Quaternary International 209 (2009) 79–94

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Pedogenic alteration of aeolian sediments in the upper loess mantles of the Russian Plain

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ARTICLE INFO

Article history:
Available online 5 April 2009

ABSTRACT

Study of the upper loess strata within the profile of surface soils highlighted the role of pedogenesis in the formation of characteristic features of loess. Loess-paleosol sequences within the study area are influenced by their position in paleocryogenic microrelief. Clear evidence of sequential loess sedimentation, accompanied by slope processes and pedogenesis, is present in soil profiles within former thermokarst depressions. Different stages of loess sedimentation are marked by cryomorphic features, solifluction stripes and buried humus horizons. The balance between the rate of sedimentation, intensity of slope processes and pedogenesis changed within the upper 3 m of loess strata. Corresponding loess strata in inter-depression areas were also formed by sequential accumulation of aeolian dust, gradually altered by initial pedogenesis that left weakly developed soil profiles without clear horizonation. Pedogenesis resulted in diverse complexes of secondary carbonates, loose soil fabric and microfabric with abundant pores of biogenic and cryogenic nature, as well as other features, characteristic of soils of cold arid environments. The uniformity of these features throughout the upper loess strata confirms the synlithogenic nature of pedogenesis that accompanied loess accumulation.

1. Introduction

Paleosols developed in loess units are traditionally regarded as good records of paleoecological and paleoclimatic changes. However, the role of pedogenesis in the formation of typical features of loess units themselves attracts much less attention. Since the very beginning of its scientific study, loess was regarded as a result of deep transformation of aeolian dust by pedogenesis. Richthofen (1882) regarded loesses as aeolian soils. Sibirtsev (1899) defined atmospheric-dust soils and Kossovich (1903) defined aeolian-loess soils in their soil classification systems. Berg (1960) stated that aeolian dust has been continuously altered by soil forming processes during gradual sedimentation, so loess sediments are actually loess soils. Obruchev (1911), who became an advocate of the aeolian origin of loess during his extensive research in Central Asia, also stressed that loess is a specific type of soil. Gerasimov (1962, 1969) regarded loess units, comprised between buried soils in temperate regions, as primitive synlithogenic cryo-arid (tundra–steppe) soils, formed in periglacial environments as loess accumulated rapidly. He pointed out that even an intensive rate of dust accumulation (up to 0.2–1 mm/a) is less than the rate of pedogenesis. Therefore, pedogenic alteration of primary aeolian sediment seems to be inevitable. Pecsi (1990) stressed: "dust only becomes loess … through diagenesis in certain ecological environments". There is still a lack of direct confirmation or quantitative assessment of pedogenic alteration of sediment within loess units themselves.

The old question remains: to what extent loess is sediment and to what extent it is soil? The goal of this paper is to clarify the role of pedogenesis in the formation of characteristic features of loess by studying the upper loess-paleosol sequences within the profile of surface soils. Studies of soils of the upper loess mantles in the southwest Russian Plain confirm that profiles of surface soils still retain clear records of the final stages of sedimentation and primary diagenetic and pedogenetic alteration of aeolian sediment.

2. Study area

High flat interfluves covered by loess mantles are common for the northern periphery of the East European loess province, designated by Velichko (1990). These surfaces form a wide arch trending southwest to northeast from Northern Ukraine and Southern Belarus to southwest and central part of European Russia and to the Urals (Fig. 1). They are parts of old denudation plateaus and moraine uplands, usually 20–50 km in diameter with elevations of 170–250 m asl, dissected by river valleys and fluvioglacial

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doi:10.1016/j.quaint.2009.03.007

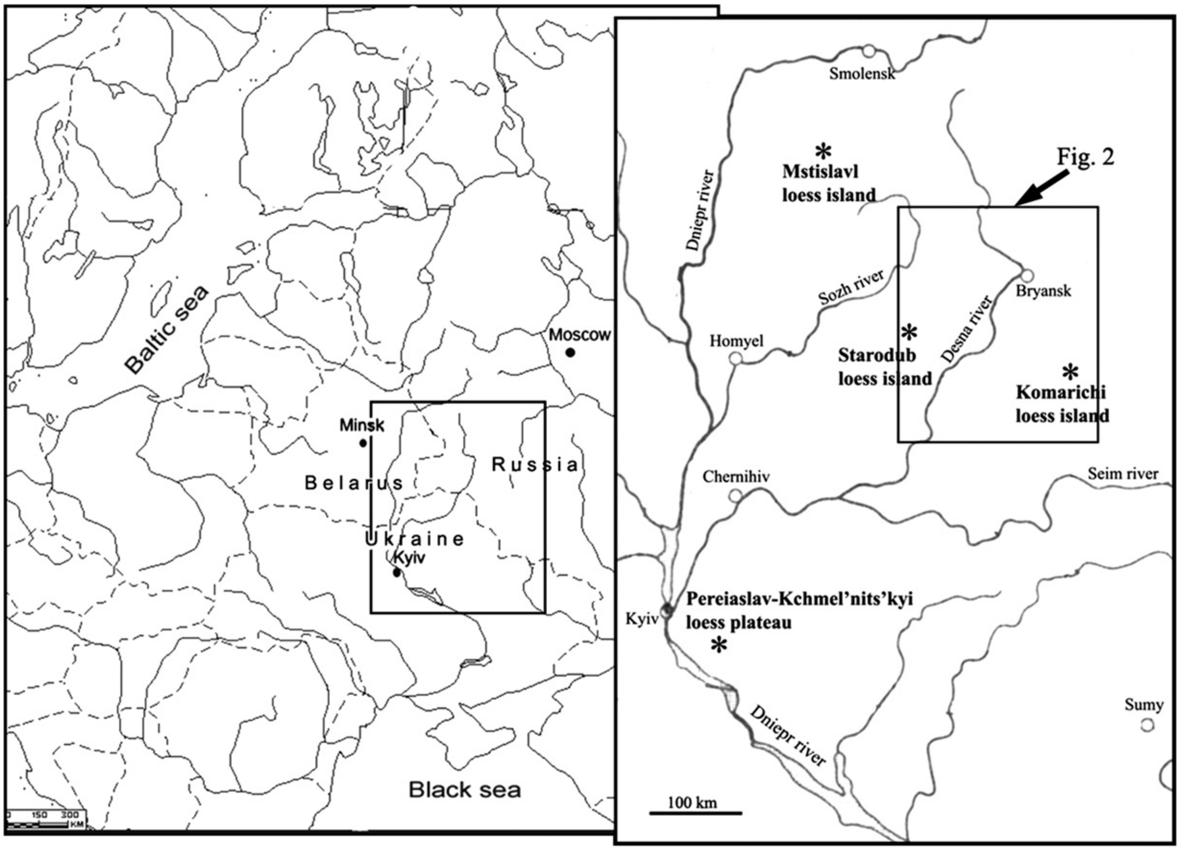

Fig. 1. Study site locations.

lowlands. Due to the loess cover of the interfluves, Dokuchaev (1948) called them loess islands (Fig. 2).

Loess islands differ in all landscape components (parent rocks, vegetation, and soil cover) from surrounding areas (fluvioglacial and moraine plains). On the other hand, being located in various environmental zones (southern taiga with Luvisols and Podzols, forest-steppe with Phaeozems and steppe with Chernozems) loess islands are characterized by a set of common features due to the similarity of parent materials. A loess mantle having a thickness of 5–10 m covers interfluves and adjacent upper river terraces. According to Velichko (1990), Late Pleistocene loess-paleosol sequences occur on the loess islands include several pedostratigraphic units (Mezin composite paleosol, Bryansk and Trubchevsk paleosols). The other common feature of loess islands is that, situated on the periphery of the Middle Pleistocene ice sheet (within and outside the limits), they were deeply influenced by periglacial conditions. The latter resulted in a swell-and-swale microtopography that complicated the surface of loess islands. Rounded depressions 0.5–1 m deep and 20–50 m wide occupy 20–30% of the terrain, forming a regular network (Fig. 3). They are the remains of thermokarst depressions.

Constitution of the upper loess strata depends on its position in a paleocryogenic complex. Microtopography has determined the soilscape pattern that is quite different from the soils of adjacent territories (Fig. 4). Soils with a buried humus (Ahb) horizon are formed within depressions. Buried humus horizons are black lenses 20–30 cm thick situated at a depth of 30–40 cm. They never occur in soils on the main surfaces. In contrast, the soils of inter-depression areas are characterized by the presence of a carbonate layer at a depth of 50–120 cm that never occurs in soils with buried humus horizons.

The following sites were considered for detailed field studies (Fig. 1): Starodub and Komarichi loess islands, Bryansk region, southwestern Russia; Mstislavl loess island, Mogilev region, Belarus; Pereiaslav-Kchmel'nits'kyi loess plateau, Northern Ukraine. These sites, spread across 450 km latitude, provide a fairly good bioclimatic sequence with uniform parent material, helping to separate modern and relic soil features from sedimentary ones. All sites are characterized by moderate humid climate with average monthly temperatures ranging from -9 °C/-5 °C in January to 16 °C/19 °C in July and precipitation ranging from 600 to 700 mm/a (Table 1). In all sites loess sediments are represented by yellowish brown porous silt loam, common for the East European loess province.

The Mstislavl loess island is a part of southern taiga vegetation subzone with mixed forests as natural vegetation and a soil cover of Luvisols (on loamy sediments) and Podzols (on sandy sediments). The loess island bordering the Sozh River left bank is a part of Middle Pleistocene moraine plain with an elevation of 200–240 m above sea level. Loess sediments cover watersheds, slopes and upper river terraces with a thick (10 m) mantle.

Both the Starodub and Komarichi loess islands are situated in forest-steppe, with broad-leaved forests as natural vegetation and Phaeozems as typical soils. The Starodub loess island, bordering the left bank of the Desna River, is a part of the Middle Pleistocene moraine plain, with an elevation of 180–210 m asl. The Komarichi loess island is a part of the ancient denudation plateau on the Usozha and Nerussa rivers watershed. Both interfluves contain a set of terrace-like surfaces with gentle slopes covered by a 5- to 10-m-thick loess mantle, producing high soil fertility and, hence, ancient cultivation of the territory and the lack of forest vegetation at present.

The Pereiaslav-Kchmel'nits'kyi loess area is situated in a typical steppe zone with Chernozems as dominant soils. The study site is