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Fabric of topsoil horizons in aridic soils of Central Asia

Fábrica de horizontes superficiales en suelos áridos de Asia Central
Tessitura dos horizontes superficiais de solos Arídicos da Ásia Central

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ABSTRACT

Two surface microhorizons –vesicular and platy– were found to be typical of the fabric of topsoil horizons in gravely loamy soils located along an arid/continental climatic gradient in the Subboreal zone of Central Asia (from southern Russia to Uzbekistan, Kazakhstan, and Mongolia). Their genesis is related to active vesiculation (for vesicular A_1 microhorizon) and cryogenesis (for platy A_2 microhorizon) against a background of high clay mobility and/or eolian accumulation of fine material. New mechanisms responsible for the formation of vesicular pores are suggested: (a) the leaching of dense complete crystal infillings (moldic voids) and (b) the development of biogenic capsules typical of iron bacteria that were diagnosed by the microbiological method of fouling Agar-covered glasses under natural conditions. In a series of studied soils, Yermic Regosols are characterized by additional specific microfeatures: (1) iron depletion from the material around the pores and formation of iron concentrations in the intraped mass owing to biogenic mobilization of iron with participation of sulfate- and iron-reducing bacteria and (2) the accumulation of organic matter (residues of microbial cells) in the vesicular pores.

RESUMEN

En este trabajo se estudiaron dos microhorizontes superficiales- vesicular y laminar- cuya fábrica se encuentra típicamente en horizontes superficiales de suelos franco gravosos situados a lo largo del gradiente climático árido/continental de la zona Subboreal de Asia Central (desde el sur de Rusia hacia Uzbekistán, Kazakhstán y Mongolia). Su génesis se relaciona con una activa formación de vesículas (para el microhorizonte A_1 vesicular) y con criogénesis (para el microhorizonte A_2 laminar) en un medio con elevada movilidad de arcilla y/o acumulación de material fino. Se proponen los siguientes nuevos mecanismos responsables de la formación de los poros vesiculares: a) el lavado de rellenos cristalinos densos (poros móldicos); y b) el desarrollo de cápsulas biogénicas típicas de bacterias de hierro que fueron identificadas mediante el método de vidrios cubiertos de Agar incrustantes bajo condiciones naturales. En la serie de suelos estudiados, los Regosoles Yérmicos se caracterizan por los siguientes microrrasgos adicionales: 1) una disminución del hierro del material que rodea a los poros y la formación de concentraciones de hierro en la masa intrapedial debido a una movilización biogénica de hierro con participación de bacterias reductoras de sulfato y hierro; y 2) la acumulación de materia orgánica (residuos de células microbianas) en los poros vesiculares.

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RESUMO

Os microhorizontes superficiais vesicular e laminar são considerados típicos da tessitura de horizontes superficiais de solos francos com bastante saibro e cascalho localizados ao longo de um gradiente climático árido/continental na zona sub boreal da Ásia Central (do Sul da Rússia ao Uzbequistão, Cazaquistão e Mongólia). A sua génese está relacionada com uma activa formação de vesículas (para o microhorizonte vesicular A_1*) e com a criogénese (para o microhorizonte laminar* A_2*) tendo como fundo uma elevada mobilidade de argila e/ou acumulação eólica de material fino. Sugerem-se novos mecanismos responsáveis pela formação de poros vesiculares: (a) a lixiviação de enchimentos cristalinos densos completos (poros moldados) e (b) o desenvolvimento de cápsulas biogénicas típicas de bactérias férricas diagnosticadas pelo método microbiológico de agar em condições naturais. Numa série de solos estudados, os Regosolos Yérmicos caracterizam-se por microcaracteres específicos adicionais: (1) depleção de ferro a partir do material em torno dos poros e formação das concentrações de ferro na massa intrapédica devido à mobilização biogénica de ferro com a participação de bactérias redutoras de sulfato e ferro e (2) acumulação de matéria orgânica (resíduos das células microbianas) nos poros vesiculares.*

KEY WORDS
Soil micromorphology, pedogenetic processes, vesicular and platy surface microhorizons, arid regions

PALABRAS CLAVE
Micromorfología de suelos, procesos de edafogénesis, microhorizontes superficiales vesiculares y laminares, regiones áridas

PALAVRAS-CHAVE
Micromofologia do solo, processos pedogenéticos, microhorizontes superficiais vesiculares e laminares, regiões áridas

1. Introduction

Arid desert and semidesert ecosystems in Eurasia occupy nearly 18 000 sq. km (Dregne 1976). They are characterized by the great diversity of soils –Kastanozems, Episalic Solonetz, Gypsic Calcisol, Yermic-Gypsic Calcisol, Yermic Regosol, and Yermic-Gypsic Regosol. The separate chapters of the recent monograph (Stoops et al. 2010) show the importance of micromorphological investigations for studying the topsoil horizons in aridic soils throughout the world (Pagliai and Stoops 2010; Gerasimova and Lebedeva-Verba 2010), however the data on the microfabric of virgin aridic soils in the Subboreal zone of Central Asia (in contrast to aridic soils of other continents and other climatic zones) are limited (Gubin 1984; Golovanov et al. 2005; Mees and Singer 2006; Lebedeva-Verba et al. 2009; Lebedeva-Verba and Gerasimova 2009). There are virtually no data on the study of fabric units within thin (from 1 mm to 5–6 cm) microhorizons in the topsoil layer of these soils (Pagliai and Stoops 2010).

A vesicular structure of topsoil horizons in the soils of arid territories is clearly manifested at the macro- and microlevels (Kubiëna 1938; Feofarova 1956; Lobova 1965; Tarchizky et al. 1984; Norton 1987; Pankova 1992; Dixon 2009). At the same time, vesicular horizons are also known in freezing virgin soils of high latitudes (FitzPatrick 1956; Harris and Ellis 1980; Van Vliet-Lanoë 1988, 2010; Gubin and Gulyaeva 1997). In temperate climates, vesicular crusts have only been described for cultivated humus-rich clayey soils (Norton and Schroeder 1987; Pagliai 1987). Micromorphological studies of topsoil horizons are of particular importance in the context of problems relating to the degradation of agrogenic soils and the development of desertification processes (Bishay and Stoops, 1975; Carnicelli et al. 1994; Pagliai and LaMarca 1979).

At present, the formation of a platy or lens-like structure in topsoil horizons of soils freezing at least to the depth of 5–15 cm is explained by the modern cryogenic processes (Rogov 2009; Van Vliet-Lanoë 2010). In the soils of arid territories within the Subboreal zone of Central Asia, topsoil horizons with a platy structure are developed under vesicular horizons (Gubin 1984; Lobova 1965; Pankova 1992; Lebedeva-Verba et al. 2009). Such horizons have not yet been described for warm aridic soils in the south of the Subboreal zone (Dixon 2009).

Diverse species of soil biota have been studied in the topsoil horizons of many aridic soils: algae, cyanobacteria, mosses, liverworts, lichens, bacteria, and fungi (Dunckerley and Brown 1997). In some cases, their amount is so great that a specific kind of topsoil horizons– biological crusts– has been distinguished (Pagliai and Stoops 2010). However, data on the micromorphological diagnostics of biological crusts are not numerous (Elbridge and Greene 1994).

Topsoil horizons are the most dynamic horizons in the profiles of aridic soils. We argue that their properties explicitly reflect the modern ecological conditions of the soil development. As the environmental conditions and, hence, the soils of arid regions are very diverse, it is important to specify the particular objects of the study. In this paper, we only consider autonomous soils of Subboreal deserts along the aridity/continentality gradient from the south of European Russia to Uzbekistan, Kazakhstan, and Mongolia.

The micromorphological features of aridic soils are important indicators of their genesis because they are taken into account in classification decisions (Allen 1985).

The aims of this paper are to (1) trace changes in the microfabric of topsoil horizons of aridic soils developed from different parent materials in the Subboreal zone of Central Asia along the gradient of aridity and continentality of the climate and (2) determine the micromorphological and microbiological properties of vesicular horizons in Yermic Regosols in the extremely arid deserts of Kazakhstan and Mongolia.

2. Materials and Methods

2.1. Study area

The microfabric of topsoil horizons was examined in 11 typical profiles of aridic soils in the Subboreal zone of Central Asia: (1) Episalic Solonetz, at the Dzhanybek Research Station in the northern part of the Caspian Lowland, Russia; (2) Gypsic Calcisol, Baer Mounds in the Astrakhan oblast, Russia; (3) Yermic-Gypsic Calcisol, Bukhara oasis in Uzbekistan; (4) Gypsic Calcisol, Yermic-Gypsic Calcisol, Yermic Regosol, and Yermic-Gypsic Regosol, piedmont plain in the Ili Depression (southern Kazakhstan); and (5) Gypsic Calcisol, Yermic-Gypsic Calcisol, Yermic Regosol, and Yermic-Gypsic Regosol, Trans-Altai Gobi Desert, Mongolia (**Figure 1**).

Figure 1. Study objects: **(1)** Episalic Solonetz, Dzhanybek Research Station, the northern part of the Caspian Lowland, Russia; **(2)** Gypsic Calcisol on the Baer Mounds, Astrakhan oblast, Russia; **(3)** Yermic-Gypsic Calcisol, Bukhara oasis, Uzbekistan; **(4)** Gypsic Calcisol, Yermic-Gypsic Calcisol, Yermic Regosol, and Yermic-Gypsic Regosol, the Ili piedmont plain, Kazakhstan; and **(5)** Gypsic Calcisol, Yermic-Gypsic Calcisol, Yermic Regosol, and Yermic-Gypsic Regosol, Western Gobi, Mongolia.

These soils were classified according to the WRB system (IUSS Working Group WRB 2006). All the studied soils are developed from clay loamy sediments of different origins (**Table 1**). The groundwater depth at the studied sites exceeded 8 m, except for the Episalic Solonetz in the Caspian Lowland, where the groundwater table was found at the depth of about 3 m.

Table 1. Location of the profiles, topography and parent materials

Region	Soil*; profile no.	Topography; coordinates	Parent material; (total thickness of the profile)
Caspian Lowland, Russia	*EpSn** Profile 69-07	Volga–Ural interfluve; 40-cm-high microelevation within a flat surface between large mesodepressions *49°22'01.8"N, 46°48'16.52"E;* *27 m above sea level*	Yellow-brown calcareous loams of Late Khvalyn age; (70 cm)
	GypCa Profile 1B	Leveled top of a Baer Mound, West Ilmeni area in the Lower Volga reaches *46°21'26.58" N, 47°56'2.30"E;* *-24 m above sea level*	Recent eolian sediments; (60 cm)
Bukhara oasis, Uzbekistan	*YerGypCa* Profile 111	Upper part of an ancient outlier in the Bukhara oasis *40°6'16.79"N, 64°59'31.30" E;* *315 m above sea level*	Ancient alluvial, covered by loesslike sediments; (70 cm)
Ili Depression, Kazakhstan	*GypCa* Profile 1-06	Piedmont plain at the foot of the Sogety Ridge *43o43’1.1"N; 78o44’09";* *530 m above sea level*	Colluvial gravelly loam; (50 cm)
	YerGypCa Profile 8-06	Piedmont plateau at the foot of the Ketmen Ridge *43o25’40"N; 79o20’17.3" E;* *969 m above sea level*	Colluvial gravelly loam and loamy sand; (50 cm)
	YerReg Profile 3-06	Flat alluvial plain; hamada *43o42’53.2"N; 79o25’29.1"E;* *615 m above sea level*	Colluvial salt-bearing gravelly loamy deposits; (25 cm)
	YerGypReg Profile 5-06	Outlier in the lower part of the piedmont plain at the foot of the Ulken-Bogutty Ridge; flat surface; hamada *43o43’33.8"N; 79o16’49.2"E;* *622 m above sea level*	Neogene saline clay; (15 cm)
Trans-Altai Gobi, Mongolia	*GypCa* Profile 30	Piedmont plain; flat interfluve *≈ 1700 m above sea level*	Colluvial gravelly loam; (60 cm)
	YerGypCa Profile 28	Piedmont plain; flat interfluve between dry valleys; *≈ 1500 m above sea level*	Colluvial gravelly loam; (40 cm)
	YerReg Profile 10	Piedmont plain; flat interfluve between dry valleys; hamada; *≈ 1200 m above sea level*	Colluvial gravelly loam slightly saline; (22 cm)
	YerGypReg Profile M43	Ancient terrace; hamada; *≈ 1000 m above sea level*	Red-earth gypsiferous Cretaceous–Paleogene clay; (20 cm)

* *EpSn* — Episalic Solonetz; *GypCa* — Gypsic Calcisol; *YerGypCa* — Yermic-Gypsic Calcisol; *YerReg* — Yermic Regosol; *YerGypReg* — Yermic-Gypsic Regosol.

Aridic soils represent a group of soils with an aridic soil water regime characterized by the acute deficit of water during a large part of the year, which is dictated by the excess of potential evapotranspiration over mean monthly precipitation. In Soil Taxonomy (Soil Survey Staff 1999), the classes of aridic or torric soil moisture regimes are specified for such soils. Aridic soils are also often referred to as desert soils. A specific feature of Subboreal deserts in Central Asia studied by us is the absence of the thermic and hyperthermic soil temperature regimes characterized by mean annual soil temperatures above 15 and 22 ºC respectively, although most of the soils with an aridic moisture regime fall into these categories of soil temperature regimes (Soil Survey Staff 1999). In the Subboreal deserts of Central Asia, however, the thermic soil temperature regime with a mean annual soil temperature slightly above 15 ºC is only typical of the southernmost part of Uzbekistan. Data on these soils are not included in our study.

All the soils under consideration are subjected to annual freezing to the depth of 60–100 cm and they remain frozen for several months (Rode and Pol'skiy 1961; Pankova 1992).

A comparative analysis of climate characteristics in the areas under study made it possible to show the following: (1) the territory in the South of European Russia is the most humid region with annual precipitation (MAP) 250 mm. The rainfall is usually in the spring (150 mm) and the summer (100 mm). At the territory of Kazakhstan and Uzbekistan the MAP decreases from 150 mm in the northern part to 77 mm in extremely arid areas. The precipitation takes place in the winter-spring period. In deserts of Mongolia the MAP decreases strongly (from 120 mm in the north to 30 mm in extremely arid regions). The rainfall (90-95%) is usually in the summer. The territories under comparison differ in their Continentality Index (Kc)[1]. The most continental are the extremely arid deserts of Mongolia, which have lower temperatures in the winter period as compared to Southern Russia, Kazakhstan and Uzbekistan (Kudrin 1960; Umarov 1975; Sokolov et al. 1962; Lobova et al. 1977; Pankova 1992). Depending on the precipitation, the depth of soil moistening shows a change from 60 cm in the northern deserts to 20-25 cm in extremely arid deserts (Yakunin 1983).

As regards the vegetation one should notice that the Caspian Lowland is characterized by a three member soil-vegetation complex with wormwood-vitex association on Solonetzes, Agropyron–wild rye– chamomile (or chamomile–vitex) association on light chestnut soils, and grassy–forb association on Mollic Kastanozems of microdepressions (Kamenetskaya 1952). Episalic Solonetzes are characterized by sparse vegetation and often have vesicular crust and typical desert subcrust horizons developed under such conditions (Rode and Pol'skiy 1961).

Vegetation subzones of deserts in Kazakhstan and Mongolia are characteristic of decreasing cover (from 16% in northern deserts to 1% in extremely arid deserts). The subzone of northern deserts is specified by predominance of saxaul communities with saltwort on plateaus composed of the Cretaceous-Paleogene rocks. In the southern deserts the higher vegetation is only met in dry valleys, whereas the elevated flats reveal no higher vegetation and represent rocky deserts (hamadas) (Rachkovskaya 1993). The absence of higher vegetation is connected not only with low annual precipitation but also with immediate evaporation of summer rainfall from the soil surface heated up to 70–80 ºC (Evstifeev and Rachkovskaya 1976). In the present research, only natural soils (without human-produced modifications) with texture no coarser than loamy sand are discussed.

2.2. Laboratory analyses

Bulk samples for the physical and chemical analyses and undisturbed samples for thin sections were collected from the genetic horizons.

Micromorphological studies were performed with an optical microscope Olympus BH-2, a photo scanner Epson Perfection 2450 Photo, and a

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[1] Kc = A x 100/0.33φ, where A is the annual amplitude of air temperatures, ºC; and φ is latitude, ºN (Ivanov 1948).

digital camera Nikon E 4500. The description of soil fabric followed the guidelines by Stoops (2003).

The chemical and physicochemical analyses were performed in the Analytical Laboratory of the V.V. Dokuchaev Soil Science Institute according to the routine methods accepted in Russia (Vorob'eva 1998).

The soil-pH was determined in water extract (1:2.5) suspension. Texture was determined by pipette method with pyrophosphate pretreatment. The carbonate content was determined by the acidimetric method, and the humus content, by the method of wet combustion. The exchangeable cations were determined by the Pfeffer method in modification by Molodtsov and Ignatova (1975). The total content of sulfate ions in order to estimate the gypsum content was detected by the method suggested by Khitrov (Khitrov and Ponizovskiy 1990).

Thin sections were prepared by M.A. Lebedev in the Laboratory of Soil Micromorphology and Mineralogy of the V.V. Dokuchaev Soil Science Institute. The area of thin sections prepared from the thin surface horizons was about 3 x 4 cm. In some cases, larger thin sections (5 x 6 cm) comprising both A_1 and A_2 microhorizons were examined. Three to four vertically oriented thin sections from the topsoil horizon were described for each soil profile.

To refine the diagnostics of the biological and biogeochemical activity of microorganisms in hamadas, the method of Rybalkina and Kononenko (1957) was applied for the Yermic Regosol (Prof. 3-06). This method allows the study of active microbial communities developing on fouling glasses under natural conditions. Agar-covered glasses were exposed in the soil for 24 h immediately after heavy rain, when the upper soil horizons were moist. In the moist soil, swelling of the agar resulted in a favorable substrate for the activity of diverse viable microorganisms. After the extraction of glasses from the soil, the agar was subjected to dehydration, and the microorganisms became fixed on the glasses in the place they had developed in the moist soil. The glasses were examined under a Biomed 6 optical microscope equipped with Webbers camera. As a result, we obtained photos showing not only the spatial structure of the active microbial cenosis but also separate stages of the functioning of the microorganisms, including their growth, feeding, division, propagation, slime excretion, colony formation, destruction of minerals and synthesis of new minerals, and accumulation of nutrients and mineral substances.

3. Results

3.1. Morphological and physicochemical properties

The topsoil horizons of the studied soil profiles had much in common: they were lighter in color and coarser in texture in comparison with the middle-profile horizons and contained two morphologically distinct surface microhorizons: a compact vesicular crust (A_1 - the upper part of the A horizon) of 1–3 cm in thickness and an underlying platy microhorizon (A_2 - the lower part of the A horizon) with a thickness of 1.5–2.0 cm.

Some physical and chemical properties of the studied soils are presented in **Table 2**.

3.1.1. *The southern part of European Russia*

Episalic Solonetz (Profile 69-07). In the field, the Episalic Solonetz of the solonetzic soil complex has a crusty topsoil with the upper dense A_1 microhorizon with vesicular porosity underlain by the A_2 microhorizon with platy structure. The topsoil horizon is characterized by a relatively high (for an aridic soil) humus content (2.1%). It does not, however, contain soluble salts, and has a very low carbonate content. Gypsum is absent in all of these topsoil horizons. The platy A_2 microhorizon has an increased content of exchangeable sodium in comparison with the vesicular A_1 microhorizon (Table 2). The soil texture is silty light loam.

Gypsic Calcisol (Profile 1B). The upper vesicular part of the topsoil A horizon is more compact than the lower part with the platy structure; the boundary between them is diffuse. The A horizon does not contain soluble salts and gypsum; it has a low humus content and contains carbonates (2.1%). The soil-pH is neutral in these topsoil horizons, which is different from that in the other soils the properties of which are considered below (Table 2).

3.1.2. *Uzbekistan*

Yermic-Gypsic Calcisol (Profile 111). The difference between the vesicular (A_1) and platy (A_2) microhorizons was not clearly pronounced. The samples were very friable and easily parted to small crumb aggregates and silty particles. The topsoil contained a significant amount of calcium carbonates (13%) and small amounts of humus (0.79%) and gypsum (0.21%); the soil texture was coarse silty loam (Table 2).

3.1.3. *Kazakhstan*

3.1.3.1. Soils developed from the Quaternary deposits

Gypsic Calcisol (Profile 1-06). The vesicular and platy microhorizons in the field were very thin and friable; the soil mass parted to granular aggregates. The soil did not contain soluble salts

Table 2. Some chemical and physicochemical properties of aridic soil in Central Asia

Country	Soil*	Horizon, (depth, cm)	pH	Humus	$CaCO_3$	Gypsum	Soluble salts	ESP	Particles <0.01 mm
				%					
Russia	*EpSn* Profile 69-07	A_1 (0-3.5)	7.5	2.10	0.3	0.00	0.01	3	18.6
		A_2 (3.5-5)						12	21.6
	GypCa Profile 1B	A_1 (0-2)	7.3	0.47	2.1	0.04	0.01	2	Not det.**
		A_2 (2-4)							
Uzbekistan	*YerGypCa* Profile 111	A_1 (0-2.5)	8.1	0.79	13.2	0.21	0.14	0	23.1
		A_2 (2.5-5)							22.8
Kazakhstan	*GypCa* Profile 1-06	A_1 (0-4)	8.5	0.81	5.1	0.05	0.03	1	9.3
		A_2 (4-8)	9.5	0.92	5.7	0.05	0.04	0.4	8.3
	YerGypCa Profile 8-06	A_1 (0-4)	8.9	1.33	11.4	0.07	0.06	2	27.0
		A_2 (4-8)	9.2	1.23	11.5	0.09	0.03	2	24.9
	YerReg Profile 3-06	A_1 (0-3)	9.1	0.18	8.1	0.12	0.23	12	44.2
		A_2 (3-5)	8.7	0.39	9.4	0.17	0.49	7	38.1
	YerGypReg Profile 5-06	A_1 (0-2)	10.0	0.00	6.4	2.60	3.14	25	45.9
		A_2 (2-5)	9.0	0.28	6.5	11.57	0.50	23	33.2
Mongolia***	*GypCa* Profile 30	A_1 (0-1.5)	8.8	0.44	11.3	0.06	0.11	7	7.7
		A_2 (1.5-3)							
	YerCa Profile 28	A_1 (0-2)	9.1	0.50	8.5	0.25	0.13	5	Not det.
		A_2 (2-4)							
	YerReg Profile 10	A_1 (0-3)	9.1	0.02	19.4	0.01	0.49	32	36.9
		A_2 (3-6)	9.0	0.52	11.3	0.51	1.71	41	
	YerGypReg Profile 43	A_1 (0-2)	9.1	0.00	5.2	0.45	0.35	6	32.3
		A_2 (2-4)	8.2	0.04	2.8	2.35	1.00	0	27.3

* *EpSn* — Episalic Solonetz, *GypCa* — Gypsic Calcisol, *YerGypCa* — Yermic-Gypsic Calcisol; *YerReg* — Yermic Regosol, and *YerGypReg* — Yermic-Gypsic Regosol. ** Not det. – not determined. *** The chemical properties are given according to Pankova 1992.

and gypsum; the calcium carbonate content reached 5.1–5.7%, and the humus content was less than 1% (Table 2). The soil texture was coarse silty loam.

Yermic-Gypsic Calcisol (Profile 8-06). The vesicular and platy microhorizons were clearly distinguished. They do not contain soluble salts, whereas the calcium carbonate content is relatively high ($CaCO_3$ = 11.5 %); the humus content is also relatively high (1.23–1.33%). The soil has a coarse silty loamy texture (Table 2).

Yermic Regosol (Profile 3-06). The vesicular and platy microhorizons had an increased density. The topsoil contains some amount of soluble salts with the predominance of chlorides and sulfates; the content of calcium carbonates reaches 8.1–9.4%, whereas the gypsum content is low (0.12–0.17%). The humus content in the A_2 microhorizon is higher than that in the A_1 microhorizon (0.39 and 0.18%, respectively) (Table 2). The soil texture is heavy: fine sandy clay in the A_1 microhorizon and fine sandy heavy loam in the A_2 microhorizon.

3.1.3.2. Soils developed from the Neogene deposits

Yermic-Gypsic Regosol (Profile 5-06). The topsoil horizon in the field was relatively compact and had distinct vesicular porosity. The content of soluble salts is higher in the A_1 microhorizon, whereas the gypsum content is higher in the A_2 microhorizon (A_1 – 2.6%, A_2 – 11.57%); the calcium carbonate content is about 6.5% (Table 2). Soluble salts and gypsum, as well as the heavy texture of the topsoil (coarse silty light clay), are inherited from the saline Neogene clay.

3.1.4. *Mongolia*

3.1.4.1. Soils developed from the Quaternary deposits

Gypsic Calcisol (Profile 30). The topsoil horizon is characterized by the low content of soluble salts, humus (0.44%), and gypsum (0.06%) and by the high content of calcium carbonates (11.3%) (Table 2). It has a loamy sandy texture.

Yermic-Gypsic Calcisol (Profile 28). With respect to the chemical and physicochemical properties, the topsoil horizon is generally similar to that in the Gypsic Calcisol. However, the humus and gypsum contents are somewhat higher: 0.44% and 0.25%, respectively (Table 2). The soil texture is loamy sand.

Yermic Regosol (Profile 10). A comparative chemical analysis of the upper vesicular and lower platy parts of the topsoil attests to certain differences between them (Table 2). The A_2 microhorizon is richer in humus (0.52%), gypsum (0.51%), and soluble salts (1.71%). The topsoil horizons in this soil profile have higher contents of soluble salts and exchangeable Na^+ in comparison with the other investigated aridic soils on Quaternary deposits of Mongolia (profiles 28, 30). This may be related to the presence of the derivatives of red-earth saline clay in the parent material (sandy clay loam).

3.1.4.2. Soils developed from the Cretaceous–Paleogene deposits

Yermic-Gypsic Regosol (Profile M43). The topsoil horizon contains negligible amount of humus (<0.04%) and soluble salts and a small amount of gypsum with a maximum (2.35%) in the A_2 microhorizon. Calcium carbonates content reaches 5.2% in the A_1 and 2.8% in A_2 microhorizons (Table 2). The texture is sandy silt loam.

3.2. Micromorphology

Table 3 illustrates the main micromorphological results.

3.2.1. *The southern part of European Russia*

Episalic Solonetz (Profile 69-07). The basic distinctive fabric of topsoil horizons in this soil is the gradual change in the microstructure from vesicular (**Figure 2A**) through platy-vesicular (**Figure 2B**) to platy (**Figure 2C**). Under higher magnification, the zones of iron depletion from the material around the pores are clearly seen. The silt-size grains of quartz and feldspars are tightly packed and do not have coatings. Upon the examination in reflected light the numerous iron nodules and the great number of the biogenic filaments (probably, algae and/or cyanobacteria) were clearly seen in the reddish brown groundmass (**Figure 2D**). The vesicular and platy porosity was developed in the silty-clay material characterized by a higher content of fine dispersed humus microforms without carbonates.

Gypsic Calcisol (Profile 1B). In the microfabric of the A_1 horizon, the fine sand particles are arranged in a nested pattern. The c/f related distribution is uneven in separate microzones, which are single spaced and double porphyric. Vesicular pores are allocated to the microzones with a higher content of phyllosilicates and micrite (**Figure 2E**).

Table 3. The main micromorphological features of the topsoil horizons

Countries	Profile	Horizon	Voids				Groundmass c/f related distribution	Micromass b-fabric	Pedofeatures							
									Carbonate		Gypsum	Salts	Fe/ Mn	Clay	Matrix depletion	Organic matter
			v	pl	pv	ch			Micrite in groundmass	Other types						
Russia	69-07	A_1	+++*	-	-	-	fm	u		-			n- sg		+++	p, or
		A_2	-	+++	+	-	fm	u-ss					n		-	p, or
	1B	A_1	+++	-	-	+	sp-dp	cr	w-m	n				c	-	p, or
		A_2	-	++	+	++	gs-dp	cr	w					c	-	p, or
Uzbekistan	111	A_1	+	-	+++	+	fm-sp	cr	m	n					-	or
		A_2	-	++	++	+	fm-sp	cr-gs	w-m	n, cp				c	-	or, ex
Kazakhstan	1-06	A_1	-	-	+++	++	ee	cr	w				c		-	or
		A_2	-	-	+++	++	fm-cp	cr	w	hc					-	or
	8-06	A_1	+++	-	-	+	op	cr-ss	s						-	or-
		A_2	-	+++	-	+	op	cr	m	c, nn					-	or
	3-06	A_1	+++	-	-	-	fm-cp	cr	s				n	c	++	ex, cl
		A_2	-	+++	-	-	cp	cr	m					c	-	p
	5-06	A_1	+++	-	-	-	fm	cr-ss	s		cri-dp-ds-crs	inf		hc	-	p
		A_2	-	+	-	++	fm	cr-gs	m		cri-crs-df	inf-c		c	-	p
Mongolia	30	A_1	++	-	++	-	op	cr	s	c					-	p
		A_2	-	+	+	+	op	cr	m	cp, hc					-	or
	28	A_1	+++	-	-	-	op	gs-cr	m				sg	c-hc	++	or, p
		A_2	-	++	-	+	op	gs-cr	m					c	-	or
	10	A_1	+++	-	-	-	fm-op	gs-cr	m				sg		+++	clr
		A_2	-	++	-	+	fm-op	gs-cr	w						-	p
	M43	A_1	+++ (m)	-	-	-	fm-op	gs-cr	m			dp, n			-	p
		A_2	-	+	-	+	fm-op	gs-cr	m		cri	n			-	p

* -, +, ++, +++ indicate increasing frequency of pedogenic features - = absent, + = rare (locally in separate zones), ++ = common, +++ = abundant.
Void: v = vesicular, pv = packing voids; pl = planes, m = moldic.
Groundmass: *c/f related distribution:* fm = fine monic, sp = single spaced porphyric; dp = double porphyric; cp = close porphyric; op = open porphyric;
Micromass: *b-fabric:* u = undifferentiated, cr = cristallitic, ss = stipple speckled, gs = granostriated.
Pedofeatures: c = coating, cp = capping; crs = crystal single; cri = crystal intergrowth; dp = dissolved pedofeatures; df = deformed pedofeatures; hc = hypocoating; inf = infilling; mi = micrite in groundmass (*degree of impregnation:* w = weakly; m = moderately; s = strongly); n = nodule; sg = segregation.
Organic matter: cl = cells; clr = cell residue, p = punctuations, or = organ residue; ex = excrement.

In A_2 microhorizon the platy structure is poorly pronounced. Thin clayey coatings cover the walls of fissures provides evidence for clay mobility (**Figure 2F**).

3.2.2. *Uzbekistan*

Yermic-Gypsic Calcisol (Profile 111). The A_1 microhorizon is characterized by the nested distribution of fine sand particles; vesicular pores are confined to the zones with the fine monic c/f related distribution (**Figure 2G**). In the series of studied soils, this particular profile is characterized by the presence of recent eolian sediments above the buried crusty horizon. The eolian material contains the rounded porous crumb aggregates typical of Haplic Calcisols on the surrounding plain, the major soil type in this part of Uzbekistan.

The A_2 microhorizon is characterized by the crumb-platy aggregates; oval-shaped excrements of soil mesofauna are present in the pores; clay particles display banded orientation (**Figure 2H**). The platy aggregates are not very distinct. As well as the covering eolian layer, they include rounded microaggregates from Haplic Calcisols inherited from the previous stage of the eolian deposition.

3.2.3. *Kazakhstan*

3.2.3.1. Soils developed from the Quaternary deposits

Gypsic Calcisol (Profile 1-06). According to the soil structure and character of pores in thin sections, the A horizon cannot be definitely subdivided into separate microhorizons. Porous crumb aggregates and compound packing voids predominate. A characteristic feature of the topsoil horizon in this soil is the great amount of filaments of desert mosses (**Figure 3 A, B**). In separate zones without filaments, isometric pores can be seen. According to Pagliai and Stoops (2010), this horizon can be classified as a biogenic crust. The aggregating role of moss filaments is clearly seen in thin sections. In the lower part of the horizon, abundant organic residues are present. The peculiar feature of the A_2 microhorizon is the presence of micrite hypocoatings around large channels.

Yermic-Gypsic Calcisol (Profile 8-06). The upper vesicular (A_1) (**Figure 3C**) and the heterogeneous lower (A_2) microhorizons are clearly distinguished. The A_2 microhorizon consists of granular and lenticular platy peds (**Figure 3D**). Upper faces of large lens-like aggregates are covered by thin clayey micritic coatings. The A_2 microhorizon contains diverse calcareous pedofeatures, including micritic coatings on rock fragments, fine micritic nodules, and intrusive and impregnative calcareous pedofeatures. Fine ferruginated organic residues are present.

Yermic Regosol (Profile 3-06). Vesicular pores of two types are distinguished in thin sections from the A_1 microhorizon: (1) small pores (0.1–0.3 mm) within the light-colored slightly compact calcareous groundmass and (2) large pores (0.8–1.2 mm) open to the surface and partly filled with eolian material (**Figure 3E**). The eolian infillings contain very small fragments of plant tissues, algal cells and filaments visible under high magnification. Rock fragments are covered by dark iron-manganic coatings. Under them, there are abundant oval-shaped excrements of the soil microfauna. Platy aggregates appear in the A_2 microhorizon; on their upper faces, matrix pedofeatures composed of striated fine material are seen (**Figure 3F**).

The high diversity developed on the fouling Agar-covered glasses attests to the high activity of the soil biota under conditions of the strong and fast moistening of the surface horizons. The frequency of occurrence of different species of microorganisms as seen on the glasses was estimated. Special attention was paid to their functional specificity, including the formation of slime, as well as to the composition and location of mineral compounds on the surface of the microorganisms or inside (Zavarzin 1972). We suppose that the formation of microaggregates of fine material detected under rock debris in the A_1 microhorizon is related to the gluing action of the slime of microorganisms (Kutovaya et al. 2012).

Green, yellow-green (**Figure 4A**), diatomaceous algae (**Figure 4B**), and dinoflagellates were typical representatives of protists; the domain of Bacteria was represented by cyanobacteria

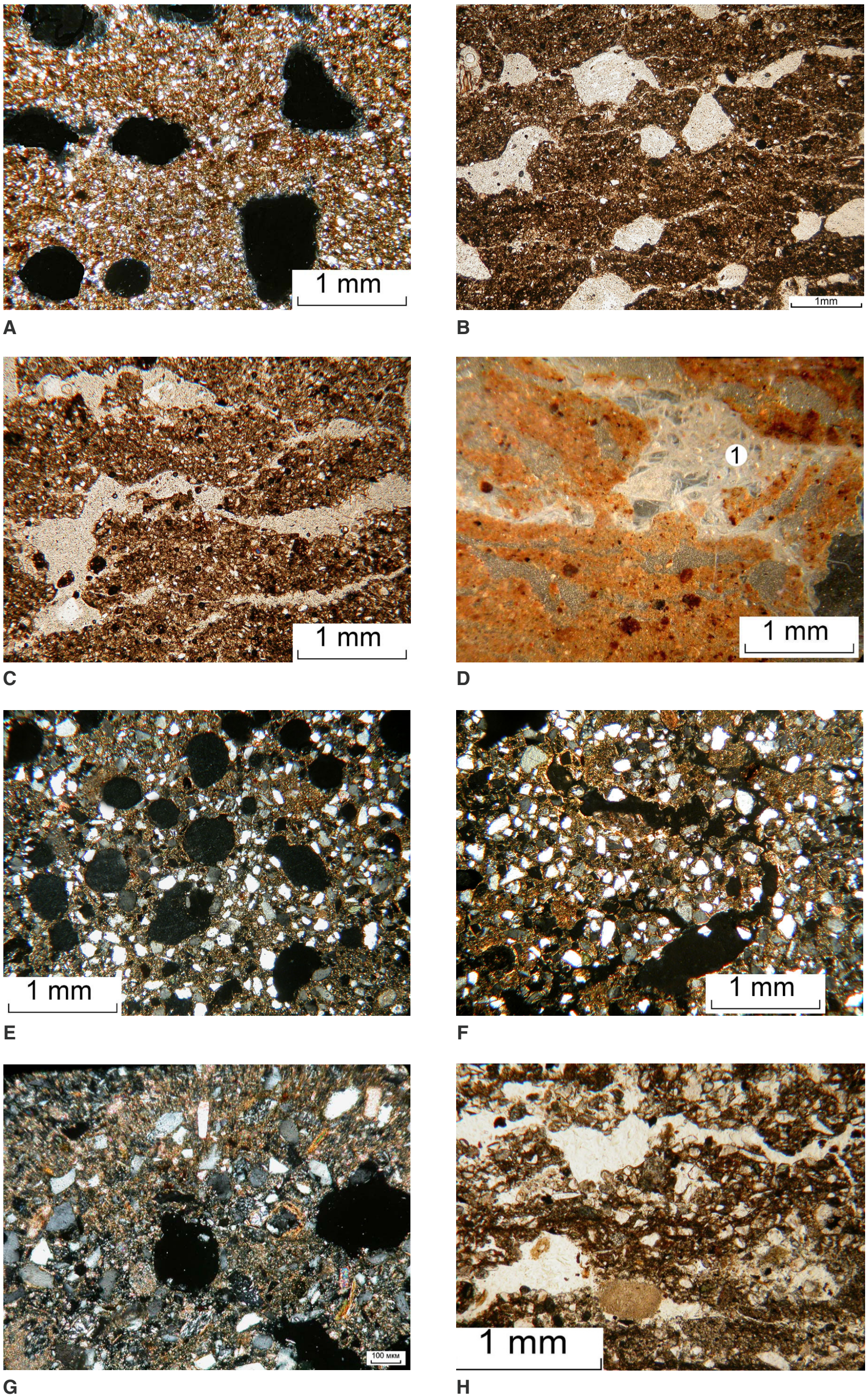

Figure 2. Fabric of topsoil horizons. (A–D) Episalic Solonetz (Russia, profile 69-07): (**A**) vesicular microstructure in Fe-humus-clayey material; thin iron-depleted zones around the pores in the upper part of the A$_1$ microhorizon (XPL); (**B**) combination of platy and vesicular microstructure in the middle part of the A$_1$ microhorizon (PPL); (**C**) platy-crumby microstructure in the A$_2$ microhorizon (PPL); and (**D**) fine iron nodules in the intraped mass of the A$_2$ microhorizon; biogenic (algal and/or cyanobacterial) filaments (marked with number 1) (reflected light). (E, F) Gypsic Calcisol on the Baer Mound (Russia, profile 1B): (**E**) abundant vesicular pores in the groundmass with crystallitic b-fabric in the A$_1$ microhorizon (XPL) and (**F**) thin clayey coatings on channel walls in the A$_2$ microhorizon (XPL). (G, H) Yermic-Gypsic Calcisol (Bukhara oasis, Uzbekistan, profile 111): (**G**) vesicular pores, fine calcitic nodules and clayey coating on quartzite fragment in the A$_1$ microhorizon (XPL) and (**H**) platy microstructure; oval-shaped excrement of soil mesofauna; banded distribution of fine material in the A$_2$ microhorizon (PPL).

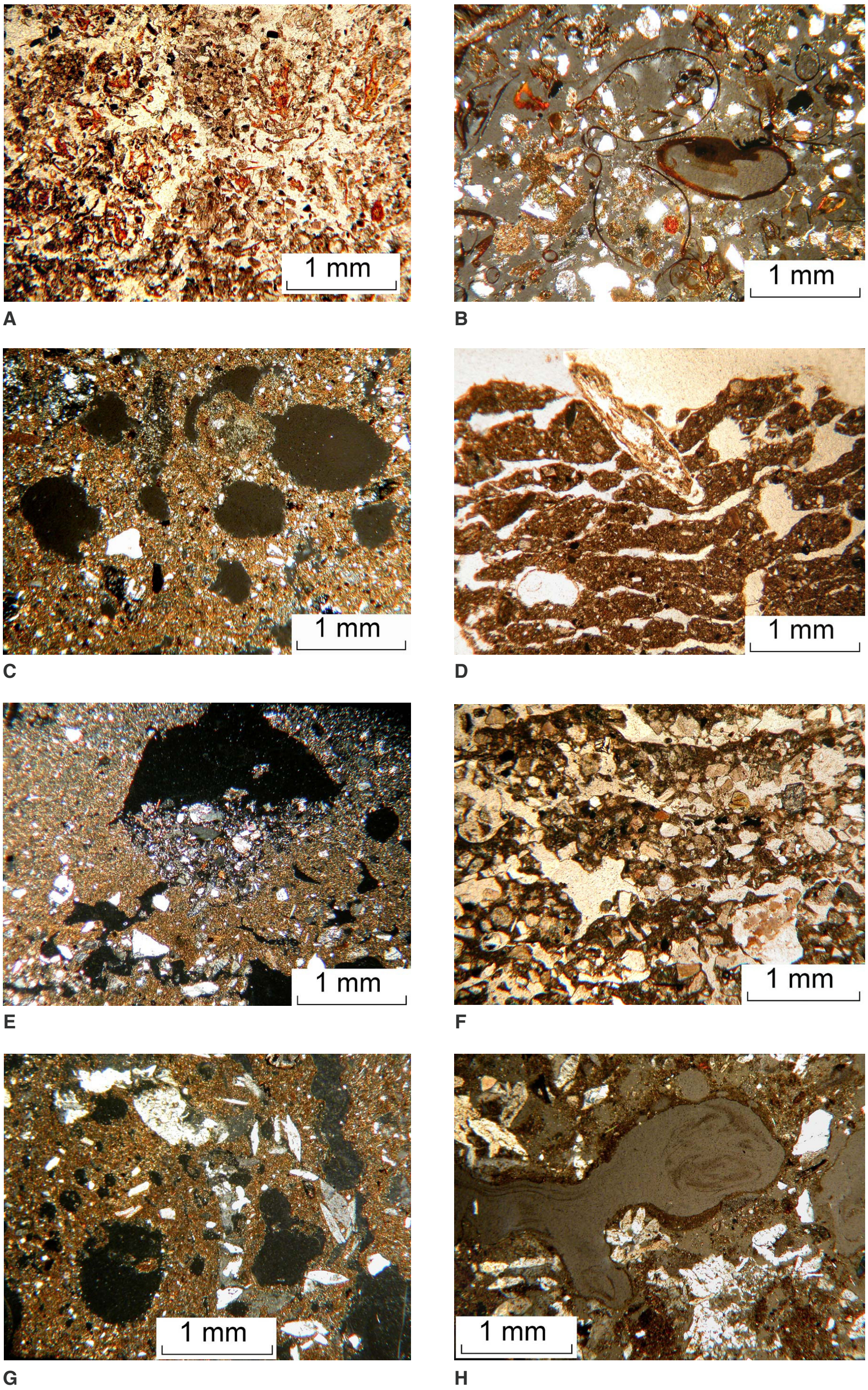

Figure 3. Fabric of topsoil horizons in aridic soils of southern Kazakhstan. (A, B) Gypsic Calcisol, profile 1-06: (**A**) crumb aggregates with moss residues in the upper part of the A$_1$ microhorizon (0-3 cm; PPL); (**B**) abundant plant residues in the lower part of the A$_1$ microhorizon (5-8 cm; XPL). (C, D) Yermic-Gypsic Calcisol, profile 8-06: (**C**) vesicular microstructure in the calcite-rich material of the A$_1$ microhorizon (XPL) and (**D**) lenticular-platy peds and coarse plant residues in the A$_2$ microhorizon (PPL); (E, F) Yermic Regosol, profile 3-06: (**E**) a vesicular pore exposed to the surface with an eolian infilling in the A$_1$ microhorizon (XPL) and (**F**) banded fabric in sandy loamy material with silty cappings on the lenticular microaggregates in the A$_2$ microhorizon (PPL). (G, H) Yermic-Gypsic Regosol, profile 5-06 : (**G**) vesicular pores of different sizes, channels, and growths of gypsum crystals of different habits in the gypsiferous-calcitic material of the A$_1$ microhorizon (XPL) and (**H**) silty coatings and quasicoatings in the channel, lenticular gypsum intergrowths, and infillings in the A$_1$ microhorizon (XPL).

(**Figure 4C**), iron bacteria, and some others. On the filaments of neutrophile *Gallionella* iron bacteria, membrane sacs and dilatations were partly or fully filled with amorphous iron compounds (**Figure 4 D**). *Leptothrix ochracea, Leptothrix discophora, Kusnezovia polymorpha*, and *Siderocaps* were also identified. At the same time, no fungal hyphae were detected on the fouling Agar-covered glasses and in inoculations from the same samples (Kutovaya et al. 2012).

3.2.3.2. Soils developed from the Neogene deposits

Yermic-Gypsic Regosol (Profile 5-06). In thin sections, abundant vesicular pores of different sizes (from 0.1 to 1 mm) and diverse gypsiferous pedofeatures are clearly observed. In the zone with vesicular porosity and close c/f related distribution, separate lens-shaped gypsum crystals of different sizes are seen in the groundmass (**Figure 3G**). In the zone with the predominance of channel pores, gypsum intergrowths with features of their destruction and recrystallization take place; coatings and internal quasi-coatings are observed in large channels (**Figure 3H**). These coatings may have different compositions; namely, pure clayey coatings alternate with clayey–salt coatings. The latter are virtually isotropic (XPL). As judged from the analysis of water extracts, the salt component is mainly represented by sodium chloride. Micritic coatings are seen on some of the rock fragments.

3.2.4. *Mongolia*

3.2.4.1. Soils developed from the Quaternary deposits

Gypsic Calcisol (Profile 30). The fabric of the A_1 microhorizon is characterized by the predominance of large interaggregate pores and small vesicular pores (**Figure 5A**). Oval calcareous nodules of 0.2–0.5 mm in size and calcareous pendants are present.

The A_2 microhorizon does not display the platy structure: crumb aggregates predominate. The microzonality of the optical orientation of clayey material is observed: zones with crystallitic, granostriated and speckled b-fabric can be distinguished. Impregnative micritic pedofeatures are clearly seen. Vesicular pores occur in the zones enriched in clayey plasma (**Figure 5B**).

Yermic-Gypsic Calcisol (Profile 28). The A_1 microhorizon is characterized by the predominance of vesicular pores (**Figure 5C**), though there are separate zones with compound packing voids. Among the vesicular pores, there are pores with smooth and with nipple-shaped walls. In the zones enriched in clay material, vesicular pores with layered Fe-clay coatings are seen (**Figure 5D**).

The A_2 microhorizon in thin sections does not display a distinct platy structure.

Yermic Regosol (Profile 10). The vesicular A_1 microhorizon in the Yermic Regosol (profile 10) differs from those in the Gypsic Calcisols and Yermic-Gypsic Calcisols in (1) the predominance of the zones with clayey-calcitic fine material having crystallitic b-fabric; (2) the presence of infillings with the high content of the cells of microorganisms visible under high magnification (**Figure 5E**) in the rounded pores; and (3) the presence of the iron-depleted zones around the pores (**Figure 5F**) with the formation of iron concentrations in the intraped mass (**Figure 5F**).

The A_2 microhorizon is distinguished from the A_1 microhorizon by the abundance of micritic calcite (carbonate impregnation), the predominance of platy peds, and fine planar pores. However, very fine vesicular pores are present inside the platy peds.

3.2.4.2. Soils developed from the Cretaceous–Paleogene deposits

Yermic-Gypsic Regosol (Profile M43). The A_1 microhorizon of these soils is especially peculiar due to the "vesicular porosity" and diverse salt and gypsiferous pedofeatures. Its fine material is clayey or carbonate-clayey. The soils reveal the dissolution of rounded nodules of soluble salts (thenardite) with the development of moldic voids (**Figure 5G**). The diagnostics of thenardite was based on optical characteristics of its crystals (Mees and Tursina 2010). As a result, such a "vesicular porosity" occurs.

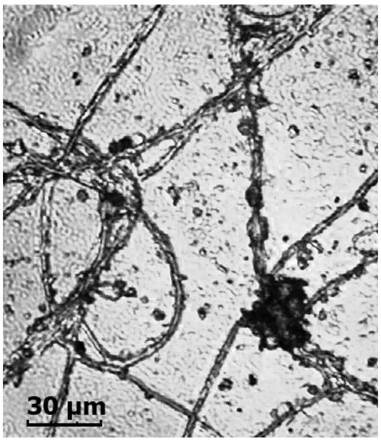

Figure 4.A

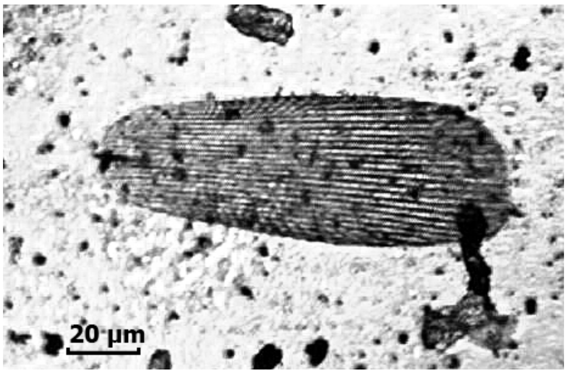

Figure 4.B

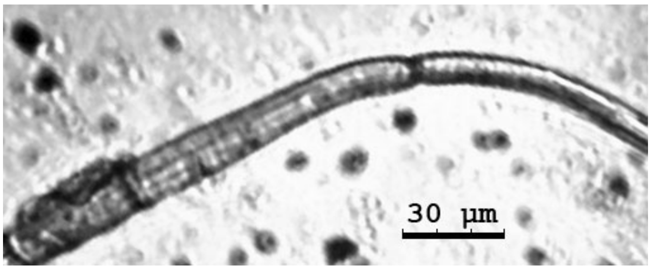

Figure 4.C

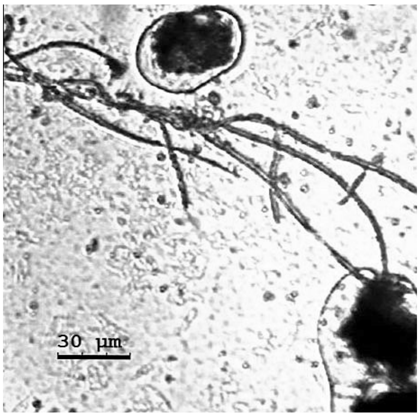

Figure 4.D

Figure 4. Active microbiota in topsoil horizons of Yermic Regosol (profile 3-06), southern Kazakhstan: (**A**) yellow-green algae, (**B**) diatoms, (**C**) cyanobacteria, and (**D**) iron bacteria.

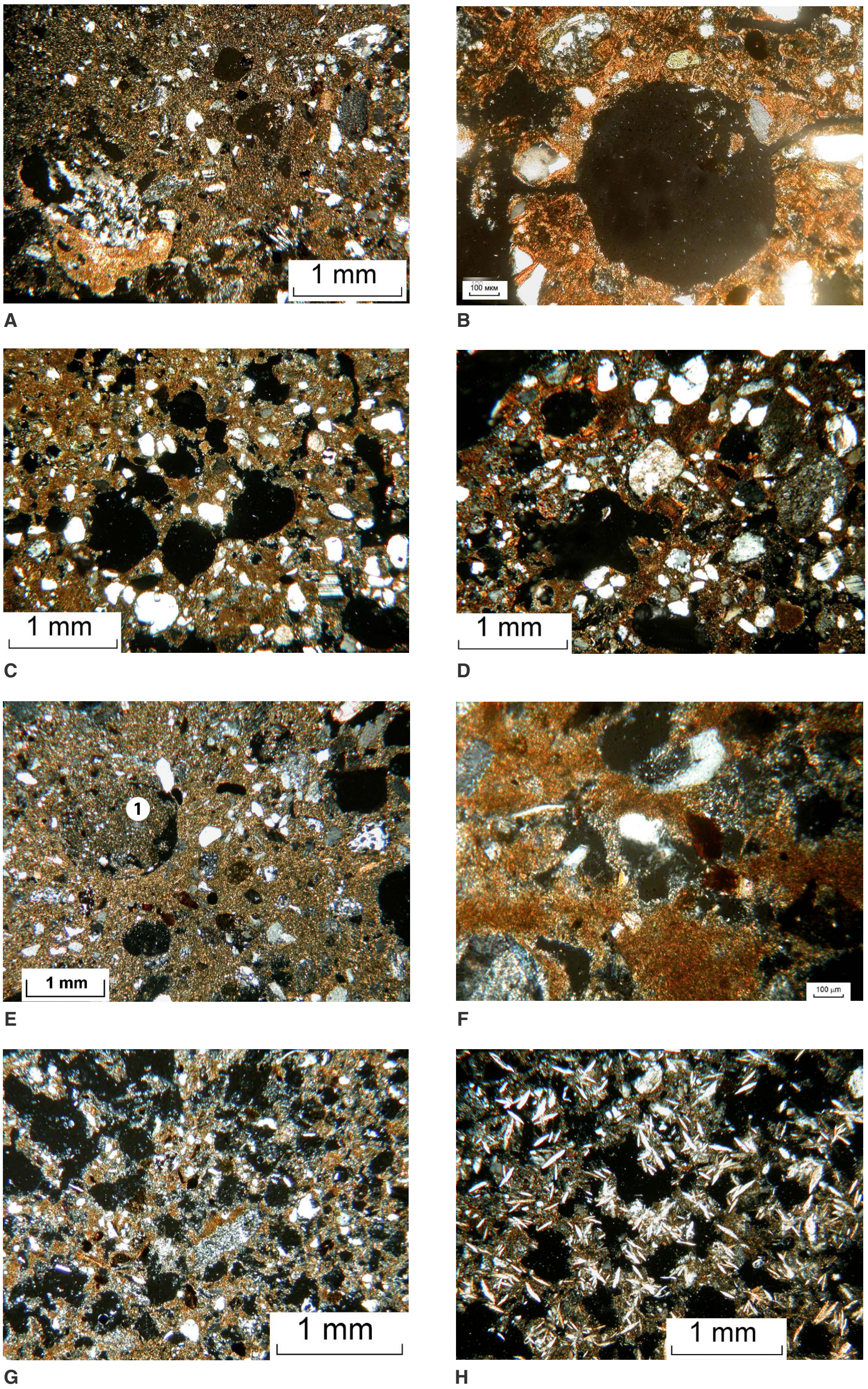

Figure 5. Fabric of topsoil horizons in aridic soils of Mongolia (XPL). (A, B) Gypsic Calcisol, profile 30: (**A**) vesicular pores in the calcite-rich material and calcite pendants on quartzite fragment in the A_1 microhorizon; (**B**) vesicular porosity in the clayey material of the A_1 microhorizon. (C, D) Yermic-Gypsic Calcisol profile 28: (**C**) zone of abundant vesicular pores, and (**D**) vesicular and nipple-shaped pores with layered iron-clayey coatings. (E, F) Yermic Regosol, profile 10: (**E**) infilling of fine gray material with the high content of humus and microbial cells (1) and (**F**) iron depletion from the material around the pores and iron concentration in the intraped mass. (G, H) Yermic-Gypsic Regosol, profile 43M: (**G**) the high porosity with a predominance of moldic pores and the remains of thenardite infillings and (**H**) openwork porosity; matrix pedofeatures with fine lenticular gypsum intergrowths.

The A_2 microhorizon is characterized by the high porosity and the predominance of matrix pedofeatures in the form of thin lens-like gypsum crystal intergrowths (**Figure 5H**). The platy aggregates have not been found.

4. Discussion

4.1. Vesicular porosity

The obtained data indicate that the formation of vesicular porosity in the studied soils is no less active than in the soils of the other arid regions of the world (Springer 1958; Lobova 1965; Evenari et al. 1974; Dregne 1976; Dixon 2009).

The vesicular pores have been found in the horizons with different compositions of the soil micromass: humus-clayey, clayey, or calcitic. The presence of vesicular pores in the horizons with different contents of carbonates allows us to suppose that their origin in the topsoil horizons may be related to different processes, which are the following:

> 1. In case of soda-saline soils, the phase transition of sodium bicarbonates into sodium carbonates with the release of CO_2 can take place upon the rapid drying of the soil. In particular, this may happen in spring in the westernmost and the least aridic of the studied soils—the Episalic Solonetzes—the surface horizons of which are depleted of soluble salts, and the high ESP (>10%) attests to the possibility of the soda formation. This increases the mobility of the clay material and results in the formation of the middle-profile solonetzic horizon with abundant clay coatings (Bouza and Valle 1993).
>
> 2. In case of the increased content of calcium carbonates, shifts in the calcium bicarbonate–carbonate equilibrium toward calcite precipitation with the release of CO_2 into the gaseous phase may take place upon changes in the soil moisture and temperature. This mechanism is particularly important during the spring maximum of precipitation, which is typical of all the studied territories except for the Trans-Altai Gobi in Mongolia, where rains occur in the summer, winters are snowless.
>
> 3. In weakly structured bare soils that are virtually devoid of the organic matter (e.g., extremely arid Yermic Regosols), the formation of vesicular pores may be due to the rapid displacement of air adsorbed on the solid soil particles by the water of summer showers; this may also take place upon the rapid soil freezing (Rogov 2009; Van Vliet-Lanoë 1985, 1988, 2010). The freezing depth in the studied soils of Mongolia reaches 1 m and more.
>
> 4. Some of the vesicular pores in the crust horizon may have the biological origin; they represent membrane sacks of iron bacteria that have been identified in the soils by the method of fouling Agar-covered glasses in natural conditions (Rybalkina and Kononenko 1957). Such configurations are physiologically important for the iron bacteria; they serve as reservoirs for concentration of amorphous iron compounds (**Figure 4D**). It can be supposed that some smallest (about 50-100 μm) rounded pores may represent the biogenic capsules (Lengeler et al. 1999; Kutovaya et al. 2012). Such small pores can be found in different types of arid soils (**Figure 2E; 3G; 5A, C, E**).
>
> 5. Rounded pores were also diagnosed in the Yermic Gypsic Regosols developed from gypsiferous Cretaceous–Paleogene deposits (**Figure 5G**). We suppose that their origin is related to the local leaching of rounded thenardite nodules (the remains of this salt can be diagnosed under high magnification). Thus, rounded pores may be the result of leaching of these nodules.

Thus, the micromorphological study of the Subboreal aridic soils along the gradient of aridity and continentality allows to suppose the polygenetic origin of the vesicular topsoil horizon typical of all of these soils. The contributions of particular processes to the origin of this horizon differ in dependence on the local conditions.

4.2. Platy horizon

Soil freezing is a typical process affecting the topsoil horizons of all the studied soils. Platy aggregates with a gradual change of particle sizes from the top to the bottom of plates (which is opposite to the contrast sorting of particles in sedimentary crusts) serve as a diagnostic feature of the process of cryogenic structuring (Rogov 2009; Van Vliet-Lanoë 2010). The manifestation degree of platy aggregates depends on the texture of surface horizons and on the soil water content before freezing. The most distinct platy aggregates are developed in well-sorted silty clay loams in arid regions with a precipitation maximum in autumn. In the studied soils a well-pronounced platy structure is typical of the A_2 microhorizon in the Episalic Solonetz. Micromorphological studies indicate that the vesicular A_1 microhorizon is gradually transformed into the layered A_2 microhorizon, what can be clearly traced in thin sections (**Figure 2A–2C**). A distinct platy structure is also typical of the aridic soils developed from the silty clay loamy deposits in Kazakhstan (**Figure 3D, F**). In both cases, the microhorizon with a platy structure (A_2) forms a paragenetic association with the overlying vesicular microhorizon (A_1). Good cryogenic structuring of the A_2 microhorizon is observed in the aridic soils subjected to freezing in a relatively moist state after autumn rains. The freezing of aridic soils in Mongolia takes place in a virtually dry state, so the platy structure is not pronounced in them. Also, we suppose that a relatively high content of soluble salts and gypsum inherited from the ancient saline deposits retards the formation of platy aggregates.

The development of the banded distribution of clay–iron–humus fine material in the A_2 microhorizon may be the result of two processes: (1) the cryogenic sorting of sandy and fine silty and clayey particles and (2) the activity of cyanobacteria that considerably decrease the water infiltration through the plates (Fox et al. 2009).

4.3. Iron mobility

Some fabric units in the studied soils attest to the mobility of iron in the vesicular horizons of aridic soils. Thus, in Episalic Solonetzes developing under moderately arid conditions (with the MAP reaching 30 mm), the zones of iron depletion are diagnosed around the vesicular pores, and fine iron nodules are formed in the intraped mass of A_1 and A_2 microhorizons (**Figure 2A, D**). The small sizes of iron nodules and the sharp form of boundaries between them and surrounding groundmass testify to the rapid formation of nodules due to the contrasting redoximorphic conditions in the processes of wetting and drying.

We suppose that the major role in the mobility of iron oxides belongs to the soil biota; in particular, to iron bacteria. It is interesting that similar fabric units have been diagnosed in the soils of extremely arid deserts in Kazakhstan and Mongolia. The study of soil microbiota in Yermic Regosols of Kazakhstan by the method of fouling Agar-covered glasses under natural conditions allowed the identification of alive and active species of neutrophile *Gallionella* iron bacteria (**Figure 4D**) and different species of *Leptothrix* iron bacteria (Kutovaya et al. 2012). The activity of these bacteria is greatly enhanced during short periods of the soil moistening and may contribute to the formation of iron-depleted zones around the vesicular pores and iron concentration in the matrix pedofeatures. The possibility of periodical local hydromorphism in the extremely aridic soils is also proved by the presence of diatom algae in them (**Figure 4B**).

4.4. Migration of salts, gypsum, and carbonates

A comparative micromorphological study of the same type of soils (Yermic Gypsic Regosols) developed from the similar parent materials in the areas with different climatic parameters attests to different intensities of the migration of soluble salts, gypsum, and calcium carbonates in them. In particular, the different amount and character of carbonate pedofeatures may be explained by differences in the seasonal distribution of precipitation. The highest amount of diverse calcitic pedofeatures (coatings, nodules, micritic impregnation of the groundmass) was identified in the deserts of Uzbekistan and Kazakhstan and in the northern deserts of Mongolia. In these regions, the maximum precipitation is typical of the cold seasons, which specifies the higher mobility of carbonates.

4.5. Clay mobility

The presence of clayey coatings in the vesicular pores of Yermic Regosols and Yermic Gypsic Regosols in Kazakhstan and Mongolia (**Figure 5D**) can be explained by the lateral migration of clay particles under conditions of the increased alkalinity in the topsoil horizons.

4.6. Eolian input of silty material

This may play a significant role in the development of the topsoils. In some cases, rounded soil aggregates (0.2–0.3 mm) typical of Sierozemic loess soils subjected to wind erosion are found in the topsoil horizon of aridic soils of Uzbekistan. The admixture of eolian material is also seen in the vesicular pores of the aridic soils of Kazakhstan (**Figure 3E**). These rounded soil aggregates are clearly identified in the soil mass because of the increased content of silt particles, distinct boundaries, and specific fabric differing from the fabric of the enclosing groundmass. The boundary between the eolian material and the crust surface is also clearly traced (Gerasimova and Lebedeva-Verba 2008). If the soil skeleton consists of nonsorted fine sandy and silty particles, their distribution in the soil mass has a clustered (porphyric) pattern. In this case, the A_1 microhorizon contains not only the vesicular pores but also packing voids shaped by the aggregates enriched in such particles. The great aggregation role in the soils developed from the eolian sediments belongs to the soil biota and, in particular, to mosses (**Figure 3A**). Elbridge (1994) also described how mosses collect eroded and transported aggregates and grains contributing to the surface stability.

5. Conclusions

(1) The results of chemical and physicochemical analyses of aridic soils with similar morphologies of topsoil horizons indicate that the A_1 and A_2 microhorizons are formed under a relatively wide range of bioclimatic conditions; they are formed from parent materials differing in their genesis, age, and salinization degree.

(2) Vesicular pores in the topsoil of aridic soils are formed in the zones with the fine monic c/f related distribution and with different mineral compositions. The composition of the fine material (the presence of carbonates, clay and silt particles, soluble salts, and gypsum) specifies the particular process of the development of vesicular porosity that can be considered as an annually reproducible element of the soil fabric. With increasing aridity, the density and thickness of the vesicular horizon is increased against the background of the mobility of clayey particles.

(3) Vesicular pores are polygenetic formations. The major process of their development is related to the emission of gases (in the form of bubbles) upon the active biochemical decomposition of organic matter with active participation of the soil microorganisms and upon phase transition of sodium and calcium bicarbonates into carbonates during the topsoil drying. In the extremely aridic soils developing from the ancient saline clayey sediments, the formation of rounded moldic pores may be due to the local dissolution of salt nodules. Some part of the rounded (vesicular) pores may be created by the microorganisms and represent

specific biogenic capsules and bulges that are physiologically important for iron bacteria.

(4) The platy structure of the freezing aridic soils in the Subboreal zone of Central Asia is created by the cryogenic structuring.

(5) The soils of extremely arid deserts have fabric units attesting to the periodical mobility of iron oxides in the anaerobic conditions. Such conditions may be periodically created in the soils after strong rainfall. A significant role in these processes is played by iron-reducing and iron-oxidizing bacteria.

6. Acknowledgments

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