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SOIL MINERALOGY

Diversity of Clay Minerals in Soils of Solonetzic Complexes in the Southeast of Western Siberia

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Abstract—Data on the mineralogical composition of clay in soils of solonetzic complexes of the Priobskoe Plateau and the Kulunda and Baraba lowlands have been generalized. The parent materials predominating in these regions have loamy and clayey textures and are characterized by the association of clay minerals represented by dioctahedral and trioctahedral mica–hydromica, chlorite, kaolinite, and a number of irregular interstratifications. They differ in the proportions between the major mineral phases and in the qualitative composition of the minerals. Mica–hydromica and chlorites with a small amount of smectitic phase predominate on the Priobskoe Plateau and in the Kulunda Lowland; in the Baraba Lowland, the portion of mica–smectite interstratifications is higher. An eluvial–illuvial distribution of clay fraction in solonetzes is accompanied by the acid–alkaline destruction and lessivage of clay minerals, including the smectitic phase in the superdispersed state. This results in the strong transformation of the mineralogical composition of the upper (suprasolonetzic) horizons and in the enrichment of the solonetzic horizons with the products of mineral destruction; superdispersed smectite; and undestroyed particles of hydromica, kaolinite, and chlorite from the suprasolonetzic horizons. A significant decrease in the content of smectitic phase in the surface solodic horizons of solonetzic complexes has different consequences in the studied regions. In the soils of the Priobskoe Plateau and Kulunda Lowland with a relatively low content (10–30%) of smectitic phase represented by chlorite–smectite interstratifications, this phase virtually disappears from the soils (there are only rare cases of its preservation). In the soils of the Baraba Lowland developed from the parent materials with the high content (30–50%) of smectitic phase represented by mica–smectite interstratifications, the similar decrease (by 10–20%) in the content of smectitic phase does not result in its complete disappearance. However, the smectitic phase acquires the superdispersed state and the capacity for migration.

Keywords: smectitic phase, mixed-layered mica–smectite interstratifications, superdispersed state of clay minerals, hydromica, chlorite, kaolinite, Chernozems, Solonetzes

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INTRODUCTION

Solonetzes and solonetzic soils represent a special group of salt-affected soils, in which soluble salts are found in the middle and lower parts of the profile, and the soil reaction is often strongly alkaline. These soils are characterized by sharp variations in the physical, chemical, and biological properties down the soil profile. The surface horizons with platy structure are light-colored, because humus substances and clay particles are removed from them. They migrate downward and form a dark-colored solonetzic horizon enriched in clay. Adverse physical properties are typical of the solonetzic horizon: in the dry state, it has a columnar structure with vertical fissures; in the wet state, it has a very low water permeability and a low bearing capacity. Salt-bearing horizons are found under the solonetzic horizon. The water and salt regimes of these soils are characterized by the alternation of the partial washing of surface horizons by ultrafresh precipitation or snowmelt water in spring and by the capillary rise of saline solutions from the deep horizons in summer. Such a regime of the soil moistening favors the accumulation of exchangeable sodium against the background of the low content of soluble salts in the upper part of the soil profile. In turn, the accumulation of exchangeable sodium favors peptization and transportation of the soil particles with downward water flows.

Solonetzes differ significantly in their hydrological regimes; sequence and thickness of soil horizons; depths and amounts of soluble salts, gypsum, and carbonates; the chemical composition of salts; and the content of exchangeable sodium in the soil adsorption complex. All these parameters are used in classifications of solonetzes [10, 11, 20]; they are taken into account in recommendations on the use and reclamation of these soils [21, 30].

Solonetzes and solonetzic soils occupy about 30.8 million hectares in Russia. They occur in the forest-steppe, steppe, dry steppe, and semidesert zones. Isolated areas of solonetzes are known in the Transbaikal region, Central Yakutia, and the Minusinsk Depression. The largest solonetzic areas are located in the middle and lower reaches of the Volga River (Povolzh'e region) and in Western Siberia (11.6 and 10.2 million hectares, respectively). Solonetzes do not form a continuous soil cover; usually, they occur in soil complexes and combinations with zonal soils occupying different portions of the area. The portion of solonetzic soils in the soil cover of some regions in Russia (Dagestan, Kalmyk Republic, east of the Stavropol region and Rostov oblast, Lower Volga region, and south of Western Siberia) is considerable.

There are numerous data on the genesis, properties, functioning, and changes of solonetzic soil complexes under the impact of reclamation measures. Significant contributions to their studies were made by K.K. Gedroits, K.D. Glinka, V.A. Kovda, A.F. Bol'shakov, E.N. Ivanova, I.N. Antipov-Karataev, N.I. Bazilevich, K.P. Pak, V.I. Kiryushin, N.P. Panov, E.A. Kornblyum, B.A. Zimovets, M.B. Minkin, V.P. Kalinichenko, V.I. Tyul'panov, N.I. Godunova, L.V. Berezin, V.N. Mikhailichenko, I.N. Lyubimova, I. Szabolcs, W.P. Kelly, E. Bresler, B.L. McNeal, J.D. Oster, K. Darab, and B. Murphy.

At the same time, data on the mineralogical composition and its distribution in the soil profiles of solonetzic complexes are few in number [7, 8, 14–16, 23–25, 32, 35]. No special comparative analysis of the mineralogical composition of solonetzic soil complexes in different regions has been performed. A comparative study of four profiles of solonetzes from different parts of Hungary can be found in [40].

Solonetzic soils can develop from different substrates. Thus, solonetzes developed from ancient kaolinite weathering mantles have been described in Kazakhstan in the area of the Dievka Experimental Station of the Dokuchaev Soil Science Institute (Kustanai oblast) by E.A. Kornblyum and I.N. Lyubimova; they are also known in the Mugodzhary Mountains [29]. Solonetzic soils may also develop from smectitic clay [1, 19, 28]. The classification position of clayey Solodized Solonetzes was widely discussed in the 1950s–1960s. Later, these soils were assigned to Vertisols [39, 41, 42]. In the new edition of the WRB system (WRB-2014), some of these soils are classified as Vertic Solonetzes. Such soils are known in Hungary and in the Kamennaya Steppe area [31]. In general, however, regional mineralogical composition of solonetzic soils has not been analyzed.

The aim of our work is to reveal regional diversity of minerals from the clay fraction of solonetzic soil complexes in the southeast of Western Siberia.

OBJECTS

We compared solonetzic soil complexes from three regions in the southeast of Western Siberia: the Priobskoe Plateau and the Kulunda and Baraba lowlands.

The Priobskoe Plateau is elevated at 170 to 250–280 m a.s.l. It is bordered by the Ob River valley in the east, the Kulunda and Baraba Lowlands in the west and northwest, and the Altai Mountains in the south. The plateau is dissected into several wide slightly inclined watersheds by the Alei River valley and ancient glacial spillways overgrown with pine forests. Watershed areas are composed of thick loesslike loams of the Middle Pleistocene, Late Pleistocene, and Holocene ages with a series of buried soils [9, 17].

Salt-affected soils on the Priobskoe Plateau are mainly found in the subzone of southern chernozems on river and lake terraces and on terraced slopes of ancient glacial spillways [26, 27]. The soil cover is represented by two- and three-member soil complexes consisting of various meadow solonetzes, meadow-chernozemic solonchakous solonetzic soils, and locally developed meadow solonchaks.

We analyzed two profiles of chernozems and nine profiles of the soils of solonetzic complexes [26, 27]. Thin silty loamy nonsaline ordinary chernozem on loesslike loams (Haplic Chernozem (Siltic, Aric) according to WRB [38]) (pit 7B) was studied on an interfluve (185 m a.s.l.) in the northeastern part of the Priobskoe Plateau, 17 km to the northwest of the city of Barnaul. Thin silty loamy nonsaline southern chernozem on loesslike loams (Haplic Chernozem (Siltic, Aric)) (pit 6M) was studied on the interfluve (243 m a.s.l.) between the Alei River and the ancient glacial spillway under the Barnaul pine forest, 20 km to the west of the settlement of Pospelikha in the Altai region. Two soil pits were studied on the second terrace (190 m a.s.l.) of the Alei River, 2 km to the west of the Mamontovo settlement (about 12 km to the southwest of Pospelikha). The major soil of the solonetzic complex in this area was represented by a solonchakous strongly saline sulfate–sodium heavy-loamy thin meadow solonetz on loesslike loams (Salic Stagnic Solonetz (Albic, Siltic, Columnic, Cutanic, Differentic, Humic)) (pit 1M). The subordinate positions in the complex (in microlows) were occupied by the deeply saline silt loamy solodized chernozemic-meadow soils (Luvic Greyzemic Chernozems (Siltic, Bathyprotosalic, Stagnic)) (pit 3M).

Seven soil pits were examined on terraced slopes of the right bank of the Kasmalinsk ancient glacial spillway (195–210 m a.s.l.) in the area of Gor'koe and Mertvoe Lakes between local district centers Romanovo and Mamontovo and the Guseletovo settlement of the Altai region. On the terrace of Lake Gor'koe, chloride–sulfate clayey silty meadow solonchaks developed from lacustrine deposits (Stagnic Solonchaks (Siltic, Sulfatic, Calcaric) were described (pit 1G). These soils occur in combination with solonetzic solonchakous slightly saline silt loamy chernozemic-meadow soils (Luvic Greyzemic Kastanozems (Siltic, Protosalic, Protosodic, Stagnic) occupying the bottoms of local hollows (pit 3G). The soil cover on higher parts of the slope is composed of meadow solonetzic complexes. Microelevations are occupied by crusty solonchakous strongly saline (chloride–sulfate) heavy loamy meadow solonetzes (Salic Stagnic Solonetzes (Albic, Siltic, Columnic, Cutanic, Differentic, Humic)) (pit 1TG). On level areas, shallow solonchakous moderately saline chloride–sulfate (pit 2TG) and soda (pit 4TG) silty loamy meadow solonetzes (Protosalic Stagnic Solonetzes (Albic, Siltic, Columnic, Cutanic, Differentic, Humic)) are formed. Microlows are occupied by solonetzic solonchakous slightly saline heavy loamy meadow-chernozemic soils (Luvic Greyzemic Chernozems (Siltic, Protosalic, Protosodic, Stagnic)) (pit 3TG). On ancient alluvial loamy sands near the bottom of the ancient glacial spillway, crusty solonchakous strongly saline loamy sandy chloride–soda meadow solonetzes (Sodic Salic Stagnic Cambisols (Siltic)) (pit 5TD) are formed.

The Kulunda Lowland represents a gently undulating plain with depressions, ravines, and numerous endorheic lakes. Two plots were studied in this area. The first plot was on the pasture of the former collective farm named after the XXI Party Congress in Blagoveshchensk district of the Altai region (115–120 m a.s.l.). It represents a slightly convex undulating surface in the lower reaches of the Kulunda River to the south of the Kulunda ancient glacial spillway. The second plot was located on the second terrace of Lake Kuchukskoe to the south of it (110–111 m a.s.l.).

On the first plot, flat summits and windward slopes of local small ridges are occupied by the complex of solonetzic southern chernozems and medium and deep solonetzes with different degrees of solodization. Complexes of solonetzic southern chernozems, southern chernozems, and solonetzes (with a predominance of solonetzic southern chernozems over solonetzes) are developed on the lower parts of the slopes. In shallow (1.0–1.5 m) depressions between the ridges, combinations of meadow-chernozemic soils and nonsolonetzic and solonetzic southern chernozems with solodized meadow-chernozemic soils are formed in closed depressions subjected to temporary waterlogging in the spring [22]. All these soils develop from loesslike loams. We studied the mineralogical composition of the clay fraction in six soil profiles. Pits 1C and Tr-3C-300 characterized medium-deep solonchakous strongly saline sulfate heavy loamy steppe solonetzes (Salic Solonetzes (Albic, Siltic, Columnic, Cutanic, Differentic)); pit 2C, a solonetzic solonchakous slightly saline sulfate silt loamy southern chernozem (Luvic Greyzemic Calcic Kastanozem (Siltic, Endoprotosalic, Protosodic)); pit 3C, a medium-deep solonchakous moderately saline sulfate heavy loamy steppe solonetz (Endosalic Solonetz (Albic, Siltic, Columnic, Cutanic, Differentic)); pit Tr-1C, a deep solonchakous strongly saline sulfate silt loamy steppe solonetz (Calcic Salic Solonetz (Albic, Siltic, Columnic, Cutanic, Differentic)); and pit 4C, a deep slightly saline silt loamy meadow-chernozemic soil (Greyzemic Chernozem (Siltic, Bathyprotosalic, Bathyprotosodic)).

The soil cover of the second terrace of Lake Kuchukskoe consists of hydromorphic complexes of meadow solonchaks with various solonetzes and solonetzic meadow-chestnut soils. We studied the mineralogical composition of three soils: a chloride–sulfate, sodium sandy to sandy loamy meadow solonchak (Calcic Gleyic Solonchak (Alcalic, Epiarenic, Siltic, Sulfatic, Ruptic)) (pit 1CG), a medium-deep solonchakous strongly-saline chloride–sulfate loamy sandy to sandy loamy meadow solonetz (Calcic Salic Solonetz (Albic, Siltic, Columnic, Cutanic, Ruptic)) (pit 2CG), and a deep solonchakous moderately saline chloride–sulfate silty loamy meadow solonetz (Calcic Protosalic Solonetz (Albic, Siltic, Columnic, Cutanic, Differentic)) (pit 3CG).

The Baraba Lowland is bordered by the Vasyugansk Plateau in the north, Priobskoe plateau in the east, and the Kulunda Lowland in the south; in the west, it borders the Neogene plain; in the northwest, the alluvial plains of the Middle Irtysh region [18]. We examined 11 soil profiles in the central part of the Baraba Lowland in the area of Lake Chany. This is a poorly drained ancient lacustrine–alluvial undulating plain with small ridges [5].

The soil cover of the tops and gentle upper slopes of the ridges consists of ordinary chernozems developed from the Late Quaternary slightly calcareous nonsaline loams under conditions of the deep (12 m) groundwater level [12, 13]. We studied the mineralogical composition of a thin tonguing nonsaline silty loamy ordinary chernozem (Haplic Chernozem (Loamic, Tonguic)) (pit 12).

In wide (2–2.5 km) depressions between the ridges, soil combinations and complexes related to meso- and microtopography and the development of salinization, solonetzization, and solodization processes are formed. The effect of each of these processes depends on the salt and water regimes of the soil [2–4]. The parent materials are represented by ancient lacustrine–alluvial loamy and clayey sediments with the high percentage of fine sand (0.05–0.25 mm). We investigated the mineralogical composition of soils in ten pits. A medium-deep solonchakous moderately saline sulfate–soda heavy-loamy meadow-steppe chernozemic solonetz (Calcic Salic Mollic Solonetz (Loamic, Cutanic, Columnic, Differentic, Humic, Hypernatric, Greyzemic)) was described on an ancient lake levee under the forb–fescue–wheatgrass steppe with the groundwater depth of 3.5–4 m (pit 31). A solonetzic solonchakous slightly saline sodic clayey chernozemic-meadow soil (Luvic Chernozem (Clayic, Protosalic, Sodic, Stagnic, Tonguic)) was described on the low part of a gentle slope of an ancient levee near the lake under the forb–leguminous–reed grass meadow (pit 33). A crusty solonchakous moderately

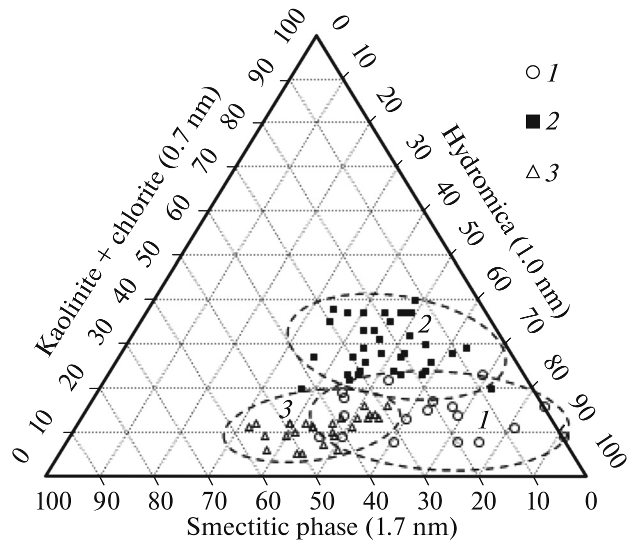

Fig. 1. Major mineral phases in the clay fraction from the lower horizons of soils of the (*1*) Priobskoe Plateau, (*2*) Kulunda Lowland, and (*3*) Baraba Lowland.

saline sodic clayey meadow-chernozemic solonetz (Calcic Salic Gleyic Solonetz (Clayic, Cutanic, Columnic, Differentic, Humic, Hypernatric)) was described in the lower position on the third lake microterrace with the groundwater depth of 2–2.5 m and salinity of 4–4.4 g/L under the saltmarsh grass meadow (pit 34). A solodized solonetzic solonchakous strongly saline sulfate–soda clayey meadow soil (Luvic Albic Gleyic Planosol (Alcalic, Epiloamic, Clayic, Protocalcic, Humic, Protosalic, Sodic)) was described under barley meadow (pit 35). At the groundwater depth of 1.5–1.9 m, lake microterraces are occupied by soda-saline clayey meadow solonchaks (Fluvic Sodic Gleyic Solonchaks (Alcalic, Clayic, Carbonatic)) (pit 37) under seepweed and by shallow solonchakous moderately saline sulfate–sodium clayey meadow-bog solonetzes (Calcic Protosalic Gleyic Solonetzes (Clayic, Columnic, Cutanic, Differentic, Hypernatric)) (pit 39) under gentle thistle–wheatgrass meadows. Boggy microdepressions are occupied by strongly solodized solonetzic solonchakous slightly saline chloride–soda heavy loamy to clayey peaty bog soils (Luvic Albic Gleyic Histic Planosols (Epiloamic, Clayic, Protosalic, Sodic)) (pit 36), solodized solonchakous strongly saline soda–sulfate heavy-loamy to clayey peaty bog soils (Albic Gleyic Histic Planosols (Epiloamic, Clayic, Protocalcic, Protosalic, Sodic)) (pit 117), and slightly solodized solonchakous slightly saline sodic clayey peaty-bog soils (Histic Gleysols (Clayic, Protosalic, Protosodic, Protocalcic)) (pit 38).

METHODS

A comparative-geographic method of soil studies in trenches and along soil catenas on the key sites with solonetzic soil complexes was applied.

The clay fraction (<1 μm) was separated by the multiple elutriation method according to Gorbunov [6].

The phase composition of minerals in the separated fractions was determined by X-ray diffractometry on an HZG-4a diffractometer. Oriented Mg-saturated slide samples were examined in the air-dried state, after solvation with ethylene glycol for two days, and after heating at 550°C for 2 h. The ratios between the main mineral phases of the clay fraction were calculated according to Biscaye [36].

To analyze the impact of pedogenesis on the mineralogical composition of the clay fraction, 161 samples of soil horizons from 32 soil pits were separated into several groups according to their geographic location, soil type, and type of genetic horizon. As the diversity of genetic horizons in the soils of solonetzic complexes was considerable, this grouping was generalized. To characterize the diversity of parent materials, we separated the group of middle-profile and lower horizons (BCA, BC, and C horizons), in which the transformation of clay minerals under the impact of pedogenetic processes is relatively weak. This group was referred to as the group of lower horizons (group 1). Surface humus (dark-humus, AU) horizons without morphological features of solodization and solonetzization were separated as group 2. Upper horizons with solodic features (AUel, EL, and SEL) composed group 3, and upper horizons with solonetzic features (ASN, BSN, and AUsn) composed group 4.

The obtained data were treated using Excel software.

RESULTS AND DISCUSSION

The lower and middle-profile horizons from the three studied neighboring regions of Western Siberia (the Priobskoe Plateau and the Kulunda and Baraba Lowlands) considerably differed in the ratios between the main mineral phases of the clay fraction: the smectitic phase (reflection at 1.7 nm), the hydromica phase (reflection at 1.0 nm), and the sum of kaolinite and chlorite phases (reflection at 0.7 nm) (Fig. 1). In this paper, the term hydromica signifies minerals assigned to the group of interlayer-deficient mica according to recommendations of the Nomenclature Committee of the International Association for the Study of Clays (Association Internationale Pour l'Etude des Argiles, AIPEA) [37].

The lower horizons of soils from the Priobskoe Plateau had the highest hydromica content (from 45 to 91%; 64% on the average), relatively low content of kaolinite and chlorite (8–23%; 14%), and widely varying content of the smectitic phase (0–45%; 22%). The phase identified by the reflection at 1.0 nm was represented by micas and hydromicas of di- and trioctahedral types with a predominance of the latter, the phase identified by the reflection at 0.7 nm consisted of kaolinite and iron–magnesium chlorites, and the swelling minerals identified by the reflection at 1.7 nm consisted of irregular interstratifications of several types with a predominance of chlorite–vermiculites and chlorite–smectites and a somewhat lower portion of mica–smectites.

The lower horizons of soils from the Kulunda Lowland had a considerably higher content of kaolinite and chlorite owing to iron–magnesium chlorites (20–40%; 30%) and a somewhat lower content of micas and hydromicas of the dioctahedral (muscovite–sericite) and trioctahedral (biotite) types (34–72%; 48%). The content of the smectitic phase represented by irregular interstratifications with smectite layers varied from 8 to 43% (22% on the average). As well as on the Priobskoe Plateau, these minerals included chlorite–smectites and chlorite–vermiculites with some participation of mica–smectites.

In the lower horizons of soils from the Baraba Lowland, the content of smectitic phase was high (29–59%; 44%), the content of hydromicas was approximately the same (32–55%; 46%), and the content of kaolinite and chlorite was low (5–16%; 11%). The swelling phase (1.7 nm) was represented by irregular interstratifications differing from those in the soils of the Priobskoe Plateau and Kulunda Lowland by the predominance of smectite layers. These minerals represented irregular interstratified mica–smectites with a predominance of montmorillonite layers in the crystallites [32]. Hydromicas included both di- and trioctahedral minerals, and kaolinite consisted of coarse crystals of clastic genesis [33].

The statistical parameters of the empirical distributions of the contents of the main mineral phases in different groups of horizons are given in the table.

Let us analyze the distribution of clay minerals in the soil profiles and the ratios between the main mineral phases in different groups of soil horizons for each region.

Priobskoe Plateau. The ratios between the main mineral phases of the clay fraction from surface humus horizons without solodic and solonetzic features (group 2) are close to those described for the lower horizons (Fig. 2). In other words, the vertical distribution of clay minerals in the profiles of ordinary and southern chernozems (Haplic Chernozems) developed from loesslike loams is characterized by the low differentiation (Figs. 3a and 3b).

In the soils of solonetzic complexes, clay minerals are strongly differentiated in the profile under the impact of solodic process in topmost horizons and the eluvial–illuvial distribution of clay particles in the course of solonetzic process.

The solodized horizons are characterized by a considerable decrease in the content of smectitic phase or its complete disappearance, which is accompanied by the relative accumulation of micas and hydromicas (Fig. 2); the contents of fine-dispersed quartz and roentgen-amorphous substances in the clay fraction also increase. This is explained by the active destruc-

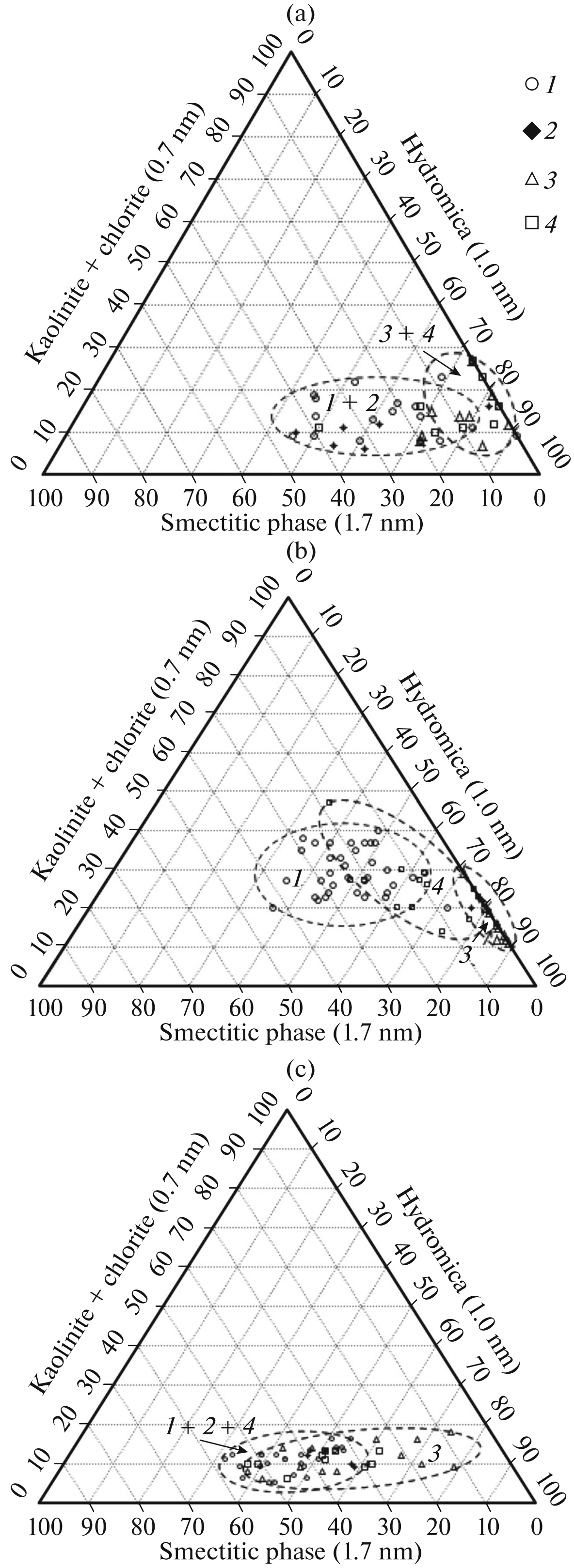

Fig. 2. Mineralogical composition of the clay fraction in different groups of soil horizons of the (a) Priobskoe Plateau, (b) Kulunda Lowland, and (c) Baraba lowland: *1*—lower horizons, *2*—humus horizons without solonetzic and solodic features, *3*—solodized horizons, and *4*—solonetz and solonetzic horizons.

Table 1. Statistical parameters of empirical distributions of major mineral phases in the clay fraction and bulk soil mass

Statistical parameter	Clay, %	Content of mineral phases					
		kaolinite + chlorite	hydromica	smectitic phase	kaolinite + chlorite	hydromica	smectitic phase
		% of clay			% of soil mass		
Priobskoe Plateau. Lower horizons							
n	18	18	18	18	18	18	18
Minimum	6.2	8	45	0	0.7	5.2	0
Lower quartile	25.5	9	51	16	2.4	14.7	4.0
Median	30.4	14	63	22	4.2	17.8	7.1
Upper quartile	33.5	17	71	35	5.2	21.3	10.1
Maximum	35.8	23	91	45	7.7	23.5	12.4
Mean	27.7	14	63	23	3.9	16.9	6.9
Standard deviation	8.6	5	14	14	2.1	5.4	4.1
Priobskoe Plateau. Humus horizons without morphological features of solodization and solonetzization							
n	6	6	6	6	6	6	6
Minimum	17.3	23	42	15	1	10.7	0.4
Median	22.6	30	47	22	2.5	13.3	6.9
Maximum	24.3	37	58	30	3.4	17.3	10.5
Mean	22.0	29	49	22	2.3	13.2	6.6
Standard deviation	2.7	5	6	6	0.8	2.4	3.6
Priobskoe Plateau. Solodized horizons							
n	9	10	10	10	9	9	9
Minimum	10.5	7	71	0	1.5	7.7	0
Lower quartile	13.7	9	72	0	1.6	11.5	0
Median	16.3	14	77	8	2.0	12.0	1.6
Upper quartile	18.9	15	81	13	2.4	13.6	2.9
Maximum	25	27	88	20	3.8	19.0	3.8
Mean	16.8	14	78	8	2.2	13.0	1.6
Standard deviation	4.7	6	6	8	0.8	3.5	1.5
Priobskoe Plateau. Solonetz and solonetzic horizons							
n	8	8	8	8	8	8	8
Minimum	12.5	10	50	0	2.0	10.5	0
Lower quartile	22.5	11	72	0	3.2	16.7	0
Median	27.5	14	76	7	3.8	19.0	2.0
Upper quartile	31.0	18	80	16	4.4	22.6	4.6
Maximum	36.8	27	85	39	5.7	26.0	14.4
Mean	26.1	16	74	11	3.8	18.8	3.5
Standard deviation	8.2	6	11	13	1.1	5.3	4.9
Kulunda Lowland. Lower horizons							
n	11	35	35	35	11	11	11
Minimum	8.2	20	34	8	1.9	3.8	2.3
Lower quartile	19.9	24	44	16	6.7	9.2	2.4
Median	26.3	28	46	23	7.8	10.8	3.9
Upper quartile	27.9	35	52	28	8.4	14.5	5.5
Maximum	32.2	40	72	43	10.0	20.6	9.0

Table 1. (Contd.)

Statistical parameter	Clay, %	Content of mineral phases					
		kaolinite + chlorite	hydromica	smectitic phase	kaolinite + chlorite	hydromica	smectitic phase
		% of clay			% of soil mass		
Mean	23.9	29	48	22	7.4	12.1	4.4
Standard deviation	6.7	6	8	8	2.2	4.8	2.4
Kulunda Lowland. Humus horizons without morphological features of solodization and solonetzization							
n	4	4	4	4	4	4	4
Minimum	1.7	16	77	0	0.3	1.4	0
Median	15.9	21	78	0	3.4	12.3	0
Maximum	23.8	22	84	3	5.2	18.6	0.4
Mean	14.3	20	79	1	3.1	11.2	0.1
Standard deviation	9.7	3	3	2	2.2	7.5	0.2
Kulunda Lowland. Solodized horizons							
n	10	10	10	10	10	10	10
Minimum	5.6	11	71	0	1.1	4.5	0
Lower quartile	13.8	12	82	0	2.3	11.3	0
Median	18.2	14	86	0	2.5	15.6	0
Upper quartile	21.3	18	88	0	2.8	18.5	0
Maximum	25.4	29	89	2	3.2	22.4	0.4
Mean	16.9	16	84	0	2.5	14.4	0
Standard deviation	5.9	6	5	1	0.6	5.6	0.1
Kulunda Lowland. Solonetz and solonetzic horizons							
n	16	16	16	16	16	16	16
Minimum	14.7	14	35	0	3.2	9.3	0
Lower quartile	22.7	20	61	0	4.2	16.4	0
Median	26.8	24	65	10	6.9	18.2	2.5
Upper quartile	34.5	27	77	16	8.5	19.7	6.7
Maximum	47.7	47	84	23	17.4	31.0	9.5
Mean	29.2	24	66	9	7.3	18.6	3.3
Standard deviation	9.7	8	13	8	3.9	5.0	3.2
Baraba Lowland. Lower horizons							
n	27	27	27	27	27	27	27
Minimum	21.2	5	32	29	1.3	8.7	9.3
Lower quartile	25.8	9	41	37	2.2	11.4	10.3
Median	31.7	11	47	44	3.4	12.7	13.7
Upper quartile	36.6	13	51	49	4.4	17.1	15.6
Maximum	47.0	16	55	59	6.6	24.9	21.7
Mean	31.8	11	46	44	3.5	14.6	13.8
Standard deviation	7.0	3	7	8	1.4	4.3	3.7
Baraba Lowland. Humus horizons without morphological features of solodization and solonetzization							
n	4	4	4	4	4	4	4
Minimum	22.6	9	48	31	2.3	11.5	7.4
Median	24.4	11	55	34	3.0	12.8	9.2
Maximum	33.5	13	59	40	3.1	19.8	10.4

Table 1. (Contd.)

Statistical parameter	Clay, %	Content of mineral phases					
		kaolinite + chlorite	hydromica	smectitic phase	kaolinite + chlorite	hydromica	smectitic phase
		% of clay			% of soil mass		
Mean	26.2	11	54	35	2.8	14.2	9.0
Standard deviation	5.0	2	5	4	0.4	3.8	1.5
Baraba Lowland. Solodized horizons							
n	10	13	13	13	10	10	10
Minimum	9.9	6	38	7	0.8	5.2	2.1
Lower quartile	16.5	8	48	19	1.6	7.8	4.0
Median	18.5	10	56	35	2.3	8.5	5.2
Upper quartile	20.4	14	68	42	2.7	12.5	7.4
Maximum	30.3	18	79	54	5.5	22.4	11.9
Mean	18.7	11	57	31	2.4	10.4	5.9
Standard deviation	5.3	4	14	15	1.3	5.1	2.9
Baraba Lowland. Solonetzic and solodized horizons							
n	9	10	10	10	9	9	9
Minimum	24.7	6	37	25	3.2	13.0	6.2
Lower quartile	33.4	10	48	30	3.3	16.0	10.4
Median	37.0	11	52	37	3.9	17.7	12.6
Upper quartile	38.6	13	59	45	4.5	19.9	14.0
Maximum	45.5	13	62	52	5.1	23.9	23.7
Mean	35.6	11	52	38	4.0	18.3	13.2
Standard deviation	5.9	2	9	10	0.6	3.5	5.0

tion of weatherable minerals in the course of solodization with a relative accumulation of less weatherable minerals and by the migration of the products of mineral destruction and some undestroyed clay particles down the soil profile.

Solonetzic and slightly solonetzic horizons of soils of the Priobskoe Plateau have a higher clay content, whereas the ratios between the main mineral phases in them are close to those in the upper solodized horizons (Fig. 2).

A specific differentiation of clay minerals recalculated per soil mass is seen in meadow solonchak developed from the layered lacustrine parent materials (Fig. 3c). The topmost light loamy layer (0–9 cm) contains soluble salts and has the high percentage (32%) of smectitic phase in the clay fraction; deeper soil horizons are silt loamy or clayey with a low portion (2–8%) of smectitic phase in the clay fraction.

The differentiation of clay minerals in the profile of chernozemic-meadow soils depends on the development of solodization and solonetzization (Figs. 3d and 3e). In the solonetzic variant, the distribution of mineral phases (calculated per bulk soil mass) in the vertical soil profile is similar to that of the total clay. In the solodized variant, the surface eluvial horizons are depleted of the smectitic phase and relatively enriched in hydromicas.

In solonetzes (Figs. 3f–3i), the eluvial–illuvial distribution of the total clay and hydromicas is pronounced, whereas that kaolinite and chlorite (recalculated per bulk soil mass) is less pronounced. The distribution of smectitic phase (recalculated per bulk soil mass) has an eluvial pattern: its recalculated per soil mass is eluvial: its content in the suprasolonetzic and solonetzic horizons is considerable lower than that in the deeper calcareous and saline horizons.

Kulunda Lowland. We investigated a small number of humus horizons without morphological features of solodization and solonetzization. The ratio of mineral phases in them is similar to that in solodized surface horizons (Fig. 2b). The content of the mica–hydromica minerals in the clay fraction reaches 71–89%, and the admixture of kaolinite and fine-dispersed quartz is small; the smectitic phase is contained in very small amounts or is absent (in 50% of cases for the humus horizons and in 75% of cases for the solodized horizon). It can be supposed that the studied meadow-chernozemic soils were subjected to solodization in the past.

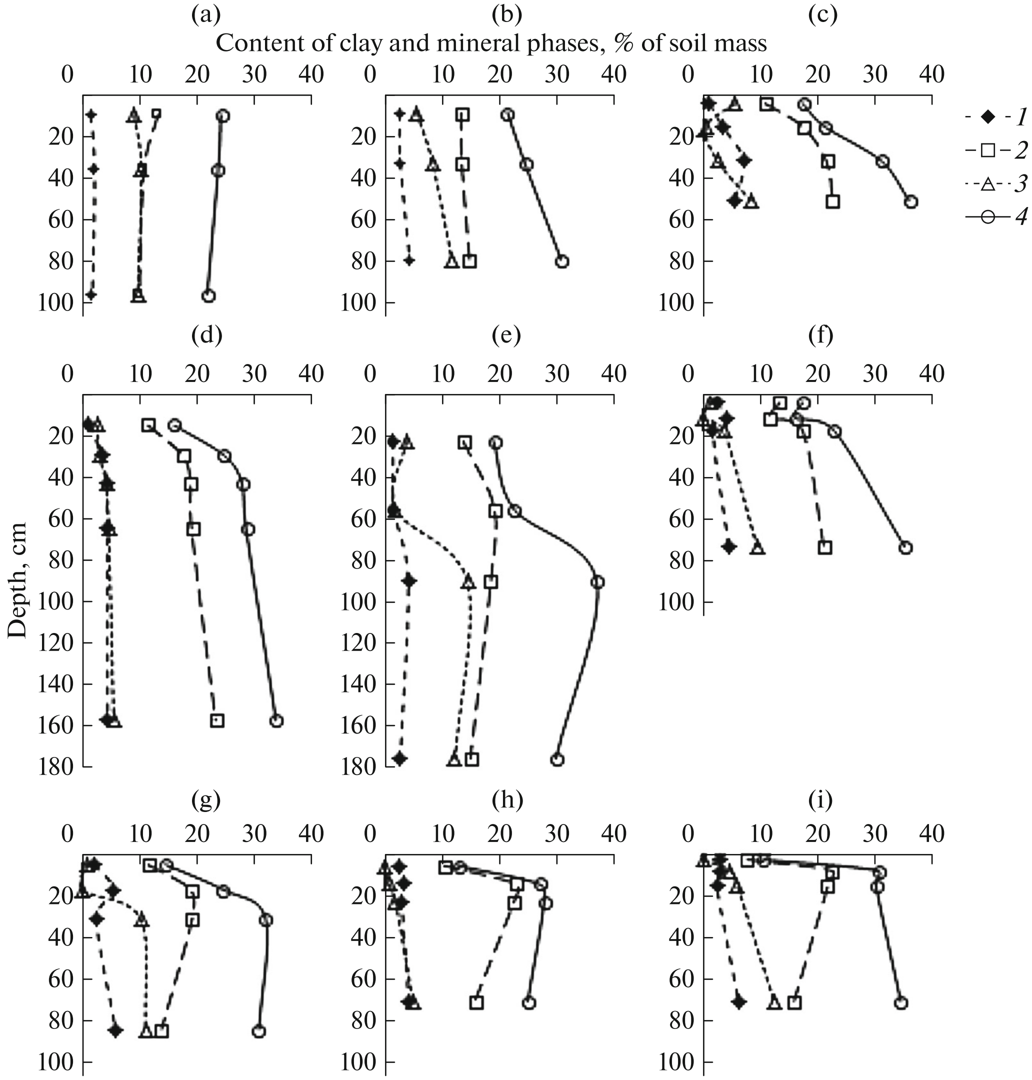

Fig. 3. Vertical distribution patterns of (*1*) kaolinite with chlorite, (*2*) hydromica, (*3*) smectitic phase, and (*4*) bulk clay fraction in soils of the Priobskoe Plateau: (a) ordinary chernozem (pit 7B), (b) southern chernozem (pit 6M), (c) meadow solonchak (pit 1G), (d) solonetzic meadow-chernozemic soil (pit 3G), (e) solodized chernozemic-meadow soil (pit 4M), (f) shallow meadow solonetz (pit 2TG), (g) shallow meadow solonetz (pit 1M), (h) shallow meadow solonetz (pit 4TG), and (i) crusty meadow solonetz (pit 1TG),

The area of maximum density of the points reflecting the mineralogical composition of solonetzic horizons (Fig. 2b) is stretched from the extreme values typical of solodized horizons to the major area corresponding to the mineralogical composition of the lower horizons. In contrast to solodized horizons, solonetzic horizons contain chlorite and a series of extremely disperse irregular chlorite–vermiculite, chlorite–smectite, and mica–smectite interstratifications. The low intensity of the reflections of the minerals attests to the presence of a large amount of amorphous substances.

The lowest differentiation of clay minerals and the total clay content in the soil profile is typical of the meadow-chernozemic soil (Fig. 4a).

Parent material of the investigated meadow solonchak (Fig. 4b) has a nonuniform lithological composition. It includes the surface loamy sandy layer of about 10 cm in thickness overlying the lacustrine–alluvial loam composing the second terrace of Lake Kuchukskoe.

The profile of the southern solonetzic chernozem is characterized by a weak eluvial–illuvial differentiation with respect to the total clay content in combination with an even less pronounced differentiation of hydromica and kaolinite with chlorite recalculated per soil mass in the vertical soil profile (Fig. 4c). The distribution pattern of smectitic phase is of the eluvial type: this phase is completely absent in the upper part of the humus horizon.

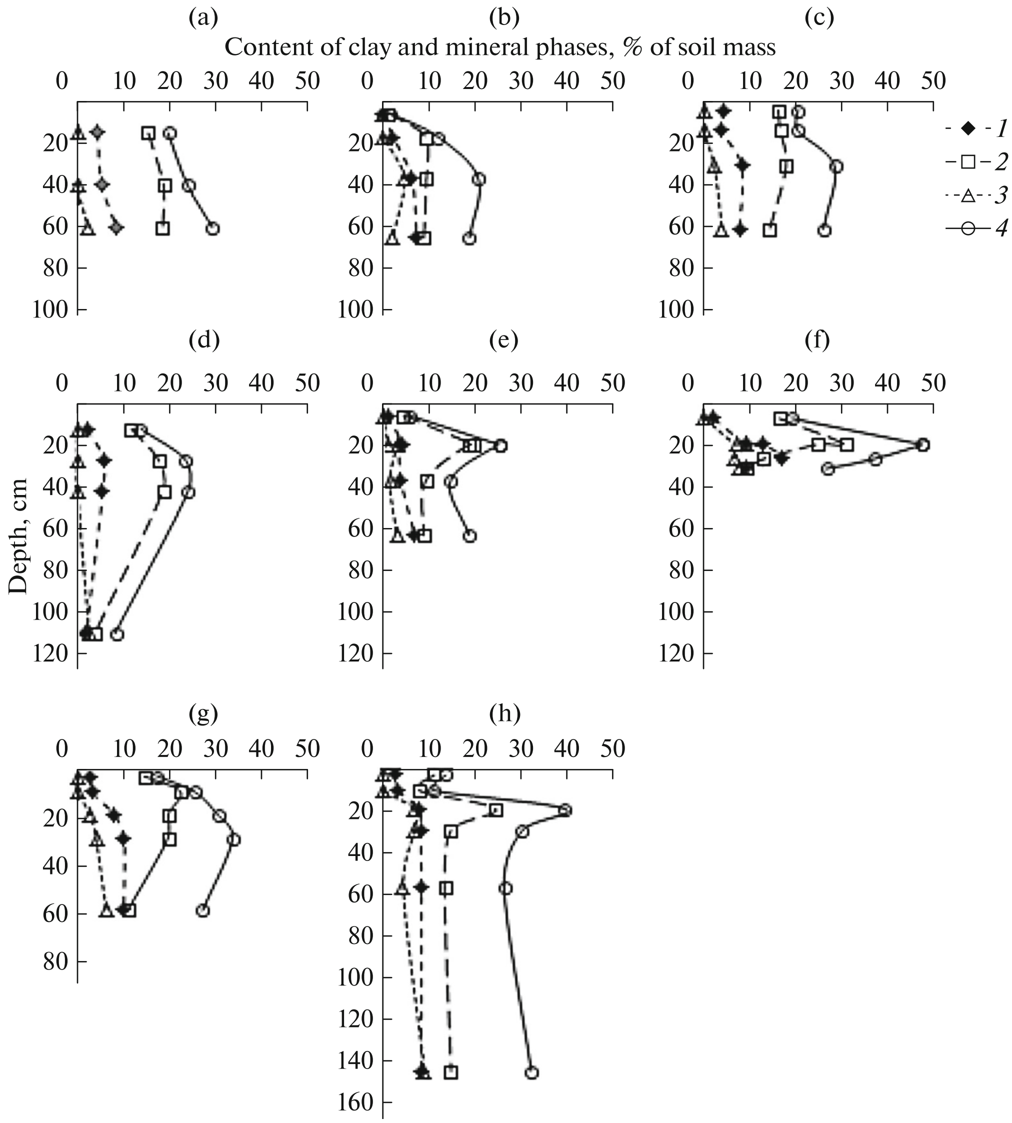

Fig. 4. Vertical distribution patterns of (*1*) kaolinite with chlorite, (*2*) hydromica, (*3*) smectitic phase, and (*4*) bulk clay fraction in soils of the Kulunda Lowland: (a) meadow-chernozemic soil (pit 4S), (b) meadow solonchak (pit 1SG), (c) solonetzic southern chernozem (pit 2S), (d) deep meadow solonetz (pit 3SG), (e) medium-deep meadow solonetz (pit 2SG), (f) medium-deep solonetz (pit Tr-3S-330), (g) medium-deep solonetz (pit 3S), and (h) medium-deep solonetz (pit 1S).

The profiles of solonetzes are characterized by the eluvial—illuvial textural differentiation (Figs. 4d—4h), mainly owing to the redistribution of hydromica and, partly, kaolinite and chlorite. The smectitic phase in the eluvial-solonetzic (suprasolonetzic) horizons is completely absent. Among the five studied soil pits, the distribution of smectitic phase is eluvial in two pits and eluvial-illuvial (with maximum in the solonetzic horizon) in three pits.

Baraba Lowland. Humus horizons without morphological features of solodization and solonetzization, solonetzic horizons, and middle- and lower-profile horizons fall into the same area on the plot showing the distribution of the three major mineral phases. Almost 50% of the samples from solodized horizon also fall into this area. Another half of solodized horizons is characterized by a significantly smaller percentage of smectitic phase in the clay fraction (on the plot, these samples are shifted to the right of the main area, Fig. 2c).

Clay minerals in the soils of solonetzic complexes from the Baraba Lowland are specified by the extremely dispersed state of smectitic phase owing to the strongly alkaline reaction in the presence of soda. This implies the distortion of the X-ray patterns of smectitic phase owing to the small size of crystallites of interstratifications. In the air-dry state, the reflection at 1.4 nm of the minerals with crystallites containing more than 50 layers is shifted toward 1.6 nm for superdispersed minerals. The solvation of superdispersed minerals with ethylene glycol does not result in a clear reflection at 1.8—2.0 nm; instead, a relatively wide “halo” appears on the initial beam [32, 34].

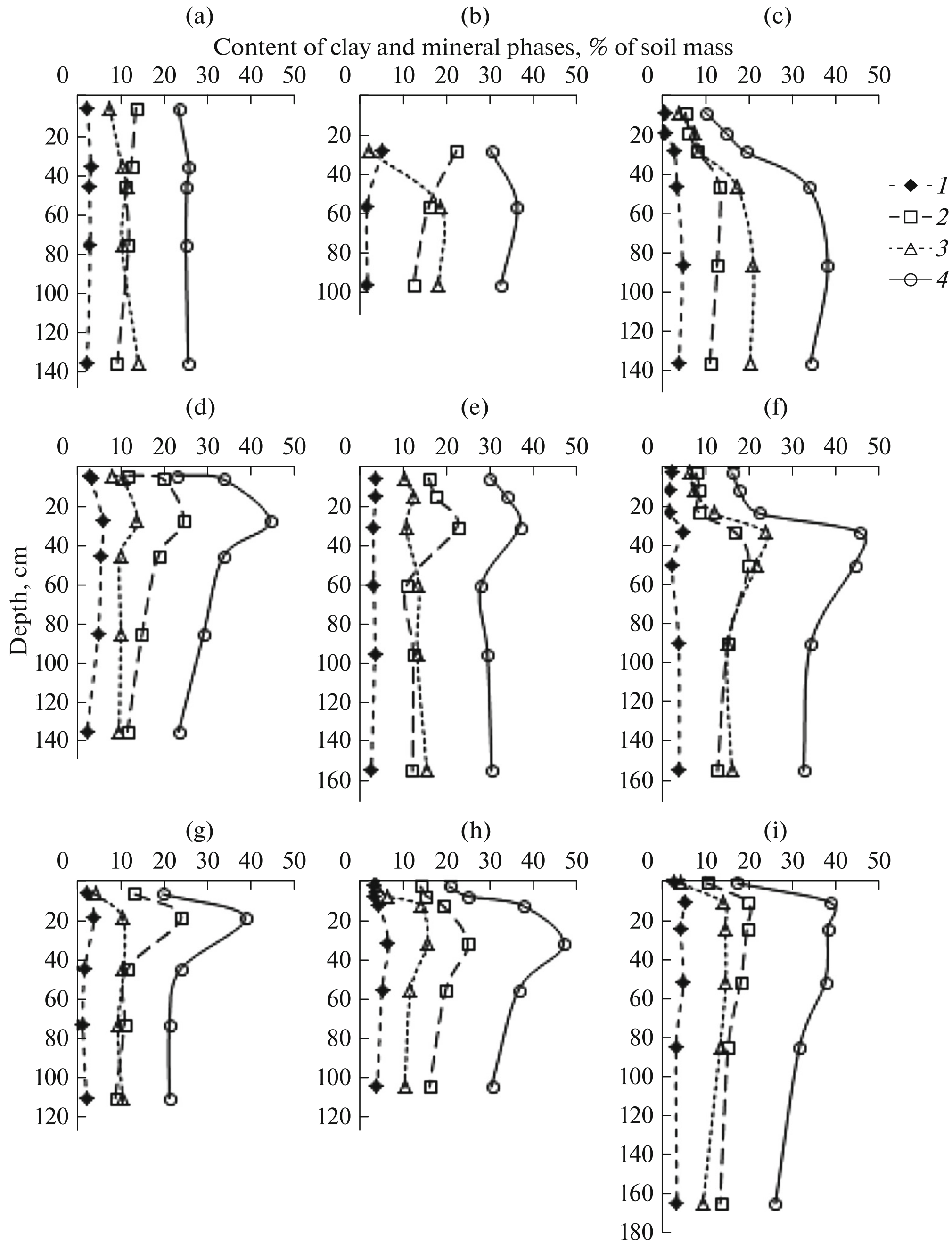

Fig. 5. Vertical distribution patterns of the content of kaolinite with chlorite (*1*), hydromica (*2*), smectitic phase (*3*), clay fraction (*4*) in soils of the Baraba Lowland: (a) ordinary chernozem (pit 12), (b) slightly solodized peaty-bog soil (pit 38), (c) strongly solodized peaty-bog soil (pit 117), (d) meadow solonchak (pit 37), (e) solonetzic chernozemic-meadow soil (pit 33), (f) solonetzic solodized meadow soil (pit 35), (g) medium-deep medium solonetz (pit 31), (h) shallow solonetz (pit 39), and (i) crusty solonetz (pit 34).

Distribution patterns of particular clay minerals and the total clay fraction in the profiles of chernozems on tops and upper slopes of the ridges in the Baraba Lowland and within the Chany Depression do not show any pronounced differentiation (Fig. 5a).

Peaty and peaty-bog solodized soils in the lowest parts of interridge depressions are mainly characterized by the eluvial distribution pattern of clay minerals (Figs. 5b and 5c).

Other investigated soils of solonetzic complexes in the depressions between the ridges are characterized by the eluvial–illuvial textural differentiation of their profiles; the distribution of clay minerals (as calculated per bulk soil mass) has similar patterns (Figs. 5d–5i), except for two profiles. In the solonetzic and solonchakous chernozemic-meadow soil, the distribution patterns of kaolinite with chlorite are even (and their contents are very low), and the distribution pattern of smectitic phase is slightly eluvial (Fig. 5e). In the medium-deep meadow-steppe solonetz on a ridge near the lake (Fig. 5g), the content of smectitic phase recalculated per soil mass is decreased in the suprasolonetzic horizon and becomes higher and stable in the solonetzic horizon and deeper.

CONCLUSIONS

Parent materials in the three regions of Western Siberia with solonetzic complexes in the soil cover are characterized by the silt loamy to clayey texture and by the presence of an association of clay minerals represented by di- and trioctahedral mica–hydromica, chlorite, kaolinite, and irregular interstratifications. At the same time, the regions differ from one another in the qualitative composition of clay minerals and in the ratios between the major mineral phases. Parent materials of the Priobskoe Plateau and Kulunda Lowland are specified by the predominance of mica–hydromica and chlorites with the minimal amount of smectitic phase. In the Baraba Lowland, the percentage of mica–smectite interstratifications with montmorillonite layers is considerably higher.

In all the three regions, the eluvial–illuvial distribution of the clay fraction typical of solonetzes is accompanied by considerable changes in the mineralogical composition of the upper suprasolonetzic and solodized horizons, where the acid–alkaline destruction of minerals and lessivage of extremely dispersed minerals are developed. These changes in the composition of suprasolonetzic horizons also affect the mineralogical composition of the solonetz horizon, which becomes enriched in the products of mineral destruction, superdispersed smectitic phase, and minerals with stiff structures coming from the suprasolonetzic horizons.

A decrease in the content of smectitic phase in the surface solodized horizons of the soils of solonetzic complexes leads to different results in the three regions. In soils of the Priobskoe Plateau and Kulunda Lowland developed from the materials with a relatively low content (10–30%) of smectitic phase represented by chlorite–smectite mixed-layer formations, this phase usually completely disappears in the suprasolonetzic and, sometimes, solonetzic horizons. The eluvial distribution pattern of smectitic phase recalculated per soil mass (without the illuvial maximum) is formed in the solonetzes of the Priobskoe Plateau. In the solonetzes of the Kulunda Lowland, both eluvial and eluvial–illuvial distribution patterns of smectitic phase in the soil profiles can be found.

In the soils of the Baraba Lowland developed from the parent materials with a higher content (30–50%) of smectitic phase represented by the mica–smectite interstratifications, the same decrease in the content of the smectitic phase (by 10–20%) in the upper horizons does not result in its complete disappearance; this mineral phase becomes superdispersed and capable of migration. In most of the studied solonetzes and solonchakous soils of the Baraba Lowland, the eluvial–illuvial distribution patterns of the smectitic phase, hydromica, and kaolinite (calculated per bulk soil mass) are established with distinct illuvial maximums in the solonetzic horizons.

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