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GENESIS
AND GEOGRAPHY OF SOILS

Soils on Hard Rocks in the Northwest of Russia: Chemical and Mineralogical Properties, Genesis, and Classification Problems

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Abstract—Soil formation on hard rocks—nepheline syenite, amphibolite, metamorphized gabbro diabase, and their derivatives—was studied in the mountainous tundra and in the northern and middle taiga zones of the Kola Peninsula and Karelia (in the Kivach Reserve). It was found that the soils developing from these rocks could be classified into three groups: (1) petrozems with the O–M profile (the most common variant), (2) podzols and podzolized podburs on the substrates with an admixture of morainic derivatives of acid rocks, and (3) shallow (<5–10 cm) pebbly soils on the substrates without an admixture of allochthonous material (the rarest variant). In soils of the third group, the pedogenic alteration of the mineral matrix does not result in the appearance of phyllosilicates in the fine fractions if these phyllosilicates are initially absent in the rock. In these soils, the processes of modern pedogenesis (rock disintegration, migration of Al–Fe-humus compounds, in situ transformation of the organic matter, and binding of iron released from the weathered silicate minerals into iron–organic complexes) are virtually undifferentiated by the separate soil horizons because of the very low thickness of the soil profiles. These soils have the Oao–BHFao–M profile; it is suggested that they can be classified as leptic podburs. An admixture of morainic material containing phyllosilicate minerals favors a more pronounced differentiation of the modern pedogenic processes by separate soil horizons even in the case of shallow soil profiles; the intense transformation of phyllosilicates takes place in the soils.

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INTRODUCTION

Pedogenesis on hard rocks is one of the fundamental problems of pedology. In Russian pedology, the study of pedogenesis on hard rocks has a long history, beginning from the pioneering study of soil on the walls of the Staroladozhskaya Fortress by Dokuchaev. Investigations into this problem include several important aspects: (1) regularities of the initial soil formation and the development of fragmentary soils [4], (2) transformation of the mineralogical composition of soils [2, 3, 6, 8, 12, 17], and (3) the role of lichens and other types of plants in the transformation of hard rocks [10, 15, 21–24]. It is shown that the direction of pedogenesis on hard crystalline rocks is specified by the rock composition and its susceptibility to weathering processes; the character of the mineral matrix and the degree of its enrichment in phyllosilicates are important factors [2, 16, 18].

Shallow stony soils underlain by hard bedrock—Leptosols—represent the most widespread soil group in the world; their area reaches 1655 million hectares [26]. Despite the great theoretical and practical significance of these soils, a number of problems concerning their properties, genesis, and classification position remain unsolved: (1) the geographic and ecological (dependent on the climate and the character of hard rocks) regularities of the morphology and composition of these soils have yet to be formulated; (2) data on the rates of fine earth formation from hard rocks are very discrepant (for example, the rates of sandstone weathering reported for a given territory in Spain differ by more than five times: from 1.6 to 8.4 mm/100 years [25]); (3) the allochthonous or autochthonous nature of the thin loose layer covering hard rock is not always clear, though this is the key question that should be solved in order to judge the mechanisms and rates of the fine earth formation; and (4) the development of the new classification system of Russian soils [11], in which the diagnostics and taxonomy of soils on hard rocks are considered in detail, requires reexamination of the previously and newly studied soils on hard rocks in order to determine their classification position.

In order to solve these and other problems of the genesis, geography, and classification of soils on hard rocks, it is necessary to accumulate and analyze the particular data on these soils developing from rocks of different composition in different parts of the world.

We studied the morphological, chemical, and mineralogical properties of very shallow soils on alkaline and basic rocks: nepheline syenites, amphibolites, and metamorphized gabbro-diabases in the mountainous tundra and taiga zones of the northwest of Russia (within the Kola Peninsula and the Republic of Karelia). The character of pedogenesis and weathering in these soils are considered, and their classification position is discussed. Our study was specially focused on the rocks that occupy relatively small areas in the northwest of Russia in order to diagnose the possible admixture of allochthonous moraine material with a distinct predominance of derivatives of granites.

OBJECTS AND METHODS

Soils on hard basic and alkaline crystalline rocks represented by nepheline syenites in the mountainous tundra of the Kola Peninsula, tectonites (rocks from the fault zone) composed of amphibolite in the northern taiga zone of the Kola Peninsula, and metamorphized gabbro-diabases in the middle taiga zone (the Kivach Nature Reserve in the Republic of Karelia) were investigated. We studied both the soils in which the fine earth is derived only from the underlying hard rock and the soils in which the fine earth contains an admixture of allochthonous moraine material.

In order to find "pure" variants of the fine earth formation and pedogenesis on the hard rocks, the methods of regular area sampling and sampling along soil microcatenas were used. The indexation of the soil horizons was given according to the new classification and diagnostic system of Russian soils [11]. The soil physicochemical properties were determined by routine methods [1]. The nonsilicate iron was determined in the dithionite extract according to the Mehra–Jackson procedure, the amorphous and poorly crystallized iron compounds were determined in the oxalate extract (according to Tamm), and iron compounds bound with the organic matter were determined in the pyrophosphate extract (according to Bascomb) [5]. The group and fractional composition of the humus was determined by the method of Ponomareva and Plotnikova. The organic matter contents in the extracts were determined by the wet (dichromate) combustion method (according to Tyurin), and the total content of organic carbon was determined using a Vario EL III element analyzer.

To verify the presence (or absence) of the allochthonous material in the substrate and to trace the character of the pedogenic changes in the minerals, the mineralogical studies of the hard rock, coarse rock fragments, and the soil fine earth were performed separately. The mineralogical composition of the hard rocks was studied in petrographic thin sections with the use of optical microscopes (Polam P-312 and Zeiss Axioplan 2). The mineralogical composition of the sand fractions was studied using the method of mineral separation in heavy liquids (bromoform with a specific weight of 2.9 g/cm^3 was used). The qualitative mineralogical composition of the clay minerals was studied by X-ray diffraction in oriented samples prepared from the clay (<0.001 mm) and silt (0.001–0.005 and 0.005–0.01 mm) fractions. The separation of the clay and silt fractions from the soil was performed using the Gorbunov procedure after the preliminary treatment of the soil with Mehra–Jackson reagent. X-ray studies were performed on a Dron 2 diffractometer with a monochromator and a cobalt anode.

RESULTS AND DISCUSSION

Soil Position in the Local Soilscapes and Soil Morphology

Mountainous dwarf shrub–lichen tundra. The studied plot is found in the Vud'yavriok Creek valley (67°40.532′N, 33°39.316′E) at 430 m a.s.l. Huge (1–2 m in diameter) blocks of nepheline syenite are elevated above the surface and are subjected to intense weathering. The products of rock weathering are accumulated at the foot of the blocks, so that the old strongly weathered material of loamy texture is buried under the freshly accumulated gravelly sandy material. As a result, an accumulative profile of the fine earth is formed, in which relatively fresh and coarse-textured material is found on the top. The products of the rock weathering are also accumulated in small cavities on the upper surface of the rock blocks. In this case, the most strongly weathered material is found on the top. The side walls of the blocks are overgrown with bearberry (*Arctostaphyllos uva-ursi*), crowberry (*Empetrum hermaphroditum*), and lichens (*Cladonia* spp. and *Cetraria nivalis*), under which the gravelly material is accumulated. The fine earth accumulations derived exceptionally from the rock blocks are only present in the nearest zone around the blocks. At some distance from them, the surface layer is composed of the allochthonous moraine material. The vegetation growing on the surface of the soils developed from the moraine is represented by dwarf birch (*Betula nana*), crowberry (*Empetrum hermaphroditum*), and mountain cranberry (*Vaccinium vitis-idaea*) covering about 50% of the surface and the lichens *Cladonia stellaris*; *Cetraria islandica*; and, in some places, *Cetraria nivalis* and *Cladonia arbuscula.* Thus, the soils developed from the hard rocks and from the pure products of their destruction occupy very small areas in the investigated tundra landscape and neighbor barren rock outcrops and the predominant soils developed from the moraine.

Pits X-05-1a and X-05-1b represent soils developed from the local accumulations of the fine earth material immediately near the blocks. These pits were made on the southern side a large rock block, on the fan of the fine gravelly material at distances of 80 cm (pit X-05-1a) and 40 cm from the rock block (X-05-1b).

The following horizons were described in pit X-05-1a.

Oaomr, 0–4 cm. A mixture of the fine gravelly material derived from the nepheline syenite and fragments of the litter and raw-humus horizons of dark gray color with brownish tint (7.5YR 2.5/2); slightly dry; abundant slightly decomposed plant remains; smooth boundary.

BHFao, 4–10 cm. Dark brown (coffee-colored) (5YR 2.5/2), slightly wet, loamy sandy to loamy material; structureless; abundant living roots and root debris of different degrees of decomposition; the gravelly material is absent; the horizon is underlain by the solid surface of nepheline syenite.

M. Smooth massive nepheline syenite; fissures and cavities on the surface are absent.

The soil horizonation in pit X-05-1b is the same: Oaomr–BHFao–M.

Pit X-05-1c was studied on the surface of the same block of nepheline syenite, on its northern side. The roughness of the block surface and the presences of numerous cavities on it favor the accumulation of the product of rock weathering in the cavities. The in situ pedogenesis in the cavities results in the development of a similar soil profile (Oao–BHFao–M), in which, however, the most strongly weathered material is found in the uppermost horizon. A characteristic feature of the studied soil profiles is the presence of a thin peaty litter horizon (O) with fragments of a raw-humus horizon (ao) underlain by a horizon bearing the properties of both the raw-humus horizon and the illuvial Al–Fe-humus (BHF) horizon. According to the system of horizon indexation accepted in [11], this horizon should be designated as the BHFao horizon. The classification position of these soils is to be discussed later.

Within the main surface around large boulders (blocks) of nepheline syenite, podzols are developed from the moraine material with some admixture of the material derived from the nepheline syenite. A profile of a humus-illuvial podzol was described in pit X-05-2 located 10 m to the south of pit X-05-1a in a closed microlow. The soil profile had the following horizonation: litter (7–0 cm)–Oao (0–3 cm)–E (3–5 cm)–BF (5–7 cm)–BHF (7–15 cm)–BC(f) (15–35 cm)–IIBC (35–43 cm). Upslope from this pit, a separate E horizon was not diagnosed in the soil profile; the eluviation features were only seen in the weak bleaching of the mineral material above the BHF horizon. The latter soil profile was classified as a podzolized podbur developed from the moraine deposits.

N o r t h e r n t a i g a . Blocky outcrops of tectonites were studied to the south of the Khibiny Mountains within the northern taiga zone (67°32.65′N, 33°46.08′E). The tectonites of mafic composition were formed from amphibolites. The height of the blocks reached 5 m, and their width was about 10 m. The rock surface was covered by cushions of *Cladonia* lichens: *C. arbuscula*, *C. uncialis,* and *C. stellaris.* Mosses (*Polytrichum commune*) were in the depressed state; sparse birch (*Betula pubescens*), mountain ash (*Sorbus aucuparia*), and spruce (*Picea obovata*) trees grew among the lichen cushions. Fine earth accumulated in the microlows and small cavities in the rock; the thickness of the fine earth layer in them was up to 10 cm. Along the periphery of the blocks, it reached 30–40 cm; in this case, the fine earth contained some admixture of the moraine material. The plant cover at such places differed from that on the surface of the amphibolite blocks in the greater number of birch, spruce, and aspen trees and the better development of mosses, herbs, and dwarf shrubs. As well as in the case with nepheline syenites, the areas of soils on pure derivatives of amphibolites were very small; soils developed from the moraine deposits predominated in the soil cover.

Pit X-05-3a was studied on the top of a large block of amphibolite. The soil profile consisted of the Oao–BHFao–M horizons.

Oao, 0–2 cm. Dark gray (5Y 2.5/1), moist, with abundant roots and pebbles of amphibolite covered by dark brown films; smooth boundary.

BHFao, 2–6 cm. Brown (5YR 2.5/2), evenly colored, slightly dry; abundant pebbles; the light loamy fine earth material has a relatively loose crumb structure; abundant living roots and root remains of different degrees of decomposition; the horizon is underlain by the massive amphibolite bedrock; rock fragments in the soil profile are covered by brown films.

M. The rock surface is dissected by small fissures; the fine earth and gravelly material is accumulated in the cavities.

An admixture of the moraine material results in some bleaching of the uppermost horizon (above the BFHao horizon); in this case, the soil profile has the following horizonation: litter (+1–0 cm)–Oao (0–2 cm)–Oaoe (2–6 cm)–BHFao (6–13 cm)–M (the amphibolite bedrock covered by fissures and cavities). Such a soil was studied in pit X-05-3b three meters to the east of the previous pit in a microlow serving as a trap for the material washed off from the top of a rock block. Upon further increase in the content of the moraine material, a profile of a podzol is formed (pit X-05-3c). The latter profile was studied on a local elevation near a large block of amphibolite. The soil fine earth contained a considerable admixture of the moraine material. The soil profile consisted of the following horizons: litter (+4–0 cm)–E (0–4 cm)–BF (4–22 cm)–M (brittle surface of the massive amphibolite bedrock).

M i d d l e t a i g a . In the middle taiga zone of Karelia, outcrops of hard rocks occupy larger areas; they are represented by metamorphized gabbro diabases that compose local residual ridges (selgas). A small ridge has been studied in the southeastern part of the Kivach Reserve (southwest of parcel 41; 62°15.195′N, 33°57.278′E). The ridge is covered with lichens (*Cla-*

donia uncialis with an admixture (3–5%) of *C. arbuscula*). There are also barren spots on the surface. The accumulation of fine earth derived from the gabbro diabase takes place in the rock fissures and cavities, as well as in the case of amphibolite weathering. The thickness of the fine earth layer near the huge rock blocks reaches 20–40 cm; it lies on top of the massive bedrock. The admixture of moraine material in this fine earth is very low. A pine stand grows on the ridge; the age of the pine trees is about 70 years; some trees are older (up to 100 years). Spruce and birch trees are found in the second story. Mountain cranberry, bilberry, and green mosses (*Pleurozium schreberi* and *Hylocomium splendens*) compose the ground cover. Pit K-04-04 characterizes the soil on the top of the ridge.

Litter, +1–0 cm. Thalli of lichens with well-preserved morphology.

Oaoe, 0–3 cm. Brownish gray (7.5YR 2.5/2), slightly dry, slightly compacted material; loose crumb structure; loamy sand to light loam (the presence of considerable amounts of organic matter hampers the determination of the texture); bleached light-colored grains are seen in the mineral mass, and their amount increases near the lower boundary: a thin (1–3 mm) bleached interlayer is formed; darker loci densely penetrated by roots are also seen near the lower boundary; the transition is clearly seen by differences in the soil color; abrupt boundary.

BHFao, 3–6 cm. Brown to dark reddish brown (5YR 3/3), slightly dry, moderately compacted loamy sand to light loam; fine crumb structure; penetrated by roots; the upper part of the underlying bedrock is brittle (can be crushed with a knife); below, the massive bedrock is found.

M. Massive bedrock; the surface is covered by a network of fissures.

Pit K-04-09 characterizes a soil developed from the fine earth derivatives of metamorphized gabbro diabases underlain by the massive bedrock of the same composition. The soil profile consists of the following horizons: litter (+4–0 cm)–Oao (0–4 cm)–BHF (4–10 cm)–BC(hf) (10–28 cm)–M. This soil can be classified as a podbur. It was described 1.5 km to the northeast of pit K-04-04 (parcel 43, upper part of a low ridge). There are also soils developed in the fissures dissecting the massive bedrock. In these soils, the BHF horizon is found immediately under the litter (litter–BHFao–M) [13]. In general, very thin soils (2–3 cm) predominate on the surface of stony ridges. These soils consist of the peaty litter horizon (Oao) underlain by the massive bedrock (M); slightly decomposed plant remains predominate in the Oao horizon. According to [11], these soils (Oao–M) are classified as petrozems. A profile of a typical petrozem has been described in pit K-04-06 on the top of a stony ridge 2.5 km to the north-northeast of pit K-04-04 (on a rise between parcels 32 and 33). The ridge was surrounded by a green moss spruce stand. The ridge surface was covered by lichens (*Cladonia*) and mosses (*Hylocomium splendens*, *Pleurozium schreberi*).

Litter, +8–0 cm. Dark gray, with brownish tint; slightly wet; densely penetrated by roots of mosses and dwarf shrubs.

Oao, 0–2 cm. Grayish brown, wet; abundant smeary organic material; some loci have a light gray-brown color; densely penetrated by roots; contains rock fragments covered by dark reddish brown films.

M. Massive bedrock with rough fissured surface.

Analytical Characterization of Soils

Mountainous tundra. All the studied soils are acid raw-humus soils; the loss on ignition in the organic horizons reaches 50–60% (Table 1). A considerable portion of organic carbon is extracted by pyrophosphate from the BHF horizon of the podzol and, especially, from the BHFao horizon of shallow leptic podburs developed from the nepheline syenite. In the BHFao horizons of the podburs, the ratio between humic and fulvic acids is close to 1.0, whereas, in the BHF horizon of the podzol (pit X-05-2), the portion of fulvic acids is much higher. Humic substances form complexes with iron compounds, which is seen from the very high portion (up to 100%) of the pyrophosphate-extractable iron (according to the Bascomb method) in the oxalate-extractable iron. In comparison with the podburs developed from the pure derivative of nepheline syenite, the fine earth material of the podzol (developed from the mixture of the allochthonous moraine material and the products of syenite weathering) has a somewhat coarser texture. In the soils developed from the nepheline syenite, the amount of oxalate-extractable aluminum is higher than the amount of oxalate-extractable iron [14]. Differentiation of dithionite- and oxalate-extractable iron compounds in the soil profile is only seen in the leptic podbur developed from the fine earth accumulated under a stony block: their contents increase in the BHFao horizon composed of the more strongly weathered material in comparison with the uppermost horizon (Table 2). The content of aluminum increases, and the contents of silicon and potassium decrease in this horizon, which is related to the weathering of nepheline and other weatherable minerals and the accumulation of the silty and clayey material. As judged from the relative contents of aluminum, silicon, and potassium, the most strongly weathered material is found in the BHFao horizon of the soil near the stony block. In the in situ soil on the top of the block, the loss of iron from the upper horizon is due to the eluviation of organomineral compounds into the BHFao horizon. The increased content of calcium in the upper horizons of all three soil profiles is conditioned by the biogenic accumulation of this element.

Table 1. Some properties of the studied soils

Horizon	Depth, cm	pH_{H_2O}	$\frac{C,\%}{Cp,\%}$	C ha/C fa	LI, %	Contents of fractions (mm), %		Fe_2O_3d	Fe_2O_3o	Fe_2O_3p	Al_2O_3o
						<0.001	<0.01	% of the soil mass			
Soils of the tundra zone											
Gravelly laterally accumulative leptic podbur, pit X-05-1b											
Oaomr	0–6	4.6	34.1/4.6	0.85	49.76	–	–	0.43	0.29	0.23	2.55
BHFao	6–12	5.4	21.8/14.4	0.96	–	8.3	27.4	0.89	0.72	0.67	11.24
Raw-humus leptic podbur, pit X-05-1c											
Oao	0–4	4.9	–/4.6	–	54.07	–	–	0.61	0.34	0.16	2.25
BHFao	4–20	5.0	25.5/13.1	–	–	14.4	31.8	1.07	0.42	0.66	4.06
Iron-illuvial podzol, pit X-05-2											
Oao	0–3	4.4	36.5/4.2	1.68	62.47	–	–	0.64	0.31	0.41	0.47
E	3–5	4.6	2.9/0.4	–	–	5.5	16.7	0.49	0.28	0.32	0.20
BHF	7–15	5.3	9.9/7.5	0.27	–	5.4	12.6	1.79	1.56	0.75	7.55
BC(f)	15–35	5.4	–/2.1	–	–	5.4	15.3	0.55	0.50	0.22	7.61
IIBC	35–43	5.6	1.7/1.0	–	–	6.0	21.1	0.58	0.22	0.12	5.63
Soils of the northern taiga zone											
Raw-humus leptic podbur, pit X-05-3a											
Oao	0–2	4.4	32.0/4.5	1.51	44.79	–	–	1.09	0.74	0.70	0.41
BHFao	2–6	4.5	7.6/2.3	0.76	–	9.7	29.1	1.07	0.48	0.50	0.26
Podzolized leptic podbur, pit X-05-3b											
Oao	1–2	4.6	19.9/3.0	0.85	45.11	–	–	0.59	0.33	0.41	0.32
Oaoe	2–6	4.5	4.6/1.0	–	9.57	3.9	12.0	0.54	0.43	0.31	0.20
BHFao	6–13	4.6	1.6/0.9	0.24	–	3.9	9.9	1.14	1.01	0.64	0.43
Iron-illuvial podzol, pit X-05-3c											
E	0–4	4.6	2.1/0.2	–	–	3.8	11.4	0.21	0.19	0.16	0.06
BF	4–22	4.8	3.7/1.9	0.19	–	4.7	11.3	4.06	2.56	0.66	3.47
Soils of the middle taiga											
Raw-humus leptic podbur, pit K-04-04											
Oaoe	0–3	4.2	10.0/3.5	–	28.9	–	–	1.83	0.94	0.68	0.62
BHFao	3–6	4.4	5.4/2.2	0.92	17.2	10.9	34.8	2.27	0.88	0.66	0.72
Typical podbur, pit K-04-09											
BHF	4–10	4.6	–/1.5	–	–	4.8	12.7	2.20	1.07	0.44	0.74
BC(hf)	10–28	4.8	–/0.8	–	–	3.5	10.0	1.99	0.76	0.30	1.07
Raw-humus petrozem, pit K-04-06											
Oao	0–2	4.0	14.4/4.3	–	50.54	–	–	2.09	0.92	0.92	0.51

Note: Here and in the other tables, the following abbreviations are used: C, total organic carbon; Cp, carbon extracted by pyrophosphate; LI, loss on ignition; contents of sesquioxides (t—total, d—extracted by dithionite, o—extracted by oxalate, and p—extracted by pyrophosphate). Dashes designate the absence of determinations.

It should be noted that the soils studied by us differ from the earlier described soils on the colluvium of nepheline syenite [14] in the higher degree of weathering of the fine earth material, which can be judged from the lower content of silicon, higher content of aluminum, and the high contents of oxalate-extractable (amorphous) and pyrophosphate-extractable (bound with organic matter) iron compounds.

The profile of the podzol is clearly differentiated with respect to its bulk elemental composition. The total aluminum content in the upper horizons (Oao to BF) is 10% lower than in the lower part of the profile,

Table 2. Bulk contents of elements and ratios between different forms of iron and aluminum compounds

Horizon	Depth, cm	SiO_2	Fe_2O_3	Al_2O_3	K_2O	CaO	MgO	TiO_2	Al_2O_3o/Al_2O_3t	Fe_2O_3d/Fe_2O_3t	Fe_2O_3o/Fe_2O_3d
		% of calcined sample									%
Soils of the tundra zone											
Gravelly laterally accumulative leptic podbur, pit X-05-1a											
Oaomr	0–4	48.55	4.89	32.48	2.53	4.45	0.99	0.89	–	–	–
BHFao	4–10	40.03	3.64	47.86	1.05	0.67	1.84	0.62	–	–	–
Gravelly laterally accumulative leptic podbur, pit X-05-1b											
Oaomr	0–6	49.21	4.42	29.39	2.28	4.34	1.47	1.16	13.2	14.7	67.4
BHFao	6–12	37.74	4.80	46.14	1.50	1.33	2.27	0.91	35.0	26.7	80.9
Raw-humus leptic podbur, pit X-05-1c											
Oao	0–4	51.26	3.77	30.13	2.10	4.22	0.76	1.08	11.3	24.4	55.7
BHFao	4–20	49.03	7.04	30.29	5.53	0.99	1.11	1.85	20.4	23.1	39.2
Humus-illuvial podzol, pit X-05-2											
Oao	0–3	61.49	5.22	17.46	3.47	4.84	1.16	2.22	4.3	19.9	48.4
E	3–5	71.24	4.53	13.06	3.85	2.06	1.19	1.88	1.6	11.3	57.1
BF	5–7	61.39	11.85	15.37	2.93	2.73	1.85	1.59	–	–	–
BHF	7–15	51.29	8.65	29.23	2.36	2.72	1.72	1.20	33.6	26.9	87.1
BC(f)	15–35	56.52	6.04	25.97	2.63	3.01	2.36	0.98	34.0	10.4	90.9
IIBC	35–43	58.84	6.48	22.45	2.59	3.15	2.72	0.99	28.3	10.0	37.9
Soils of the northern taiga											
Raw-humus leptic podbur, pit X-05-3a											
Oao	0–2	61.44	10.32	11.30	0.67	8.43	1.62	2.93	5.3	15.4	67.9
BHFao	2–6	61.44	11.39	11.96	0.30	8.01	2.17	2.75	2.5	10.8	44.8
M	6–↓	54.76	17.23	12.04	0.12	10.57	2.87	1.26	–	–	–
Podzolized leptic podbur, pit X-05-3b											
Oao	1–2	62.27	7.30	15.55	1.28	5.84	1.21	2.90	3.0	11.8	55.9
Oaoe	2–6	68.66	6.89	11.68	0.39	6.59	1.56	2.00	1.9	8.5	79.6
BHFao	6–13	58.09	16.06	13.04	0.70	5.62	2.46	2.58	3.6	7.7	88.6
Iron-illuvial podzol, pit X-05-3c											
E	0–4	73.94	3.62	12.76	1.48	3.10	1.50	0.96	0.5	6.0	90.5
BF	4–22	55.46	12.64	20.80	1.14	3.39	1.70	1.25	18.8	36.3	63.0
Soils of the middle taiga											
Raw-humus leptic podbur, pit K-04-04											
Oaoe	0–3	67.95	7.57	14.44	0.50	4.85	1.77	1.69	5.0	28.3	51.4
BHFao	3–6	67.87	8.36	12.36	0.45	5.14	2.29	1.66	6.3	29.7	38.7
M	6–↓	60.65	9.92	11.43	0.27	8.80	5.40	1.10	–	–	–
Typical podbur, pit K-04-09											
BHF	4–10	67.98	8.13	15.31	1.07	2.77	2.07	1.25	5.3	30.4	48.6
BC(hf)	10–28	64.06	7.57	17.32	1.23	2.75	3.24	1.33	7.3	32.5	38.2
Raw-humus petrozem, pit K-04-06											
Oao	0–2	61.74	9.93	12.93	1.08	7.36	1.54	2.65	5.9	31.5	44.0
M	2–↓	63.06	11.19	13.32	0.18	6.19	2.94	1.98	–	–	–

in which the portion of the oxalate-extractable aluminum reaches 30% of the total aluminum. Considerable differences in the total contents of this element point to the difference in the sources of the fine earth material. In the upper horizons (Oao–BF), the allochthonous moraine material predominates; in the lower horizons, the fine earth mainly consists of the products of weathering of the nepheline syenite. The distribution of nonsilicate iron compounds has an eluvial–illuvial pattern typical of Al–Fe-humus soils.

N o r t h e r n   t a i g a. In the soils developed from the derivatives of amphibolites in the northern taiga zone, as well as in the soils developed from nepheline syenite in the tundra zone, the soil texture is somewhat coarser and the degree of differentiation of the soil profile is stronger in the profiles with a greater thickness of the fine earth material. The organic carbon content is high, particularly in pit X-05-3a, including the BHFao horizon of this soil, which may be due to the location of this pit in a microlow on the surface of the amphibolite block. The continuous moss–lichen cover and the shallow embedding by the hard crystalline rock create a trap for the organic substances leached off from the surface litter. These substances are sorbed on the loose products of the rock weathering filling the fissures and cavities on the surface.

With respect to the bulk content of silicon oxides, the amphibolite rock belongs to the group of basic rocks (Table 2). The fine earth material derived from the amphibolite (even in the case of the absence of allochthonous admixtures, as in pit X-05-3a) differs from the initial rock in the higher content of silica and lower contents of iron and calcium; the SiO_2 content in the fine earth corresponds to the intermediate rock. With an admixture of moraine material, the SiO_2 content in the fine earth increases, and the soil profile differentiation becomes more pronounced. In pit X-05-3a, iron is not removed beyond the soil profile; in this soil, the portion of nonsilicate iron (extracted by dithionite) in the Oao horizon is increased. In pit X-05-3b, the dithionite-extractable iron also tends to accumulate in the Oao horizon; at the same time, this horizon is impoverished in oxalate-extractable iron. In the podzol, the redistribution of nonsilicate iron compounds is well pronounced. In the E horizon, about 90% of the nonsilicate iron is represented the oxalate-extractable (amorphous) iron. The processes of transformation of the organic matter and iron-bearing minerals take place in different soil horizons. Thus, in pit X-05-3a, the oxalate-extractable (amorphous) iron is mainly represented by the iron–organic compounds. In pits X-05-3b and, especially, X-05-3c (in the podzol), a considerable part of the amorphous iron compounds is not bound with the organic matter.

M i d d l e   t a i g a. Strongly acid soils are developed from the hard bedrock. Though the loss on ignition in these soils is considerable, it is generally lower (except for the petrozem) than that in the studied tundra and northern taiga soils. The content of amorphous iron compounds is approximately equal to the content of organic-bound (pyrophosphate-extractable) iron compounds. With an increase in the thickness of the soil horizons (pit K-04-09), the accumulation of crystallized nonsilicate iron compounds becomes more pronounced. Data on the bulk chemical composition of the fine earth from the studied pits attest to the homogeneity of the initial material (Table 2). The soils are characterized by high contents of iron, magnesium, and titanium. In a thicker profile of a typical podbur (pit K-04-09), the presence of moraine admixtures is seen in the lower content of calcium, which may be due to the admixture of stable K–Na feldspars. In contrast to the soils developed from the nepheline syenite and amphibolite, the accumulation of the local material derived from the gabbro diabase is sufficient for the development of a relatively thick soil.

Mineralogical Composition

M o u n t a i n o u s   t u n d r a. In the fragments of nepheline syenite, the presence of nepheline, potassium feldspars, sodic pyroxene (aegirine), and alkaline amphibole (riebeckite) is detected; also, minerals of the astrophyllite–lamprophyllite group (nesosilicates typical of the alkaline rocks) and sphene (a nesosilicate typical of nepheline syenite in which it may form concentrations) are present (Fig. 1a). The analysis of sand fractions from the BHFao horizon (pit X-05-1a) has not shown the presence of any allochthonous admixture (Table 3). In the heavy fraction, nepheline is represented by massive concentrations of xenomorphic grains with a bright orange-red color. In the light fraction, potassium feldspars predominate. The presence of hydrobiotite in the coarse fractions should be noted. As shown by Dobrovol'skii [9], the micaceous group of nepheline syenite is often found in the Kola Peninsula.

In the clay and silt fractions of soils developed from the nepheline syenite, the amorphous phase is diagnosed by the maximum peak at 20°–30° (2θ). The swelling labile mineral phase (the smectitic phase) is only present in the clay fraction from the BHFao horizon of the pit made at some distance from the bedrock block (pit X-05-1a). This phase is absent in the fine silt fraction from the same horizon; it is also absent in the material of the peaty litter horizon (Fig. 2a). The appearance of smectitic minerals in the most strongly weathered material is explained by the degradation of the hydrobiotite found in the sand fractions. In other words, the formation of the silt and clay fractions in the soils is mainly due to comminution and dissolution of minerals from the coarser fractions. These processes result in the accumulation of the X-ray-amorphous mineral phase in the clay and fine silt fractions. The presence of smectitic minerals is indicative of the great degree of mineral weathering.

The pebbly material from the upper part (the E and BF horizons) of the podzol (pit X-05-2) belongs to the

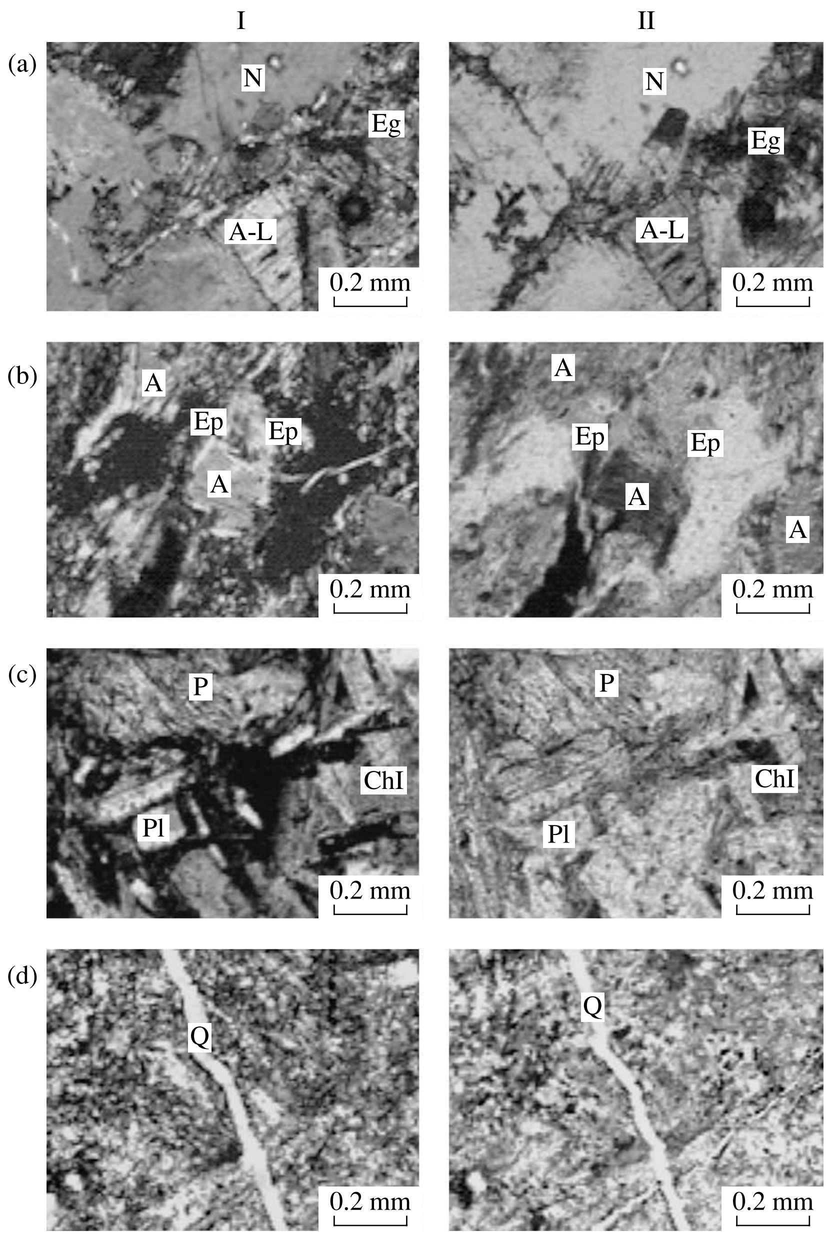

Fig. 1. Photos of thin sections (I—crossed nicols, II—parallel nicols): (a) nepheline syenite, (b) amphibolite, (c) relicts of the ophitic (diabase) structure in the metamorphized gabbro diabase, (d) quartz-filled veins in the metamorphized gabbro diabase. Designations: (N) nepheline, (Eg) aegirine, (A–L) minerals of the astrophyllite–lamprophyllite group, (A) amphibole, (Ep) epidote, (P) pyroxene, (Pl) plagioclase, (Chl) chlorite, and (Q) quartz.

epidote–amphibole–biotitic gneiss rock. Its mineralogical composition differs from that of nepheline syenite and is characterized by the increased contents of quartz and plagioclase minerals. The presence of allochthonous pebbles in the upper part of this soil explains the revealed differences in the bulk elemental composition and the contents of oxalate-extractable aluminum between the upper and lower horizons.

The mineralogical composition of sandy fractions from the BHF horizon of the podzol also differs from that of the BHF horizon of the podburs developed from the pure derivatives of nepheline syenite. In the heavy fraction, nepheline is absent, the content of amphiboles (hornblende and actinolite) is increased, and the content of pyroxenes (diopside and augite) is decreased. Garnet (almandine), metallogenic minerals, epidote, and biotite are present. In the light fraction, quartz minerals inherited from the gneiss rock predominate. Micas predominate in the silty fractions from the podzolic (E) horizon; in the clay fraction, the portion of mixed-layered poorly ordered chlorite–vermiculite (the product of degradation of chlorites) increases, and the portion of fine-dispersed quartz decreases. X-ray diffraction

Table 3. Mineralogical composition of soils and bedrocks

Pit no., bedrock (M); minerals, %	Fractions			
	sand		silt (medium and fine)	clay
	heavy	light		
X-05-1a; nepheline syenite: nepheline, potassium feldspar, aegirine, riebeckite, minerals of the astrophyllite–lamprophyllite group, sphene, and metallogenic minerals	BHFao: pyroxenes (36), nepheline (28), amphiboles (25), and sphene (11)	Orthoclase and microcline (92) and hydrobiotite (8)	Oaomr: amorphous material BHFao: Amorphous material	Amorphous material and smectitic phase
X-05-2; epidote–amphibole–biotitic gneiss (pebble from the E horizon): quartz + plagioclases (70–75), biotite (15), hornblende (5), epidote (5); sphene, metallogenic minerals, and apatite (~1)	BHF: amphiboles (47), pyroxenes (20), garnet (7), metallogenic minerals (3), epidote (11), biotite (3), and sphene (9)	Quartz (67), feldspars (28), and hydrobiotite (5)	E: micas, chlorite, kaolinite, mixed-layered chlorite–vermiculite (smectitic), quartz, and amphibolite BHF: smectitic phase and mica	
X-05-3a; amphibolite: amphiboles (50–55), epidote (30–35), chlorite (3–5), metallogenic minerals (5–7), and quartz (5–7)	BHFao: rock fragments (71–74), amphiboles (19–11), epidote (up to 3), pyroxene, garnet, and metallogenic minerals	Quartz (53–67) and feldspars	Oao, BHFao: clay minerals are absent	
X-05-3b; pebble: leucocratic binary plagioclase–microcline granite	BHFao: amphiboles (88), pyroxenes, sphene, garnet, biotite, zircon, and rutile	Quartz (44), feldspars (41), and hydrobiotite (15)	Oaoe, BHFao: clay minerals are absent	Oaoe: smectitic phase and quartz BHFao: phyllosilicates are absent; quartz
X-05-3c; leucocratic binary plagioclase–microcline granite (pebble from the E horizon): microcline (60–65), quartz (20–30), plagioclases (7–10), muscovite and biotite (1–3)	E: hornblende (40–50), pyroxenes (12), garnet (13–17), epidote (9–17), sphene, metallogenic minerals, biotite, zircon, and rock fragments	Quartz (44), feldspars (48–55), and hydrobiotite (1–9)	E: Mica, chlorite, vermiculite, quartz, and amphibole	Smectitic phase, micas, quartz, and amphiboles
	BF: hornblende (45), pyroxenes (7–19), garnet (7–20), epidote (7–19), sphene, metallogenic minerals, biotite, and rock fragments	Quartz (51–62), feldspars (34–42), and hydrobiotite (4–7)	BF: Mica, chlorite, quartz, and amphibole	Micas
K-04-04; metamorphized gabbro diabase: plagioclase, clinopyroxene, amphiboles, biotite, epidote, sphene, and quartz	BHFao: monocline pyroxenes (72–77), metallogenic minerals (5–8), hornblende, epidote, and sphene	Quartz and feldspars	Oaoe and BHFao: mixed-layered chlorite–vermiculite, chlorite, micas, quartz, and amphibole	Oaoe: the same* + talc + kaolinite and vermiculite BHFao: the same* + talc and kaolinite

* Data on the silty fractions from the same horizon.

patterns obtained from the clay fraction in the lowermost horizons are similar to those from the BHFao horizon in pit X-05-1a (the peaks of clay minerals are relatively weak and indistinct). In general, the mineralogical effect of the admixture of gneiss-derived material is most pronounced in the E horizon.

N o r t h e r n t a i g a. The group of amphiboles in the composition of amphibolite rock fragments is represented by hornblende and actinolite. The metallogenic minerals are substituted for sphene, and quartz grains have a predominantly granoblastic texture (Fig. 1b). This set of minerals dictates the specificity of

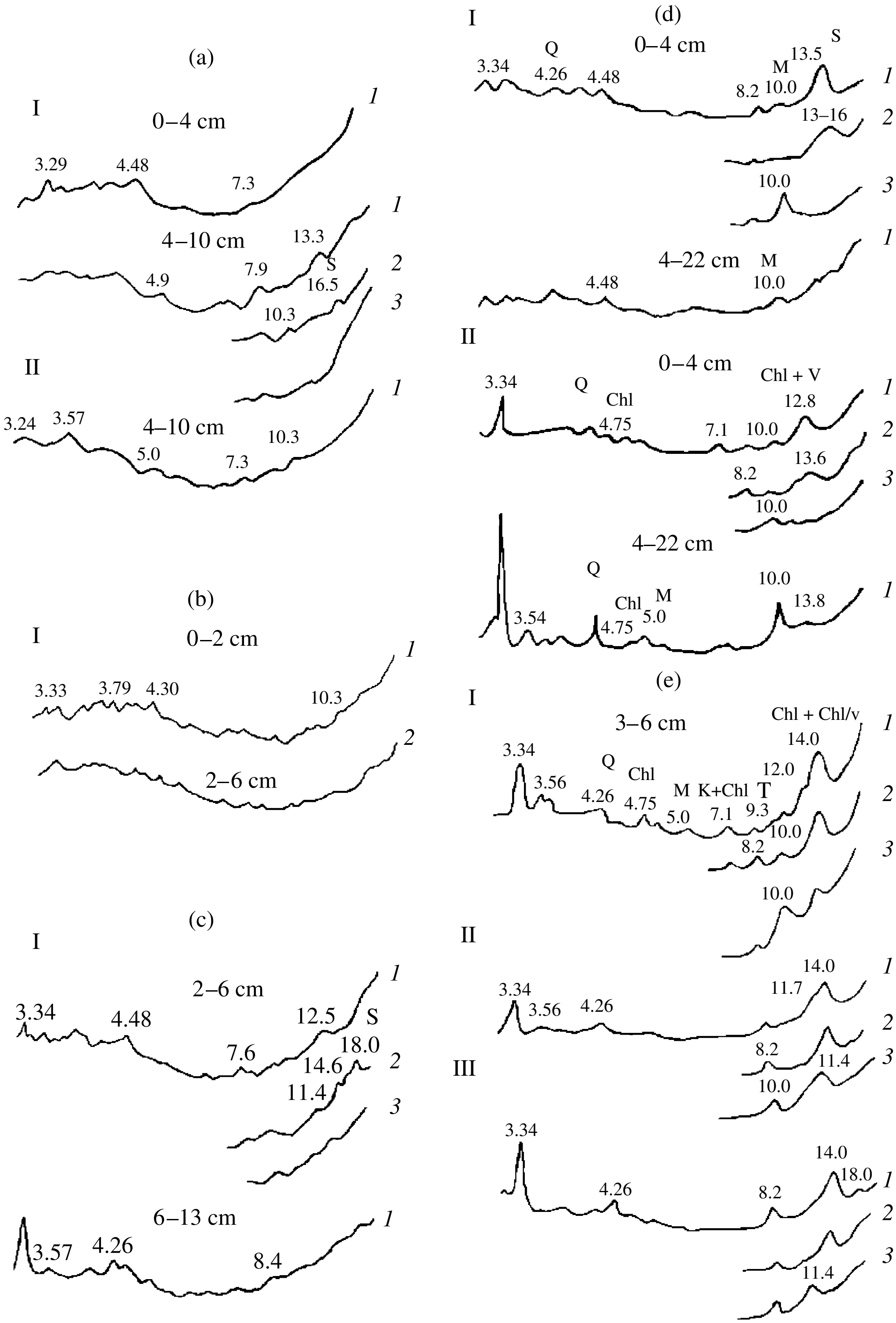

Fig. 2. X-ray diffraction curves obtained for (I) clay, (II) fine silt, and (III) medium silt fractions from (a) pit X-05-1a, (b) pit X-05-3a, (c) pit X-05-3b, (d) pit X-05-3c, and (e) pit K-04-04. Peak positions are indicated in Å. Designations: (S) swelling labile (smectitic) phase, (M) micas, (Chl) chlorite, (V) vermiculite, (K) kaolinite, (T) talc, (Chl/V) mixed-layered chlorite–smectite, and (Q) quartz; (*1*) Mg-saturated specimens, (*2*) specimens saturated with ethylene glycol, and (*3*) specimens heated at 550°C for 3 h.

the bulk elemental composition of the fine earth material: the high content of iron is due to the predominance of amphiboles, the high content of calcium is due to the presence of epidote, and the high content of titanium is due to the presence of sphene and rutile.

The group of amphiboles in the sandy fractions from the BHFao horizon of the soil developed from the amphibolite (pit X-05-3a) is represented by hornblende. Epidote grains are of lemon yellow and pale yellow color, they are short-prismatic, and their contents increase with a decrease in the sand fraction size. Pyroxenes are represented by diopside; garnets, by almandine; and metallogenic minerals, by magnetite and goethite. The mean weighted percentage of heavy minerals in the fractions of 1–0.25 and 0.25–0.01 mm is about 90%, which points to the low content of quartz (which is also low in the amphibolite) and feldspars (predominantly, plagioclases).

In the clay and fine silt fractions, the reflection peaks of phyllosilicates are virtually absent (Fig. 2b). Our results confirm the earlier obtained data on soil development from quartzless parent materials that do not contain phyllosilicates in significant amounts. In particular, such objects were studied by Chernyakhovskii [20] in the areas with diabases in Karelia. He demonstrated that the destruction of pyroxenes and plagioclases in these rocks is accompanied by the formation of brown-colored films, whereas phyllosilicates do not appear in the soil. The pebbly material from pits X-05-3b and X-05-3c is derived from the leucocratic binary plagioclase–microcline granite rather than from the amphibolite. Its secondary transformation involves chloritization (substitution of chlorite for biotite), sericitization (substitution of sericite for plagioclases), and weak iron plating along the subparallel fissures and on the surface of mineral grains.

In sandy fractions from the BHFao horizon of pit X-05-3b, amphiboles are represented by hornblende and a small amount of actinolite. In comparison with pit X-05-3a, the degree of comminution of the initial bedrock increases; amphibole grains are covered by iron films. Among pyroxenes, diopside and minerals of the aegirine–augite series are present; garnets are represented by almandine. In the light-weight fraction, feldspars are represented by microcline. In sandy fractions from the podzol (pit X-05-3c), the admixture of autochthonous material is seen in the lower portions of heavy minerals (16% in the E horizon and 25% in the BF horizon) and amphiboles. The portion of feldspars in the light-weight fraction increases with a decrease in the size of the sandy fractions.

In pit X-05-3b, the presence of smectitic minerals is only detected in the clay fraction from the Oaoe horizon; in the silt fraction from this horizon and in the silt and clay fractions from the BHFao horizon, phyllosilicates are absent (Fig. 2c). In the podzol, phyllosilicates are present in the silt fraction: micas predominate in the BF horizon, and vermiculite as the product of mica degradation is present in the E horizon. A much lower content of quartz in the E horizon in comparison with the BF horizon should be noted. In the clay fraction from the E horizon, the transformation of micas is more pronounced and leads to the appearance of smectitic minerals (Fig. 2d). The smectitic phase is accumulated in the E horizon, i.e., the rate of its formation exceeds the rate of its eluviation from this horizon. In the BF horizon, only mica is diagnosed among the clay minerals.

The prepedogenic and pedogenic transformation of amphibolites has not led to the accumulation of phyllosilicates in the parent material. The silt and clay fractions of the soil fine earth are formed due to a gradual comminution of coarser fractions. In the case of the admixture of moraine material containing phyllosilicates, the pedogenesis enhances the transformation of silicates in the podzolic horizon. The analysis of the mineralogical data confirms the conclusion about the lithogenic heterogeneity of the profile of the podzol.

Middle taiga. Relics of the ophitic and amygdaloidal structures are seen in the gabbro diabase rock: idiomorphic laths of plagioclase and relics of clinopyroxene point to the initially basic composition of the rock (Fig. 1c). Metamorphism and epigenetic transformation of the initial rock resulted in the predominance of amphiboles partly replaced by chlorite and in the appearance of quartz veins (Fig. 1c). According to the SiO_2 content, this rock belongs to the group of intermediate rocks. The high content of CaO and the low content of K_2O in the rock are due to the predominance of plagioclases among feldspars. The high content of titanium is due to the presence of sphene, and the high contents of magnesium and iron are due to the presence of magnesium–iron silicates. This rock is classified as a metamorphized gabbro diabase. In the sandy fractions from the BHFao horizon (pit K-04-04), the portion of hornblende increases from 3% in the coarse and medium sand fractions to 16% in the fine sand fraction.

In the silt and clay fractions separated from the soil (K-04-04), the presence of clay minerals derived from the parent material is detected. Mixed-layered chlorite–vermiculite predominates in these fractions; the degradation of chlorite takes place in the medium silt and finer fractions (Fig. 2e). In the clay fraction, as well as in the silty fractions, chlorite, micas, and kaolinite are present; in addition, talc is present in small amounts (it is diagnosed by a stable peak at 9.3 Å), and mixed-layered chlorite–vermiculite is detected. The portion of vermiculitic layers in the mixed-layered minerals increases in the peaty litter horizon. In the podbur (pit K-04-09), the mineralogical composition of the finest fractions is identical to that in pit K-04-04. Clay minerals are not differentiated in the profile of the podbur; however, its BC horizon is enriched in fine-dispersed quartz. The clay fraction of the petrozem (pit K-04-06) does not contain talc; the content of chlorite in it is very low, which points to the considerable transformation of this mineral in the peaty litter horizon.

In general, the results of the mineralogical analyses indicate that the reserves of phyllosilicates in the nepheline syenite and amphibolite are relatively low. The prepedogenic alteration of metamorphized gabbro diabases of Karelia resulted in a considerable accumulation of phyllosilicates in these rocks. Upon the rock weathering, phyllosilicates are released and accumulate in the silt and clay fractions of the soil fine earth. The degradation of micas and chlorite in the course of soil formation leads to the appearance of mixed-layered chlorite–vermiculite. In the case of more intense weathering and transformation of mafic rocks, the smectitic phase becomes predominate in the clay fraction, which has been demonstrated in the study of soils developed from gabbro diabases on Valaam Island [2].

Genesis of the Fine Earth Material and Pedogenesis on Hard Rocks

Our study has shown that quite different soils may develop from the hard rocks in the tundra and taiga zones. Petrozems with the O–M profile are the predominant type of soils. However, other types of shallow soils are also formed from the autochthonous products of the bedrock weathering (the autochthonous character of these products is proved by the consecutive mineralogical analysis of the rock fragments and sand, silt, and clay fractions). In these soils, the processes of rock disintegration, Al–Fe-humus migration, in situ transformation of the organic matter, and binding of iron compounds released from weathered silicates into iron–organic complexes take place simultaneously in all the mineral horizons of the thin soil profiles. In this case, the Al–Fe-humus pedogenesis is not accompanied by the considerable transformation of clay minerals in the silt and clay fractions. Thicker soil profiles are formed in the case when the allochthonous moraine material of the acid mineralogical composition is admixed with the autochthonous products of bedrock weathering (as in the mountainous tundra and northern taiga zones of the Kola Peninsula) or when the local weathering products are subjected to redistribution and accumulation in favorable geomorphic positions (as in the middle taiga zone of Karelia). In these soils, the processes of organic matter transformation, Al–Fe-humus migration, and mineral weathering are somewhat differentiated in the soil profiles, and a more complex system of genetic horizons is developed.

Different mechanisms of the fine earth formation can be distinguished in the studied objects. The fine earth formation from the metamorphized gabbro diabases in the middle taiga zone and from the amphibolites in the northern taiga zone proceeds very slowly. There are no buried organic horizons in the thin profiles of the products of weathering of these rocks. Thus, it can be supposed that no significant redistribution of the fine earth material on the surface of massive bedrocks took place in the Holocene. The following scheme of the fine earth accumulation can be suggested. Some part of the fine earth represents the products of the pre-Holocene rock weathering that were trapped in the cavities and fissures on the bedrock surface and were not denuded during the last glaciation. In the Holocene, vegetation settled, first of all, in these places with the initially accumulated fine earth, which provided plants with necessary nutrients. The settling of vegetation enhanced the biogenic impact on the rock due to both the biochemical action of the plants and the products of their decomposition and the mechanical action of the plant roots. Thus, the formation of the fine earth in the fissures and cavities was intensified. As for the massive bedrock surface between the fissures, it is subjected to a somewhat weaker action of lichens and mosses. The organic matter produced by these plants forms a film on the bedrock surface; this film may protect the rock from further decomposition. The possible retardation of the rock weathering and fine earth formation by the protective organic films on the rock surface has been discussed in [19]. It is probable that this mechanism is responsible for the observed discrepancy of data on the rate of hard rock disintegration under the impact of lichens (about 1–10 mm/100 years) and data on the much lower rate of the fine earth accumulation on the bedrock surface during the Holocene (<5–10 cm per 10000 years, or 0.5–1.0 mm/100 years). In general, the accumulation of the fine earth on the bedrock surface during the Holocene was very uneven. The predominant accumulation took place in the fissures and cavities that initially contained some amounts of the pre-Holocene fine earth material. The intensity of weathering processes in such fissures and cavities was higher than that on the main surface. Such a pattern of the bedrock disintegration and the fine earth accumulation can be referred to as a fractal pattern.

A different pattern of weathering processes is typical of the nepheline syenite bedrock in the tundra zone. This bedrock is more susceptible to weathering because of the high content of nepheline. Massive blocks of nepheline syenite are subjected to relatively intense destruction by the processes of physical disintegration and chemical weathering (dissolution of weatherable minerals). The products of weathering are accumulated in the cavities and fissures on the surface of the massive bedrock and at the foot of massive blocks of the bedrock elevated above the main surface. In the latter case, they may bury the organic horizons of the adjacent soils. The lower part of the thickness of the weathering products at the foot of massive rock blocks is strongly weathered and has a loamy texture. The upper part of this thickness consists of the relatively fresh weathering products of the coarser (gravelly sand) texture. In general, the weathering (disintegration) of nepheline syenite proceeds more evenly. It can be referred to as frontal disintegration. The same disintegration pattern is typical of the hard gypsiferous rocks [7].

Problems of Soil Classification

Despite the low thickness of the studied soil profiles, they bear morphologically distinct pedogenic features resulting from the accumulation and transformation of organic matter and the Al–Fe-humus migration. The analytical data also confirm the development of these processes. It is suggested that the middle horizon in the studied soil profiles can be distinguished as a specific organogenic Al–Fe-humus horizon BHFao. It differs from a typical Al–Fe-humus horizon (BHF) in the high content of organic remains, the high loss on ignition, and a somewhat higher C_{ha}/C_{fa} ratio. The soils with the O–BHFao–M profile can be classified as the type of leptic podburs (from Gr. *Leptos* (shallow)) and the subtype of raw-humus leptic podburs. These soils differ from typical podburs, as the O(AO) and BHF horizons in them are virtually superimposed on one another because of the very shallow profile. The soils described in pits X-05-1c, X-05-3a, and K-04-04 belong to the subtype of raw-humus leptic podburs; the soil described in pit X-05-3b (Oaoe–BHFao–M) belongs to the subtype of podzolized raw-humus leptic podburs.

At the same time, the soil developed from the colluvial gravelly loamy derivatives of the nepheline syenite (pit X-05-1a, Oaomr–BHFao–M) should be distinguished as a laterally accumulative gravelly leptic podbur, as this soil develops under conditions of the periodic input of fresh gravelly and fine earth material onto the soil surface from the adjacent block of nepheline syenite. However, we attribute this soil to the trunk of postlithogenic soils (to the type of leptic podburs), because the main features of the soil profile are formed by the normal pedogenesis (by the in situ transformation of the organic and mineral materials and the vertical migration of Al–Fe-humus compounds). The soils described in pits X-05-2 and X-05-3c are classified as humus-illuvial and iron-illuvial podzols, respectively; the soil of pit K-04-09, as a typical podbur; and the soil of pit K-04-06, as a raw-humus petrozem.

CONCLUSIONS

(1) Soils that develop from the derivatives of hard rocks in the mountainous tundra and in the northern and middle taiga zones of the northwest of European Russia under lichen or moss–lichen associations can be attributed to three soil groups: (1) petrozems with the O–M profile (the most common variant), (2) podzols and podzolized podburs developing from the substrates with an admixture of moraine material of acid composition, and (3) very shallow (<5–10 cm) pebbly soils developing from the pure products of bedrock weathering (without an admixture of allochthonous materials). The latter variant occupies minor areas. The recent pedogenic processes in these soils—disintegration of rock fragments, Al–Fe-humus migration, in situ transformation of the organic matter, and the binding of iron released from the weathered silicates into the iron–organic complexes—take place virtually in the same horizon because of the very low thickness of the soil profile. These soils with the Oao–BHFao–M profile can be distinguished as the subtype of raw-humus leptic podburs.

(2) The fine earth formation from the bedrock may proceed differently depending on the bedrock composition. In the case of nepheline syenites, the frontal disintegration of the bedrock takes place. In the case of amphibolites and metamorphized gabbro diabases, the fractal disintegration of the bedrock in fissures and cavities takes place. A positive feedback exists between the initial accumulation of the fine earth in the fissures and cavities, the predominant development of plant roots in these zones, and the enhanced biological and biochemical weathering in them. The formation of fine earth fractions is due to comminution and dissolution of the bedrock (in nepheline syenites), comminution (in amphibolites), and comminution and degradation of the lithogenic phyllosilicates contained in the coarse fractions (in gabbro diabases).

(3) Upon the initial absence of phyllosilicates in the bedrock, these minerals are also absent in the soil silt and clay fractions. The pedogenic alteration of the initial mineral soil matrix is very weak and does not lead to a significant accumulation of clay minerals in the soils. The admixture of the allochthonous moraine material with considerable reserves of phyllosilicates predetermines the more pronounced pedogenic differentiation of the soil, even in the case of very shallow profiles. The profiles of such soils are clearly differentiated by their chemical and mineralogical indices. They are classified as podzolized podburs and humus–illuvial podzols (which have been described in the mountainous tundra) and as iron-illuvial podzols (which predominate in the soil cover of taiga landscapes with bedrock outcrops).

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