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Micromorphological diagnostics of pedogenetic, eolian, and colluvial processes from data on the fabrics of crusty horizons in differently aged extremely aridic soils of Mongolia

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ABSTRACT

The micromorphological and microtomographic studies of differently aged extremely aridic soils in the Trans-Altai Gobi Desert of Mongolia allowed us to determine the rates and sequences of processes associated with sedimentogenesis and pedogenetic transformation of the parent material. In the most developed extremely aridic soils, the topsoil or the surface Aye horizon consisting of the layers of different compositions and geneses (eolian and colluvial sediments) displays vesicular voids, which are virtually absent in the young soils. Two different mechanisms of the origin of vesicular voids are suggested: (a) in the case of the fresh eolian material, the bicarbonate–calcium equilibrium is displaced towards the formation of calcite with the release of CO_2 under the impact of changes in the moisture and temperature; (b) in the case of the dense silty clay material, the release of sorbed air (nitrogen and oxygen) from the dry soil particles takes place under the impact of atmospheric precipitation. The locally acting pedogenesis in these soils specify the development of hypocoatings and typical coatings consisting of the amorphized phyllosilicates with the disordered structure inside the vesicular voids and the formation of iron microconcentrations and iron films on mineral grains.

1. Introduction

Desert (aridic) soils occupy approximately 46.1 M km^2, or 31% of land area of the Earth. They are particularly widespread in Australia (6.25 M km^2, or 82% of the continent) and Africa (17.66 M km^2, or 59% of the continent). In Asia, the aridic soils occupy about 14.4 M km^2, or 33% of the total area (Dregne, 1976). Though the aridic soils are characterized by different morphological properties of the middle-profile horizons (including cambic, argillic, calcic, petrocalcic, gypsic, petrogypsic, nitric, salic and duripan horizons) (Buol et al., 1997; Southard, 2000), the formation of the vesicular topsoil horizon (Av) is typical of most of these soils (Springer, 1958; Dixon, 2009; Turk and Graham, 2011). In this paper, it is designated as the Aye horizon (topsoil horizon with yermic properties according to WRB 2014) (IUSS Working Group WRB, 2014).

In recent years, specific features of the fabric of crusty horizon in desert soils have attracted attention of researchers in relation to the problem of objective diagnostics of the properties of desert soils and the role of the surface vesicular crusty horizon in the development of desert features (Figueira and Stoops, 1983; McFadden et al., 1998; Anderson et al., 2002; Golovanov et al., 2005; Fox et al., 2009). Micromorphological and microtomographic methods open new possibilities for a better understanding of the properties and ecological functions of desert soils and diagnostic features of desertification (Figueira and Stoops, 1983; Lebedeva-Verba et al., 2009). Being very informative, these methods make it possible to analyze temporary changes in the pedogenetic processes within the desert zone, including the extremely aridic soils of Mongolia that remain insufficiently studied. The study of desert soils of different ages allows us to assess the rate and sequence of processes associated with sedimentogenesis and pedogenetic transformation of the parent material.

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2. Materials and methods

2.1. Study sites

The microfabric of topsoil layers in the topsoil was examined in three typical profiles of aridic soils in the Subboreal zone of Central Asia: Fluvic Solonchak (Yermic) (profile 1) in the Eikhiin-Gol oasis and Skeletic Gypsisol (Siltic, Yermic) (profile 2) and Skeletic Gypsiric Regosol (Siltic, Yermic) (profile 3) in the Trans-Altai Gobi Desert of Mongolia (Fig. 1). The soils were classified according to the WRB system (IUSS Working Group WRB, 2014). They are developed from gravely sandy loamy and sandy clay sediments of different geneses.

All these objects are found in the south of Mongolia within the zones of true deserts with shrubs (profile 2) and extremely arid deserts virtually devoid of higher vegetation (profiles 1 and 3). The studied soil profiles compose an evolutionary sequence of the extremely arid pedogenesis. Thus, profile 1 is a young soil formed in place of the deflated solonchak in the central part of the Ekhiin-Gol oasis; profiles 2 and 3 are the well-developed extremely aridic soils formed from the gypsum-bearing (profile 2) and gypsum-free (profile 3) deposits.

In the deserts of Mongolia, the MAP decreases from 120 mm to 50 mm in the extremely arid regions. The rainfall mainly (90–95%) takes place in summer. Profile 1 is located in the most continental and extremely arid desert of Mongolia (Table 1). The soils are subjected to annual freezing to a depth of 60–100 cm and remain frozen for several months (Pankova, 1992).

Table 1
Climatic characteristics.

Profile	Mean January temperature, °C	Mean July temperature, °C	Precipitation, mm	Potential evaporation, mm
2	−12	+22.3	100–120	800–900
1, 3	−8	+26.4	50–70	900–1200

Fluvic Solonchak (Yermic) — profile 1 (43°14′49.8″ N, 98°59′52.8″ E, 1000 m asl) is a young extremely aridic soil in the central part of the Ekhiin-Gol oasis with relic tugai vegetation dominated by *Populus tremula* and *Phragmites communis* and halophytic shrubs *Reaumuria soongorica*, *Lycium ruthenicun*, *Nitraria sibirica*, and *Tamarix ramossisima*. The oasis is found in the Trans-Altai Gobi Desert at the heights up to 1300 m asl within the old alluvial-delta plain of the Ekhiin-Gol temporary watercourse crossing the hilly piedmont plain at the foot of the Tsagan-Bogdo Ridge from south to north. This oasis includes several gently sloping delta-alluvial (old lacustrine) terraces composed of nonsaline loamy deposits of 0.5–2.5 m in thickness with interlayers of sandy gravelly material and underlain by gravels. Profile 1 is located on the middle terrace (Timofeev, 1986). At a depth of 4–5 m, the red-colored clayey Cretaceous–Paleogene deposits are found; in some places, they are exposed to the surface along the banks of the local temporary watercourse. A number of faults stretching in the east–west direction serve as the zone of the deep head water discharge onto the surface in the form water springs. According to the soil survey of 1978 (Pankova et al., 2004), Solonchaks predominated in the oasis. A specific feature of these soils in the oasis is that they are developed around the springs of fresh (TDS < 1 g/L, normally about 500–700 mg/L; pH 7.6 to 8.3) groundwater. The development of thick (10–15 cm) salt crusts at the soil surface is explained by the sharply exudative soil water regime (potential evaporation exceeds precipitation by 10 times). The soil salinity sharply decreases down the soil profile, so that the lower horizons are virtually devoid of soluble salts. *Fluvic Solonchak (Yermic)* (profile 1) is considered a young desert soil formed in place of the former crusty solonchak with the salt crust of about 10–15 cm in thickness. As a result of overgrazing, the salt crust was destroyed and eroded by wind together with the fine mineral fractions. The former surface silty salt horizon was partially preserved under several shrubs of *Reaumuria soongorica*; it contains about 10% of neutral soluble salts (Table 2). After the wind erosion of salts and fine earth particles, the sandy gravelly material of the layered alluvial deposits was exposed to the surface and formed a desert pavement. The absence of restoration of the thick salt crust in the studied profile may be associated with deepening of the groundwater level because of the erosional cutting of temporary watercourse in just 2 m from the studied soil pit. Temporary water streams after formed every year due to melting of icings around the water springs in the fault zone (Gunin, 1990; Pankova, 1992).

Skeletic Gypsisol (Siltic, Yermic) —profile 2 (43°03′07.7″ N, 103°44′01.3″ E; 1483 m asl) is located 100–150 km southwards of Dalandzadgad on the southern piedmont plain composed of alluvial (proluvial) deposits at the foot of the Gurvan-Saikhan Ridge. Thin vegetation is represented by small desert shrubs *Anabasis brevifolia*. The soil surface is covered by desert pavement with black desert varnish on the upper sides rock fragments.

Fig. 1. Location of studied profiles.: 1 — Profile 1; 2 — Profile 2; 3 — Profile 3.

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