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GENESIS AND GEOGRAPHY OF SOILS

Soils and the Soil Cover of the Arkaim Reserve (Steppe Zone of the Trans-Ural Region)

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Abstract—Soils of the Arkaim Reserve in the area around a unique settlement–fortress of the Bronze Age in Chelyabinsk oblast have been studied. These soils are generally typical of the entire Trans-Ural Plateau. The soil properties are characterized in detail on the basis of factual data on 170 soil pits and four soil catenas. The soil cover of the reserve is specified into six geomorphic groups: (a) denudational surfaces of the low mountains, (b) accumulative–denudational surfaces of the low mountains, (c) denudational–accumulative plain surfaces, (d) lacustrine–alluvial plain surfaces, (e) floodplain surfaces, and (f) slopes and bottoms of the local ravines and hollows. Chernozems occupy about 50% of the reserve; solonetzes and saline soils, 32%; meadow chernozems, 7%; and forest soils, 1%. The soils of the reserve are relatively thin; they have a distinct tonguing of the humus horizon and are often saline and solonetzic. The latter properties are inherited from the parent materials and are preserved in the soils for a long time under the conditions of a dry continental climate. The genetic features of the soils differ in dependence on the composition and age of the parent materials. With respect to the thickness of the soil profiles and the reserves of soil humus, the soils can be arranged into the following lithogenic sequence: the soils developed from the eluvium of igneous rocks—redeposited kaolin clay—montmorillonite–hydromica nonsaline and saline loams and clays. The content of C_{org} in the upper 20 cm varies from 2.5 to 5.6%, and the reserves of C_{org} in the layers of 0–0.5 and 0–1.0 m reach 57–265 and 234–375 t/ha, respectively. The soils of pastures subjected to overgrazing occupy two-thirds of the reserve. Their humus content is 10–16% higher in comparison with that in the analogous plowed soils. Another characteristic feature of the humus in the soils of the pastures is its enrichment in the labile fraction (28–40% of C_{org}).

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INTRODUCTION

We have studied soils of the Arkaim Reserve (52°37–40′N, 59°32–37′E). It was organized in order to protect a unique fortress–settlement constructed 3800–4000 years ago and discovered by Zdanovich [2, 16–18]. The reserve was named after Mount Arkaim (398 m), the highest local point. Data on the environmental conditions, soil cover patterns, and properties of the salt-affected soils of the reserve have been published in a number of works [4, 7, 8, 13]. The reserve is characterized by the great diversity of the parent materials differing in their genesis, age, and properties. In this paper, we analyze specific features of the soils developed from different parent materials; special attention is paid to the humus state of these soils, which is important in the context of the further soil monitoring in the reserve.

INVESTIGATION METHODS

The major soil properties were determined according to [1]; the composition of the humus was determined according to Tyurin's method [10]. In the field work, four soil catenas crossing the reserve were studied in detail. Their total length reached 16.4 km; the soil pits were spaced 200–300 m apart from one another along the catenas. Overall, more than 170 soil pits were examined.

THE ENVIRONMENTAL CONDITIONS OF THE RESERVE

The Arkaim Reserve is found in the Bredinsk district of Chelyabinsk oblast 400 km from Chelyabinsk near the junction of the Utyaganka and B. Karaganka rivers. The reserve (3500 ha) was organized in 1992. It is found on the eastern slope of the Urals in the southwestern part of the Trans-Ural Plateau at 300–400 m a.s.l. Tectonic uplifts in the Late Oligocene predetermined the formation of the river network, ridges, and mounts elevating above the peneplain surface at about 50–100 m [9].

Climate. This region has a continental climate with a mean annual temperature of +1...+3°C, a mean January temperature of –17...–18°C, and a mean July

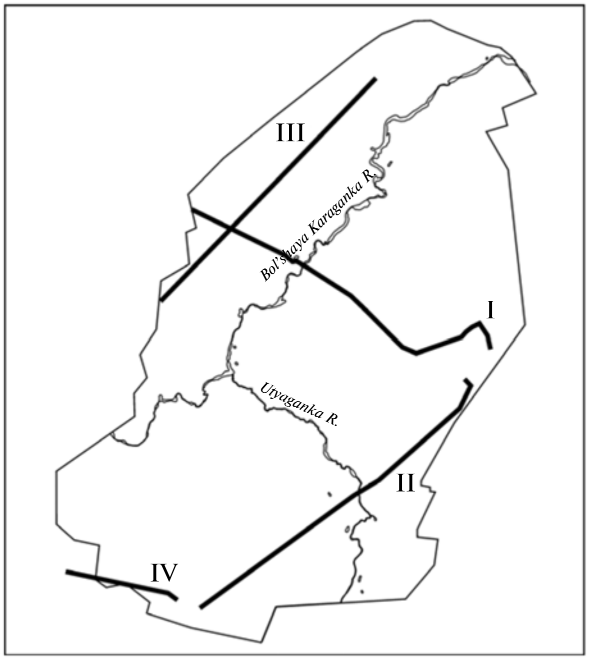


Fig. 1. Location of soil catenas studied in the Arkaim Reserve.

temperature of +19...+20°C. The accumulated sum of the daily temperatures above 10°C reaches 1950–2300°C, and the length of the frostless period is 111–125 days. The mean annual precipitation in the region is about 300–360 mm with 45% of this amount in the form of heavy summer rains and only about 10–12% in the form of winter snow. The depth of the snow cover does not exceed 0.25 m. The depth of the soil's freezing is 0.8–2.0 m. During the snowmelt season, the soil remains frozen, and meltwater does not penetrate into it. The potential evaporation reaches 450–650 mm. The humidity factor is about 0.4–0.8. Frequent dry winds may damage crops; the soils are subjected to wind erosion.

The soil-forming rocks of the reserve are very diverse [6]. They are represented by the Quaternary, Neogene–Quaternary, and Neogene clays and loams; redeposited Mesozoic kaolin weathering mantles; and the eluvium of Paleozoic crystalline rocks. The Devonian deposits are represented by basalt and andesite. Rhyolites and basalts of the Early Carboniferous period are widespread. Mottled and brown-colored Miocene clays occupy minor areas. The Pliocene sediments are widespread; they are specified into the lower (red clays) and upper (sand deposits) complexes. The Quaternary deposits are developed in river valleys.

The Mesozoic deposits are widespread in the Trans-Ural region [11, 12] and are represented by redeposited kaolin clay 1–40 m in thickness; these sediments may differ in their color, structure, and other properties. Thus, in the areas of acid rocks, structureless whitish kaolinite clay with inclusions of quartz grains and, in some cases, iron hydroxides is developed. Compact and porous brown-colored clay is formed in the areas of ultramafic rocks. Differently colored clay sediments are developed from schist and volcanic deposits. In general, the kaolin clays are depleted of alkaline-earth elements and carbonates and are characterized by their low cation exchange capacity and low content of adsorbed Ca; the portion of adsorbed Mg is high (up to 40% of the CEC), and the portion of adsorbed Na is up to 15% of the CEC; often, these deposits contain soluble salts and display solonetzic properties.

Table 1. Structure characteristics of the upper soil horizons in the Arkaim Reserve (n = 1–4)

Soil, land use	Aggregation factor	Dry sifting, aggregates 0.25–10 mm	Water-stable aggregates >0.25 mm
Ordinary chernozem, pasture	1.9	66	73
Ordinary chernozem, plowland	1.7	63	51
Ordinary chernozem on kaolin clays, pasture*	1.1	53	44
Underdeveloped chernozem on kaolin clays, pasture	0.9	49	44
Chernozemic meadow soil, plowland	2.0	67	52
Meadow soil, pasture	2.3	70	
Meadow-swampy soil, pasture	1.3	57	46
Soddy alluvial soil, pasture	3.3	77	67
Underdeveloped forest soil, forest	3.0	75	57

* The parent materials for the other soils are indicated in the text.

Table 2. Properties of forest soils in the Arkaim Reserve

Horizon	Depth, cm	pH_{water}	Exchangeable cations, meq/100 g				Fractions, %		Bulk density, g/m^3
			Ca^{2+}	Mg^{2+}	$H^+ + Al^{3+}$	Total	<0.01 mm	<0.001 mm	
Underdeveloped gray forest soil on the eluvium of rhyolite, forest, pit 9									
AO	0–4	6.2	40	10		50	24	3	0.95
AY	4–10	5.9	24	9	0.2	33	50	18	1.05
EB	10–20	5.5	13	4	0.6	18	27	4	1.05
B	20–35	5.9	12	5	1.0	18	22	3	1.41
BC	35–50	6.2			1.8		15	2	1.44
Solod on the eluvium of rhyolite, forest, pit 8									
AU	0–15	5.5	33	9	0.2	42	47	16	1.00
EL	15–28	5.2	17	4	1.2	23	54	20	1.36
EL	28–42	4.8	10	5	1.4	16	56	17	1.50
BT	42–68	4.3	–	–	1.2	24	64	25	1.62
BC	68–100	4.3	–	–	–	–	55	25	1.62
C	100–120	4.4	–	–	–	–	42	18	1.62
Swampy meadow soil on the Neogene–Quaternary sediments, fallow, pit 3									
H	0–20	6.0	22	6	–	28	39	9	1.05
Hg	20–40	5.9	14	2	–	16	53	14	1.16

Vegetation. The natural plant cover is mainly represented by forb–feather grass–fescue communities [5]. Virgin plots are covered by meadow oat grass and feather grass (*Stipa korjinskyi*) steppes. Species typical of meadow steppes are found on the slopes of local mounts and in the bottoms of the hollows. Low shrubs (pea shrub and spiraea), forb–feather grass, and forb–oat grass associations are common on the backslopes. Birch and larch–birch stands are preserved in depressions and occupy about 1% of the area. Wormwood associations predominate on saline, solonetzic, and weakly developed soils. Petrophytic associations are developed in the areas of rock outcrops. The riparian flora is rich and diverse. Swamped areas are covered by sedges, reed grass, and willow shrubs.

Intensive overgrazing has resulted in degradation of the vegetation in the reserve. Flat parts of the studied area were plowed up in the late 1950s. By the beginning of the 1980s, the area of plowed soils increased from 583 to 1077 ha. At that time, a part of the plowed area was sown with brome grass, lucerne, and *Onobrychis*. After the organization of the reserve, plowing was stopped. Since 1991, formerly plowed areas have been transformed into fallow lands overgrown with brome-grass.

The groundwater in the massive crystalline rocks is slightly saline and contains SO_4–Cl–HCO_3 anions and Ca and Mg cations [3]. The groundwater in the areas of loose sediments is of HCO_3–SO_4 and HCO_3–Cl composition; Na ions play a significant role among the cations. The groundwater table is found at the depth of about 6 m; it rises to 1–3 m below the surface in the floodplain areas.

SOILS AND THE SOIL COVER

We examined more than 170 soil pits along four soil catenas with a total length of 16.4 km (Figs. 1–2). Botanical, geological, and geomorphological investigations were also performed. Catena I crosses the valley of the Bol'shaya Karaganka River upstream from the junction with the Utyaganka River. Its length is 5.4 km, and it includes all the geomorphic elements typical of the reserve. Overall, 26 soil pits were examined along this catena. Catena II (5 km, 20 soil pits) crosses the valley of the Utyaganka River upstream from the junction with the B. Karaganka River. Catena III (4.6 km, 26 soil pits) characterizes soils developed on ancient weathering mantles on the slopes of low mounts on the right bank of the B. Karaganka River. In particular, we examined soils developed from the Mesozoic kaolin weathering mantles. Catena IV (1.4 km, 8 soil pits) crossed the depression filled with Neogene and Neogene–Quaternary clays and loams at absolute heights of 358–380 m.a.s.l. The study of the soil profiles along these catenas showed the diversity of the soils, biocenoses, and parent materials; the major features of the soil cover pattern were revealed.

The soil cover of the reserve can be specified into six genetic groups [7]: denudational and accumulative–denudational surfaces of low mounts and denudational–accumulative, alluvial–lacustrine, floodplain, and valley areas [7]. The soil cover patterns typical of these areas are characterized below.

The soil cover of the denudational surface of the area of low mounts (340—400 m a.s.l.). In places of the outcrops of acid rocks (rhyolites), low ridges alternate with ravine depressions filled with colluvial deposits. Weakly developed chernozems and forest soils predominate in this area. These are thin (25–50 cm) soils with a high humus content, increased stoniness (40–60%), good structure, and light or medium loamy textures (Figs. 2–4; Tables 1 and 2).

Under steppe vegetation, weakly developed chernozems are formed. The reserves of $CaCO_3$ in these soils are relatively low; calcareous coatings are found on the lower sides of pebbles. Carbonates are accumulated in these soils due to the eolian deposition and the biogenic accumulation. These soils with a relatively shallow profile have a higher humus content in the fine earth of the upper horizon in comparison with normally developed chernozems. The soil humus is of the fulvate–humate composition; the degree of humification is moderate. The content of the third fraction (the fraction tightly bound with clay minerals) of humus acids is high (Figs. 5, 6).

Under forest vegetation, immature forest soils are formed. These soils are characterized by their slightly acid reaction and a sharp decrease of the humus, the CEC, and the content of exchangeable calcium with the depth. The degree of base saturation is relatively low (47%). The labile fractions of the humic and fulvic acids predominate in the composition of the humus.

In the hollows receiving additional snowmelt, steppe and swampy solods are formed. Swampy solods occur under forests with excessive moistening. The solods are characterized by their well-differentiated profile, acid reaction, high exchangeable and total acidities, low exchange capacity, and the presence of Na in the exchange complex. The humus content reaches 8–11% in the upper humus horizon and decreases to less than 1% in the solodic horizon. The content of fraction 1a of the fulvic acids (extracted by acid upon the soil's decalcification) in the humus of the solods is high (contrary to the other soils of the reserve). The content of the clay fraction in the solodic horizon is 1.5–2.3 times lower than that in the illuvial horizon, while the content of exchangeable bases in the solodic (eluvial) horizon is 2.3–3.3 times lower than that in the illuvial horizon. Swampy solods differ from steppe solods in the higher pool of humus, higher CEC, and lower content of exchangeable sodium.

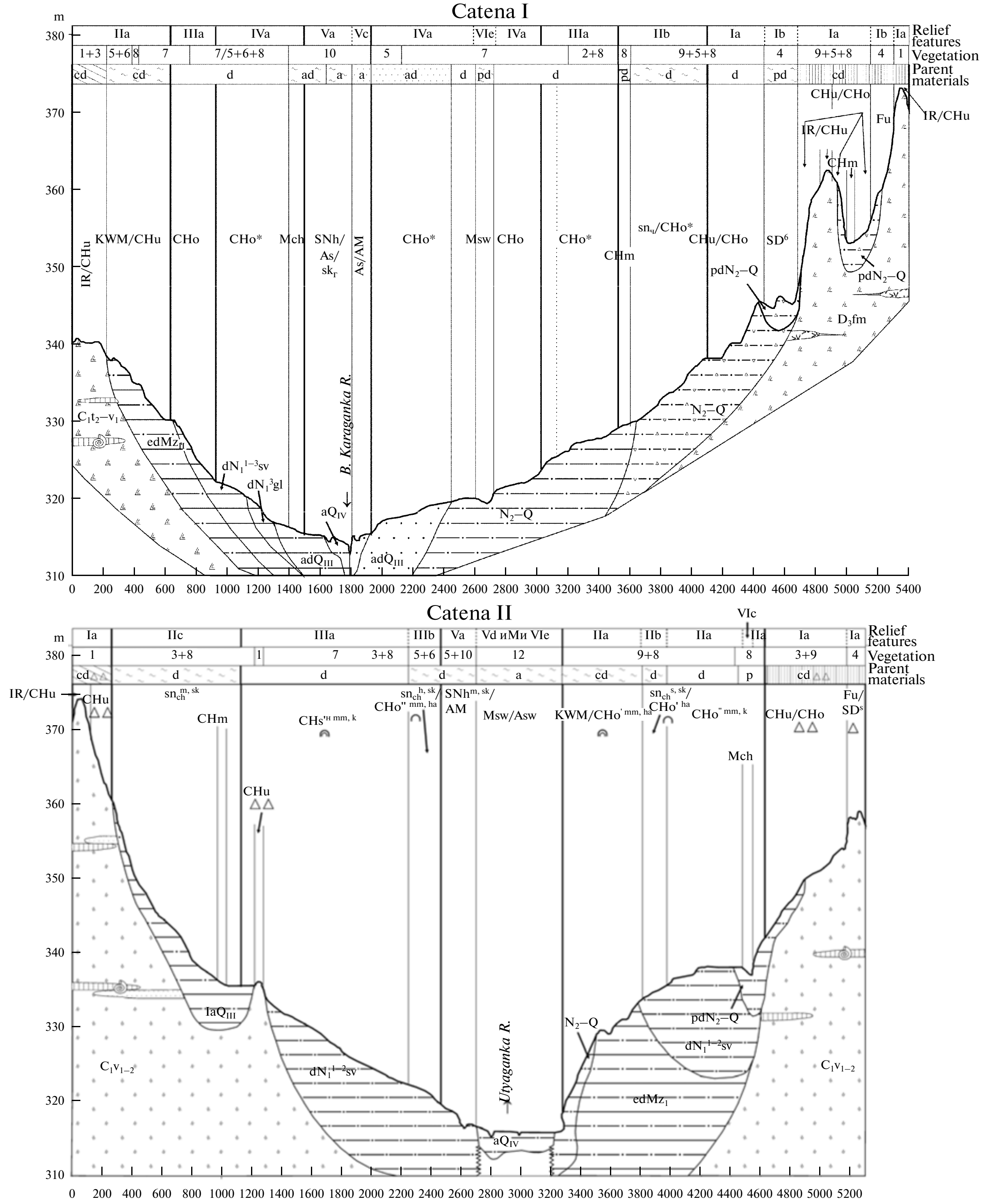
The soil cover of accumulative–denudational surfaces of the low mounts (350–370 m a.s.l.) is represented by chernozems and solonetzes developed from the redeposited Mesozoic kaolin weathering mantles and Neogene clays and loams.

The soils developed from kaolin weathering mantles are characterized by their low content of exchangeable calcium in the kaolin clays; the small biomass hampers the soil's development. Specific features of these soils are related to their position on the surfaces subjected to denudation. The low infiltration capacity of the parent material is also an important factor affecting the soil's development.

Ordinary chernozems developed from kaolin deposits are usually thin, slightly alkaline, and heavy loamy. They are characterized by poor aggregation and a low absolute content of exchangeable sodium, though its percentage in the exchange complex is high (Table 3). Their profile has pendent carbonate, gypsum, and salt horizons. The maximum contents of gypsum and soluble salts (up to 2.5–3%) are in the BC horizon (Table 4).

The organic matter content sharply decreases down the soil profile. The soil humus is of the humate–fulvate or humate composition (the C_{ha}/C_{fa} is 1.3–2.2). The degree of humification is high in the

Fig. 2. Schemes of catenas I–III. Relief features: I—denudation surfaces (Pg–N) (Ia—mounts, ridges, leveled surfaces, and slopes dissected by micro- and mesohollows; Ib—north-facing slopes dissected by micro- and mesohollows); II—accumulative–denudational surfaces (Pg–N) (IIa—slopes dissected by hollows, IIb—gentle parts of slopes, and IIc—depressions between mounts); III—denudational–accumulative surfaces (N2–Q) (IIIa—upper parts of slopes dissected by hollows, IIIb—lower parts of slopes dissected by hollows, and IIIc—hollows and ravines); IV—alluvial–lacustrine surfaces (IVa—ridges, slopes, and hollows; IVb—flat areas with hollows); V—floodplain surfaces (Va—ridges and small mounds with depressions between them; Vb—flat areas with microlows; Vc—mouths of large hollows and ravines; and Vd—dry oxbow depressions and backswamps); VI—ravines and hollows (Q) (VIa–VIe—hollows and ravines of different lengths, depths, widths, and catchment areas). Age of the deposits: Q—Quaternary, N—Neogene, Mz—Mesozoic, C—Carboniferous, D—Devonian, and S—Silurian. Parent materials: a—alluvium, d—deluvium (colluvium), e—eluvium of igneous bedrock, *p*—proluvium (deposits of temporary streams), IR—igneous rocks, and KWM—kaolin weathering mantles. Plant communities: (1) wormwood–fescue and fescue–feather-grass of stony surfaces, (2) meadow oat-grass steppes, (3) *Stipa korjinskyi* steppes, (5) wormwood–feather-grass communities of solonetzes, (6) wormwood–fescue communities, (7) fallows with weeds, (8) meadow steppes and steppe meadows, (9) forb–feather-grass steppes, (10) *Hordeum brevisubulatum* and floodplain meadows, (11) thrift–*Leymus* and *Leymus–Artemisia lerchiana* communities, and (12) sedge, reed, and *Typha* communities. Soils: CH—chernozems (CHu—underdeveloped, CHo—ordinary, CHs—southern, and CHm—meadow-chernozemic); M—meadow soils (Mch—chernozemic meadow, M—typical meadow, and Msw—meadow swampy); SN—solonetzes (SNa—automorphic and SNh—hydromorphic); SK—solonchaks; As—soddy alluvial, Am—meadow alluvial, SD—solod, Fu—underdeveloped forest; sn—solonetzic; and k—calcareous.


Catena I
Relief features
Vegetation
Parent materials
IIa IIIa IVa Va Vc IVa VIe IVa IIIa IIb Ia Ib Ia Ib Ia
1+3 5+6 8 7 7/5+6+8 10 5 7 2+8 8 9+5+8 4 9+5+8 4 1
cd cd d ad a a ad d pd d pd d d pd cd
IR/CHu
KWM/CHu
CHo
CHo*
Mch
SNh/ As/ skr
As/AM
CHo*
Msw
CHo
CHo*
CHm
snu/CHo*
CHu/CHo
SD6
CHu/CHo
IR/CHu
CHm
Fu
IR/CHu
pdN2–Q
pdN2–Q
D3fm
N2–Q
N2–Q
C1t2–v1
edMz1
dN1 1–3sv
dN1 3gl
aQIV
B. Karaganka R.
adQIII
adQIII
Catena II
VIc
Ia IIc IIIa IIIb Va Vd иMи VIe IIa IIb IIa IIa Ia Ia
1 3+8 1 7 3+8 5+6 5+10 12 9+8 8 3+9 4
cd d d d a cd d d p cd
IR/CHu
CHu
snch m, sk
CHm
CHs'' mm, k
snch h, sk/ CHo'' mm, ha
SNh m, sk/ AM
Msw/Asw
KWM/CHo' mm, ha
snch s, sk/ CHo' ha
CHo'' mm, k
CHu/CHo
Fu/ SDs
Mch
CHu
IaQIII
C1v1–2
dN1 1–2sv
Utyaganka R.
aQIV
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C1v1–2
m

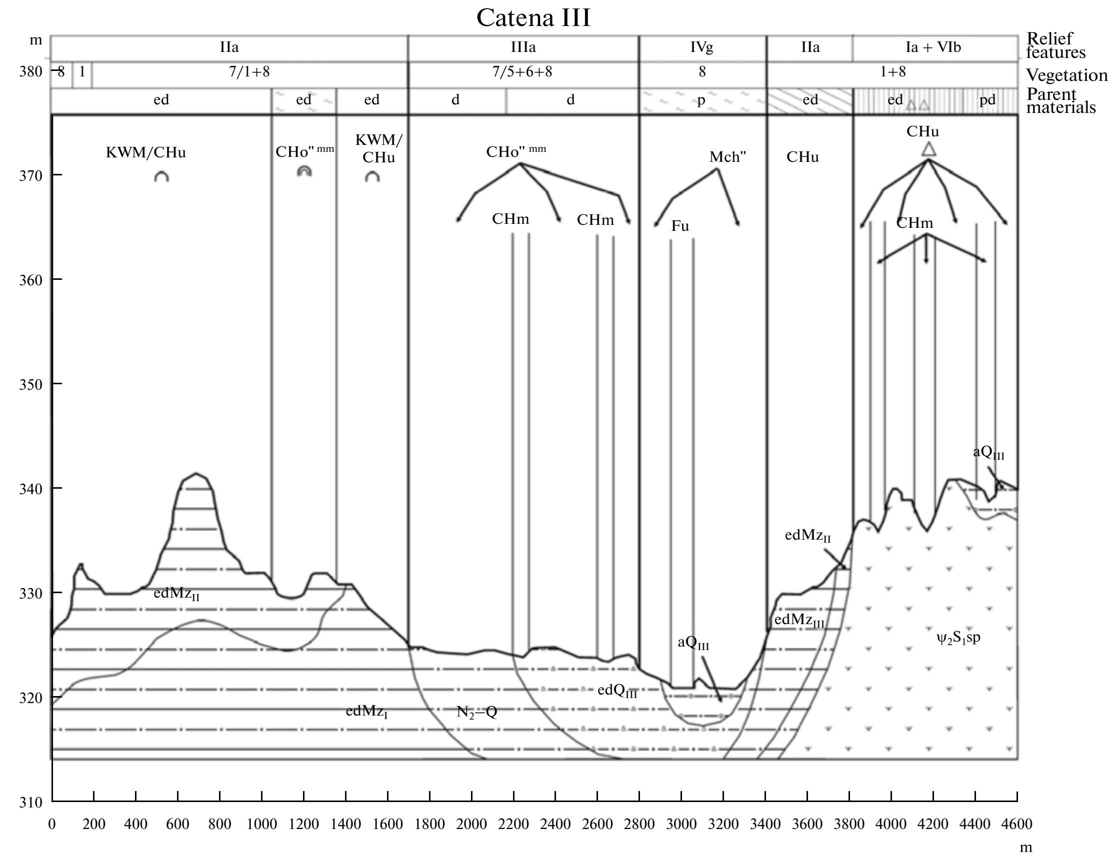

Fig. 2. (Contd).

A horizon (up to 40%) and decreases to 23% in the lower horizons. The portion of humus acids of the second fraction is lower, and the portion of humus acids of the first fraction is higher than in the chernozems developed from the hydromica–montmorillonite clays (Fig. 5, 6). This attests to the higher lability of the humus in the soils developed from kaolin deposits.

Soils developed from the Neogene clays and loams. These deposits were mainly formed due to water erosion of ancient weathering mantles. Gentle slopes and saddles between the mounts are characterized by their poor drainage. Erosion and accumulation of sediments on these slopes is absent. On gentle slopes, thin solonetzic and saline ordinary chernozems and chernozemic solonetzes are developed. The saddles between the mounts are the areas of accumulation of clay material and salts. Shallow and medium-deep solonchakous solonetzes are formed in these areas.

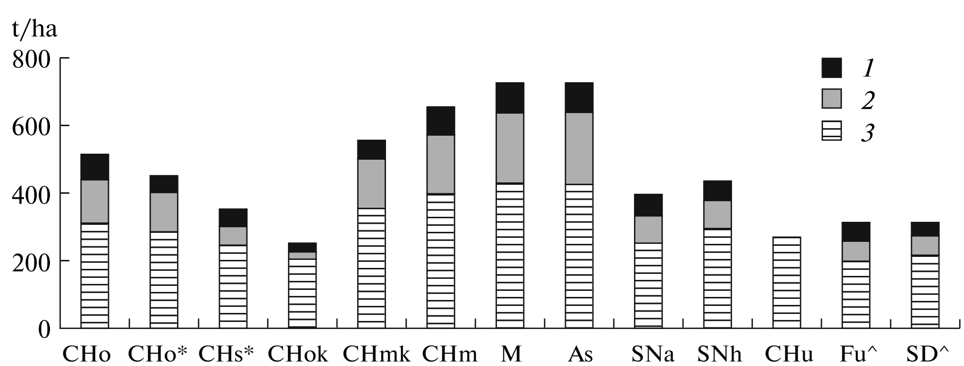

Fig. 3. Humus reserves in soils of the Arkaim Reserve ($n = 3–10$). Layers: (*1*) 0–0.5 m, (*2*) 0.5–1 m, and (*3*) 1–1.5 m. In the soil indices, * indicates plowlands and ^ indicates forest; the other soils are under pastures. K denotes kaolin mantles (data on other kinds of parent materials are given in the text).

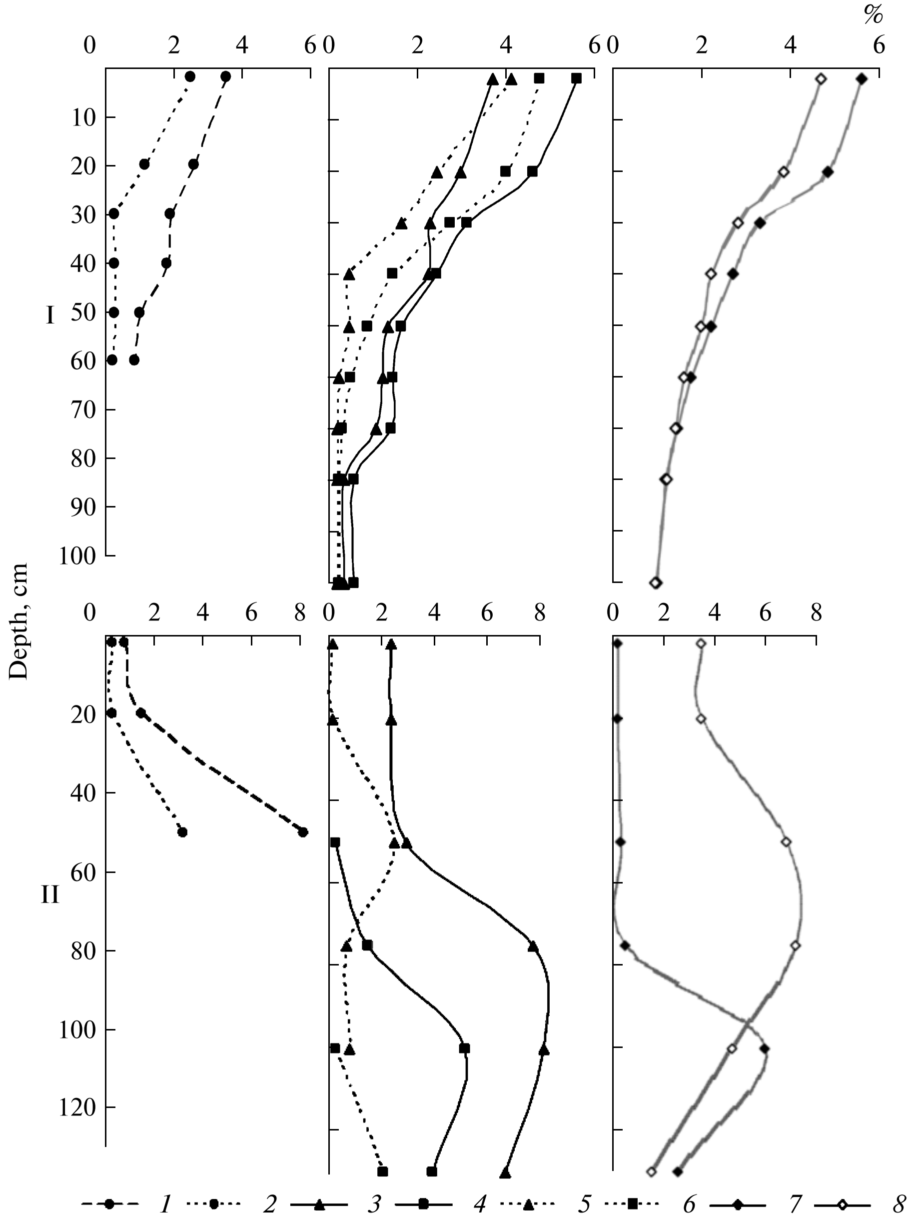

Fig. 4. The contents of (I) C_{org} and (II) $CaCO_3$ in the soils of the Arkaim Reserve developed from different parent materials (n = 5–15). Rhyolite eluvium: (*1*) underdeveloped chernozems. Kaolin clays: (*2*) underdeveloped chernozems, (*5*) ordinary chernozems, and (*6*) chernozemic meadow soils. Illite–montmorillonite loams and clays: (*3*) ordinary chernozems, (*4*) chernozemic meadow soils, and (*7*) meadow soils. Alluvial sediments: (*8*) alluvial soils.

Sulfates and chlorides predominate in the composition of the soil salts.

The automorphic and hydromorphic chernozemic solonetzes in the reserve have a strongly varying (from 5 to 20 cm) thickness of their humus horizon, as well as the depth of the salt-bearing horizon, the degree of salinity, and the chemical composition of salts. Automorphic solonetzes are found in complexes with chernozems. They have a high cation exchange capacity; the sodium percentage in the exchange complex varies from 15 to 30%, and the percentage of exchangeable magnesium is about 40–45%. The soil's reaction is slightly alkaline, carbonates appear from the surface, and soluble salts occur at a shallow depth. The organic matter content is 3–5% in the upper horizon and 2–2.5% in the solonetzic horizon. The organic matter in the A1 horizon is of humate composition with a predominance of the second (Ca-bound) fraction. Among the fulvic acids, the first fraction predominates; the portion of the third fraction (the fraction tightly bound with minerals) is also considerable.

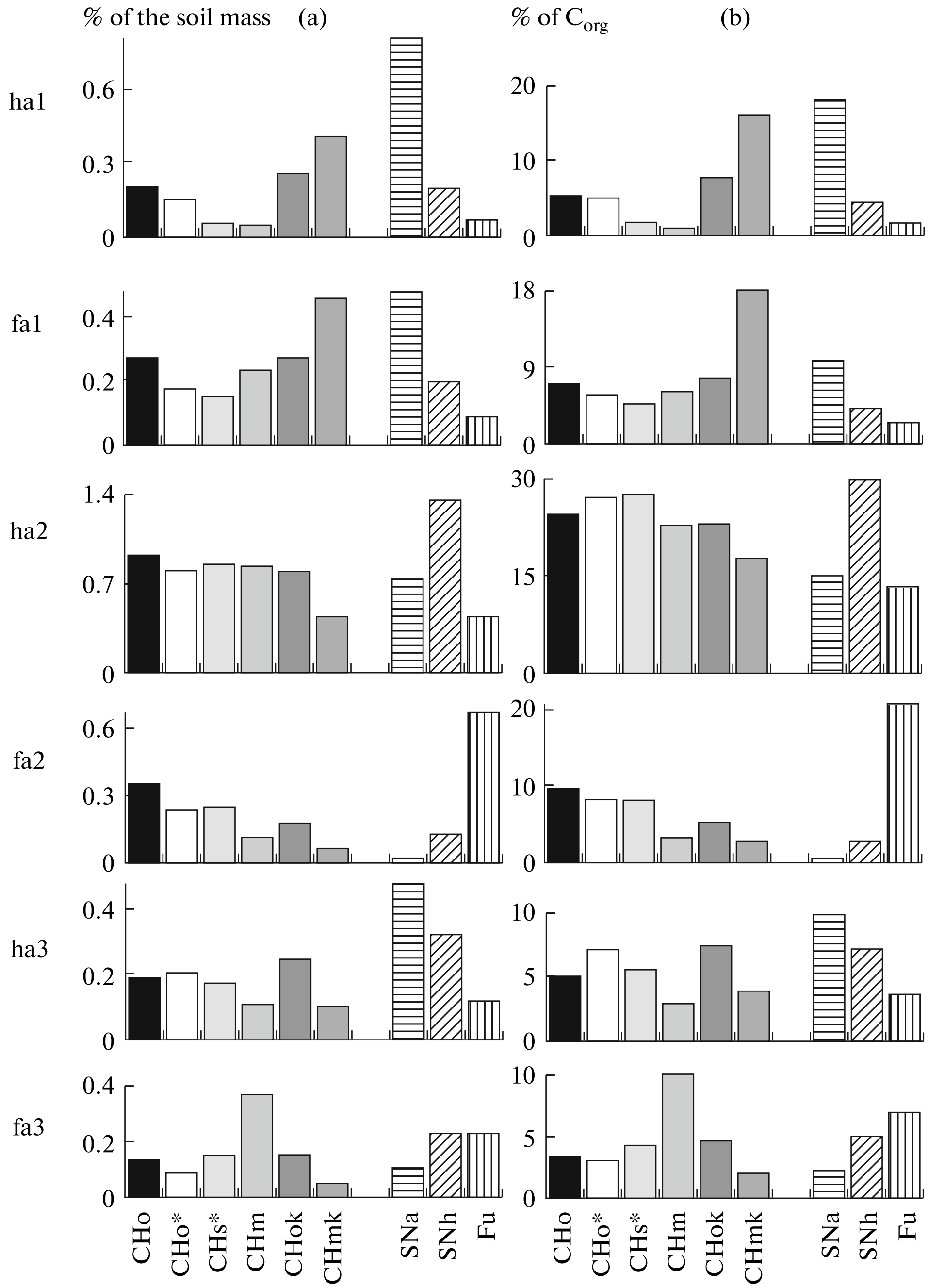

Fig. 5. Fractional and group composition of the humus in the soils of the Arkaim Reserve.

The soil cover of the denudational–accumulative surfaces (320–360 m a.s.l.). These surfaces are composed of the Neogene and Quaternary colluvial clayey and loamy hydromica–montmorillonite deposits. They represent valley-like depressions and lacustrine–colluvial plains with small hills and relatively shallow hollows. The good aggregation, high water retention capacity, and relatively high infiltration capacity of the parent materials favor the soil development under steppe vegetation. Full-profile ordinary and southern chernozems predominate on these surfaces. In the upper part of the lacustrine–colluvial plain, residually saline Neogene clays are present at a shallow depth. In this area, thin calcareous ordinary chernozems occur in combination with solonetzes.

Ordinary chernozems are typical of level surfaces with slopes of less than 5°. Tonguing of the humus horizon is clearly pronounced in them, as well as in other chernozems of the Trans-Ural region. This tonguing is less pronounced in the loamy sandy vari-

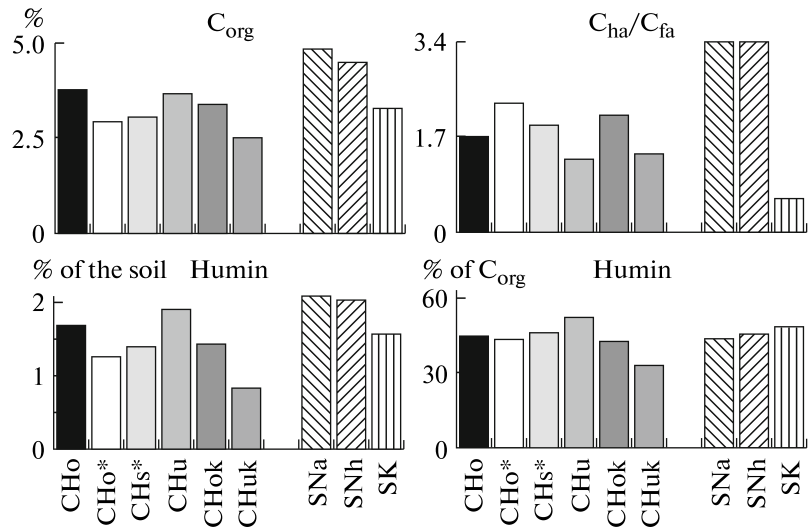

Fig. 6. The contents of C_{org} and humin and the C_{ha}-to-C_{fa} ratio in the chernozems and salt-affected soils of the Arkaim Reserve.

ants. Soil cracks and fissures are clearly pronounced against the background layered character of the parent material and penetrate to a depth of 0.5–2.0 m; the width of the major cracks is up to 5–10 cm. They are filled with deposits from the above-lying layers characterized by a higher humus content and better aggregation in comparison with the surrounding material. There are two–three generations of humus tongues in the former cracks. The older humus tongues are brown-gray, and the younger humus tongues are dark gray.

Calcium predominates in the exchange complex of these soils, though the portion of exchangeable magnesium is considerable. This is related to the paleohydromorphism of these soils [7, 9]. The carbonate concentrations are diverse: calcareous nodules, soft segregations, and disperse calcite in the soil mass. The carbonate profile of the chernozems changes in dependence on the local mesotopography. The thickness of the leached layer is about 40 cm on the elevated ridges and up to 60–80 cm in the hollows. Calcareous and solonetzic chernozems are formed on the slopes of local hills. In such positions, the surface runoff is considerable, and the amount of water infiltrating into the soil is low; the ascending migration of carbonates predominates in the soils. Soil erosion (particularly, in plowed areas) also leads to a higher concentration of carbonates in the upper horizons.

The humus content in the upper layer of the plowed clayey and loamy ordinary chernozems is 4.3–5.6%; under the pastures, it is 1% higher. The humus content in the B horizon sharply decreases to 0.7–1.2%. The degree of humification is high (up to 44%). The soil humus is of the humate or fulvate–humate composition (the C_{ha}-to-C_{fa} ratio is 1.1–2.8). In the solonetzic chernozems, this ratio is lower. The second (Ca-bound) fraction of humus acids predominates.

Southern chernozems occupy minor areas in the reserve. These are usually medium deep, medium humus, deeply saline, and slightly or moderately solonetzic. Many of their features are similar to those of ordinary chernozems. The southern chernozems are specified by the presence of a gypsiferous horizon, the lower water stability of the aggregates, the more pronounced solonetzic features, and the higher salinity. The southern chernozems of the reserve can be considered relicts of the former aridization periods preserved in the areas with relatively shallow embedding by the saline and gypsiferous Pliocene clays.

The soil cover of the Quaternary alluvial–lacustrine surfaces (310–320 m a.s.l.) is represented by full-profile chernozems and solonetzes developed from alluvial and colluvial loams and clays in the valleys of the Utyaganka and B. Karaganka rivers. These are relatively flat surfaces with karst sinkholes and with residual mounts of bedrock. The portion of solonetzes and meadow soils is higher than that within the denudational–accumulative surface. The soil textures vary from loamy sands to clays.

The soil cover of floodplain surfaces (307–314 m a.s.l.) is composed of various alluvial soils, hydromorphic solonetzes, and solonchaks developed from the alluvial clays and loams. The meso- and microtopography of the floodplain is related to the flood dynamics. They determine the great contrast of the soil cover on the floodplain. Hydromorphic solonetzes and solonetzic alluvial soils are developed on elevated elements of the relief, and meadow alluvial soils and hydromorphic solonchaks occur in depressions. The soil cover pattern becomes less complicated in places where the soils are developed from loamy sands. Solonetzes and

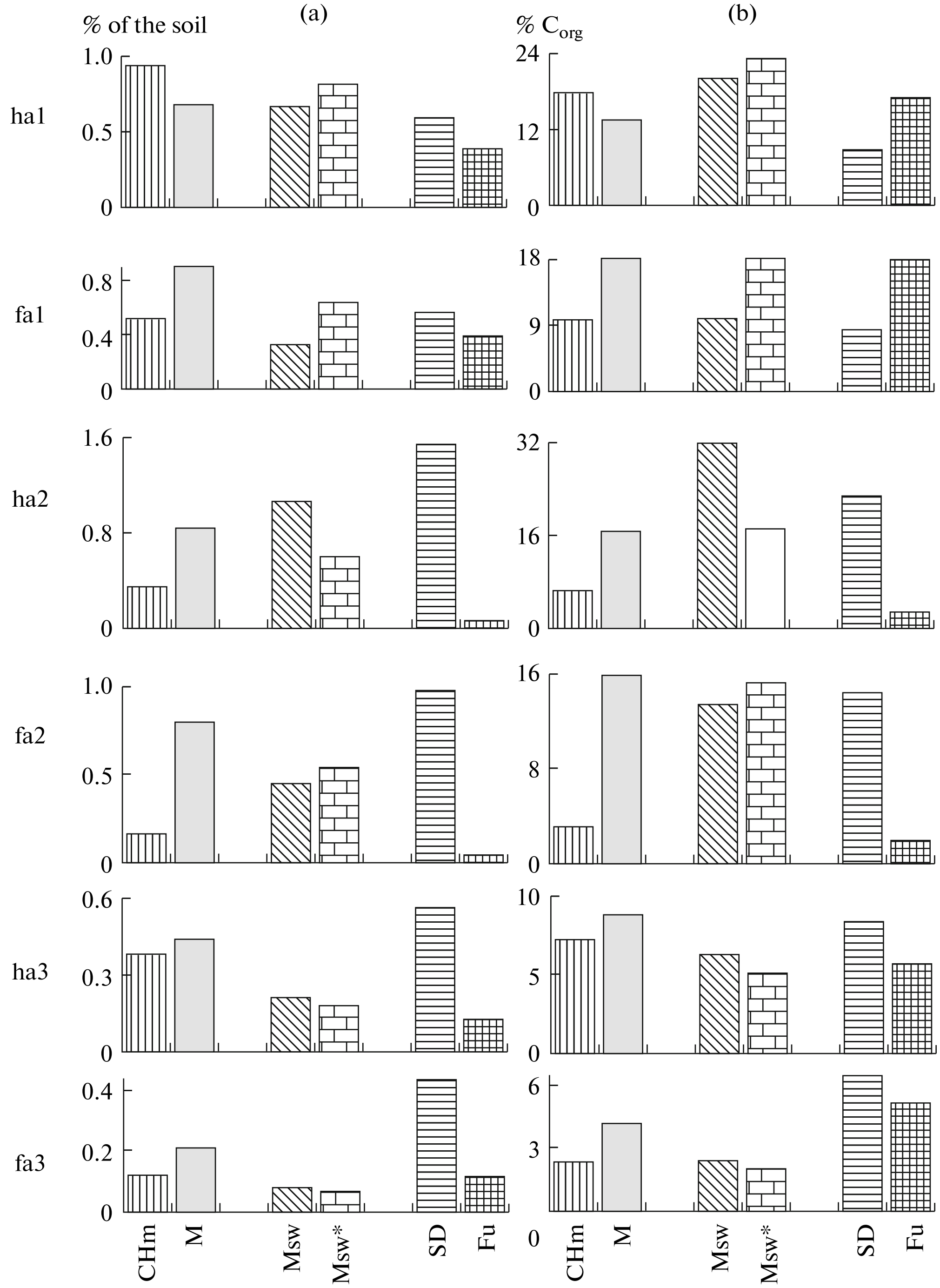

Fig. 7. Fractional and group composition of the humus in hydromorphic and forest soils of the Arkaim Reserve.

saline soils disappear in these places (the left bank of the B. Karaganka River). In places subjected to overgrazing, complexes of hydromorphic solonetzes and solonchaks are formed. In the central swampy part of the floodplain of the Utyaganka River, swampy alluvial and meadow-swampy soils are developed. All the soils contain some amounts of sulfate–chloride salts.

Alluvial soils. Meadow and soddy alluvial soils predominate on the floodplains. They have a layered morphology and are characterized by their slightly alkaline or alkaline reaction and variegated textures with a predominance of heavy loamy soils. Gley features are usually present in the soil profiles. The humus content is high in the upper horizons and decreases sharply (in

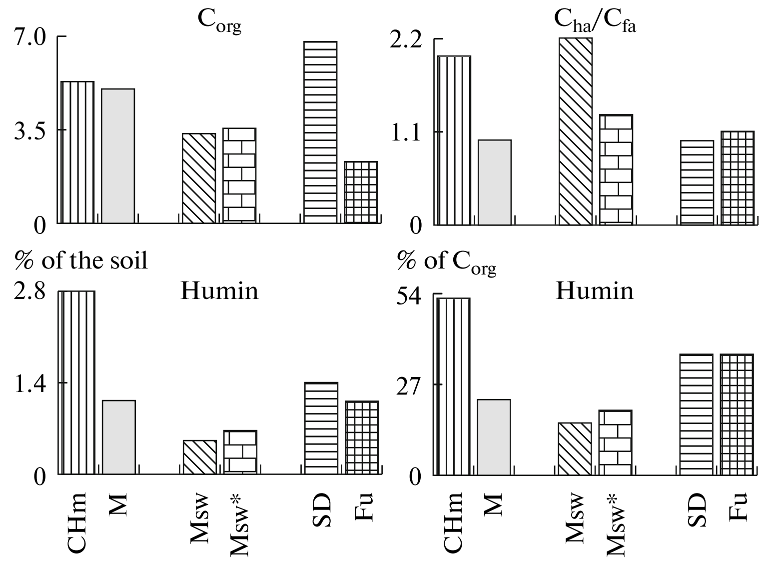

Fig. 8. The contents of C_{org} and humin and the C_{ha}-to-C_{fa} ratio in hydromorphic and forest soils of the Arkaim Reserve.

the soddy alluvial soils) or gradually (in the meadow alluvial soils) down the soil profile. The soddy alluvial soils contain the highest reserves of humus among the floodplain soils. The content of salts varies considerably; the soil water extracts have a chloride–sulfate composition with a considerable content of bicarbonate ions. The distribution patterns of the soluble salts in the soil profiles attest to the predominance of the evaporative soil water regime. Alluviation and soddy processes play the leading role in the development of alluvial soils.

Meadow solonetzes are formed on floodplains under the impact of saline groundwater. The automorphic solonetzes were characterized earlier. The hydromorphic solonetzes differ from them by the shallower depths of the carbonate, gypsiferous, and salt horizons; the higher humus content; and the higher C_{ha}/C_{fa} ratio (2.5–3.0). The soluble salts are represented by sodium and magnesium chlorides and sulfates.

Hydromorphic (gley) solonchaks occupy small microdepressions between solonetzes. They are characterized by their slightly alkaline reaction and their high content of soluble salts (mainly, chlorides) in the upper horizons. Fulvic acids predominate over humic acids. In the fractional composition of the humus, the second fraction predominates, and the content of the third fraction is high.

Meadow swampy soils are formed in karst sinkholes with periodic or permanent water stagnation. The surface horizon has a peaty character, and gley features are vividly displayed in the mineral horizons. The meadow swampy soils are leached of soluble salts, gypsum, and carbonates. The have a slightly acid reaction, a heavy loamy texture, and a high humus content; the soil humus is of the fulvate–humate type with a considerable amount of labile humus acids.

The soil cover in the network of ravines and hollows is represented by meadow-chernozemic, chernozemic-meadow, and meadow soils developed from alluvial and proluvial clays and loams. These soils occupy about 7% of the reserve. The network of ravines and hollows can be subdivided into seven orders [14, 15]. Thus, the hollows of the first order have no tributaries. At the confluence of hollows of the same order, a hollow (valley) of a higher order is formed. The hollows of the first and second orders are the youngest; their position changes with time. They occur on all the types of surfaces and reflect the dynamics of the modern and ancient soil formation. The soils in the hollows of the first and second orders differ from the background soils by their heavier texture and greater content of fine earth in the stony soils. As a rule, these are chernozemic with some meadow features. The hollows of the third order are relatively stable. Meadow chernozemic soils are developed in them. These soils have a thicker humus horizon and a higher humus content than the chernozems; the distribution of humus in the soil profile has a more even pattern. The hollows of the fourth and fifth orders represent important elements of the erosional network. Chernozemic meadow soils are developed in the hollows of the fourth order under the impact of considerable additional moistening. These are thick soils. No tonguing of the humus horizon is observed in them, and carbonates are leached off from the upper soil layers to the BC horizon.

Meadow soils are formed in the mouths of the hollows of the fifth order. Additional moistening of these soils results in the development of compact carbonate

Table 3. Properties of steppe soils in the Arkaim Reserve

Horizon	Depth, cm	pH_{water}	Exchangeable cations, meq/100 g				$CaCO_3$, %	Fractions, %		Bulk density, t/m^3
			Ca^{2+}	Mg^{2+}	Na^+	Total		<0.01 mm	<0.001 mm	
Ordinary chernozem on the Neogene–Quaternary sediments, plowland, pit 6										
PU	0–18	7.3	35	12	0.2	47	2	36	15	1.25
AU/BC	18–38	7.9	28	10	0.3	39	1	48	25	1.57
BC	54–75	8.4	17	18	1.3	37	1	59	36	1.67
Cf	75–110	8.7	17	22	2.8	42	12	56	26	1.7
Solonetzic and solonchakous ordinary chernozem on kaolin clay, pasture, pit 44										
AO	0–5	6.8	24	17	1.8	43	0	43	9	0.95
AU	5–18	7.0	22	19	2.0	43	0	54	21	1.17
AU/BCA	18–30	7.2	26	9	2.1	37	4	54	16	1.58
BCs	50–80	7.2	–	–	–	–	1	43	8	1.50
Cs	100–150	6.9	12	12	2.2	26	–	44	11	1.40
Moderately solonetzic southern chernozem on the Neogene–Quaternary sediments, plowland, pit 18										
PU	0–26	7.8	64	15	3.2	83	4	47	20	1.35
AU/BCA	26–50	8.1	42	7	3.4	53	10	51	28	1.46
BCA	50–95	8.5	20	16	3.4	40	20	58	30	1.53
BCAns	120–140	8.6	–	–	–	–	–	55	31	1.50
Cns	140–165	8.0	–	–	–	–	–	47	18	1.54
Chernozemic meadow soil on the Neogene–Quaternary sediments, pasture, pit 31										
AU	0–25	6.4	44	0.6	0.3	45	1	22	2	1.38
AUB	25–40	6.3	28	0.6	0.2	29	1	39	5	1.50
B	40–55	6.6	14	1	0.2	16	0	39	7	1.57
BC	55–70	6.9	14	1	0.2	15	0	34	10	1.65
Underdeveloped slightly solonetzic chernozem on the eluvium of basalt, pasture, pit 49										
AU	0–12	6.5	44	8	1.2	53	0.1	32	12	–
AUB	12–24	7.1	36	10	1.3	47	0.1	35	19	–
BC	24–50	7.8	32	12	1.5	46	10	17	14	–
Hydromorphic shallow solonetz on the Neogene–Quaternary sediments, pasture, pit 20										
AU	0–8	7.6	42	10	3.1	55	–	48	12	1.40
BSNth	15–29	8.1	32	20	3.3	55	–	58	25	1.47
BMKth	30–66	8.4	24	14	2.5	41	–	61	27	1.45
BCAthg	66–96	8.8	36	17	3.7	47	–	76	40	1.49

Note: Dashes indicate the absence of determination.

pedofeatures and abundant iron concentrations and iron–manganic nodules. In some profiles, gley features are present. These soils are characterized by the even color of the humus and transitional horizons and by the presence of indistinct humus tongues. Their profile is thicker, and their humus content (5–6% in the A horizon) is somewhat higher than that in the ordinary chernozems. This is related to the deposition of humified material on the soil's surface and to the high productivity of the meadow cenoses. The soil organic matter is of the humate and fulvate–humate types; the degree of the humification rate and the content of the second fraction of humic acids are somewhat lower than in the chernozems, whereas the con-

Table 4. Chemistry of salts in salt-affected soils of the reserve, meq/100 g of soil

Horizon	Depth, cm	Total salts, %	CO_3^{2-}	HCO_3^{2-}	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	K^+
Shallow hydromorphic solonchakous meadow solonetz on the Neogene–Quaternary sediments, pasture, pit 20										
AU	0–8	0.4	0	1.6	1	6	1.6	0.8	0.3	–
BSNth	15–29	3.7	0	1.1	30	56	18	84	3.7	–
BMKth	30–66	3.4	0	0.8	31	44	6	90	3.3	–
BCAthg	76–96	2.6	0	0.6	25	32	4	70	2.6	–
[AUg]	96–120	1.9	0	0.8	18	24	2	54	1.9	–
[Bg]	120–140	1.1	0.1	1.2	10	12	1	32	1.1	–
Gleyed chloride solonchak on alluvial clay and loam, pasture, pit 35										
S	0–8	5.6	0	0.6	66	52	13	20	76	0.12
Sg	8–22	2.4	0	1.10	25	24	1.4	3	37	0.03
BGs	22–24	2.2	0	0.9	25	22	1.4	3	35	0.01
Gs	70–120	1.3	0	0.8	15	12	1.4	2	20	0.02
Gleyed sulfate–chloride solonchak on alluvial clays and loams, pasture, pit 36										
S	5–31	1.2	0.5	1.70	10	14	1.4	1.2	18	0.03
BCAg,s	51–61	0.9	0.5	1.4	8	10	0.8	0.6	14	0.01
BG	68–81	0.1	0.3	1.2	0.4	1.2	0.4	0.2	2.2	0.01
G	143–165	0.1	0	1.2	0.4	0.6	0.6	0.2	1.6	0.02
Medium-deep moderately solonetzic and deeply saline southern chernozem on the Neogene–Quaternary sediments, plowland, pit 18										
PU	0–26	0.1	0	0.8	0.1	1.4	1.2	0	0.9	–
BCA	50–95	0.1	0.1	1.1	0.2	1	0.6	0.2	1.4	–
Cca,s	120–140	1.5	0	0.6	2.2	40	20	10	7	–
	140–165	0.9	0	1.0	5.8	16	4	8	8	–
Medium-deep slightly solonetzic and solonchakous heavy loamy ordinary chernozem on kaolin clay, pasture, pit 44										
AO	0–5	0.1	0	0.5	0.2	2	0.4	0.2	1.2	–
AU/BCA	18–30	0.5	0	0.6	6.5	3	3	3	5.8	–
BC	50–80	2.6	0	0.5	30	28	32	22	17	–
C	100–150	0.8	0	0.3	12	3	4	7	8	–

tent of the first fraction of humic acids is higher (up to 30%). Among the fulvic acids, the first fraction predominates, which attests to the relatively high mobility of the humic substances.

Large flat-bottom ravines—the Sosnovyi Log and the Kopytin Dol—are hollows of the fifth order, and the valleys of the Bol'shaya Karaganka and the Utyaganka Rivers are hollows of the sixth and the seventh orders.

CONCLUSIONS

The soils of the Arkaim Reserve organized in the area of a unique settlement–fortress of the Bronze Age in Chelyabinsk oblast have been studied. Overall, 170 soil pits along four soil catenas crossing the reserve have been examined. Six genetic groups of the soil cover have been specified with respect to the local geomorphic conditions: (a) the denudational surfaces of the low mounts, (b) the accumulative–denudational surfaces of the low mounts, (c) the denudational–accumulative plain surfaces, (d) the alluvial–lacustrine plain surfaces, (e) the floodplains of local rivers, and (f) the network of hollows and ravines. They differ in their absolute heights (with variations from 310 to 400 m a.s.l.), the composition of the parent materials (acid and mafic igneous rocks, kaolin clayey mantles, and montmorillonite–hydromica mantles), and their age (from the Devonian to the Late Holocene). They also differ in their meso- and microtropography, the vegetation (forest, steppe, meadow, and swampy), the geochemical conditions of the migration of the elements, and the history of the soil formation. The main soils of the reserve are as follows: the underdeveloped chernozems and forest soils of the low mounts, the calcareous ordinary chernozems in complexes with solonetzes on slopes, the ordinary chernozems of plain surfaces, the alluvial soils and hydromorphic solonetzes and solonchaks on the floodplains, the meadow soils of hollows with variously pronounced hydromorphic features, and the solods in depressions under birch forests; minor areas are occupied by southern chernozems. In general, chernozems occupy about 50% of the reserve; solonetzes and saline soils, 32%; chernozemic meadow soils, 7%; and forest soils, 1%.

On denudational surfaces, the hard crystalline bedrock is relatively resistant to weathering; good drainage conditions and small catchment areas specify the low rate of erosion on these surfaces. The soils are developed from relatively thin gravelly weathered mantles. The profiles of underdeveloped chernozems and forest soils on such surfaces are formed relatively quickly, and their further development proceeds slowly in parallel to the weathering of the hard bedrock. The rates of the soil formation and denudation are approximately equal. The humus content in these soils developed under steppe vegetation is somewhat higher than that in the soils developed under forests because of the higher regular input of plant residues.

On the accumulative–denudational surfaces composed of the Mesozoic kaolin deposits, the soil development is hampered because of the poor substrate, low vegetation productivity, and active erosional processes. In comparison with the soils developed from the montmorillonite–hydromica loamy and clayey substrates, these soils have a lower humus content; the first fraction of the humus acids predominates, and the content of the second fraction is low. In general, the soils developed from kaolin mantles are very specific and are considered to be relict soils.

On the denudational–accumulative surfaces composed of the Neogene and Quaternary montmorillonite–hydromica clays and loams, full-profile ordinary chernozems are developed. The soils developed on the floodplains and in the bottoms of local hollows and ravines have an age of two–three thousand years; they are formed synchronously with the deposition of new portions of alluvial sediments. The floodplain soils have been subjected to repeated salinization–desalinization cycles depending on the intensity of the floods.

Salt-affected soils occupy no less than 30% of the reserve. They are represented by solonetzes and solonchaks. Taking into account the presence of differently saline chernozems, the area of salt-affected soils is even larger. The soil salinity and solonetzic features are related to the presence of exchangeable sodium and soluble salts in the parent materials, the relatively poor drainage of the territory, and the presence of saline groundwater in the river valleys at a shallow depth. In the B horizon of the Trans-Ural chernozems, the solonetzicity is sometimes manifested in its morphology despite the absence of the chemical indices of the solonetzic process. Many researchers consider this solonetzicity to be a relict feature [9, 11]. The presence of salts in the deep horizons of the chernozems is also considered to be a relict feature attesting to the previous hydromorphic stages of the soil's development. Under the modern climatic conditions, the degree of salinity in the deep horizons of these soils gradually decreases.

The organic carbon content in the upper (0–20 cm) soil layer varies within 2.6–5.6%; the soils differ in the reserves of C_{org} in the upper 50 cm: from 50 to 250 t/ha. The soils under pastures occupy 2/3 of the reserve. They are subjected to strong overgrazing. However, the humus content in them is 10–16% higher than that in their plowed analogues. The soil humus under the pastures is enriched in the first (labile) fractions of humic substances (28–40% of C_{org}).

The chernozems of the reserve, as well as all the chernozems in the Trans-Ural region, differ from their analogues on the East European Plain in the thinner humus horizon, the higher humus content in the topsoil, the distinct tonguing of the humus horizon, and the frequent occurrence of salinity and solonetzic features. These specific features of the studied chernozems are explained by the dry continental climate, the poor drainage of the territory, and the presence of salts and exchangeable sodium in the ancient redeposited weathering mantles that serve as the parent materials or underlie the soils at a relatively shallow depth.

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