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A conceptual magnetic fabric development model for the Paks loess in Hungary

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ABSTRACT

We describe magnetic fabric and depositional environments of aeolian (loess) deposits from Paks, Hungary, and develop a novel, complex conceptual sedimentation model based on grain size and low-field magnetic susceptibility anisotropy data. A plot of shape factor (magnetic fabric parameter) and dry deposition velocity estimated from grain-size reveals primary and secondary depositional processes during the sedimentation of loess. Primary ones are driven by gravity, with poorly oriented MF for fine grain materials, and by tangential stress, with flow-aligned or flow-transverse fabric for coarser grain sediments. The fabric developed by a primary process is called depositional magnetic fabric. Secondary processes develop in unconsolidated sediments, beginning right after deposition and terminating before the start of diagenesis. Under slow sedimentation conditions, deposited materials are likely to be exposed near the surface for longer periods. Therefore, relatively strong winds with a stable direction can alter the fabric of non-buried surficial sediments. As a result, grain orientations may change from scattered, non-flow oriented fabric to flow-oriented fabric. This type of fabric, developed by a secondary process, is called transformed magnetic fabric, and is characterized by relatively well-defined grain orientation, which allows us to estimate a dominant wind direction.

1. Introduction

Low field anisotropy of magnetic susceptibility (AMS) provides a useful tool to characterise magnetic fabric (MF) of materials. MF, characterised by AMS, reflects the alignment of magnetic contributors in the material, including high saturation magnetization minerals, which have preferred dimensional orientation (pdo) controlled magnetic anisotropies (e.g. magnetite and maghemite) and other minerals with crystallographic preferred (crystallographic axis) orientation (cpo) controlled magnetic anisotropies (e.g. paramagnetic minerals). Therefore, the MF can provide potential insight into various processes, including the type and orientation of material transport, flow energy, post-sedimentary processes, and stress fields (Tarling and Hrouda, 1993). AMS has been often applied to loess, loess-like sediments, and paleosols since the pioneering studies of Liu et al. (1988). The MF of these sediments reflects various sedimentary and post-sedimentary environments.

Through the development of not flow-oriented (poorly lineated, mainly foliated) fabric, the gravitational force dominates over the tangential force. The not flow-oriented fabric displays quasi-horizontal foliation with a dip of a few degrees and scattered alignment of the elongated grains in a horizontal plane, without any characteristic fabric lineation. According to Derbyshire et al. (1988), the fabric of the 'typical' (i.e. Aeolian) loess is isotropic. The poorly lineated, mainly foliated loess theory is supported by studies of Hus (2003) and Wang and Løvlie (2010). Hus (2003) observed that gravitational force and compaction play leading role in developing the MF of loess. The original aim of the experiments of Wang and Løvlie's (2010) was not the characterization of the AMS of loess, although they simulated the sedimentation of loess by dry deposition and wetting the deposited material. They also reported the magnetic fabric results (e.g. streoplot analysis) which shows the poorly lineated, mainly foliated MF (Wang and Løvlie, 2010; Fig. 2, page 397).

Major characteristics of a flow-aligned fabric are that elongated grains tend to align in parallel with the transport direction and usually display an up-flow tilting (imbricated MF, a-axis imbrication). A 5–20° dip to the horizontal plane of foliation is indicated by the deviation of minimum magnetic suceptibility (k_{min}) from the vertical (e.g.

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Thistlewood and Sun, 1991). The k_{min} deviation from vertical and its orientation was defined as a marker of imbrication of magnetic particles, and used to infer paleowind directions by Nawrocki et al. (2006).

The poorly or better clustered orientation of elongated grains, distributed along the imbrication (foliation) plane defines current orientation (mainly deposition orientation). This MF type is the most common in loess deposits, and has widely been used for the estimation of paleowind directions (e.g. Begét et al., 1990; Thistlewood and Sun, 1991; Sun et al., 1995; Wu et al., 1998; Lagroix and Banerjee, 2002, 2004a; Bradák, 2009; Liu and Sun, 2012; Ge et al., 2014; Peng et al., 2015; Xie et al., 2016). Various methods were developed to verify the orientation and wind-blown origin of the MF. Comparison of confidence ellipsoids and various AMS parameters were used to quantify the accuracy of maximum magnetic susceptibility (k_{max}) orientations as indicators of paleowind directions (Lagroix and Banerjee, 2004b; Zhu et al., 2004; Zhang et al., 2010). Determination of the deviation of k_{min} inclination from vertical is also a commonly applied method to separate the fabric of undisturbed (wind-blown, less than 20°) and redeposited/reworked loess (e.g. Zhu et al., 2004). Theoretically if the dust is deposited on a nearly horizontal surface the orientation of a bedding dominated fabric will be defined by the minimum susceptibility axis (k_{min}), its orientation being the pole to the bedding plane. The maximum and intermediate susceptibility axes (k_{max} and k_{int}) will lie in the bedding plane. The primary axis defining the depositional plane is k_{min}. Unfortunately, some essential criteria of this method include the statistically significant lineation of the fabric, which cannot be met in various cases (e.g. low energy transport during 'dust falls'). Similarly, the pronounced deviation of k_{min} from vertical does not necessarily mean redeposition (e.g. imbrication).

In biaxial prolate orientation (shear stress related)/flow-transverse fabric (sedimentary process related) (AB plane imbricated fabric, pencil fabric), the a-axes of clasts are aligned perpendicularly to the flow direction, and the intermediate axes are aligned in the flow direction. Two different types of sedimentary flow-transverse fabrics are described in the literature: I) in this fabric the orientations of principal susceptibilities are well separated, and current orientation is indicated by a 10–20° dip of the foliation plane (k_{min}) and the orientation of intermediate magnetic susceptibility (k_{int}). II) this type of stereoplot of flow-transverse fabric is characterised by well-clustered k_{max} directions, and k_{min} and k_{int} are intermixed along an axis on the foliation plane. The development of MF is interpreted as indicating strong currents, traction and rolling of grains during transportation and a stable condition after deposition (Tarling and Hrouda, 1993; Tauxe, 1998). In both types, the transport direction is perpendicular to the orientation of k_{max}. Similar fabrics are also reported from Alaskan loess and interpreted as the results of shear stress (Lagroix and Banerjee, 2004b) and reconstructed in the laboratory environment (Rees, 1983), but in general such flow-transverse fabrics are rare, especially in loess sediments (Lagroix and Banerjee, 2004b; Bradák et al., 2011; Bradák-Hayashi et al., 2016; Zeeden et al., 2015).

New observations and interpretation of the loess MF suggest that surface processes (e.g. permafrost, erosion by run-off water and redeposition), the paleogeomorphology (e.g. slope, local depressions) and pedogenic processes play more profound roles during dust deposition and the post-depositional period than previously expected (e.g. Lagroix and Banerjee, 2004a; 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 being developed under such conditions. If sedimentation takes place on a slope, the dip direction can be identified by the alignment of principal susceptibilities; the tilt of k_{min} directions from vertical and inclination of the plane defined by the intermixed k_{max} and k_{int} from the horizontal plane (Rees, 1966; 1971; Bradák et al., 2011; Ge et al., 2014). The deviation of k_{min} from vertical ('slope deposition-like fabric') was interpreted as resulting from a cryptic post-depositional deformation/reworking during permafrost processes (Lagroix and Banerjee, 2004a; Taylor and Lagroix, 2015) (Fig. 1e). Biogenic activity may cause isotropic magnetic fabric through pedogenesis. However, Ellwood (1984) found no difference between the magnetic fabrics of non-bioturbated and bioturbated materials. By contrast, the deviation of k_{min} inclination from vertical, along with the chaotic alignment of the principal susceptibilities and isotropic magnetic fabric was observed in different paleosols (Hus, 2003; Matasova et al., 2001). As a possible indicator of bioturbation, inverse magnetic fabric was found in paleosols intercalated in loess layers in some studies (Matasova and Kazansky, 2004; Bradák et al., 2011; Bradák-Hayashi et al., 2016). For an inverse fabric, the direction of k_{max} is perpendicular to the almost horizontal bedding plane (k_{max} inclination ~90°). The inverse fabric is caused by the vertical orientation of the grains (pdo) (Bradák-Hayashi et al., 2016). The results of magnetic fabric measurements are supported by micromorphological studies, demonstrating the vertical orientation of grains in the fabric of paleosols. Originally the term was used to describe magnetic fabric with the same character driven by crystallographic anisotropy of siderite, or due to uniaxial single domain magnetite (Rochette, 1988). Nevertheless, inverse fabric is rarely observed in loess sequences. Such a fabric was identified only one profile in paleosol horizons (Bradák et al., 2011; Bradák-Hayashi et al., 2016). The 'inverse fabric' indicates both the vertical alignment of minerals (pdo) due to vertical pedogenic processes and crystallographic anisotropy (cpo) of minerals such as fine-grained magnetite or siderite (Hrouda, 1982; Rochette, 1988; Márton et al., 2010).

Despite the clear relationship between transport/depositional direction and MF orientation revealed by extensive works on loess magnetic fabric and paleowind directions, only a few studies have attempted to improve our understanding of MF parameters related to transport velocity and energy (e.g. Zhang et al., 2010; Bradák and Kovács, 2014). No investigations have mentioned so far that MF changes may be due to changing transport/deposition energy. This study aims at revealing the relationship between various transport/depositional energies and MF development, thereby describing the depositional environment during the formation of loess primary MF.

2. Materials and methods

2.1. Materials

The Paks loess profile is located north of the town Paks in the Pannonian Basin, Hungary, on the right bank of the Danube River. In the brickyard, a 16-m thick loess/palaeosol sequence was cleaned and sampled (Fig. 1). The sediments analysed in this study are yellow and yellowish-grey in colour, and consists of fine-grained, silty, or silty sand materials with a homogeneous matrix or occasionally poorly developed fine laminated structure. Based on their grain size distribution (GSD), the samples are classified into three groups: fine-grained loess (fL; GSD volumetric mean < 34 μm) dominated by silt components; medium-grained loess (mL; GSD volumetric mean 34–63 μm) with a larger amount of coarse silt; and coarse-grained loess/very fine sand (cL; GSD volumetric mean > 63 μm) with a significant fine sand component (e.g. sandy loess and very fine aeolian sand samples, 63–125 μm). The sedimentary characteristics of the samples collected are described in detail in Supplementary Material 1. Based on GSDs and sedimentary character (homogeneous structure and no sign of redeposition), all samples were identified as wind-blown in origin. Indicators of redeposition such us poorly sorted materials, lenticular bedding and lamination containing clayey paleosol and silty loess laminae were not observed in the sampled layers. The few identified laminas in the sequence are made up of the same materials consistent with as those in the homogeneous part and the laminas may have developed due to temporary fluctuations of the transportation energy. Thus, these samples are considered as excellent material to identify possible MF changes due to variations in transportation energy. Signs of bioturbation such as biogalleries and burrowing, and indicators of pedogenesis

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