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Saharan dust deposition in the Carpathian Basin and its possible effects on interglacial soil formation

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ABSTRACT

Several hundred tons of windblown dust material are lifted into the atmosphere and are transported every year from Saharan dust source areas towards Europe having an important climatic and other environmental effect also on distant areas. According to the systematic observations of modern Saharan dust events, it can be stated that dust deflated from North African source areas is a significant constituent of the atmosphere of the Carpathian Basin and Saharan dust deposition events are identifiable several times in a year. Dust episodes are connected to distinct meteorological situations, which are also the determining factors of the different kinds of depositional mechanisms. By using the adjusted values of dust deposition simulations of numerical models, the annual Saharan dust flux can be set into the range of 3.2–5.4 $g/m^2/y$.

Based on the results of past mass accumulation rates calculated from stratigraphic and sedimentary data of loess–paleosol sequences, the relative contribution of Saharan dust to interglacial paleosol material was quantified. According to these calculations, North African exotic dust material can represent 20–30% of clay and fine silt-sized soil components of interglacial paleosols in the Carpathian Basin. The syngenetic contribution of external aeolian dust material is capable to modify physicochemical properties of soils and hereby the paleoclimatic interpretation of these pedogene stratigraphic units.

1. Introduction

The study of aeolian dust and dust storms is an area of growing interest and importance in Earth and atmospheric science communities. Huge amount of mineral dust particles (which diameters range from several hundred nanometres to ~100 μm) is emitted from arid and semiarid areas. The most intense and active dust source areas are located in North Africa accounting for the 50–70% of global mineral dust emission (Goudie and Middleton, 2001). Several hundred tons of windblown dust material are lifted into the atmosphere every year and are transported northward from Saharan source areas into direction of Europe (Moulin et al., 1998; Stuut et al., 2009). Recently, a considerable number of studies have grown up around the subject of direct and indirect climatic effects of mineral dust even at areas situating relatively far from the sources (Harrison et al., 2001; Kohfeld and Tegen, 2007; Maher et al., 2010). Dust particles are capable to absorb, scatter and reflect the incoming shortwave and outgoing longwave radiation and have also an effect on the overall planetary energy balance by changing the surface albedo. Additionally, dust storms transport important nutrients to seas and oceans enhancing the primary phytoplankton production and influencing the uptake of atmospheric CO_2.

Beside several other environmental effects, aeolian dust plays also an important geological role as parent material of aeolian dust deposits (e.g. loess–paleosol series, windblown material in deep sea sediments, dust layers in ice cores) (Pye, 1987, 1995). These records of mineral dust deposition indicate that the amount of atmospheric windblown dust was several orders of magnitude higher in certain periods. Activity of source areas, amount of emitted mineral dust, as well as frequency and magnitude of Saharan dust intrusions into Europe are showing a wide diversity, indicating that even moderate climatic fluctuations are causing significant changes in the dust budget. In general, Pleistocene glacials were

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accompanied by high dust emissions from major source areas due to the interactions of main controlling mechanisms (e.g. availability of loose fine-grained material, land surface characteristics, wind speed and gustiness caused by more steepened meridional temperature gradients). Mediterranean marine sediments and terrestrial sequences of PeriSaharan desert loess deposits suggest also an enhanced dust deposition from Saharan sources during Pleistocene cold periods (Yaalon and Dan, 1974; Tsoar and Pye, 1987). The increased North African dust emission was caused by the more uneven annual distribution of rainfall, gustier winds and more intense cyclogenesis caused by more frequent penetration of cold Arctic air-masses.

During interglacials, the Saharan dust emission was reduced compared to glacials. However, significant role of Saharan dust addition in interglacial soil formation has been reported from several sites around the Mediterranean: MacLeod (1980) used grain size analyses to support the windblown origin of pedogene units in Greece; Durn et al. (1999) and later Durn (2003) concluded that red soils in Croatia was developed from previously deposited dust material based on clay minerals and geochemical indicators; Genova et al. (2001) investigated terra rossa in Sardinia to infer an aeolian origin, while Jackson et al. (1982) identified Saharan dust as parent material of soils in Italy, as did Jahn et al. (1991) in Portugal, Nihlén and Olsson (1995) in Crete and Atalay (1997) in Turkey. According to the immobile trace element analyses of Muhs et al. (2010) in Majorca, the addition of Saharan dust was a dominant factor in the formation of soils in the area. Jordanova et al. (2013) studied relict reddish pedogene units in Bulgaria and their measurements of trace and rare element content and magnetic data suggested a North African aeolian contribution during the soil formation.

The windblown origin of certain types of widespread red Mediterranean soils has been a matter of debate for ca. hundred years (Leiningen, 1915; Leiningen and Graf, 1930). Rapp (1983) stated that the development of terra rossa soils in south Europe is not a result of the residual weathering of the bedrock, but the parent material of soils might be originated from the Sahara. At several places, the residuum origin from the underlying (mainly limestone) bedrock is not probable. The unrealistic amounts of required carbonate rock dissolution, mineralogical issues, quartz-rich soils on carbonate-rich, quartz-free bedrocks cannot be explained by the 'residue theory' of these units. Addition of aeolian dust particles as an enrichment was proposed by Kubiëna (1953) and this theory was later developed by Yaalon and Ganor (1973), and Yaalon (1997). The term 'aeolian contamination' was introduced also by Yaalon and Ganor (1973), to describe soil property changing modifications made by aeolian increments. Identification of external aeolian dust material in soils is a challenging problem, however, nowadays, the role of aeolian dust as parent material of soils and soils with different degrees of aeolian influence has been known from several locations in the Mediterranean, as well as in other parts of the world.

In spite of the more intense glacial North African dust emission, the recognition of Saharan dust material in Central European loess–paleosol sequences regarded as ones of the most important climate archives has remained a challenging problem. According to a simplified model of aeolian dust sedimentation, dust accumulation is a result of local, dust storm-related coarse-grained ($30 <$ μm: middle- and coarse-silt fraction with a casual presence of very fine-sand ($<\sim100$ μm)) dust deposition and an additional incorporation of fine-grained background dust load (<20–30 μm: clay, fine-silt fraction). The source of the coarse-grained sub-population is local material, deflated from loosely consolidated Upper Miocene and Lower Pliocene deposits eroded from the Alps and Carpathians, from floodplain deposits and from the deposits of the former Lake Pannon (Kovács et al., 2008, 2011; Bokhorst et al., 2011). At the same time, the origin of fine-grained component is primarily the result of deposition of dust particles from distant sources, and partly post-depositional alteration and disintegration of aggregates (Bokhorst et al., 2011). Present-day far-travelled North African dust samples collected in Europe are almost totally composed of clayey and fine-silty material with occasional occurrence of some slightly larger mineral particles. The Pleistocene glacial loess formation was primarily determined by deposition of silty material from local sources, transported by NW winds (Bokhorst et al., 2011), the signals of fine-grained dust addition from distant sources were depleted by the enhanced local dust fluxes.

Local dust accumulation in the Carpathian Basin was terminated during interglacials (Vandenberghe et al., 2014). So far, however, very little attention has been paid to the role of syngenetic external dust accretion to interglacial paleosols in the Carpathian Basin, albeit present-day Saharan dust events have been considerably frequent. It is assumed that the amount of interglacial North African dust deposition was similar to the recent conditions. The interpretation of paleosol records must also take into account possible incorporation of far-travelled dust material from distant sources. This is especially true for the Carpathian Basin, where after the infilling and desiccation of Lake Pannon terrestrial windblown dust accumulation played the most prevailing role in sedimentation.

This paper is aimed at providing (1) a complex review of the frequency, synoptic background, transportation routes and intensity of present day Saharan dust events and deposition of windblown desert particles in the Carpathian Basin; and (2) an estimate on the past Saharan dust sedimentation and its possible influence on soil properties of past soils (modified by syngenetic, external dust addition) of the Carpathian Basin.

2. Materials and methods

2.1. Investigation area

The Carpathian Basin (CB: 45°–48.5°N, 16°–23°E) is located in Central Europe and its subsiding depression is framed by the Alps, Carpathians and Dinaric mountain ranges. More than half of the area is covered by aeolian dust deposits, mainly the products of Pleistocene glacial loess formation periods (Marković et al., 2011, 2015; Újvári et al., 2014), however, sediments of older dust accumulation intervals have also been preserved as Pliocene (and partly Pleistocene) red clay deposits (Kovács et al., 2011, 2013). The thick aeolian dust deposits of the area provide insight into the cyclic climatic variations of the Quaternary glacial-interglacial periods and are one of the most important terrestrial archives of past climatic changes is Europe. The thick, pale yellow loess deposits are the product of the increased dust flux of cold and dry glacial periods, while during warmer and moister interglacials, soils were formed from the formerly deposited aeolian loess (Varga et al., 2012; Újvári et al., 2014; Vandenberghe et al., 2014).

In this paper, a generalized loess–paleosol sequence is the basis of our calculations, which was set up primarily based on the Paks loess section, situated on the right bank of the River Danube in the mid-Carpathian Basin. The accumulation of the well-known Paks Loess Formation started in the latest part of the Lower Pleistocene and represents a record of approximately the last 1 million years of windblown dust accumulation in the Carpathian Basin (Horváth and Bradák, 2014; Újvári et al., 2014; Marković et al., 2015). The Late and partly, Middle Pleistocene loess deposits are separated by different kinds of interglacial steppe, forest-steppe and brown forest soils, while the older pedogene horizons are rubefied red soils (so-called Paks Double 1 [PD1], Paks Double 2