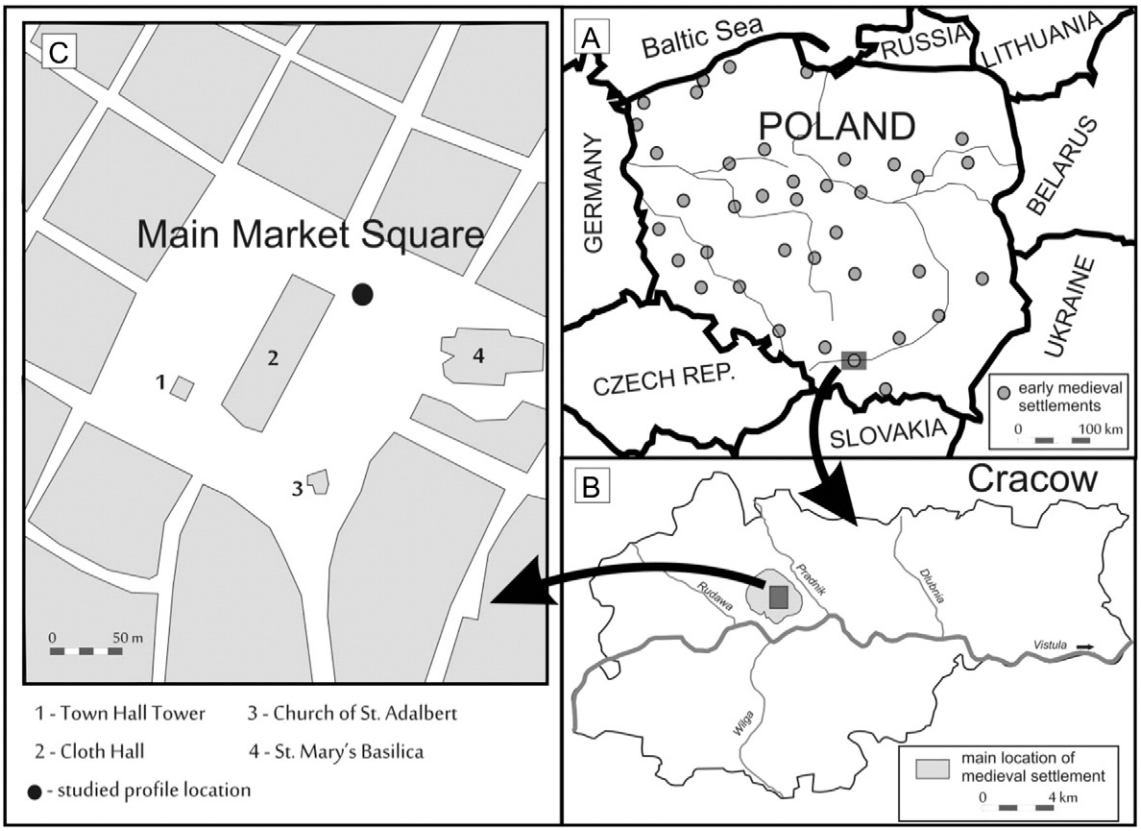

Fig. 1. Medieval settlement locations in Poland and sampling area. A — most important settlement centres in Poland in the eleventh century (GUS, 1994); B — Map of Krakow with location of dense building complex in the Middle Ages (Bańcik, 2013); C — location of the studied profile between current buildings in Krakow's Main Market Square.

2015). Identifying the BC content in relation to overall carbon content in a soil profile allows one to evaluate the effects humans in the pedogenesis process (Baumgardner et al., 2002; Rumpel et al., 2006; He and Zhang, 2009). A characteristic of BC is that it is highly stable within the organic components of soil OM over many years and even centuries (Schmidt and Noack, 2000; Lorenz and Lal, 2010).

The pH values in CLs vary and are higher compared to those in NHs. This is due to the anthropogenic origin of materials such as those used in construction and containing CaO or $CaCO_3$ (Alexandrovskaya and Alexandrovskiy, 2005; Alexandrovskiy et al., 2012; Golyeva et al., 2014). The phosphorus content and its relation to the carbon content in soils may be considered a determinant of human activity in the formation of CL (Konecka-Betley and Okołowicz, 1998; Zhang et al., 2001). There is usually high phosphorus accumulation in CLs (Engovatova and Golyeva, 2012). Phosphorus in urban soils is considered an important indicator of anthropogenesis due to its stability

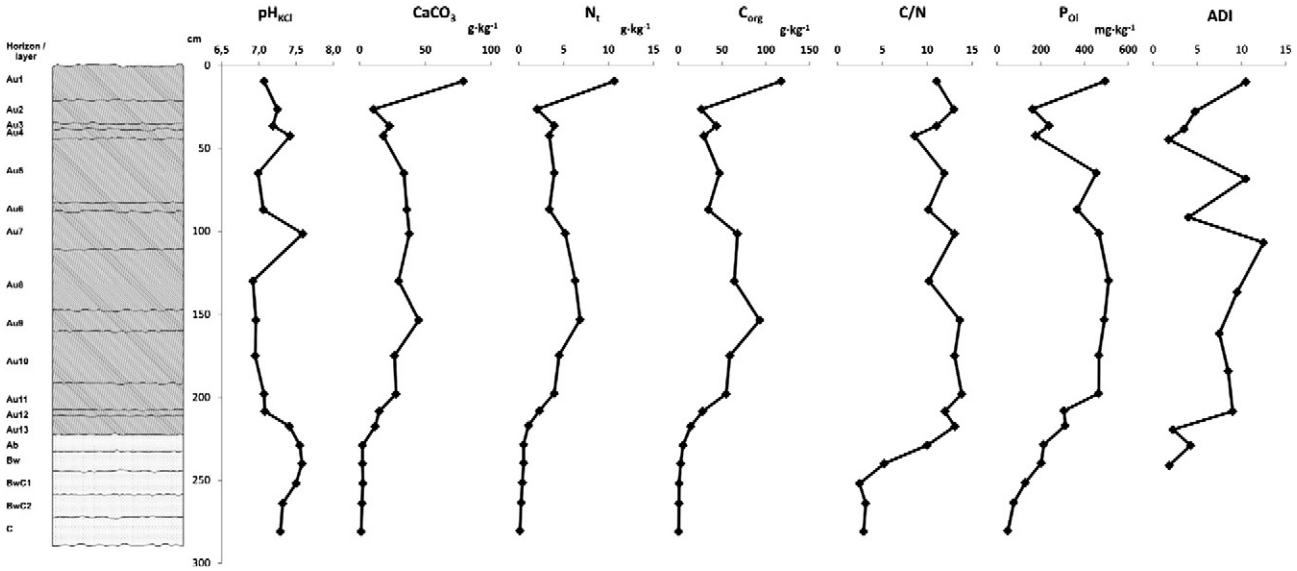

Fig. 2. Studied soil profile and selected CL and NH properties.