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# Microbial biomass and basal respiration in Sub-Antarctic and Antarctic soils in the areas of some Russian polar stations

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## Abstract

Antarctica is the unique place for pedological investigations. Soils of Antarctica have been studied intensively during the last century. Antarctic logistic provides the possibility to scientists access the terrestrial landscapes mainly in the places of polar stations. That is why the main and most detailed pedological investigations were conducted in Mc Murdo Valleys, Transantarctic Mountains, South Shetland Islands, Larsemann hills and Schirmacher Oasis. Investigations were conducted during the 53rd and 55th Russian Antarctic expeditions on the base of soil pits and samples collected in Sub-Antarctic and Antarctic regions. Soils of diverse Antarctic landscapes were studied with aim to assess the microbial biomass level, basal respiration rates and metabolic activity of microbial communities. The investigation conducted shows that soils of Antarctic are quite different in profile organization and carbon content. In general, Sub-Antarctic soils are characterized by more developed humus (sod) organo-mineral horizons as well as the upper organic layer. The most developed organic layers were revealed in peat soils of King-George Island, where its thickness reach even 80 cm. These soils as well as soils under guano are characterized by the highest amount of total organic carbon (TOC) 7.22–33.70 %. Coastal and continental soils of Antarctic are presented by less developed Leptosols, Gleysols, Regolith and rare Ornhitosol with TOC levels about 0.37–4.67 %. The metabolic ratios and basal respiration were higher in Sub-Antarctic soils than in Antarctic ones which can be interpreted as result of higher amounts of fresh organic remnants in organic and organo-mineral horizons. Also the soils of King-George island have higher portion of microbial biomass (max 1.54 mg $g^{-1}$) than coastal (max 0.26 mg $g^{-1}$) and continental (max 0.22 mg $g^{-1}$) Antarctic soils. Sub-Antarctic soils mainly differ from Antarctic ones in increased organic layers thickness and total organic carbon content, higher microbial biomass carbon content, basal respiration and metabolic activity levels.

## 1 Introduction

Soil of Antarctic are known as very diverse in morphology, chemistry, texture and mineralogical composition (Abakumov, 2010a). Essential pedodiversity of Antarctic is caused by difference of geographical conditions in latitude gradient as well as by existence of so-called Antarctic oasis's which are isolated each from other by ice sheets and snow massives (Gilichinskiy et al., 2010; Mergelov and Goryachkin, 2010). According to Bockheim and Ugolini (1990), there are three soil-climatic zones in Antarctic: Sub-Antarctic zone of tundra or tundra-barren soils (here soils are the most diverse and developed); zone of coastal Antarctic, presented by barrens and polar deserts (here the soil diversity is lesser, and solum consist of 5–10 cm only), finally, zone of real continental Antarctic landscapes, where the soils are quite primitive and even presented by so called endolithic soils of severe polar deserts (Mergelov et al., 2010, 2012). The coastal part of Antarctic presented mainly by so-called Antarctic oasis's, i.e ice and snow free terrestrial ecosystems.

In fact, the soils of Antarctic contain low soil TOC, meanwhile, its content is quite different: from zero level in ahumic regolith soils (Ugolini and Bockheim, 2008; Campbell and Claridge, 1987) to 3–4 % in soils under mosses, lichens, cereals (Abakumov, 2010b; Simas et al., 2008) and even 30–40 % of organic matter in soils, formed under guano (Simas et al., 2007). The differences in C/N ratios are known as more sufficient for Antarctic soils – these changes from 70 in polar deserts to 2–3 in guano enriched soils of maritime Antarctic (Abakumov, 2010b).

TOC is presented not only by colloidal forms of humus (humic and fulvic acids, humin), there is essential portion of detrite forms which provide the organic carbon redistribution (Hopkins et al., 2008) or endolitic accumulation of organic matter (Vestal, 1988; Abakumov et al., 2010; Mergelov et al., 2012). The humification degrees are differentiated lesser between the soils of Antarctic zones. Thus, the humification index – ratio of carbon of humic acids to fulvic acids ($C_{ha}/C_{fa}$) belong to the fulvate (less than 0.5) or humate-fulvate (0.5–1.0) type. This means that humification as well as organic matter transformation appears not in high degree in these polar soils, but we can expect and essential differences, caused by local conditions and latitude geographical and climatic gradient.

Previous works were carried out on changes of microbial biomass and respiration rates along the geographical gradient of polar regions. It was shown that metabolical activity is relatively higher in subantarctic soils in comparison to the continental ones (Gilichinskiy et al., 2009). According to Yoshitake et al. (2007) carbon (C) and nitrogen (N) content are not considered limiting factors to heterotrophic respiration in high Arctic soils). Kumar et al. (2013) considered that changes in soil temperature are not critically affecting on arctic soils According to Dennis et al. (2013) effect of the warming on soil microbial community is expected as different for soil of sub Antarctic and Antarctic landscapes. Soil respiration have been interpreting as predicted by organic phosphorous and total nitrogen content in Sub Antarctic soils in case of different habitats comparison (Lubbe and Smith, 2012). Latitudinal research of different Antarctic soils shows that temperature sensitivity of microorganisms increases with mean annual soil temperature, suggesting that bacterial communities from colder regions were less temperature sensitive than those from the warmer regions (Rinnan et al., 2009). Thus, we can summarize that there is essential changes in soil microbial activity between real Antarctic soil high latitude and maritime sub-Antarctic soils. These differences are caused by temperature sensitivity of organisms, different enzymatic activity and different pools of C, N and phosphorous. The data of soil basal respiration and biological activity are very poor or absent for soils of different climatic zones of Antarctic. These data are urgent for soil carbon turnover modeling, for simulation of green house gases emission and soil organic dynamics in conditions of changing climate. That is why the aim of our investigation is to compare the microbiological activity in soils of 3 latitude zones of Antarctic from the places of situation of Russian polar Antarctic stations. To achieve these aim the following objectives were formulated:

1. to identify soil types and chemical characteristics in the studied areas,

2. to determine and interpret the values of soil respiration, microbial biomass and metabolic quotients in different climatic and vegetation zones of Antarctic.

## 2 Materials and methods

### 2.1 Study site

The study sites are situated in different climatic regions of Antarctic: Russkaya valley (Mary Byrd land), Larsemann hills (Princes Elizabeth Lands) and King-George island (South Shetlands archipelago, Antarctic Peninsula). These plots present coastal-continental Antarctic, coastal Antarctic and sub-Antarctic climatic regions correspondingly. Some data on soil diversity and its features were published by Vlasov et al. (2005), Lupachev and Abakumov (2013), Gilichiskiy et al. (2009), Mergelov and Goryachkin (2012), Simas et al. (2007, 2008), Abakumov (2013), Abakumov et al. (2013) and others. Climatic conditions are quite different in all plots investigated. The most severe conditions are in the Russkaya station, while the King-George Island is characterized by the most warm and humid conditions.

Russkaya station is situated on the Berks peninsula, Mary Byrd land, Western Antarctic, 74°46′ S, 136°48′ W. Annual temperature is –12.4 C, precipitation is evaluated as 2000 mm, maximal wind velocity is 77 $\mathrm{m\,s^{-1}}$. Basalts, granites and gneisses are main components of bedrock composition (Lupachev and Abakumov, 2013). Plant cover presented mostly by lichens and mosses, and some algae, while they vegetate on the former penguin rockeries.

Progress station is situated on the coast of the Larsemann hills, Princes Elizabeth Lands, Eastern Antarctic, 69°30′ S., 76°19′ E. Annual temperature is –9.8 C, mean wind velocity is 6.7 $\mathrm{m\,s^{-1}}$ with maximum about 53 $\mathrm{m\,s^{-1}}$, annual precipitation is about 250 mm.

The Bellingshausen station belongs to the Fildes peninsula, King-George Island, 62°12′ S, 58°58′ W, 40 m a.s.l.). The parent material is presented by andesite, basalt, and tuffs, the coastal areas are covered by maritime sands and gravels, moraines and some fluvioglacial materials cover the periglacial plots (Peter et al., 2008). The mean annual temperature of air is –2.8 °C, in Australian summer (January and February) the mean monthly temperature rise up to 5–6 °C in soil humus horizons (Abakumov, Andreev, 2010) The total annual precipitation reaches 729 mm, the number of days with precipitation is varies from 22 to 30 days in month. The wind velocity is 9.3 $\mathrm{m\,s^{-1}}$ (Peter et al., 2008) with maximum about 28 $\mathrm{m\,s^{-1}}$. Vegetation of the Fildes peninsula is quite diverse on species of plants (Abakumov, 2011), mono species plant communities are so common as mixed ones, both in coastal part and in plateau of peninsula. This affords possibly for many authors to identify it as tundra or Antarctic tundra (Casanov-Kathny, Cavieres, 2012), of cause if compare with Northern Hemisphere this d to be classified as some intermediate between tundra and barrens. Anyway, plant communities of King-George island are the most developed and rich throughout the Antarctic.

As for period of biological activity of soils (number of days with temperature above zero) it is about 12–20 days on Russkaya plot, 30–40 days on the Progress plot and maximum 90 days in the Bellingshausen station (as it is estimated by termochrone loggers in situ of humus horizons). This index is critical for mineralization and humification process.

## 2.2 Soil sampling

The sampling of the soils and organic layers were conducted during 53rd Russian Antarctic expedition (RAE) from 14 January 2008 to 25 February 2008 and during 55th RAE from 4 December 2008 to 12 February 2010 on the scientific vessel *Academician Fedorov*. Soil descriptions were partly published previously (Abakumov et al., 2008, 2010). Briefly, soils of the King-George Islands are represented by Gleysols, Crysols, Leptosols and Lithosols as well as one profile of Peat soils. Soil of the Larsemman hills were Gleysols on the lake coasts and one example of so-called Regolith or “Ahumic soils” according to Tedrow and Ugolini (1966). Regolith and Leptosols were typical for the landscape of the Russkaya station. At least 3 individual samples were taken from each horizon of soil profile.

All samples were collected during Australian summer. The soil samples were taken into special containers by volume about 200 $cm^3$. The samples were stored in a freezer on the vessel to exclude the transformation processes, then the samples where store under the temperature 0 °C in laboratory before the analyzing procedures

### 2.3 Laboratory analyses

The soil color was determined with the use the Munsell color chart in the laboratory of scientific vessel. The TOC was determined in air dried soil by wet combustion in solution of potassium dichromate in sulphuric acid (Tyurin or Walkey–Blak method), nitrogen content was assessed by Kjeldal method. Carbon of microbial biomass ($C_{mic}$) where determined in field moist samples with the chloroform fumigation-extraction method. 5 g of soil where fumigated in chlorophom with following extraction of dissolved organic matter (DOC) by 0.5 M $K_2SO_4$, filtration and evaluation of DOC portion by dichromate method. The DOC of control samples was determined in extracts without fumigation. Soil basal respiration (BR) was evaluated in laboratory closed chambers within 10 days of incubation. Metabolically quotient was calculated as ratio of respirator C-$CO_2$ to $C_{mic}$ per day of incubation (Jenkinson, 1976; Vance, 1987).

### 2.4 Statistical analyses

Data obtained were statistically analyzed with SIGMAPLOT 8.0 program (mean values, paired *t* test, data normal distribution was assessed previous to use a parametric test) to compare data on Sub-Antarctic and Antarctic soils. Significant differences were considered as a $P < 0.05$.

# 3 Results and discussion

## 3.1 Soil morphology

All the soils investigated were identified on the type level (mainly, according to WRB, 2006) and were considered as weakly developed soils without evident differentiation into horizons (Fig. 1). These soils are typical representatives of Leptosols on Russkaya station and King-George island, Ahumic soils of Regoliths on Russkaya station and Larsemann hills, Lithosols on King-George island and Post orhnitosol (Russkaya station) and current ("active") Orhnitosol (King-George island). Permanent and temporal over moisted soils with some redoximorphic features of gleyification were characteristics for Larsemann hills.

Regoliths did not show any morphological evidences of humus accumulation and were presented by slightly different layers of mineral materials. Gleysols were determined on the base of gray-blue color of mineral part, in upper part of solum they had organic or organo-mineral grayish horizon. Leptosols are described mostly under the lichens and mosses on the dense bedrocks. Ornhitoosols should be divided on two categories: those which are currently occupied by penguins and those, which are the former penguin rockeries, invaded now by birds. We suppose to call as Post Orhnitosols for last one.

## 3.2 Carbon content and general soil properties

Soils investigated were different on organic carbon content. TOC values variate from 0.05–1.22 % in soils of Larsemann hills to 4–7 % in organo-mineral horizons of King-George island soil to more than 30 % in peat (turf) material. The differences in carbon values and absorbed water where statistically significant for Sub Antarctic and Antarctic soils: $P < 0.03$ and $P < 0.01$ correspondingly. The lowest organic carbon content was fixed for regolith soil, which is not really soil, but so called "ahumic" soil according to Tedrow and Ugolini (1966). These ahumic soil-like bodies contain almost only mineral compound and only very small portion of organic components and were described in Larsemann hills oasis. Ahumic soils are typical for severe landscapes, where soil formation is limited by low organic matter production. At the same time there are soils with essentially higher portion of carbon in this Antarctic oasis. These soils were classified as Gleysols, i.e. soils seasonally covered by water and then, in the end of Australian summer became under sub areal environment. These soil where called as "seasonal amphibious soils" (Abakumov and Krylenkov, 2011). Soil organic carbon content in soils of King-George Island was comparable with those that have being published previously (Abakumov, 2010; Zhao, 2000). The organic carbon values are in a good correspondence with the absorbed water levels. This is very important for soils which are known as soils with low fine earth content (Abakumov, 2010; Campbell and Claridge, 1987). All the soils investigated are mostly slightly acid; there are no alkaline ones between them due to absence of effect of ocean salts accumulation and because of acid or neutral composition of parent materials, there were not statistical differences between thes soils investigated. The fine earth content in general is essentially higher in soils of King-George island than in soils of continental oasis's ($P < 0.04$) due to different intensity of weathering (Vlasov et al., 2005) and genesis of under laying bedrocks (Peter et al., 2008).

### 3.3 Microbiological characteristics of soils

The differences between Sub-Antarctic and Antarctic soils in carbon content, soil microbial biomass and basal respiration were statistically significant ($P < 0.01$ for all indexes). The values of microbial biomass carbon was, generally the highest in Sub-Antarctic soils of King-George Island, especially in upper organic horizons in comparison with soils of coastal Antarctic landscapes (Larsemann hill, Russkaya station). The same trend was revealed for basal respiration of soils. The metabolic soil activity was higher in Sub-Antarctic soils that can be interpreted by higher amounts of fresh organic remnants in well-developed organic horizons. Metabolic ratios were sufficiently lesser in soils of coastal Antarctic oasis's. This could be explained as result of more severe climatic conditions as well as more homogenous composition of organic remnants with simultaneous decreased total organic carbon content. Two soils (Regolith and one of Gleysols) of the Larsemann hills show more decreased metabolic ratios in upper layers than in deeper ones. In contrast the second Gleysol of this oasis shows the controversial distribution of these values owing to development of oxidation processes in Gox (gleyic redoximorphic) horizon. These soil is so-called seasonal or amphibious soil (Abakumov and Krylenkov, 2011), where the sub aquatic condition changes by sub aeral one at the end of Australian summer. This is the reason of intensification of microbial processes in the upper solum. Levels of microbial biomass were essentially lesser in Russkaya station soils due to more severe climatic conditions. The metabolic ratios were less variable in soils of Russkaya station than in case of Larsemann hills.

We summarize that soils of different Antarctic zones are different on levels of carbon content, basal respiration and metabolic quotient. The most homogenous group is soils of the most severe climate of Russkaya station. Further, the diversity of soils as well as diversity of climatic conditions increases on the direction to the north. This results in increasing of variability of microbial community characteristics and rate of total organic matter accumulations. Thus, our data confirm the hypothesis of Rinnan et al. (2009) that there is geographical trends in microbial communities sensitivity in latitudinal sequence in Antarctica and they are also in a good correspondence with previous published data on metabolic activity of Sub-Antarctic and Antarctic (Gilichinskiy et al., 2010).

## 4 Conclusions

Soils of diverse Antarctic landscapes were investigated to assess the microbial biomass level, basal respiration rates and metabolic activity of microbial communities. The investigation shows that soils of Antarctic are quite different in profile organization and carbon content. In general, Sub-Antarctic soils are characterized by more developed humus (sod) organo-mineral horizons as well as the upper organic layer.

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The most developed organic layers were revealed in peat soils of King-George island, where its thickness reaches even 80 cm. These soils as well as soils under guano characterizes by the highest amount of organic carbon. Coastal and continental soils of Antarctic are presented by less developed Leptosols, Gleysols and Regolith with some Ornhitosol as well. In general, organic carbon content is lesser in Antarctic soils than in Sub-Antarctic ones. The metabolic activity and basal respiration were higher in Sub-Antarctic soils than in Antarctic ones by reason of higher amounts of fresh organic remnants in organic and organo-mineral horizons. Also the soils of King-George island contain higher portion of microbial biomass than coastal and continental Antarctic soils. These data support the conclusions that Sub Antarctic soils differ from Antarctic ones in increased thickness of organic layers and total organic carbon content, higher microbial carbon content, basal respiration and metabolic activity levels. Thus, this short assessment of biogenic processes state shows that geographical trends take place in changes of organic matter transformation indexes.

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**Table 1.** Morphological features and chemical characteristics of Antarctic soils.

| Soil | Horizon | Color | TOC, [%] | Hygroscopic water, [%] | pH in water | Fine earth, [%] |
|---|---|---|---|---|---|---|
| Leptosol, Russkaya station | W | 10 YR 5/3 | 4.67 ± 0.23 | 2.58 ± 0.014 | 5.90 | Nd |
| Post ornithosol, Russkaya station | O | 10 YR 5/3 | 0.60 ± 0.03 | 2.41 ± 0.08 | 5.80 | 11 |
| Regolith, Russkaya station | $C_1$<br>$C_2$ | 5YR 6/1<br>5YR 6/1 | 0.52 ± 0.03<br>0.87 ± 0.05 | 1.00 ± 0.08<br>1.98 ± 0.15 | 5.40<br>3.30 | 5<br>9 |
| Regolith, Larsemann hills | $C_1$<br>$C_2$ | 5YR 6/1<br>5YR 6/1 | 0.08 ± 0.01<br>0.05 ± 0.01 | 0.22 ± 0.01<br>0.31 ± 0.02 | 6.39<br>7.77 | 7<br>16 |
| Gleysol, coast of the Steppet lake, Larsemann hills | G<br>G | 7,5 YR 6/1<br>5YR 6/1 | 1.22 ± 0.05<br>0.83 ± 0.09 | 0.36 ± 0.02<br>0.41 ± 0.03 | 3.57<br>5.70 | 53<br>26 |
| Gleysol, coast of the Reid lake, Larsemann hills | Cox<br>G | 5YR 6/2<br>5 Y 4/4 | 0.37 ± 0.04<br>0.50 ± 0.06 | 0.23 ± 0.01<br>0.33 ± 0.02 | 6.80<br>7.04 | 28<br>21 |
| Lithosol, King-George Island | O<br>AY<br>C | 10 YR 5/3<br>5YR 6/1<br>5YR 6/1 | 6.34 ± 0.19<br>1.73 ± 0.07<br>0.80 ± 0.07 | 6.34 ± 0.25<br>4.73 ± 0.15<br>– | 5.60<br>6.50<br>6.60 | Nd<br>18<br>34 |
| Lithosol, King-George Island | O<br>AY<br>C | 10 YR 4/2<br>10 YR 5/2<br>5YR 6/1 | 11.25 ± 045<br>1.20 ± 0.04<br>0.95 ± 0.09 | 9.00 ± 0.74<br>4.66 ± 0.25<br>7.42 ± 0.32 | 4.74<br>6.10<br>4.85 | Nd<br>56<br>56 |
| Organic Gleysol, King-George Island | O | 10 YR 4/2 | 14.02 ± 0.74 | 8.41 ± 0.12 | 6.33 | Nd |
| Peat soil, King-George Island | O | 7,5 YR 5/6 | 33.7 ± 0.98 | 9.57 ± 0.58 | 5.25 | Nd |
| Ornhitosol, King-George Island | Ocopr | 2,5 YR 4/4 | 7.56 ± 0.12 | 0.65 ± 0.04 | 6.01 | Nd |
| Ornhitic Leptosol, King-George Island | Ocopr | 2,5 YR 4/4 | 7.22 ± 0.21 | 13.25 ± 0.85 | 7.30 | 9 |
| Leptosol, King-George Island | W | 10 YR 5/3 | 1.32 ± 0.05 | 0.75 ± 0.04 | 5.40 | 47 |

**Table 2.** Microbial biomass, Basal respiration and methabolical quotient in soils.

| Soil | Horizon | $C_{mic}$, [$mg\,g^{-1}$] | Basal respiration, [$mg\,g^{-1}\,day^{-1}$] | Metabolical quotient |
|---|---|---|---|---|
| Leptosol, Russkaya station | W | 0.11 ± 0.01 | 0.006 | 0.06 |
| Post ornithosol, Russkaya station | O | 0.17 ± 0.01 | 0.011 | 0.07 |
| Regolith, Russkaya station | $C_1$ | 0.11 ± 0.01 | 0.006 | 0.06 |
| | $C_2$ | 0.22 ± 0.02 | 0.012 | 0.06 |
| Regolith, Larsemann hills | $C_1$ | 0.26 ± 0.02 | 0.005 | 0.02 |
| | $C_2$ | 0.14 ± 0.02 | 0.020 | 0.14 |
| Gleysol, coast of the Steppet lake, Larsemann hills | G | 0.20 ± 0.03 | 0.004 | 0.02 |
| | G | 0.20 ± 0.02 | 0.014 | 0.07 |
| Gleysol, coast of the Reid lake, Larsemann hills | Cox | 0.23 ± 0.02 | 0.014 | 0.06 |
| | G | 0.17 ± 0.01 | 0.002 | 0.01 |
| Lithosol, King-George Island | O | 0.49 ± 0.03 | 0.060 | 0.10 |
| | AY | 0.16 ± 0.01 | 0.010 | 0.06 |
| Lithosol, King-George Island | O | 1.20 ± 0.05 | 0.100 | 0.08 |
| | AY | 0.23 ± 0.01 | 0.003 | 0.01 |
| Organic Gleysol, King-George Island | O | 0.41 ± 0.02 | 0.040 | 0.10 |
| Peat soil, King-George Island | O | 1.54 ± 0.09 | 0.080 | 0.05 |
| Ornhitosol, King-George Island | Ocopr | 0.92 ± 0.07 | 0.050 | 0.05 |
| Ornhitic Leptosol, King-George Island | Ocopr | 0.74 ± 0.06 | 0.090 | 0.12 |
| Leptosol, King-George Island | W | 0.34 ± 0.04 | 0.009 | 0.03 |

**Fig. 1.** Study areas in Antarctic: 1 – Russkaya station, 2 – Larsemann hills, 3 – King-George Island.

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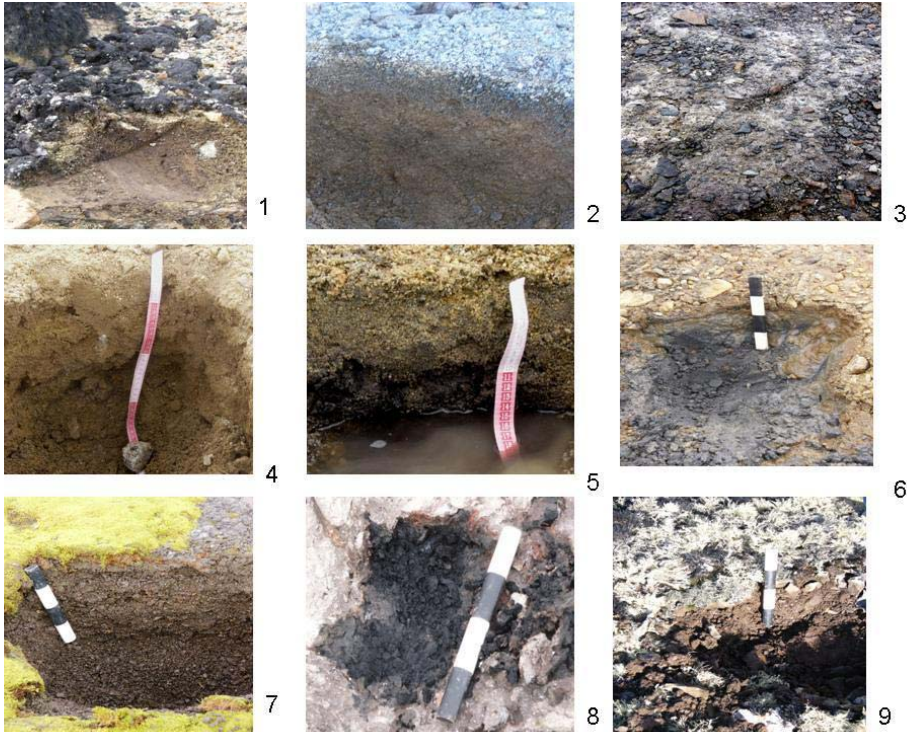

**Fig. 2.** Soil profiles investigated: Russkaya station: 1 – Leptosol, 2 – Regolith, 3 – Post ornhitosol surface, Larsemann hills: 4 – Regolith, 5 – Gleysol, Steppet Lake, 6 – Seasonal Gleysol, Reid lake, King-George island: 7 – Lithosol, 8 – Orhnitosol, 9 – Leptosol.