Soil formation from ultrabasic rocks in bioclimatic conditions of mountainous tundra (the Polar Urals, Russia): Mineralogical aspects

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Abstract
Mineral associations of soils located in mountainous tundra derived from and underlain by ultrabasic rocks using the example of the Polar Urals were studied. Key plots are located on a flat summit and a slope of the Rai-Iz massif where ultrabasic rocks are represented by a dunite - harzburgite complex and the Rai-Iz massif, on a moraine ridge consisting mostly of basic material with admixtures of ultrabasic rocks.
The mineral association in all studied sola is a result of (i) disintegration of easy weathering ultrabasic rocks that are a source of olivine, pyroxenes, serpentine, talc, and chlorite; (ii) influence of allochthonous material enriched by quartz and feldspars; and (iii) pedogenic neoformation and decomposition of saponite; and (iv) development of iron (hydr)oxides in micro-cracks of olivine, pyroxenes, and serpentine and fragments of plant tissues. Clay minerals associations in sola are determined by resources of ultrabasic rocks even in case of mixture of ultrabasic and basic rocks when the latter are predominant. The acidic effect of moss and lichens seems to be a reason for selective decomposition of the most unstable minerals despite the pH value of bulk samples.

Key Words
Dunite-harzburgite complex, phyllosilicates, pedogenesis

Introduction
Weathering of ultrabasic rocks and mineral association of soils derived from ultrabasic rocks have extensively been studied and pedogenesis has been characterized in rather wide spectrum of bioclimatic conditions (Wildman *et al.* 1968; Ducloux *et al*. 1976; Wilson *et al.* 1984; Alexander 1988; Bulmer and Lavkulich 1994; Bonifacio *et al*. 1996; Caillaud *et al*. 2004; Gaudin *et al*. 2004). Nevertheless, soil formation from ultrabasic rocks in cold, humid climate as well as permafrost influence on the silicate matrix is not well known. In mountainous tundra permafrost affects rock disintegration and the increase in their dispersion which affects silicate sustainability.
The aim of the present work was to investigate silicate associations changes and transformation in soils derived from and underlain by ultrabasic rocks and to assess the relative importance of pedogenesis in bioclimatic conditions of mountainous tundra using the example of the Polar Urals.

Methods
The mineral compositions of the hard rocks and sola were studied in thin section by optical microscopy using Zeiss Axioplan 2 and Polam P-312 microscopes. The mineral association of clay size fraction (<1 μm) separated by sedimentation was studied. Ammonium hydroxide was used as a peptizing agent. The XRD patterns were obtained from oriented specimens using DRON-2 X-ray diffractometer, with CoKα radiation and a monochromator in the diffracted beam. Pretreatment of samples included saturation with Mg, ethylene glycol solvation, heating at 350ºC and 550ºC, and boiled for 2 h with 1 N HCl. A Rigaku-MiniFlex2 diffractometer (CuKα) was used for powder samples of rocks and fine earth.
Light and heavy fractions (specific weight < 2.9 and > 2.9, correspondently) of sand fractions were investigated by immersion method.
Bulk chemical composition was done by X-ray fluorescence analysis. Various forms of Fe and Al were also measured on the base of dithionite (Mehra and Jackson) and oxalate extractable procedures. The pH values were measured potentiometrically in the suspension with a soil: H_2O ratio of 1:2.5 (shaking for 2 h).

Results
Ultrabasic rocks represented by a dunite - harzburgite (peridotite with orthopyroxene) complex make up the Rai-Iz massif, the Polar Urals. Climate conditions are characterized by mean annual temperature -9.0 (ºC) and precipitation 800 (mm). Studied soils are represented by Haplic Regosol (Eutric) (Pit Y-01-07); Haplic Cryosols (Reductaquic) (Pit Y-02-07), and Stagnic Leptosol (Eutric) (Pit Y-04-07) (WRB 2006).

Key plots are located: (i) on a flat summit at an altitude of 664m of the Rai-Iz massif, permafrost was at a depth of 30 cm (Pit Y-02-07); (ii) southern slope of the Rai-Iz massif covered by colluvial blocks of ultrabasic stones at an altitude of 300m (Pit Y-01-07); and (iii) the Rai-Iz massif at an altitude of 300m, on a moraine ridge consisting mostly of basic material with admixture of ultrabasic rocks (Pit Y-04-07).
In the studied sola crushed stones and gravels make up 70% of the total volume; they are mainly composed by basic (meta-gabbro amphibolites, Pit Y-04-07) and ultrabasic (serpentinous dunites (olivinite), Pit Y-01-07 and Y-02-07) rocks. Despite significant difference of their mineral association and chemical composition (Table), clay size fraction (<1 μm) of sola is characterized by the same phyllosilicate association: (i) inherited from ultrabasic rocks (talc, serpentine, and chlorite); (ii) mineral of smectite group (saponite) that is a result of pedogenesis; and (iii) illite as a trace, the origin of this mineral is not clear (Lessovaia and Polekhovsky 2009).

Table 1. Some properties of studied sola.

Horizon, depth	pH	Chemical composition of sola fine earth and rocks, % in ignited sample									Fe_2O_3d	Fe_2O_3o	Al_2O_3o
	H_2O	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	MnO	TiO_2		%	
Haplic Cryosols (Reductaquic), Pit Y-02-07													
Ah 0-4 cm	7.2	54.59	5.05	10.62	1.35	25.88	0.75	0.63	0.23	0.38	2.68	1.79	0.08
Bg 4-15 cm	7.0	56.00	5.70	11.25	1.43	22.57	0.86	0.96	0.20	0.42	4.05	2.57	0.11
Bgf 15-30 cm	8.0	65.92	8.66	7.10	1.44	13.23	1.35	1.20	0.07	0.65	1.53	0.66	0.11
R	–	44.52	0.72	12.87	0.85	40.34	0.10	trace	0.21	0.02	–	–	–
stones, surface of permafrost circle	–	44.40	0.90	13.39	0.89	39.86	0.05	trace	0.15	0.01	–	–	–
Haplic Regosol (Eutric), Pit Y-01-07													
A 0-2 cm	6.6	–	–	–	–	–	–	–	–	–	–	–	–
C1 2-10 cm	8.1	56.70	6.53	8.43	1.43	23.93	0.93	1.11	0.12	0.49	1.48	0.60	0.11
C2 10-25	8.3	55.76	6.24	8.71	1.50	25.13	0.84	0.77	0.16	0.46	1.48	0.58	0.09
25-52	8.4	57.23	6.67	8.50	1.43	23.54	0.93	0.74	0.12	0.50	1.28	0.53	0.10
C3 52-70 cm	8.6	55.12	6.16	8.85	1.36	26.04	0.82	0.71	0.15	0.43	1.82	0.56	0.10
R	–	49.20	3.83	9.46	0.96	32.43	3.01	0.37	0.13	0.25	–	–	–
Stagnic Leptosol (Eutric), Pit Y-04-07													
Ah 0-2 cm	7.1	53.22	6.82	10.99	2.77	23.56	0.70	0.71	0.22	0.44	1.90	1.10	0.21
Bwh 2-10 cm	7.1	53.57	7.01	11.22	2.76	22.77	0.68	0.74	0.23	0.45	2.37	1.17	0.26
BC 10-40 cm	7.6	59.06	8.49	10.03	2.04	17.39	1.00	0.87	0.17	0.56	1.66	0.78	0.22
BCg 40-60 cm	7.4	62.89	9.52	9.37	2.24	12.62	1.19	1.08	0.14	0.65	1.86	1.01	0.17
R	–	52.11	17.85	13.68	5.15	7.65	0.79	1.64	0.40	0.63	–	–	–

Notes: d – dithionite extractable; o - oxalate extractable; «–» - no data.

In light fraction quartz and feldspars that are not related with ultrabasic substrate are predominant even in case of Pit Y-02-07 whose location suggests that solum has been isolated from the influence of material that is outside of the Rai-Iz massif. Heavy fraction is enriched by pyroxenes that are usual for harzburgite but not for olivinite, though the latter were the source of stones in the solum. Therefore solum silicate matrix belongs to ultrabasic rocks as well as allochthonous substrates. The admixture of allochthonous material determines the silica abundance in the fine earth (<1mm), especially in the basal horizon. As a result the silica content is much higher than in rock (Table 1).
In Haplic Cryosols (Reductaquic) (Pit Y-02-07) besides fragments of more or less weathered ultrabasic rocks and minerals originated from ultrabasic rocks (olivine, pyroxenes, amphiboles, chlorites, and sometimes large particles of serpentine) that are frequent in thin sections of soil horizons, quartz and plagioclases are present. In this solum weathering and pedogenesis concerning mineral matrix, resulted in (i) the disintegration of rock fragments that led to their more similar sizes in the upper horizon; and (ii) iron (hydr)oxides development in micro-cracks of olivine, pyroxenes, and serpentine and fragments of plant tissues, frequently demonstrating preserved cellular texture, especially in the upper horizon.
Opposite to Haplic Cryosols (Reductaquic) (Pit Y-02-07) in Stagnic Leptosol (Eutric) (Pit Y-04-07) a solum mineral matrix is enriched by the presence of fragments of meta-gabbro amphibolites and amphiboles including hornblende, especially in a basic horizon (Figure). In meta-gabbro amphibolites high temperature regional metamorphism resulted in replacement of pyroxenes by amphiboles, sericitization of plagioclases, and replacement of some of the melanocratic minerals by quartz.
Thus meta-gabbro amphibolites are a possible source of plagioclases and quartz in solum on moraine ridge as well as in sola on ultrabasic substrate. The portion of minerals from basic rock including quartz decreases

in the upper horizons. Fragments of pyroxenes and serpentinite developed from olivinite are found in abundance in the upper horizons of Stagnic Leptosol (Eutric) (Pit Y-04-07). Thus, being a source of easily weathered minerals, ultrabasic rocks lead to soil formation on a matrix that is enriched in usual phyllosilicate association on ultrabasic rocks and is represented by serpentine, chlorite, and talc. The replacement of olivine in veins by serpentine, talc, and chlorites is identified in rock.
Iron (hydr)oxides formation is not so intensive in this solum as in Pit Y-02-07. Pyroxenes are more affected by this process than serpentines. According to chemical composition this solum is similar to sola on ultrabasic rocks that confirm the more significant influence of ultrabasic rocks than basic ones.
More pronounced disintegration and iron (hydr)oxides formation in Haplic Cryosols (Reductaquic) (Pit Y-02-07) could be explained by permafrost influence leading to increase of silicate dispersion with consequence transformation/ decomposition.

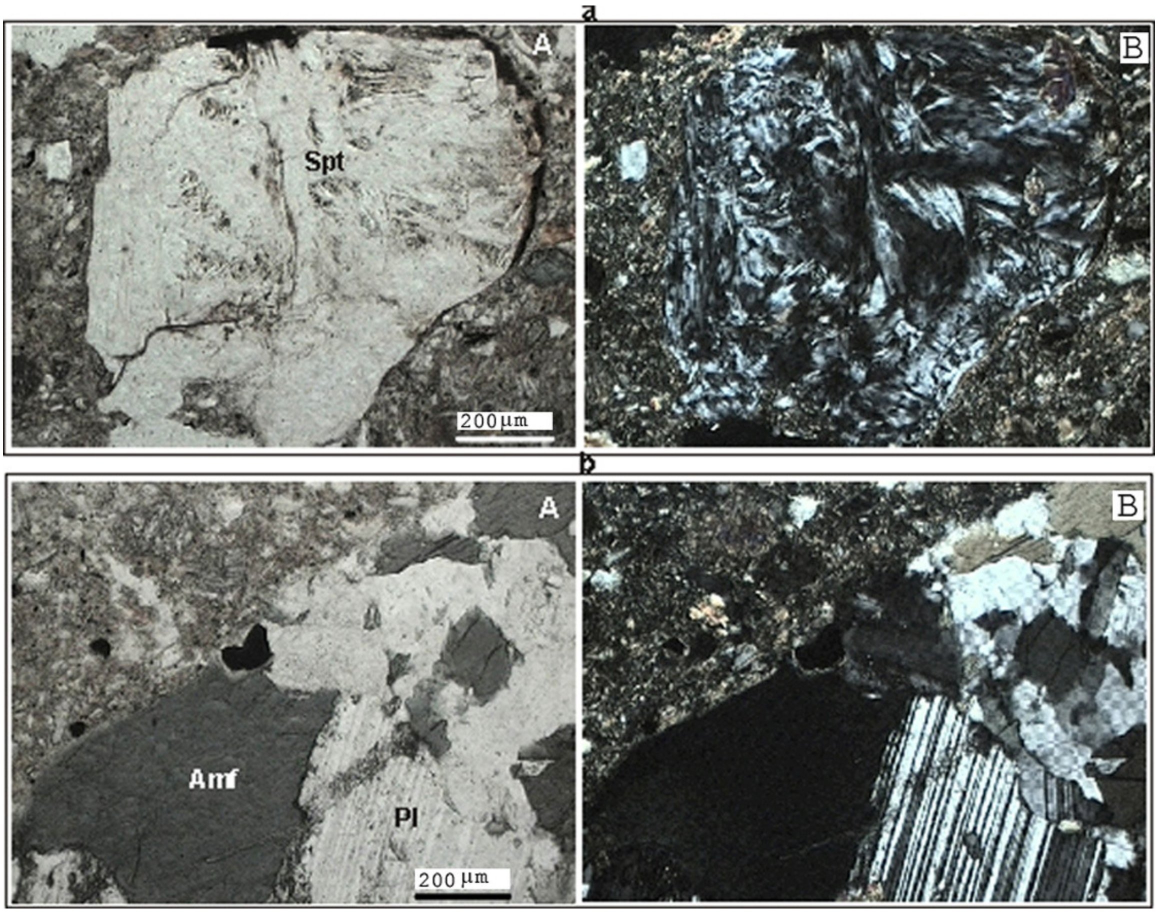

Figure 1. Thin section of horizon BC 10-40cm, Stagnic Leptosol (Eutric), Pit Y-04-07: **fragments of (a) serpentinite developed from olivinite and (b) part of meta-gabbro amphibolites. Spt – serpentine, Amf – amphibole, Pl – plagioclase. A: plain polars; B: crossed nicols.**

Dispersed olivine due to its extreme susceptibility to weathering is likely to be a source for iron (hydr) oxides. Iron removal from silicates matrix is reflected by increase of dithionite - and, especially oxalate extractable iron in the upper part of sola that is more remarkable in Haplic Cryosols (Reductaquic) (Pit Y-02-07), less intensive in Stagnic Leptosol (Eutric) (Pit Y-04-07), and the least in Haplic Regosol (Eutric) (Pit Y-01-07).
The rate of olivine dissolution significant rises simultaneously as pH decreases (Franke and Teschner-Steinhardt 1994). Although the studied sola are characterized by neutral – alkaline pH value, except horizon A, Pit Y-01-07, keeping by high amounts of exchangeable Mg, weakly films of Fe-Al-organo complexes on stones are present in Bwh horizon of Stagnic Leptosol (Eutric) (Pit Y-04-07) indicating the translocation of poorly crystalline iron and aluminum oxides. Moreover pedogenesis resulted in the decomposition of significant portion of pedogenic saponite in the upper horizons. Pedogenic saponite may be concentrated in the basal horizons and absent from more acidic upper horizons (Wilson and Berrow 1978).
In studied sola saponite decomposition appears to be most intensive in Pit Y-02-07, where the pH value is neutral. The instability of silicate matrix, especially saponite and olivine could be explained by the

decomposing acidic effects of moss and lichens despite neutral-alkaline conditions of the bulk samples. This effect is the strongest in the case of Pit Y-02-07, and decreases from Pit Y-04-07 to Pit Y-01-07, where the vegetation cover is almost absent.

Conclusion

The mineral association in studied sola of mountainous tundra is a result of (i) disintegration of easy weathering ultrabasic rocks that are a source of olivine, pyroxenes, serpentine, talc, and chlorite; (ii) influence of allochthonous material enriched by quartz and feldspars, and (iii) pedogenic neoformation and decomposition of saponite.

Clay minerals associations in sola are determined by resource of ultrabasic rocks even in case of mixture of ultrabasic and basic rocks when the latter are predominant.

The acidic effect of moss and lichens seems to be a reason of selective decomposition of the most unstable minerals despite the pH value of bulk samples. The silicate decomposition as a result of the acidic effect increases in Haplic Cryosols (Reductaquic) due to more pronounced rock disintegration.

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