Soil Formation in the Taiga–Steppe Ecotone of the Selenga Mountains, Western Transbaikal Region

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Abstract—A new view on the genesis and properties of soils in landscapes of the taiga–steppe ecotone in the Selenga Mountains of western Transbaikalia is suggested with due account for the modern approaches toward soil classification in Russia. The specific environmental conditions—dry and sharply continental climate, mountainous topography with pronounced intermontane depressions, and predominantly coarse-textured parent materials—affect the pedogenesis. Soddy-podzolic soils (Albic Retisols) are formed on the interfluves, and raw-humus burozems (brown taiga soils), including residual-calcareous burozems (Eutric Cambisols) are developed on the upper parts of slopes. Eutric Cambisols are characterized by the high base saturation, a sharp drop in the humus content down the profile, and a pronounced pedogenic structural organization of the mineral mass. Albic Retisols display textural differentiation. Gray-humus and dark-humus soils are characterized by the immediate transition from the humus-accumulative part to the parent material as evidenced by the physicochemical properties. Fine sand and coarse silt fractions predominate in these soils, and second (Ca-bound) fractions of humic and fulvic acids predominate in the composition of their humus. These are base-saturated loamy sandy or light loamy soils with a neutral of slightly alkaline reaction. The middle-profile horizons are poorly pronounced. These soils compose a genetic series in the landscape-geochemical catena of the northern macroslope of the Tsagan-Daban Range.

Keywords: forest–steppe ecotone, parent materials, geochemical catena, genetic series of soils, Cambisols, Retisols

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INTRODUCTION

Soils of the Selenga Middle-Mountain region (Western Transbaikalia) are formed in the taiga–steppe ecotone: a transitional ecosystem with the alternation of Central Asian steppe and North Asian taiga landscapes. The area with dissected topography in the arid and cold climate is characterized by a regular penetration of warm dry air from the steppe zone to taiga and of cold moist air masses from mountain ridges to the steppe zone, which determines the development of forest–steppe biogeocenoses [13].

Landscapes of the taiga–steppe ecotone of the Selenga Mountains are well developed. This transitional zone is well pronounced in the western Transbaikal region, as well as in the northwestern and eastern Khentei, east Khubsugul region, and Khangai Mountains [14, 15]. The history of such ecotones is closely related to the long-term evolution of landscape and climatic conditions in the Holocene; their general trend was analyzed in [4, 6, 11, 30].

The boundaries between plant formations in the taiga–steppe ecotone changed many times in the Holocene; such changes were accompanied by a significant reorganization of the soil profiles towards the forest or steppe type of pedogenesis [28].

Soils of the taiga–steppe ecotone in western Transbaikalia were studied by many scientists [12, 18, 21, 23–27].

Ufimtseva [23] and Nogina [18] compiled systematic lists of forest-steppe and steppe soils of western Transbaikalia, in which soils were specified into two large groups of mountains and intermontane depressions. Based on these works, Tsybzhitov and Reimkhe distinguished low-humus and medium-humus chernozems in the forest-steppe landscapes of the Selenga Mountains. In the middle of north-facing slopes at the altitudes of 750–850 m a.s.l., these soils give way to dark gray forest soils.

The specificity of the soil cover in this region was noted by many researchers. N.A. Nogina considered soddy-forest soils of Transbaikalia to be a specific natural object of still incompletely clear genesis. The term soddy for these soils is not quite adequate, because the main feature of soddy horizons—active biological accumulation of elements and predomination of

humic acids in the soil humus—is only manifested in a very thin surface layer, and the main soil profile considerably differs from it. Makeev supposed that the development of soddy soils in the southern taiga subzone is related to the parent materials enriched in bases and primary minerals [17].

According to pedological concepts of the 20th century, soil formation in the mountains was considered specific, and such soils were assigned to a separate group of mountainous soils. Soils of piedmonts were classified within zonal types and subtypes similar to soils of plains [10]. Soils of the taiga—steppe ecotone of the Selenga Mountains were classified as miin particular assigned to mycelial-calcareous (with carbonate pseudomycelium) chernozems and gray forest soils. In the new substantive-genetic classification [9], these soils are identified as dark-humus and gray-humus soils, which were absent in the previous classification system [10].

Soils of the Selenga Mountains are insufficiently studied, so there is a need in their research with due account for the new principles and approaches given in [9, 19].

The aim of this work is to characterize specific features of the formation and properties of soils in the taiga—steppe ecotone of the Selenga Mountains and to determine their classification position in the new classification system.

OBJECTS AND METHODS

As formulated by Polynov [20], continental areas are specified by siallitic in situ weathering mantles (orthoeluvium) combined with calcified orthoeluvium on slopes. Calcified weathering crusts are related to geochemical processes, when calcium carbonates released from the rocks are not removed away with atmospheric waters, but only migrate in the deeper layers of the weathering crust, where they precipitate to form calcified sediments. Carbonate accumulations are typical of colluvial and alluvial fans on piedmonts and of river terraces.

Distribution pattern of soils in the studied area is controlled by the mountainous topography with tops of ridges elevated at about 700−1600 m a.s.l. Ridges and intermontane depressions of Western Transbaikalia are stretched from the west-southwest to the east-northeast. The main ridge have a dome-like shape. Shadowed windward and sunny leeward slopes are clearly pronounced. The Tsagan-Daban Ridge in the center of the Selenga Middle Mountain region has been shaped by erosional processes throughout the Mesozoic and Cenozoic eras. Weathered mantle (eluvium) on leveled tops and on slopes of northern aspect has a loesslike character. The bottoms of intermontane depressions have an undulating topography with clearly expressed colluvial aprons and with river valleys with flat slightly inclined terraces and floodplains

composed of well-sorted loesslike loamy sands and light loams. The 50-km-long northern macroslope of the Tsagan-Daban Ridge is dissected by short valleys and has more complicated and diverse landscapes and soils than a relatively short and dry southern slope.

The climate of Western Transbaikalia is sharply continental: the mean annual precipitation does not exceed 250−300 mm and its most part (50−55%) occurs in summer. The absence of stable snow cover favors deep soil freezing [8].

The plant cover of the Tsagan-Daban Ridge is characterized by the widespread larch—small-leaved forests with rich herbaceous ground cover on the upper parts of slopes. Lower areas of shadow slopes are covered by pine—birch forests. Pine forests and xerophytic steppe grass communities are allocated to southern slopes and windward western spurs of ridges.

Specifics features of soil-forming rocks attract great attention of researchers. The investigated area is mainly composed of intrusive (granites, syenites, and diorites) and effusive (basalt) rocks of different ages.

We studied a soil catena on the northern macroslope of the Tsagan-Daban Ridge (Fig. 1). Soil pits characterized the main elements of the macro- and mesotopography: ridge tops and uppermost slopes (eluvial and transeluvial positions), northern and western slopes (transeluvial and transaccumulative positions), and southeastern slope (transeluvial position) of the Kuitun second-order ridge.

These soils are formed on carbonate-free mantle loams, loamy sands, loesses, and loesslike sediments. Loesses are of eolian genesis, and loesslike sediments are of colluvial genesis [2].

The comparative geographical and profile-genetic approaches were used in the study of key sites. The morphological description of soil horizons was performed according to [22]. Physicochemical and chemical soil properties were analyzed by routine methods [5]. The elemental composition of soils was examined with the use of the gravimetric, titrimetric, spectrophotometric, and flame-photometric methods with a preliminary treatment by the method of acid decomposition and alloying with soda [1]. Iron was determined in the Tamm and Mehra—Jackson extracts. Soil carbonates were preliminary destroyed and removed with a 2% solution of acetic acid. Particle-size distribution was analyzed by the pipette method according to Kachinskii [3]. Soil color was determined in the dry state using Munsell color charts.

Soil types were determined according to [9, 19, 29].

RESULTS AND DISCUSSION

The researches of the soil cover of the northern macroslope of the Tsagan-Daban Ridge demonstrated the following distribution pattern of weathering crusts: coarse gravelly orthoeluvium on the top of ridges at 1000−1400 (1600) m a.s.l. and siallitic calcified elu-
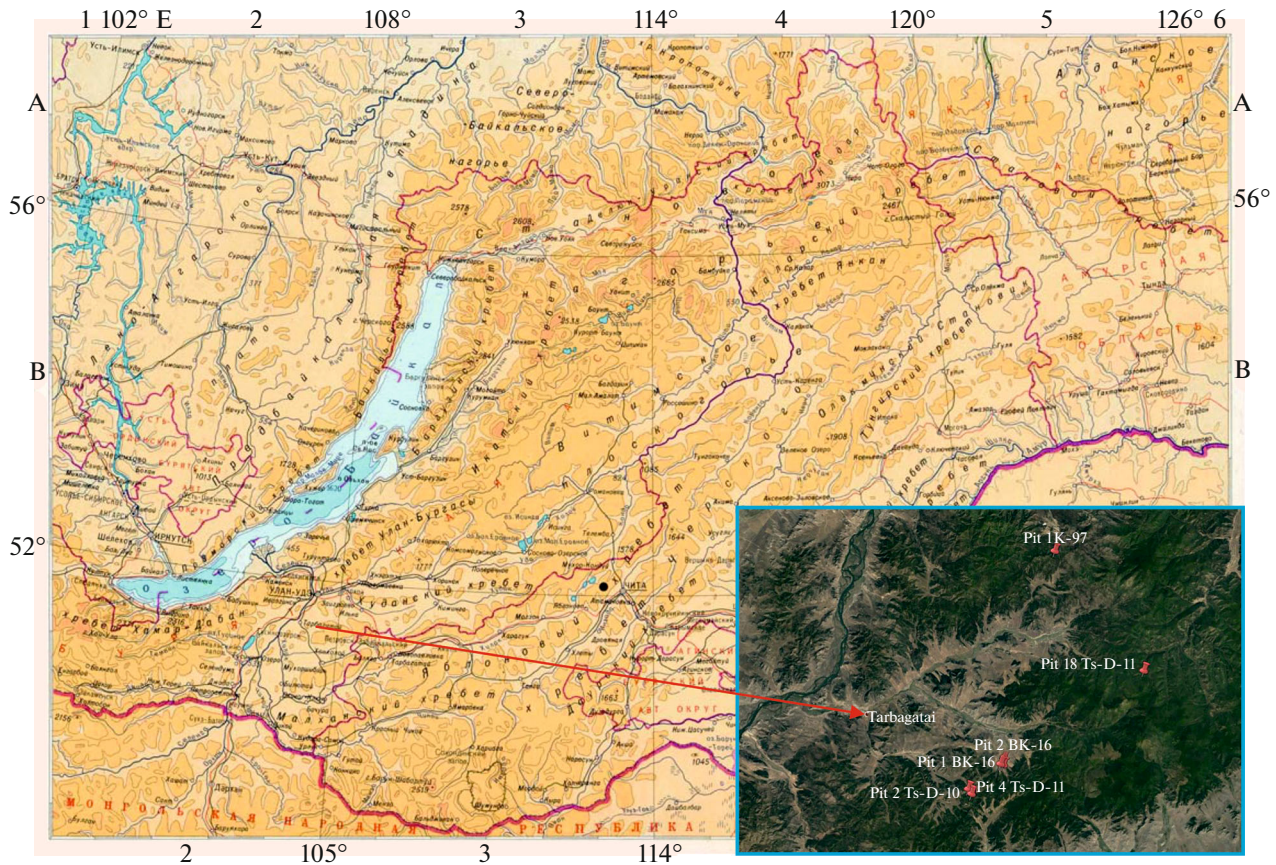
Fig. 1. Schematic map of key plots on the northern macroslope of the Tsagan-Daban Ridge in the Selenga Mountains.

vium on level surfaces at 900−1000 m a.s.l., where the bedrock is mainly represented by granitoids. Mantle loams (2−3 m in thickness) are characterized by loamy texture with a predominance of coarse silt and fine sand, yellowish brown color, and crumb−angular blocky structure; they are relatively homogeneous. Slopes at 670−900 m a.s.l. are covered by calcified eluvium and colluvium. Loess sediments contain carbonates and have a uniform crumb structure, yellowish brown color, and light loamy texture with a predominance of coarse silt and fine sand fractions. Their thickness on slopes may reach 10−15 m [2]. Loesslike sediments are layered and contain inclusions of gravels; they have a loamy sandy texture with a predominance of fine sand and coarse silt fractions, yellowish brown color, and weak structure. River terraces with wide depressions at 580−670 m a.s.l. are covered by sands underlain by calcified eluvium (Fig. 2).

Specific features of weathering and lithogenesis in the Selenga Mountains determine the main regularities of the genetic and spatial variability of soils.

Pit 18Ts-D-11 (51°27′36.00″ N, 107°54′29.00″ E) was examined on the upper part of the northeastern slope of 1°−2° of the Tsagan-Daban Ridge in the eluvial position. This area represents the uppermost part

of the Skorodumka River catchment; it is elevated at 980 m a.s.l. The plant cover is a rich-forb larch−birch forest with Siberian pine. Dominant ground-cover species are *Vaccinium vitis-idaea* subsp., *Pirola rotundifolia* L., and *Carex pediformis* C.A. Meyer. Codominants include *Rhododendron dauricum* L., *Cotoneaster melanocarpus* Fischer ex Blytt, *Maianthemum bifolium* (L.) F. W. Schmidt., *Rubus saxalitis* L., *Geum rivale* L., *Paris quadrifolia* L., and *Dryopteris filixmas* (L.) Schott. The projective cover is 90%. The soil is classified as a soddy-podzolic on carbonate-free mantle loam (Eutric Albic Retisol (Cutanic, Ochric)).

The soil horizonation is as follows: O (0 to 4 cm)−AO (4 to 15 cm)−AY (15 to 20/26 cm)−EL (20/26 to 38 cm)−BT1 (38 to 57 cm)−BT2 (57 to 80 cm)−BC (>80 cm). The accumulative part of the profile consists of forest litter and brownish dark gray (10YR 4/1) raw-humus horizon. The gray-humus (AY) horizon is grayish light brown (10YR 5/3) slightly dry sandy loam with crumb structure; slightly compacted; porous; with abundant tree and grass roots; and with distinct wavy boundary. The eluvial (EL) horizon is pale yellow (10YR 6/4) slightly dry sandy loam; compact, with thin platy structure and light- colored skeletans on the surface of plates; porous; inclusions of fine
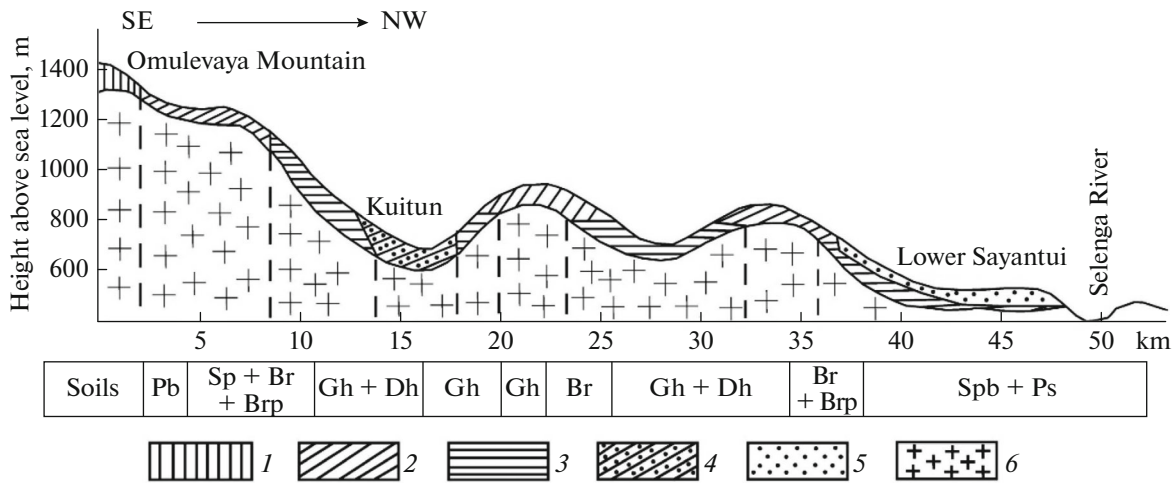
Fig. 2. Landscape-geochemical catena on the northern macroslope of the Tsagan-Daban Ridge: (*1*) raw-humus orthoeluvium; (*2*) siallitic calcareous eluvium (mantle loams); (*3*) calcareous eluvium (loesses and loesslike sediments); (*4*) calcareous colluvium; (*5*) sands underlain by calcareous eluvium; (*6*) granitoids. Soils: Pb—raw-humus podburs; Sp—soddy-podzolic; Br—raw-humus burozems; Brp—podzolized raw-humus burozems; Gh—gray-humus; Dh—dark-humus; Spb—soddy podburs; Ps—psammozems.

roots; distinct wavy boundary; the transition is visible by color. The BT1 horizon is ocherous brown (10YR 5/8) slightly dry heavy loam with crumb–angular blocky structure; compact, porous, with skeletans and clay films on ped faces. The BT2 horizon is yellowish brown (10YR 5/6) slightly dry silt loam with crumb–angular blocky structure; compact, porous. There are coffee-colored coatings on ped faces. The boundary is slightly wavy, and the transition is seen from changes in the color and density. The BC horizon is whitish pale-yellow (10YR 6/6), slightly dry, light loamy, and very dense. Thin skeletans and clayey coatings are seen on ped faces.

Soddy-podzolic soils are characterized by the surface input of organic matter with formation of the raw-humus horizon and mobile fulvate humus. A thin humus-accumulative horizon (5−11 cm) with a low humus content points to insufficiently intensive humification. Lessivage is evidenced by numerous coatings in the BT horizon. The subeluvial BEL horizon is absent; in the lower part of the EL horizon, there are residual fragments of the BT horizon, whose amount gradually increases downward the profile [9]. The soil is saturated with bases throughout the profile; the reaction is acid in the soil horizons and neutral in the parent material. The soil profile is clearly differentiated into the eluvial and illuvial parts according to data on the bulk elemental composition.

Pit 4Ts-D-11 (51°21′11.59″ N, 107°32′33.33″ E) was studied in the transeluvial position on the southwestern slope of 2°−3° near the Barskii pass at 920 m a.s.l., under the rich-forb pine−larch−birch forest affected by fire. Dominant species: *Calamagrostis epigeios* (L.) Roth and *Bromopsis inermis* (Leysser) Holub. Codominants: *Aster alpinus* L., *Galium*

boreale L., *Fragaria vesca* L., *Rubus saxalitis* L., *Artemisia gmelinii* Web. Ex Stechm., and *Maianthemum bifolium* (L.) F.W. Schmidt. The projective cover was 15−20%. The height of the grass layer was 20−40 cm. The soil was classified as a raw-humus light-loamy pyrogenic-transformed burozem on loess (Eutric Cambisol (Siltic)).

The soil has the following horizonation: Opir (0 to 2.5 cm)−AO (2.5 to 9/12 cm)−AUpir (9/12 to 20/23 cm)−BMel (20/23 to 50 cm)−BM (50 to 78 cm)−BC (78 to 100 cm). The forest litter is loose and consists of needles, leaves, and charcoal pieces. The raw-humus horizon is dark gray (10YR 3/2) and consists of differently decomposed plant residues with mineral admixtures. The dark-humus horizon is dark gray (10YR 3/2) slightly dry sandy loam with crumb structure; rather compact; porous; with inclusions of charcoal and numerous tree and grass roots; wavy boundary; the transition is from changes in the soil color. The structural-metamorphic BMel horizon is unevenly colored with a predominance of yellowish brown (10YR 5/4) color and with whitish skeletans on ped faces. Slightly dry light loam, with angular blocky−crumb structure; compact; porous; with inclusions of charcoal particles and roots; smooth diffuse boundary. The BM2 horizon is yellowish brown (10YR 5/6) slightly dry silty loam with angular blocky−crumb structure; relatively dense; porous; smooth boundary. The BC horizon is brownish-yellow (10YR 5/8) slightly dry light loam; relatively dense, porous.

Raw-humus burozems are characterized by the surface input of organic matter with the formation of thick raw-humus horizon and thin dark-humus horizon (9−20 cm). They are saturated with bases; the

structure is angular blocky parting to crumbs. The content of clay and iron oxides is increased in the BM horizon. The reaction is slightly acid in the upper and middle-profile horizons and neutral in the lower horizons and parent material. Humus is of the fulvate–humate type with a predominance of brown humic acids of the first fraction.

According to [10], the studied soil belongs to the subtype of slightly unsaturated brown forest soils.

Pit 2Ts-D-10 (51°21′34.00″ N, 107°32′17.00″ E) was excavated in the transeluvial position on the northwestern slope of 3°–4° at 900 m a.s.l. under the rhododendron–forb larch–pine–birch forest with *Vaccinium vitis-idaea* subsp., *Carex pediformis* C.A. Meyer, and *Pirola rotundifolia* L. as dominants and *Rhododendron dauricum* L., *Rosa acicularis* Lindley, *Fragaria vesca* L., *Rubus saxalitis* L., *Galium boreale* L., *Sanguisorba officinalis* L., *Cypripedium guttatum* Sw., and *Spiranthes amoena* (Bieb.) Sprengel as codominants. The projective cover reached 70–80%. The grass cover was 30–40 cm in height. The soil was classified as a raw-humus residual-calcareous light loamy burozem on loesslike sediments (Eutric Cambisol (Humic, Siltic)).

The soil profile consists of the following horizons: O (0 to 2 cm)–AYao (2 to 6/10 cm)–BMel (6/10 to 37 cm)–BM (37 to 65 cm)–Cca (65 to 90 cm). The forest litter consists of the residues of leaves, small branches, and needles. The AYao horizon is brownish dark gray (10YR 4/2) nonuniform slightly dry loose light loam; wavy boundary; the transition is seen from changes in the color. The BMel horizon is yellowish brown (10YR 5/4) tinted white slightly dry light loam with crumb structure; compact, porous; with inclusions of tree roots and crushed stone; smooth boundary; gradual transition. The BM horizon is yellowish brown (10YR 5/6) slightly dry light loam; crumb structure; compact, porous; inclusions of roots and crushed stone; smooth boundary; the transition is seen from the rise in the stone content. The Cca horizon is pale yellow (10YR 6/8) with whitish mottles (10YR 6/6); slightly dry sandy loam; structureless, very compact, with inclusions of stone debris; slightly effervescent.

Raw-humus residual-calcareous burozems are characterized by a thin humus horizon (4–8 cm). The organic matter content in the AYao horizon is 23% and then sharply decreases down the soil profile. Metamorphic BMel and BM horizons are specified by the pedogenic structural organization of the mineral mass with the formation of crumb structure and with an increased content of clay and oxalate-extractable iron oxides. The reaction is neutral in the humus-accumulative horizon, slightly acid in the BMel horizon, and alkaline in the Cca horizon. The soil profile is saturated with bases; calcium predominates in the soil adsorption complex. The soil humus is of the humate–fulvate type with a predominance of the first fraction

of fulvic acids. The bulk elemental composition is relatively stable in the entire profile, except for a slightly increased R_2O_3 content in the upper mineral horizon. The increased content of oxalate-extractable iron is typical of the upper horizons.

The areas of soddy-podzolic soils, raw-humus burozems, and raw-humus residual-calcareous burozems have a sporadic pattern. These soils are formed on the interfluves and upper parts of slopes under larch–birch forests with rich herbaceous ground cover. These factors favor the development of pedogenic alteration (metamorphism) in the middle-profile horizons; textural differentiation takes place in soddy-podzolic soils.

Pit 1K-97 (51°37′15.00″ N, 107°46′60.00″ E) was excavated in the transeluvial position on the southeastern slope (4°–6°) of the Kaitun Ridge at 790 m a.s.l. under the birch–larch–pine forest with thin grass cover formed after a fire. *Vaccinium vitis-idaea* subsp., *Pirola rotundifolia* L., *Antennaria dioica* (L.) Gaertn were dominant species. Codominants were represented by *Rhododendron dauricum* L., *Rosa acicularis* Lindley, *Fragaria vesca* L., *Carex pediformis* C.A. Meyer, *Pulsatilla turczaninovii* Krylov et Serg., *Lathyrus humilis* (Ser.) Sprengel, and *Trifolium lupinaster* L. The projective cover was about 5–10%.

The soil described in this pit was classified as a postpyrogenic light loamy typical gray-humus soil on carbonate-free loamy sands (Eutric Cambisol (Ochric, Siltic)).

The soil has the following horizonation: O (0 to 2 cm)–AYpir (2 to 17 cm)–AC (17 to 40 cm)–C1 (40 to 56 cm)–C2 (56 to 90 cm). The forest litter consists of weakly decomposed needles, bark, small pine branches and cones, and charcoal fragments. The humus horizon is brownish dark gray (10YR 4/2) slightly dry light loam; crumb structure; compact; porous; with inclusions of numerous charcoal fragments and roots; ocherous-colored mottles are seen against the background of the brownish gray color; diffuse smooth boundary. The AC horizon is brownish gray (10YR 4/3) slightly dry light loam with crumb structure; compact, porous; with inclusions of charcoal particles; smooth boundary; the transition is seen from changes in the color. The C1 horizon is yellowish brown (10YR 5/4) slightly dry sandy loamy, structureless, compact, and porous. There are inclusions of coal particles. The boundary is level, and the transition is seen by compactness. The C2 horizon is yellowish-brown (10YR 5/4), slightly dry loamy sand; structureless, rather compact, and porous; few inclusions of charcoal particles.

Gray-humus (soddy) soils are widespread in the taiga–steppe ecotone of the Selenga Mountains on slopes of different aspects in the transitional and transitional-accumulative positions at 620–800 m a.s.l. These soils are formed under mixed small-leaved–larch–pine forests [25, 26]. Taiga herbs predominate

Table 1. Particle-size distribution data

Horizon	Depth, cm	Content of fraction, %; size of particles, mm					
		1.0–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001
Gray-humus typical soil (Pit 1K-97)							
AYpir	2–17	0	54	25	5	7	9
AC	17–40	0	33	46	4	3	14
C1	40–56	0	61	20	5	7	7
C2	56–90	0	59	26	4	5	6
Dark-humus residual-calcareous soil (Pit 1BK-16)							
AU	0–30/40	0	25	48	8	11	8
AC	30/40–55	0	21	52	6	13	8
Cca1	55–75	0	26	51	6	8	9
Cca2	75–90/100	0	28	51	8	7	6
Cca3	90/100–125	0	27	51	6	7	9
Gray-humus residual-calcareous soil (Pit 2BK-16)							
AY	0–13/19	2	41	38	4	9	6
AC	13/19–30	1	39	40	4	7	9
Cca1	30–55	1	37	41	5	7	9
Cca2	55–70	0	39	40	6	8	7
Raw-humus burozem (Pit 4 Ts-D-11)							
AUpir	9/12–20/23	0	19	56	8	10	7
BMel	20/23–50	0	33	38	8	9	11
BM2	50–78	0	16	47	9	11	17
BC	78–100	0	36	35	7	10	12
Raw-humus residual-calcareous burozem (Pit 2 Ts-D-10)							
AYao	2–6/10	0	55	23	11	7	4
BMel	6/10–37	1	32	45	6	3	13
BM	37–65	6	54	20	3	5	12
Cca	65–90	31	50	4	3	2	10
Soddy-podzolic soil (Pit 18 Ts-D-11)							
AY	15–20/26	0	20	55	9	11	5
EL	20/26–38	0	18	57	9	12	4
BT1	38–57	0	17	41	8	10	24
BT2	57–80	0	24	43	6	8	19
BC	>80	0	30	45	4	10	11

in the ground cover. The parent materials are represented by sandy, gravelly, and loesslike materials. The humus-accumulative and litter horizons are thin; their total thickness is about 10–20 cm.

Pyrogenic features are seen everywhere in the studied soils. They are preserved for a long time after fire. Charcoal particles have been found in the entire profile, including the parent material. This is explained by the redistribution of soil material by lateral and radial flows in transit positions on slopes.

The humus content in the gray humus horizon is low and sharply decreases down the profile. The soil reaction is neutral. Calcium predominates among exchangeable cations. The soils are saturated with bases. They have a light loamy or loamy sandy texture with a predominance of fine sand and coarse silt fractions. The soil humus is of the humate–fulvate type. Humus horizons of post-pyrogenic soils and horizons transitional to soil-forming rocks are characterized by an increased content of humic substances strongly bound to clay minerals and sesquioxides. This is obviously related to the fact that fine mineral particles with great specific surface are capable of binding humus under the impact of forest fires and high temperatures [7].

Gray-humus soils have a lower humus content in comparison with gray forest soils. A sharp decrease in the humus content downward the soil profile is typical of them. Textural differentiation is absent. According to [9, 19], these soils can be classified as the type of gray-humus soils in the order of organic-accumulative soils.

Pit 1BK-16 (51°22′54.60″ N, 107°36′25.08″ E) was excavated in the trans-accumulative position 3 km to southeast of the settlement of Bol'shoi Kunalei on the lower part of colluvial fan on of the north-facing 3° steep slope at 690 m a.s.l. under the herbaceous birch−pine forest with cotoneaster. *Poa botryoides* (Trin. Ex Griseb.) Roshev., and *Thermopsis lanceolata* R. Br. S. str. predominated in the grass cover. Codominants were represented by *Carex pediformis* C.A. Meyer, *Potentilla tanacetifolia* Willd. Ex Schlecht., *Antennaria dioica* (L.) Gaertn., *Galium boreale L.,* and *Goniolimon speciosum* (L.) Boiss. The projective cover was about 30−35%. The soil was identified as a residual-calcareous light loamy dark-humus soil on loesslike sediments (Eutric Cambisol (Siltic)).

The soil profile consists of the following horizons: AU (0 to 30/40 cm)−AC (30/40 to 55 cm)−Cca1 (55 to 75 cm)−Cca2 (75 to 90/100 cm)−Cca3 (90/100 to 125 cm). The humus-accumulative horizon is dark gray (10YR 3/2) slightly dry light loam; crumb structure; compact; porous; with inclusions of grass roots; sharp wavy boundary. The transitional AC horizon is yellowish brown (10YR 5/6) slightly dry light loam with platy−crumb structure; rather compact, porous, with inclusions of fine roots; smooth boundary. The transition is seen from the rise in the soil density. The Cca1 horizon is yellowish brown (10YR 5/6) slightly dry light loam with weak crumb structure; dense, porous; few roots; slightly effervescent in the lower part; smooth boundary. The Cca2 horizon is brownish pale-yellow (10YR 5/8) slightly dry light loam; weak crumb structure; loose, porous, slightly effervescent. A brown mottle (8 × 9 cm) is seen in the right part. Wavy boundary. The Cca3 horizon is whitish pale yellow (10YR 6/4) slightly dry light loam; weak crumb structure; compact; porous; effervescent.

Dark-humus soils are formed on the lower parts of colluvial aprons (trans-accumulative positions) at 670−720 m a.s.l. under grass−forb communities with both taiga and steppe species [26]. These soils are almost completely plowed and transformed into agro−dark-humus soils. The parent material is loesslike sediment.

The thickness of the dark-humus horizon with crumb structure reaches 40 cm. The humus content is medium in the dark-humus horizon and sharply decreases in the Cca horizon (Table 2). The reaction is neutral or alkaline. The adsorption complex is saturated by calcium cations. The second fraction of humic acids predominates in the composition of humus (Table 3). The boundaries of mineral horizons are smooth or slightly wavy. The soils have a light loamy texture with predominant coarse silt and fine sand fractions. The soil profile is not differentiated with respect to the bulk elemental composition (Table 4).

The studied soils are developed from loesslike sediments and are characterized by pedogenic accumulation of carbonates in fine earth. Carbonate pedofeatures are indistinct; the presence of carbonates is seen from effervescence with HCl. The absence of calcareous nodules (beloglazka, loess dolls, etc.) in chernozemic soils of the Transbaikal region was noted by Nogina n [18]. In the studied soils, there is no diagnostic carbonate-accumulative horizon; the accumulation of carbonates is described as a diagnostic feature. The depth of carbonates is variable and depends on season and climatic moistening cycles.

Carbonates in the studied soils are of the secondary nature and are represented by disperse cryptocrystalline calcite. It precipitates in the soil upon alternation of sharp drying and moistening of the horizons; carbonates precipitate from colloidal solutions [16].

The humus content is medium and decreases down the profile; the soil structure is relatively weak. These soils can be classified as dark-humus soils in the order of organo-accumulative soils. They do not meet the criteria for chernozems.

Soils of steppe biocenoses in the western part of Transbaikal region were previously classified as low-humus chernozems with farinaceous carbonates [18, 21, 23, 27].

Pit 2BK-16 (51°22′49.18″ N, 107°36′42.84″ E) was examined in the transeluvial position on steep (10°−15°) western slope 2.5 km to the southeast of the settlement of Bol'shoi Kunalei (the Elan' Severnaya Depression) at 720 m a.s.l. under the herbaceous pine forest with cotoneaster. The projective cover was 25−30%. *Koeleria cristata* (L.) Pers. s. str. and *Potentilla tanacetifolia* Willd. Ex Schlecht predominated among herbs. Codominants were represented by *Stipa krylovii* Roshev, *Carex pediformis* C.A. Meyer, *Poa botryoides* (Trin. Ex Greseb.) Roshev., *Antennaria dioica* (L.) Gaertn., *Veronica incana* L., *Thermopsis lanceolata* R. Br. s. str., and *Goniolimon speciosum* (L.) Boiss. The soil was identified as a residual-calcareous light loamy gray-humus soil on loesslike sediments (Eutric Cambisol (Ochric, Siltic)).

The soil profile has the following horizonation: AY (0 to 13/19 cm)−AC (13/19 to 30 cm)−Cca1 (30 to 55 cm)−Cca2 (55 to 70 cm). The gray-humus horizon is brownish gray (10YR 4/4) dry loamy sand with crumb structure; compact and porous, with inclusions of grass roots and gravels. It does not effervesce with 10% HCl. The boundary is pocket-like, and the transition is visible by color. The transitional AC horizon is yellowish brown (10YR 5/6) slightly dry light loam with crumb structure; dense, porous, with inclusions of roots and gravels; smooth boundary. The transition is seen from changes in the soil density. The Cca1 horizon is brownish yellow (10YR 5/8) slightly dry,

Table 2. Some chemical soil properties

Horizon (depth, cm)	pH$_{H_2O}$	Humus	CO$_2$	Adsorbed cations		Ac*	BS, %	Fe$_2$O$_3$, %	
				Ca^{2+}	Mg^{2+}			o	d
		%		cmol(+)/kg					
Gray-humus typical soil (Pit 1K-97)									
AYpir (2−17)	6.6	1.61	−	16.6	3.0	3.1	86	1.10	−
AC (17−40)	6.7	0.43	−	12.1	1.5	2.8	83	1.10	−
C1 (40−56)	7.1	0.23	−	13.6	3.4	2.1	89	0.83	−
C2 (56−90)	7.1	0.17	−	8.8	4.4	1.8	88	0.29	−
Dark-humus residual-calcareous soil (Pit 1BK-16)									
AU (0−30/40)	6.8	4.69	−	25.0	2.78	1.2	96	0.60	1.30
AC (30/40−55)	7.0	1.05	−	19.4	2.78	0.6	97	0.29	0.95
Cca1 (55−75)	7.1	0.55	0.09	12.0***		−	−	0.38	0.71
Cca2 (75−90/100)	7.2	0.57	0.09	10.0***		−	−	0.30	0.66
Cca3 (90/100−125)	8.1	0.48	1.22	8.0***		−	−	0.28	0.68
Gray-humus residual-calcareous soil (Pit 2BK-16)									
AY (0−13/19)	7.3	2.19	−	21.2	4.55	0.6	98	0.54	1.83
AC (13/19−30)	7.4	0.78	−	17.2	3.13	0.4	98	0.51	0.85
Cca1 (30−55)	8.1	0.66	0.80	26.0***		−	−	0.38	0.72
Cca2 (55−70)	8.4	0.78	6.20	14.0***		−	−	0.28	0.79
Raw-humus burozem (Pit 4 Ts-D-11)									
AUpir (9/12−20/23)	6.0	6.75	−	33.8	16.3	3.5	94	0.64	2.1
BMel (20/23−50)	6.0	0.81	−	14.0	7.0	1.4	94	0.60	1.0
BM2 (50−78)	6.2	0.42	−	21.3	13.8	1.1	97	0.36	1.56
BC (78−100)	6.5	0.28	−	23.0	11.0	0.9	97	0.28	0.80
Raw-humus residual-calcareous burozem (Pit 2 Ts-D-10)									
AYao (2−6/10)	6.9	23.10**	−	45.2	7.1	5.2	91	0.60	1.35
BMel (6/10−37)	6.0	0.83	−	13.3	7.0	1.4	94	1.00	1.40
BM (37−65)	6.4	0.46	−	10.7	3.3	0.7	95	0.70	1.04
Cca (65−90)	7.9	0.75	−	12.0***	12.0***	−	−	0.10	0.90
Soddy-podzolic soil (Pit 18 Ts-D-11)									
AY (15−20/26)	5.3	2.55	−	13.0	5.0	2.8	87	0.56	1.00
EL (20/26−38)	5.6	0.56	−	10.4	3.3	1.8	88	0.40	0.72
BT1 (38−57)	5.9	0.51	−	17.0	7.0	1.9	93	0.68	0.66
BT2 (57−80)	6.0	0.22	−	18.0	8.0	1.4	95	0.48	0.82
BC (>80)	6.5	0.16	−	13.7	7.5	0.9	93	0.28	0.48

　* Total (hydrolytic) acidity.
　** Loss on ignition.
*** Adsorption capacity.
Dashes stand for "not determined," BS is base saturation.

light loam with blocky−crumb structure; compact, porous; inclusions of fine roots and gravels; slightly effervescent; smooth boundary. The Cca2 horizon is pale yellow (10YR 6/4) slightly dry light loam with crumb structure; dense, porous, with intense effervescence.

Gray-humus residual-calcareous soils on loesslike sediments develop under forb−grassy steppe communities in transitional and trans-accumulative positions on western and southern slopes at 650−750 m a.s.l., at the contact with dark gray soils [24]. Representatives of both taiga and steppe flora are found in the ground cover. The soils are actively used in agriculture and are now transformed into agrozems. The thickness of the gray-humus horizon is about 20 cm. The humus content is low and sharply decreases down the profile. The

Table 3. Group and fractional composition of humus

Horizon (depth, cm)	C, %	Humic acids				Fulvic acids					Nonhydrolyzable residue	$\dfrac{C_{HA}}{C_{FA}}$
		1	2	3	Σ	1a	1	2	3	Σ		
Gray-humus typical soil (Pit 1K-97)												
AYpir (2−17)	0.94	11	14	10	35	6	7	9	29	51	14	0.69
AC (17−40)	0.25	2	14	10	26	8	6	4	20	38	36	0.69
Dark-humus residual-calcareous soil (Pit 1BK-16)												
AU (24−39/43)	2.72	5	28	6	39	5	9	9	11	34	27	1.15
Gray-humus residual-calcareous soil (Pit 2BK-16)												
AY (0−13/19)	1.27	3	8	13	24	6	8	20	12	46	30	0.52
AC (13/19−30)	0.45	1	7	11	19	5	7	26	14	52	29	0.38
Raw-humus burozem (Pit 4 Ts-D-11)												
AUpir (9/12−20/23)	3.92	19	9	14	42	3	18	6	8	35	23	1.20
Raw-humus residual-calcareous burozem (Pit 2 Ts-D-10)												
AYao (2−6/10)	13.40	6	8	11	25	5	15	1	9	30	55	0.85
BMel (6/10−37)	0.48	1	2	9	12	12	8	7	6	33	45	0.35
Soddy-podzolic soil (Pit 18 Ts-D-11)												
AY (15−20/26)	1.48	15	3	8	26	9	28	1	9	47	27	0.57

Table 4. Bulk elemental composition of soils, % of calcined sample

Horizon (depth, cm)	SiO_2	Al_2O_3	Fe_2O_3	K_2O	CaO	Na_2O	MgO	TiO_2	MnO	$\dfrac{SiO_2}{Al_2O_3}$	$\dfrac{SiO_2}{Fe_2O_3}$	$\dfrac{SiO_2}{R_2O_3}$
Gray-humus typical soil (Pit 1K-97)												
AYpir (2−17)	65.30	11.12	4.93	1.77	3.10	1.24	2.61	0.51	0.16	9.97	35.06	7.76
AC (17−40)	66.59	10.73	5.41	2.29	4.53	0.92	2.22	0.51	0.09	10.56	32.62	7.98
C1 (40−56)	67.50	12.70	4.84	1.90	5.02	1.14	1.09	0.53	0.08	8.99	37.47	7.25
C2 (56−90)	67.54	12.62	5.06	1.92	4.25	1.09	1.82	0.53	0.07	9.07	35.16	7.21
Dark-humus residual-calcareous soil (Pit 1BK-16)												
AU (0−30/40)	65.42	14.06	5.36	2.31	3.23	3.41	1.89	0.44	0.14	7.89	32.03	6.33
AC (30/40−55)	66.91	13.79	4.90	1.92	2.43	3.06	2.35	0.33	0.13	8.25	35.94	6.71
Cca1 (55−75)	63.84	12.05	4.70	2.24	4.94	3.02	3.36	0.39	0.15	9.01	36.66	7.23
Gray-humus residual-calcareous soil (Pit 2BK-16)												
AY (0−13/19)	67.31	14.47	5.04	1.55	2.65	2.24	2.52	0.34	0.14	7.89	35.03	6.44
AC (13/19−30)	67.77	13.93	4.45	2.27	2.66	3.09	1.98	0.33	0.13	8.23	40.29	6.84
Cca1 (30−55)	66.78	14.78	3.39	2.26	4.88	2.26	1.53	0.32	0.13	7.67	52.95	6.70
Cca2 (55−70)	64.55	14.78	3.73	2.26	5.11	3.32	2.71	0.32	0.14	7.41	46.74	6.40
Raw-humus residual-calcareous burozem (Pit 2 Ts-D-10)												
AYao (2−6/10)	57.22	14.19	5.19	2.88	3.64	2.68	1.94	0.16	0.38	6.86	28.88	5.54
BMel (6/10−37)	66.68	14.47	5.04	1.47	2.50	2.34	1.94	0.35	0.12	7.82	34.69	6.38
BM (37−65)	67.02	14.06	4.33	2.08	2.33	3.12	1.83	0.32	0.10	8.21	41.33	6.76
Cca (65−90)	67.85	11.82	3.61	4.64	2.02	2.19	1.39	0.21	0.12	9.74	49.13	8.13
Soddy-podzolic soil (Pit 18 Ts-D-11)												
AY (15−20/26)	69.64	12.95	4.24	2.12	2.23	2.36	1.17	0.39	0.30	9.13	42.96	7.53
EL (20/26−38)	65.71	14.78	4.94	1.52	2.19	2.58	1.40	0.50	0.10	7.54	35.29	6.22
BT1 (38−57)	65.92	15.80	6.18	2.14	2.45	3.64	1.55	0.43	0.13	7.08	28.15	5.66
BT2 (57−80)	65.20	15.85	5.27	2.94	2.19	3.35	1.32	0.44	0.12	7.01	32.91	5.78
BC (>80)	65.79	15.12	4.69	1.73	3.16	3.06	0.92	0.37	0.16	7.40	37.76	6.19

reaction is slightly alkaline in the upper horizon and alkaline in the deep horizons. Calcium predominates among exchangeable cations. The soils are saturated with bases. The texture is loamy sandy or light loamy, with a predominance of fine sand and coarse silt fractions. Humus is of the fulvate type, and the second fraction of fulvic acids predominates. The soil profile is not differentiated with respect to the bulk elemental composition.

Soils of south-facing slopes developing from loess-like sediments and consisting of the humus-accumulative horizon and parent material without middle-profile horizons belong to gray-humus soils of the order of organo-accumulative soils according to the new Russian soil classification system.

In the taiga–steppe ecotone of the Selenga Mountains, the soils of this order are developed both under steppe and forest vegetation. They are characterized by the soddy (humus-accumulative) process. Gray-humus soils are most widespread and are allocated to slopes of different aspects under herbaceous larch–pine forests. Gray-humus soils with disperse carbonates are formed under steppe communities or light coniferous forests with steppe-like ground cover on south-facing slopes. Dark-humus soils with residual carbonates are allocated to colluvial aprons and develop under herbaceous birch–pine forests.

The studied soils, except for soddy-podzolic soils, have undifferentiated profiles according to data on the bulk content of R_2O_3. The accumulation of Fe_2O_3 in the upper horizons is related to the weathering intensity. Biogenic elements (CaO, MgO, and MnO) tend to accumulate in the upper horizons. The SiO_2 is evenly distributed in the profiles; some increase in its content is seen in the lower horizon of the raw-humus residual-calcareous burozem with a predominance of sand fractions.

Data on the forms of iron in the studied soils indicate that weakly crystalline forms of iron predominate among nonsilicate iron compounds, and their content increases in the deep horizons.

CONCLUSIONS

Soils of the taiga–steppe ecotone were studied in the Selenga Mountains in the western part of the Transbaikal region. The following conclusions can be made.

(1) Soil forming conditions—slope aspect, lithological heterogeneity, specific features of vegetation, and climatic continentality—control the distribution pattern of soils.

(2) Raw-humus burozems and raw-humus burozems with residual carbonates are formed in trans-eluvial positions on the upper parts of slopes. Texture-differentiated soddy-podzolic soils are allocated to eluvial positions on the tops of local ridges. These soils are specified by the processes of pedogenic alteration (metamorphism) of the middle-profile

horizons and textural differentiation. Gray-humus soils are formed in transitional (slopes) and trans-accumulative (footslopes) positions on slopes of different aspects. Gray-humus with residual carbonates occupy insolated areas on the slopes with steppe vegetation in the ground cover, and dark-humus soils with residual carbonates are allocated to lower parts of colluvial aprons. These soils are characterized by a pronounced humus accumulation and an immediate transition from the humus-accumulative part of soil profile to the parent material. Middle-profile horizons are indistinct or have a transitional character.

(3) The low content of nonsilicate iron with a predominance of amorphous and weakly crystallized forms attests to a relatively weak manifestation of pedogenic processes under conditions of sharply continental climate.

(4) Pedogenic accumulation of carbonates does not lead to the formation of diagnostic carbonate-accumulative horizons with distinct carbonate concentrations. It is only manifested at the level of diagnostic soil features; residual carbonates inherited from the parent material are often present in the soils.

(5) Slightly pronounced redistribution of substances in the studied soils attests to the significant role of features inherited from the parent materials. The latter affect the soil reaction and the contents and distribution of calcium and magnesium cations and iron forms in the oxalate and dithionite extracts.

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