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Relevance of ultrafine grains in the magnetic fabric of paleosols

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A R T I C L E I N F O

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A B S T R A C T

The effects of pedogenic magnetic grains on the magnetic fabric of paleosols were investigated using samples from the Paks loess profile, Hungary. Rock magnetic experiments, electron probe microanalysis, and scanning electron microscopy revealed characteristic signatures of (post-)pedogenic influences on the original sedimentary fabric. No differences were observed between low- and high-frequency fabric, suggesting that the particle orientation distribution of superparamagnetic particles was isotropic or nearly isotropic. In some samples with low frequency dependence, the presence of superparamagnetic contributors was negligible compared to the coarser magnetic contributors. No inverse fabric was identified, indicating that stable single-domain magnetite had a negligible contribution to the fabric. Despite differences in the magnetic mineral content, the relative contributions of coarse and ultrafine grains appeared to be constant. Various methods of altering or preserving the sedimentary fabric during (post-)pedogenic processes were described. Some processes, such as the hydromorphic effect, weakened the anisotropy of the original fabric and strengthened the orientation of the grains. Meanwhile, other processes, such as post-burial, compaction of materials, and fragmentation, strengthened the foliation with increasing anisotropy. Processes that can fix the fabric and magnetic fabric of paleosols will allow us to use the fabric to determine the paleowind direction in the Pleistocene interglacial periods in future studies.

1. Introduction

Ultrafine superparamagnetic (SP) grains contribute substantially to the Quaternary paleoenvironment magnetic proxies and enhance the magnetic susceptibility of terrestrial loess-paleosol sediments, reflecting precipitation changes. The origin of such fine grains is related to various processes that are strongly connected to pedogenesis (Maher and Taylor, 1988; Forster et al., 1994). Thus, the magnetic enhancement of loess and paleosol by chemical (e.g., weathering) and biogenic (e.g., bacterial) processes during pedogenesis is called a pedogenic model (Evans, 2001). By contrast, a large input of coarse magnetic particles by strong winds can cause high magnetic susceptibility in loess (Begét and Hawkins, 1989). This is called a wind-vigor model.

The frequency dependence of magnetic susceptibility (volumetric: k_{FD}; mass: χ_{FD}) can be used to estimate the authigenic SP particle content in loess-paleosol sequences and thus can contribute to the reconstruction of detailed climate variation in glacial-interglacial cycles (e.g., Hao et al., 2012). The pedogenic formation of magnetic minerals depends strongly on climate, in particular precipitation. Therefore, the SP grain content in paleosols is considered a proxy for paleoprecipitation (Maher et al., 1994; Panaiotu et al., 2001).

The anisotropy of magnetic susceptibility (AMS) provides a useful tool for characterizing the magnetic fabric of materials. The magnetic fabric reflects the alignment of magnetic contributors, which include high-saturation magnetization minerals, and shows the preferred dimensional orientation (pdo)-controlled magnetic anisotropies (e.g., magnetite and maghemite) and other minerals and crystallographic (crystallographic axis) preferred orientation (cpo)-controlled magnetic anisotropies (e.g., paramagnetic minerals). Therefore, the magnetic fabric can provide insights into various processes, including the type and orientation of material transport, flow energy, post-sedimentary processes, and stress fields (Tarling and Hrouda, 1993). Since a pioneering study by Liu et al. (1988), numerous magnetic fabric studies have been conducted on loess, mainly to determine the characteristic paleowind direction during various periods of the Quaternary (e.g., Matasova et al., 2001; Lagroix and Banerjee, 2002, 2004; Zhu et al., 2004; Bradák, 2009; Zhang et al., 2010; Liu and Sun, 2012; Ge et al., 2014; Peng et al., 2015; Zeeden et al., 2015; Xie et al., 2016). In these studies, AMS values represent the bulk magnetic fabric information for loess-paleosol sediments consisting of detrital coarse-to-fine grains and pedogenic ultrafine grains.

New observations and interpretations of the magnetic fabric of loess

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have suggested that pedogenic processes play a more profound role in the development of magnetic fabric than previously assumed (e.g., Bradák et al., 2011; Bradák and Kovács, 2014; Ge et al., 2014; Taylor and Lagroix, 2015; Bradák-Hayashi et al., 2016). Disturbed, altered, and inverse fabrics are easily developed in paleosol layers during pedogenic and post-pedogenic processes. An inverse fabric was found in paleosols intercalated in loess layers (Matasova and Kazansky, 2004; Bradák et al., 2011; Bradák-Hayashi et al., 2016). For an inverse fabric, k_{max} is perpendicular to the nearly horizontal bedding plane (k_{max} inclination: ~90°). The vertical orientation of grains in the inverse fabric indicates the operation of vertical pedogenic processes and may reflect the crystallographic anisotropy of minerals such as siderite (Hrouda, 1982; Rochette, 1988; Márton et al., 2010).

Frequency-dependent AMS is a new technique (Hrouda, 2011; Hrouda and Ježek, 2014) that has been tested in various materials (e.g., loess and paleosols) (Hrouda et al., 2017). The fabric of ultrafine grains can be characterized by measuring the AMS at a high frequency (AMS_{HF}). Thus, AMS_{HF} has the potential to isolate a component of the fabric provided by ultrafine pedogenic grains in paleosols. The appearance of ultrafine magnetic contributors can alter the results of AMS measurements. For example, the stable single-domain particle of magnetite has inverse fabric (see above), and the alignment of neoformed SP components can weaken or disturb the orientation of the original sedimentary fabric. Therefore, revealing the influence of pedogenesis and separating the pedogenic fabric is important for reconstructing paleoenvironments, in particular paleowind direction.

We compared the sedimentary and pedogenic magnetic fabric of various paleosols to determine the possible relevance of the magnetic fabric of pedogenic SP grains in Quaternary paleoenvironment reconstructions.

2. Materials and methods

2.1. Materials

The Paks loess profile, one of the key sections of the European Loess Belt, is located to the north of the town of Paks in the Pannonian Basin, Hungary, on the right bank of the Danube River (Horváth and Bradák, 2014; Újvári et al., 2014; Marković et al., 2015). A 16-m-thick loess/paleosol sequence was sampled from a brickyard after the area was cleaned during the latest research campaign between 2015 and 2016. The recent field observation and lithostratigraphic subdivision of the sequence is presented in Fig. 1. Four well-developed soil layers were identified in the succession (see below; Fig. 1). The main characteristics of the paleosol layers were based on the properties summarized in Harden (1982).

A well-developed, red paleosol layer (15.25–16.5 m; PD2) > 1 m thick was present at the base (Fig. 1; Supplementary Material 1), with the lowest part consisting of a secondary carbonate-rich layer. The carbonate-rich layer was overlaid by a red (moist: 7.5YR5/4; dry: 7.5YR6/4 Munsell color) clayey layer with massive, angular blocks. The upper half of the layer was red (7.5YR5/4; 7.5YR6/4) and clayey. Based on the physical and pedogenic properties of the upper subhorizon of the layer, it was characterized by a less-developed granular ped structure compared to the lower part of the same layer. In the lower part of the section, there was another red (7.5YR3/4; 7.5YR5/4), clayey, well-developed paleosol layer (12.9–13.7 m; PD1) with a granular, angular blocky ped structure (Fig. 1). There was a secondary carbonate horizon in the lower part of the paleosol layer characterized by loess dolls and various secondary carbonate infiltrations and carbonate coatings. The two red paleosol layers were separated by an approximately 1.5-m-thick loess unit. They were identified as a Paks Double (PD) soil complex consisting of two warmer Mediterranean-like soils and were named the Paks Double 2 (PD2) and Paks Double 1 (PD1), respectively (Horváth and Bradák, 2014; Újvári et al., 2014).

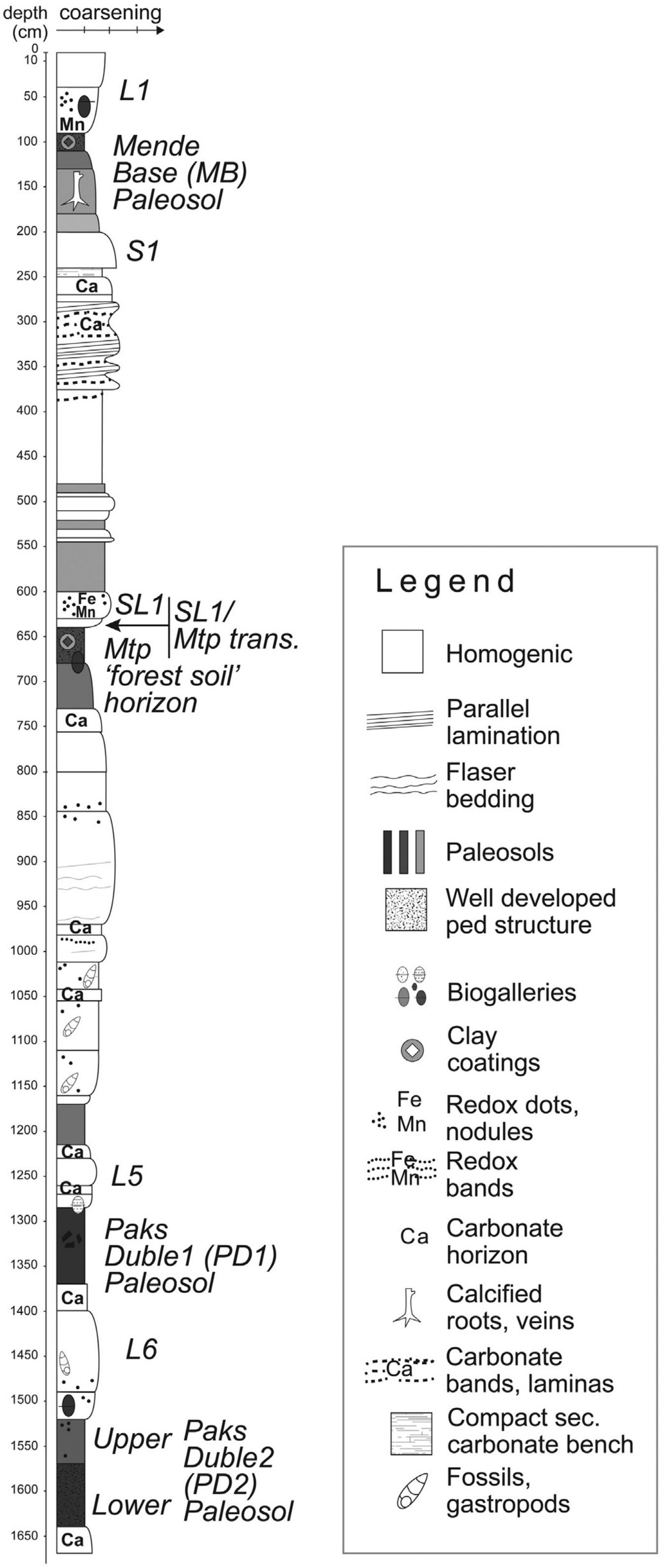

Fig. 1. Stratigraphic position of the sampled paleosol horizons in the studied part of the succession. For more information about the recent chronostratigraphic subdivision of the site, please see Horváth and Bradák (2014) and Újvári et al. (2014).

A brown (2.5Y6/3; 2.5Y8/2), homogeneous paleosol layer with a well-developed, massive pedogenic structure was present in the middle part of the succession (6.4–7.3 m; Mtp) (Fig. 1). A carbonate-rich pedogenic horizon was observed in the lowermost part of the layer. The