Soils of mid and low antarctic: diversity, geography, temperature regime

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Abstract
The study of the Russian stations areas of Antarctica is very important in world soil geography as it is a kind of transit in soil-forming conditions between Dry Valleys from one side and Grearson Hills and Antarctic islands on the other one having been studied earlier by soil scientists from New Zealand, USA, Brazil and Germany. As for soil classification in the study areas Leptosols (Entisols) predominate but not Cryosols (Gelisols). The thawing depth of soils is more than the thickness of loose materials, cryoturbations are not well pronounced, and the thawing depth in sandy and stony materials here is often more than 1 m. So, Nudilithic Leptosols or Lithic Cryorthents predominate among soils. All the regions of the Russian Antarctic stations may be referred to two soil geographical divisions - Low-Antarctic humid barrens (Bellingshausen stations at King George Island) and Mid-Antarctic semihumid transitional zone between Cold deserts and humid Antarctic barrens (Novolazarevskaya, Molodezhnaya, Progress, Mirnyi, Leningradskaya, Russkaya stations on the continent).

Key Words
Soils, Antarctic, diversity, genesis, geography, temperature regime.

Introduction

Nowadays, the majority of Antarctic soil investigations are taking place in West Antarctic – mostly in Dry Valleys, McMurdo Sound and King George Island (Bockheim 2002; Bockheim and Balks 2008; Campbell and Claridge 1987). Much less is known for Mid Antarctic of the East Antarctic: the northernmost Grearson Hills were studied for their soils (Beyer and Boelter 2007) as well as Bunger Hills (Glazovskaya 1958) and a part of Enderby Land (MacNamara 1969). The study of the Russian station areas in Antarctic is very important in world soil geography as it is a kind of transit in soil-forming conditions between Dry Valleys from one side and Grearson Hills and Antarctic islands from another one.

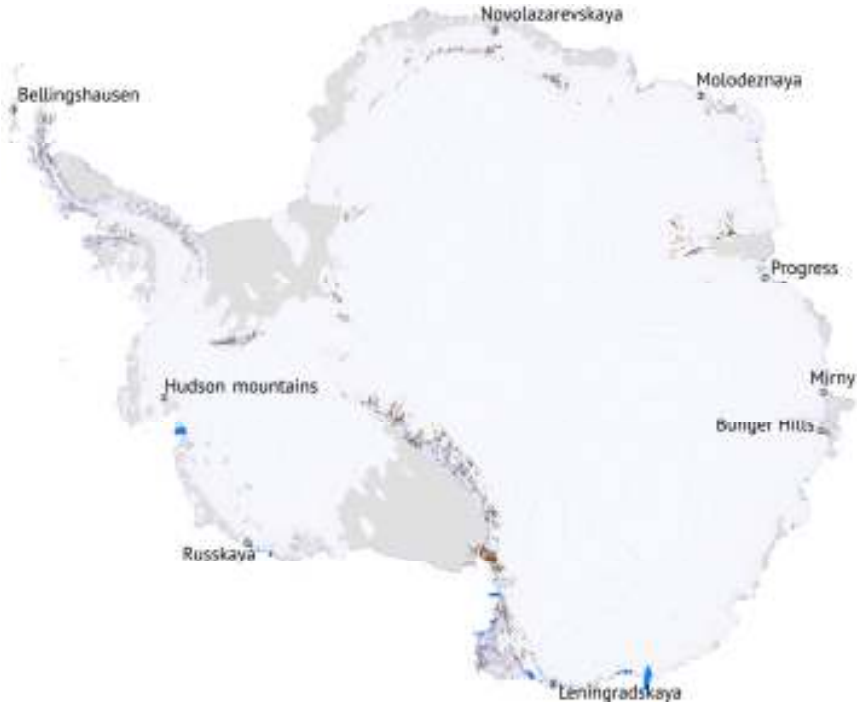

Figure 1. Antarctic map by Antarctic Digital Database with points of soil investigations.

Objects and methods

The soil study of all coastal Russian Antarctic stations Novolazarevskaya (coordinates 70°46'S, 11°50'E), Molodezhnaya (67°40'S, 45°23'E), Progress (69°23'S, 76°23'E), Mirny (66°33'S, 93°01'E), Leningradskaya (69°30'S, 159°23'E), Russkaya (74°46'S, 136°52'W) and the station Bellingshausen (62°12'S, 58°56'W) on the King George Island, as well as of Hudson mountains (74°33'S, 99°09'W), Lindsey Island (73°76'S, 102°00'W) were carried out (Figure 1). The field soil description and the microscopic analysis were fulfilled. Soil organic matter (SOM) analysis was done according to Ponomareva and Plotnikova method for humic (ha) and fulvic acids (fa) extraction and C and N contents were determined by wet combustion (Tyurin and Kjeldahl methods respectively). Microbial biomass was measured by fumigation method (Jenkinson 1998) and metabolic quotient was calculated as basal respiration/microbial biomass ratio (Method of Soil Analysis 1994). Ground temperatures were measured by U12 HOBO loggers (Onset corp).

Results

Soil diversity.

The following groups of soils were distinguished.

1) Organo-mineral soils with macro-profiles (induced by input of organic material from the ocean – «ornithogenic» и «post-ornithogenic») – the active interaction of guano with soil minerals takes place here. Humus content was maximal in soils of penguin beaches, but the level of microbiological activity here was the lowest. Microbiological transformation of organic matter appeared to be more intensive in soils with decayed and leached guano. Intensive processes of weathering start in these post-ornithogenic soils. Soils under the plants residues are characterized by prevailing of fulvic acids over the humic acids. The average Cha/Cfa ratio is 0,5. It was less in Hudson mountains and maximum in some sub-Antarctic soils. Soils of littoral organic material accumulation shows the higher amount of raw organic matter in organic horizons. Here humus is not associated with soil mineral part. These two soil types – under guano and littoral algae layers are typical for sea-shore territories. Meanwhile, some soils under penguin guano forms even in continental parts, situated at 4-5 km from seashore.

2) Organo-mineral soils with micro-profiles (first centimeters depth) within fine-earth material under mosses, lichens and algae. Soils of continental Antarctica contain about 0.3-1.0% of organic carbon or less, while in some sub-Antarctic soils this parameter rises up to 3% (table 1). The content of carbon that can be potentially mineralized was higher in sub-Antarctic soils and in all ornithogenic soils. It is explained by high amount of fresh organic matter and climatic specificity of the landscapes. Humus of continental soils was more stable to mineralization than maritime soils' organic matter. SOM from King George Island was more enriched by nitrogen in comparison to SOM of continental soils. Microbial biomass was on the same level in all continental soils, but in some soils of King George Island it was essentially higher than in continental ones. Metabolic activity was essentially higher in all soil of sub-Antarctic which very good corresponds with the mineralization losses of SOM. Micromorphological study shows the higher degree of plant residues decaying and humification in sub-Antarctic soils than in continental ones by the climatic reasons. Period of biological activity is about 60 days in sub-Antarctic, while it is not more than 15 days in continental Russkaya station.

Table 1. Soil organic matter characteristics for upper horizons.

C total, %	C/N	Cha / Cfa	Cha/Ctotal, %	Microbial biomass, µg/g	Metabolic quotient
			Russkaya station		
0,27	15,8	0,39	9.3	490	0.01
			Leningradskaya station		
0,48-1,02	14,0-19,9	0,33	6.9-8.2	310	0.06
			Hudson mountains		
0,42-0,67	49,1 -78,4	0,12	5.0-6.0	300	0.01
			Bellingshausen station (King-George)		
0,61-3,00	6,5-12,2	0,17-0,73	3-7.3	310-740	0.09-0.26

3) Ahumic soils (by J.Tedrow) - soils with anisotropic profiles on fine earth materials without macroscopic life; the anisotropy is formed by abiogenic processes (cryogenic structure formation and blow-out of the fine earth from upper horizons). Such soils occupy large areas in continental part. These soils show strong weathering process which expressed in salts accumulation in whole profile and formation of salts crusts, which good correspond with data, obtained previously (Bockheim and McLeod 2006).

4) Endolithic soils - the results of the pedogenesis here is intra-fissure fine earth and newly formed minerals of iron (hydr)oxides bringing to both intra-fissure space and rock surface the brown and red colors (Figure 2). They are the most widely spread soils in Antarctic. The life in continental Antarctic save itself in stones as the fine earth is not reliable due to strong winds (Friedmann and Ocampo 1976). The great amplitude of rock temperature results in numerous small fissures in granites and gneiss which are colonized by autotrophic algae under transparent minerals, e.g. quartz. The role of these organisms in transformation of minerals is very important. In these small fissures the processes of iron-containing silicates weathering, releasing of ferrous forms from mineral lattice and their oxidation take place. Due to these processes surface and intrafissual films of brown (7.5YR) and even red (up to 10R) colors form on the rocks having initial Munsell hue of 5Y and 2.5Y. Besides that in stone blocks the etching of feldspars and quartz also takes place as well as the formation of fine sand and silt material (Figure 2).

Soil classification

As for soil classification in the study areas Leptosols (Entisols) predominate but not Cryosols (Gelisols). The thawing depth of soils is often more than the shallow depth of loose materials, cryoturbations are not well pronounced, and the thawing depth in sandy and stony materials here is often more than 1 m, especially on the northernmost stations (Figure 3). So, Nudilithic Leptosols or Lithic Cryortents predominate among soils. The strong transformation of iron (hydr)oxides in Antarctic soils to be taken into account for soil classification needs the widening of the WRB criteria for Chromic prefix, as now it is only fit for loose subsurface horizons. Some films on the stone surfaces are characterized by a high content of iron (up to 15%) and aluminum (up to 10%). The Si/Fe+Al ratio here is about 2-3 which is a result of amorphous iron and aluminum accumulation in films. At the same time the surfaces of stones could be enriched by organic matter, locally concentrated here due to the activity of epilitic communities of fungi, algae and lichens. Soils of King George Island were classified as ornithosols (Leptosols Ornitic), Lithic Leptosols and Haplic Leptosols. Soils in a very windy and cold valley near the Russkaya station besides Cryosols were represented by Lithic Leptosols, while soils of Leningradskaya station and in Hudson mountains were Haplic Leptosols and Lithic Leptsols. Lindsey Island was covered by actual ornithosols and post-ornithogenic soils.

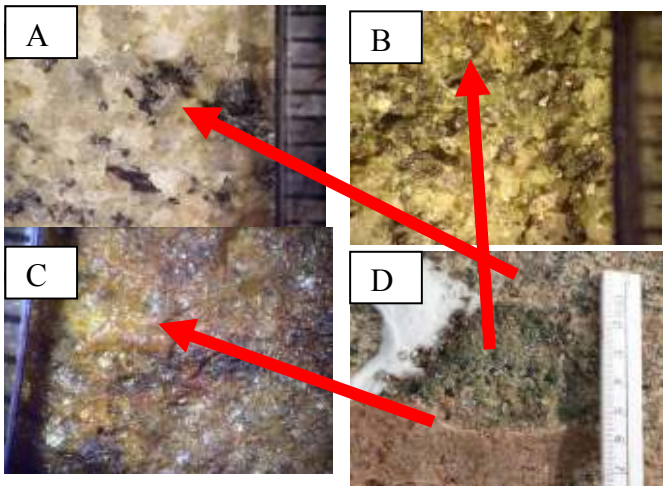

Figure 2. Microphotographs of endolithic soils near Molodeznaya station: A – fresh enderbite (granite with hornblende) rock surface; B – zone of weathering of Fe containing minerals and fine earth formation; C – reddish polished film on the rock surface; D – general view of endolithic soils.

Soil geography

All the regions of the Russian Antarctic stations may be referred to two soil geographical divisions – Low-Antarctic humid barrens (Bellingshausen stations, King George Island) and Mid-Antarctic semihumid transitional zone between Cold deserts and humid Antarctic barrens (Novolazarevskaya, Molodezhnaya, Progress, Mirny, Leningradskaya, Russkaya stations). There is some difference within the second division related to humidity. The southernmost stations (Novolazarevskaya, Russkaya) have more severe and arid conditions. Soils of maritime Antarctica are acid, with low content of exchangeable bases, profile-differentiated in chemical composition. These soils were formed on moraines, fluvioglacial sands and alluvium, while soils from continental Antarctica were formed on debris of massive crystalline rocks. Salts and iron films are revealed only in continental soils. Smectite dominates in clay fraction of all soils, but sometimes illite and kaolinite occur. Profile distribution of mineral was strongly affected by stratigraphy of

parent materials. Soils of Russkaya and Leningradskaya stations as well as soils of Hudson mountains do not show the process of secondary clay minerals formation. Here only mechanical crushing of minerals occurs with strongly expressed corrasion of the surface. The maximum intensity of weathering and formation of secondary mineral was revealed in soils of King-George Island.

Temperature regime

The permafrost and soil mean annual temperature on King-George Island is close to zero (-0,25°C). Such temperature indicates the north border of permafrost in Antarctic and the probability of permafrost degradation and disappearance of permafrost-affected soil in the case of warming.

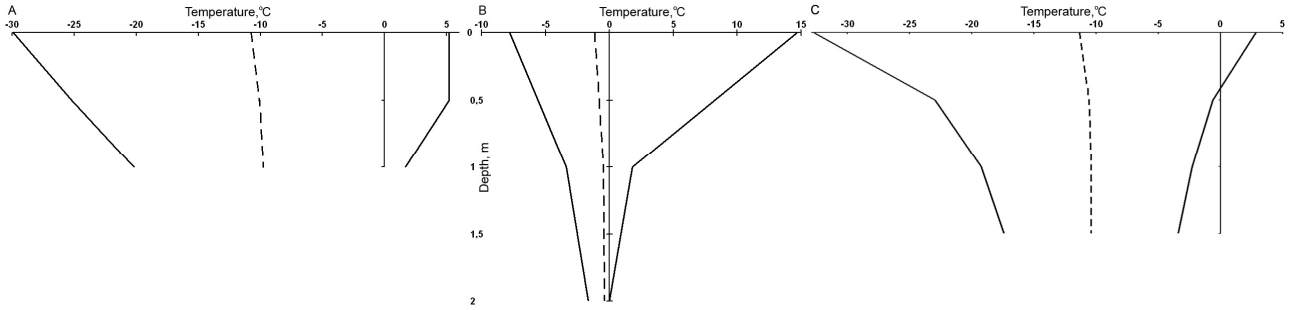

Figure 3. Soil temperature regime during the year on Molodezhnaya (latitude is 67°40'S) (A), Bellingshausen (62°12'S) (B) and Russkaya (74°46'S) (C) stations.

Conclusion

This study shows the diversity of soils in previously unexplored regions of Eastern and Western Antarctic most of which can be attributed to Mid-Antarctic semihumid transitional zone between Cold deserts and humid Antarctic barrens. Both Nudilithic Leptosols and Cryosols predominate in ice-free oases, and areas of Leptosols are even larger. The endolithic soils formed by interactions of cryptoendolithic algae and lichens with minerals in cryogenic superficial cracks of solid rocks are widespread in oases. The depth of active layer on the continent is close to or even more than 1 m because of coarse texture of substrates and thin, if any, organic horizon. King-George Island is on the north border of permafrost in Antarctic. The gained data give the additional material for the Soil Data Base of Antarctic, which is being created now in the context of ANTPAS program.

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