Vertical electric resistivity sounding of natural and anthropogenically affected cryosols of Fildes Peninsula, Western Antarctica

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Abstract

Natural and anthropogenically-affected Cryosols of the Fildes Peninsula (King George Island, NW Antarctic Peninsula) from the surroundings of Russian polar station Bellingshausen were investigated by vertical electric sounding. The aim of the study was to asses the thawing depth and active layer thickness. Natural Turbic Croysols showed lesser thickness of active layer than the soils of former reclaimed wastes disposals. Average thickness of the active layer was 0.3-0.4 m in natural soil and 1.3-1.4 m in anthropogenically-affected ones. This was affected by the change in the temperature regime of soils, and related to the destruction of upper organic layer and mechanical disturbance of the active soil layer on the waste polygons. It was shown, that the use of vertical electric sounding methodology in the soil surveys is useful for the identification of the permafrost depth without digging of soil pit. This method allows the identification of soil heterogeneity, because the electric resistivity (ER) values are strongly affected by soil properties. ER also intensively changes on the border of different geochemical regimes, *i.e.* on the border of the active layer and the permafrost. The lowest ER values were found for the upper organic horizons, the highest for permafrost table. Technogenic Superficial Formations exhibit lower resistivity values than natural soils. Therefore, disposition of WP and disturbance of the soil surface, results in permafrost degradation and an increase in the active layer thickness.

Key words: soils, Antarctic, Vertical Electric Sounding (VERS), Wastes Polygons (WP)

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Introduction

Soils and terrestrial ecosystems of the Antarctic attracts the interests of soil scientists, ecologists, geologists and chemists because of the isolation of landscapes and ecosystem from direct effects from other continents and due to relatively low anthropogenic disturbance of region. The severe conditions in Antarctic result in formation

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of weakly developed organic soils and specific soil cover with the dominance of Cryosols, Leptosols and Regoliths (Vlasov et al. 2005, Campbell et Claridge 1987). The soils and biosediments of different parts of the Antarctic have been investigated in aspects of morphology (Glazovskaya 1958, Bockheim et Hall 2002, Mergelov et al. 2012, Abakumov 2010, Abakumov et Mukhametova 2014, Abakumov et al. 2008), texture and lithology (Beyer et al. 2000, Abakumov 2010), mineralogy (Shaefer et al. 2008), geography (Campbell et Claridge 1987, Gilichinskiy et al. 2010), micromorphology (Kubiena 1970, Ilieva et al. 2003), and anthropogenically-induced changes (Balks et al. 2002, Kirtsideli et al. 2010). Many studies are connected to the accumulation of biogenic elements, humus formation and humification (Bolter 2001, Blume et al. 1996). Recent investigation has showed essential anthropogenic pollution of the Fildes Peninsula (Amaro et al. 2016, Padeiro et al. 2016).

Maritime Antarctica is characterized by the temperature and humidity conditions that differ from other parts of the Antarctic continent. Therefore, the soils of this region are considered as most developed in vertical scale and more weathered and differentiated than the soils from other regions. The most investigated area in terms of pedology in the Western Antarctic is the King George Island, the Fildes Peninsula in particular (Bockheim 2015). Soils of the Fildes Peninsula has been investigated by many researchers. Soil diversity and genesis was described with a special relation to environmental conditions (Bölter 2011, Gilichinskiy et al. 2010). Geochemical state of the soils were described by Lee et al. (2004) with the emphasis given to the geochemistry of parent materials. Soil biological features were investigated in relation to soil development by Bölter (2011). Data on initial processes of soil organic matter formation, *i.e.* humification and transformation, were published during the last decade (Abakumov et al. 2014, Abakumov 2010, Abakumov et Mukhametova 2014). The anthropogenic impact for the soils of the Fildes Peninsula was evaluated as well, especially in terms of spatial impact assessment of different factors (Peter et al. 2008), polycyclic aromatic compounds accumulation and redistribution (Abakumov et al. 2014, 2015) and trace elements geochemistry (Lu et al. 2012).

Nowadays, anthropogenic impact on the natural ecosystems of the Fildes Peninsula is expressed not only in contamination, but also in various other disturbances, such as *e.g.* soil ovecompaction caused by mechanical impact, soil surface consumption by a waste disposal and changing of the thermal regime on the areas and surroundings of the overwintering stations (Peter et al. 2008, Rakusa-Sushevskiy 1998). In this respect, soil thermic regime of the Fildes Peninsula was assessed in details by Michel et al. (2014). It was shown that the maximal thaw depth in Turbic Crysols was 117.5 cm. At the same time, active layer depths in Antarctic are quite variable and depend on the soil texture, landscape position, type of vegetation cover and the distance from the oceanic waters (Abramov et al. 2011). Permafrost table in soils is faced to the friable ground in many investigated plots, but, at the same time, permafrost can be situated inside the massive crystallic rock (Gilichinskiy et al. 2010). In such case active layer depth determination with the use of steel bar penetration became impossible (Gilichinskiy et al. 2010).

Active layer thickness and the depth of the permafrost layer are the basic features of soil cover of the Polar region and can be assessed by different direct or indirect methods. The classic method is to dig the soil profile or to drill the soil-ground mass. It is also possible to push a sharpened steel bar into the soil or ground until the frozen ground is encountered. There is still a difficulty to assess the steel bare penetration rate in case of grounds, which contents the features of wastes disposal and/or accumulations or high portion of stons of different size. While the still bare penetration and drilling became not very effective in the investigation the soil-anthropic-layer strata's, the electric resistivity measurements like a nonpenetrative method became more informative tool for investigation of soil-permafrost complex organization and its layer stratification. That is why the use of Vertical Electric Sounding (VERS) became actual for the Antarctic environments, in which the Circumpolar Active Layer Monitoring (CALM) plots can not be established. This is especially true for the places with the weak soil layer, underlayed by massive crystallic rock. The second aspect of the VERS methodology application is that it might be used in the presence of metallic and plastic wasted residues in soils of the polar station surroundings. This prevent the steel bar penetration into the soil-ground complex.

Nowadays, direct-current resistivity (DC resistivity) methods are used for the identification of permafrost depth and soil profile heterogeneity. Geophysical methods have many advantages (Scot et al. 1990) and have been widely used for permafrost identification and evaluation of soil permafrost layer vertical stratification (Hauck et al. 2003). This is a quantitative method, which allows carrying out quick measurements of ER along the different soil profiles, stratas and the permafrost layer. The key advantage of these methods is that the equipment is portable, easy to handle and can be used in severe climatic expedition conditions. The second one is the ability to detect the permafrost depth or to specify soil stratification without drilling or soil-pit preparation. A one-dimensional model can be assumed for mapping of the permafrost depth in relatively homogenous conditions, whereas the two-dimensional approach was proposed for plots with a high degree of inhomogeneity (Hauck et al. 2003, Pozdnyakov 2008). It is well known that electric conductivity and resistivity depend on soil chemical and physical properties, especially salt content, soil texture class of the fine earth, coarse fraction content, and soil moisture (Pozdnyakov 2008, Magnin et al. 2015). It was substantiated previously (Pozdnyakov 2008) that vertical electrical resistivity sounding (VERS) method is useful for the identification of separate soil horizons and stratas. The method of VERS allows to identify the contrast between soil horizons and layers changes in vertical scale and provides the precise information about solum-parent material organization. On the basis of the published data (Pozdnyakov 2008, Hauck et al. 2003, Gibas et al. 2005, Smernikov et al. 2008, Vanhala et al. 2009, Turu et Ros Visus 2013), we suppose that there are essential changes in the values of electrical resistivity on the transition from the solum to the permafrost (Abakumov et Tomashunas 2016, Alekseev et al. 2016, Abakumov et al. 2017). Moreover, it has been previously shown, that values of electric resistivity (ER) are different for clays, sands, over-moisted layers and permafrost. ER can be only about 10-30 Ωm in clay textured substrata's, about 500 Ωm in dry sand or even up to 40000-80000 Ωm in permafrost layers. Measurements of ER and ER visualization are well known methods for permafrost mapping and identification of soil-lithological heterogeneity in a vertical scale (Pozdnyakov 2008, Marchenko 2007).

The task which is underestimated for polar environment is the role of anthropogenic disturbances in the formation of the profile changes of electric resistivity values in soils, affected by precense of wastes disposal in surroundings of polar stations. Polar stations use the soil cover as the soil as the specific ecosystem service of "of soil space".

There are many current and former WPs on the territory of the Fildes Peninsula (plots 3-7). The former and reclaimed wasted disposal still shows the residual technical hard remnants inside the soil profiles. That is why we suppose that soil active layer will be affected by the presence of hard metallic and other remnants of the station activity.

Therefore, the aim of this study was to measure ER in various soils of the Fildes Peninsula, identify the depth of permafrost and active layer thickness, and identity the differences in permafrost layer in the natural environments and under the former WPs.

Material and Methods

Study sites

The soil profiles were described and VERS procedure in field was conducted during the 61st Antarctic expedition from January 17, 2016 to February 25, 2016. Soil descriptions were partly published early (Abakumov et al. 2008, 2010). Soils investigated belongs to Sub-Antarctic maritime zone (King George Island, South Shetland archipelago), Antarctic region. The "Bellingshausen" station (Russian scientific and logistic center on King George Island, 62° 12´ S, 58° 58´ W, 40 m a.s.l.) is situated on the Fildes Peninsula. The parent materials here are presented by andesites, basalts, and tuffs, the coastal areas is covered by maritime sands and gravels, while the periglacial plots are occupied by moraines and some fluvioglacial materials (Peter et al. 2008). The average annual temperature of air is -2.8°C, in Austral summer (January and February) the average monthly temperature rise up to 0.7-0.8°C (Abakumov et Andreev 2010). The soil surface temperature, however, is essentially higher when it is free from ice and snow. The total annual precipitation reaches 729 mm, the number of days with precipitation is from 22 to 30 days in month. The wind velocity is about 9.3 m s^{-1} (Peter et al. 2008) with maximum about 28 m s^{-1}. Vegetation diversity of the Fildes Peninsula is quite high in comparison with the ice-free landscapes of other Antarctic regions (Peter et al. 2008, Parnikoza et al. 2011, Abakumov 2011). Monospecific plant communities as well as mixed ones are common for both coastal part and in plateau of peninsula (Peter et al. 2008). This provides a possibility to many authors to identify it as a tundra or Antarctic tundra (Convey 2003, Casanova et Cavieres 2012). Plant communities of King George Island are the most developed and richest in whole the Antarctic (Peter et al. 2008, Parnikoza et al. 2011). There are plots of former penguin rockeries (*Pygoscelis* sp.), rocks affected by sea petrel (*Laurus dominicanus*) and fresh moraines in periglacial part, but not exactly on the territory of Bellingshausen station. The Fildes Peninsula presented mainly by tundra environment, or in some cases, by barrens communities, that is why the organic layer plays an important role in regulation of the thermic regime of the upper solum. At the same time an essential disturbances of soil surfaces are typical for the areas of stations locations and, especially for the locations of WPs, located in surroundings of the stations facilities. These disturbances could affect not only soil stratification and solid phase composition, but also the thawing depth and general solum stratification (Abakumov et Andreev 2011).

Two soil type were investigated near the location of Russian station Bellingshausen – Turbic Cryosols and Turbic Cryic Technosols ([1]) in the former waste disposal. These WP strongly affect the soil cover of the area about 1 ha in surroundings of the station (Fig. 1) and in during the 2015 they were reclaimed and the most of the technical hard materials were moved to the "Neftebaza" place where they were secondary stored into the former oil tank. Now the technical hard remnants still persist in the soil profiles of the territory of former

WP, and are mixed with soil mass due to cryogenic process. That is why our working hypothesis was that the presence of technical hard material may affect the soil horizontal organization as well as soil thermic regime. Previously it was shown (Abakumov et Andreev 2011), that the presence of developed organic horizons on the soil surface provide the specific temperature dynamic in soil profile, generally it expressed in decreased annual soil temperatures because of isolation of soil by organic layers.

The soil cover disturbance could also change the soil thermic characteristic by increasing of thawing depth. The working hypothesis of this study was to evaluate the soil electric resistivity values in soils of natural landscapes and those landscapes, which were changed by previous wastes disposals. Soils, investigated (Fig. 2) are classified as Turbic Cryosols in case of natural environments and Turbic Cryic Technosols in cases of former WP. Natural soils are covered by organic layer, composed by bryophyte and lichens, while soil of the former disposal have not any organic layer. That is why the organic carbon content in anthropogenically-affected soil is lower than in natural ones. The main difference between two types of investigated soil is the portion of the coarse (skeletal) fraction, which is essentially higher in soil of former disposal. This is, evidently caused by presence of technical hard remnants, and this give an opportunity to classify soil as Technosols. All the soil investigated has an acid fine earth and contains no any salts, the total organic carbon content is not high (Table 1) and this can not essentially effect the ER values.

Plot number	**TOC (%)**	**N (%)**	pH_{H_2O}	pH_{CaCl_2}	**Coase fraction (%)**	**Soil Type**	**Presence of technical hard material**
1	1.49 ±0.12	0.22	5.07	4.57	27	Turbic Cryosol	No
2	2.53±0.16	0.32	5.21	4.89	35	Turbic Cryosol	No
3	0.54±0.03	0.02	5.89	4.90	22	Turbic Cryic Technosols	Technical hard remnants
4	0.30±0.03	0.02	5.12	4.89	47	Turbic Cryic Tecnosols	Technical hard remnants
5	0.38±0.03	0.02	4.93	4.52	67	Turbic Cryic Tecnosol	Technical hard remnants
6	1.02±0.06	0.06	4.67	3.89	45	Turbic Cryic Technosol	Technical hard remnants
7	0.97±0.05	0.08	5.15	4.80	53	Turbic Cryic Technosol	Technical hard remnants
8	1.22±0.07	0.09	4.38	4.10	21	Turbic Cryosol	No
9	2.93±0.23	0.23	4.80	4.60	29	Turbic Cryosol	No
10	6.41±0.23	0.39	4.77	4.54	35	Turbic Cryosol	No
11	4.76±0.21	0.51	6.69	6.60	28	Turbic Cryosol	No
12	1.14±0.05	0.05	4.21	4.01	27	Turbic Cryosol	No
13	2.43±0.06	0.29	4.77	4.54	26	Turbic Cryosol	No
14	2.20±0.03	0.26	3.55	3.10	32	Turbic Cryosol	No

Table 1. Soil general properties (upper solum). Data on carbon content were determined in 4 replications, standart deviation values are given after ±.

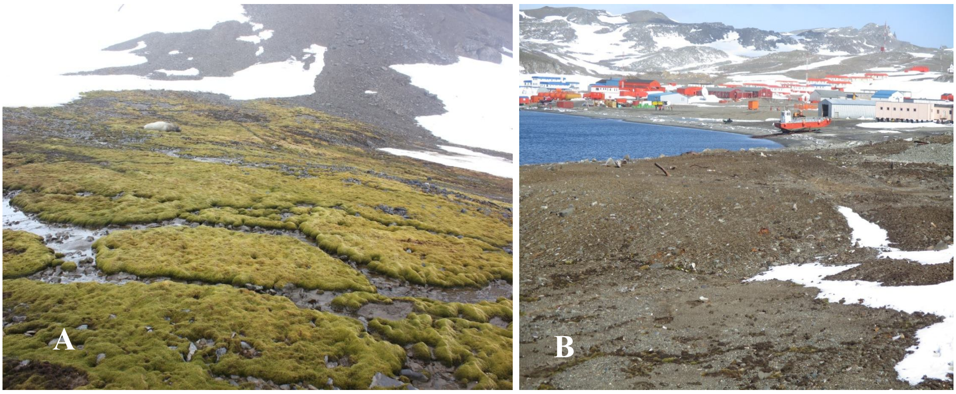

Fig. 1. Surface of a natural landscape (A) and of the former reclaimed waste disposal near the Bellingshausen station, Fildes Peninsula (B).

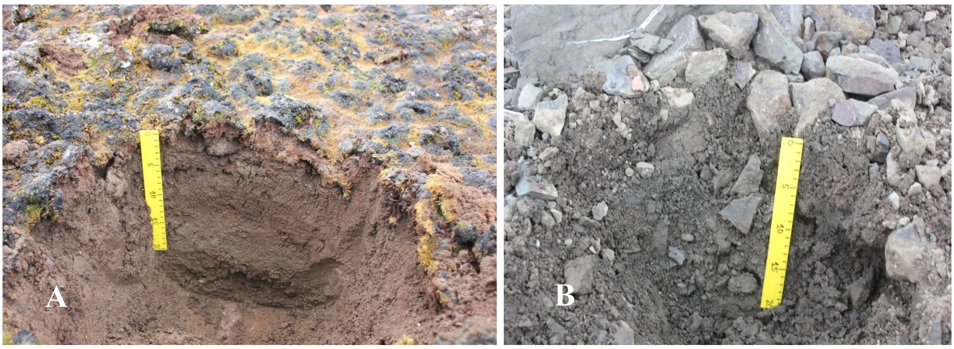

Fig. 2. Natural (A), and anthropogenically-affected soils (B) in the surroundings of the Bellingshausen station, Fildes Peninsula.

Methods of ER measuring

The ER values of the soil profiles, separate horizons and upper permafrost layers can be estimated from the vertical electrical sounding data, which provides the values on the changes in the electrical resistivity throughout the profile from the soil surface without digging pits or drilling. This method allows dividing the soil layer vertically into genetic layers with different properties and characteristics and to evaluate the current active layer depth (Pozdnyakov et al. 1996, Pozdnyakov 2008). Typically, different soil layers have different ER values. That is why, the sharp changes in ER values in soil profiles can be interpreted as results of transition of one horizon to another (Pozdnyakov 2008, Ohashi et al. 2012).

In our study, the resistivity measurements were performed using four-electrode (AB + MN) arrays of the AMNB configuration with use of the Schlumberger geometry (Marchenko 2007). A Landmapper ERM-03 instrument (Landviser, USA) was used for the VERS measurements in this study. Vertical electric soundings using the Schlumberger configuration were carried out at nine locations on different part of the

"Bellingshausen" station surroundings. Totally 14 soil plots were chosen for investigation: 10 natural soils and 4 WPs. The natural soil were situated in surroundings of station, but not far than 500 m, while the WPs plots were situated very close to the station territory. The apparent resistivity readings at every VERS point were automatically displayed on the digital readout screen and then written down on the field note book with taking into account the geometry factor.

A VERS was used to study the upper 0- to 3-m thick layer in greater detail. The distance between the A and B electrodes ranged from 20 to 600 cm while the distance between the M and N electrodes was constant – 10 cm. The distance between M and N electrodes was constant, while the distance between A and B horizons was changed according to nessesary depth of sounding which is proportional to the (A-B)/2 values. The electrodes were placed on the soil (ground) surface with depth of penetration into soil about 0.5 cm. The distance between M and N electrodes were constant, while the distance between A and B electrodes changed from 10 to 600 cm. The soils were "sounded" thoroughly and found to vary between 10 cm and 3 m in A-B distances. A 1D layer model (Marchenko et al. 2007) of apparent and real resistivity's processing and visualization were used. This model provides the data on apparent resistivity values changes with the depth (ρ), the layers thickness (h) and layer depth (z).

Totally 14 soil profiles from the different parts of the surroundings of the Bellingshausen station have been investigated. Field data presented by three replications of measurements at each point, totally 14 soil profiles were investigated. The geometric factor, K, was first calculated for all the electrode spacing's using the formula: $K = \pi \times (AB/2+MN/2) \times (AB/2-MN/2)/(2xMN/2)$ for Schlumberger array. The values obtained, were then multiplied with the resistance values to obtain the apparent resistivity, ρa, values. Then the apparent resistivity, ρa, values were plotted against the electrode spacing's (1/2AB) on a log-log scale to obtain the VERS sounding curves using an appropriate computer software ZONDIP.

The modeling of the VERS measurements carried out at 14 measuring points has been used to derive the geo-electric sections for the various profiles. These have revealed that there are mostly two or three geologic layers beneath each VERS station. Three resistivity sounding curve types were obtained from the studied area and these are the 1 ($\rho1>\rho2< \rho3$), 2 ($\rho1< \rho2<\rho3$) and 3 ($\rho1>\rho2< \rho3>\rho4$) type curves.

Results and Discussion

Fig. 3 and Table 2 show data and interpretation for the sites investigated. Measured apparent resistivity values (black dots) are plotted against half electrode distance and fitted by manual curve resulting from inversion process. Solid black line denotes the layer model and the thin lines show the calculated model apparent resistivity curve. The purpose of the program ZONDIP is to determine the resistivity of the rectangular blocks that will produce an apparent resistivity pseudo-section that agrees with the actual measurements. The depths of the layers can also be changed manually by the user. The optimization method basically tries to reduce the difference between the calculated and measured apparent resistivity values by adjusting the resistivity of the model blocks. However it must be stated that small-scale lateral inhomogeneities do not allow a very good agreement between model and observed data.

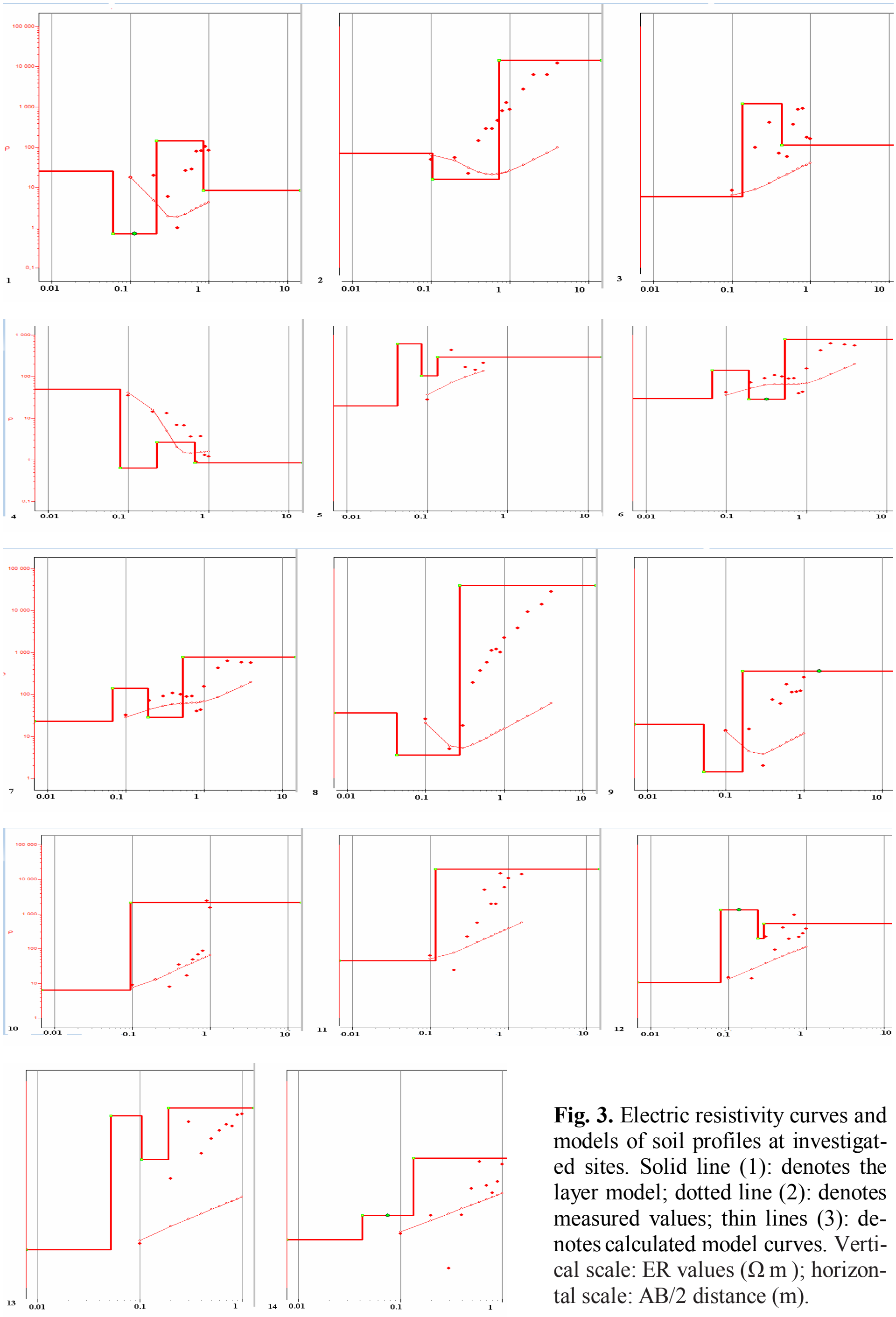

Fig. 3. Electric resistivity curves and models of soil profiles at investigated sites. Solid line (1): denotes the layer model; dotted line (2): denotes measured values; thin lines (3): denotes calculated model curves. Vertical scale: ER values (Ω m); horizontal scale: AB/2 distance (m).

VERS section	P-modelled resistivity (Ω m)	Z-bottom layer depth (m)	Depth permafrost table (m)
1	25.7	0.06	
	0.7	0.2	
	147.0	0.6	
	860.0	0.8	0.8
2	70.0	0.0	
	16.0	0.1	
	14355.7	0.7	0.7
3	6.0	0.0	
	1211.0	0.1	
	114.3	0.4	0.4
4	49.7	0.08	
	0.6	0.1	
	2.7	1.1	
	150.0	1.3	1.3
5	20.0	0.0	
	611.8	0.04	
	103.6	0.08	
	150.5	1.1	1.1
6	30.0	0.0	
	141.4	0.07	
	28.6	0.2	
	791.1	1.3	1.3
7	22.9	0.0	
	141.4	0.07	
	28.6	0.2	
	791.0	1.4	1.4
8	364	0.0	
	3.6	0.04	
	35565.5	0.5	0.5
9	19.6	0.0	
	1.4	0.05	
	364.0	0.4	0.4
10	6.4	0.0	
	6956.0	0.6	0.6
11	45.7	0.0	
	19378.0	0.3	0.3
12	10.7	0.0	
	1328.6	0.08	
	199.3	0.2	
	105.9	0.3	0.3
13	8.6	0.0	
	1470.0	0.05	
	1310.0	0.1	
	22853.0	0.5	0.5
14	15.0	0.0	
	57.0	0.04	
	710.0	0.4	0.4

Table 2. Modeled resistivity and evaluated depth of permafrost table.

Results of soil VERS measurement (*see* Table 2) show essentially heterogeneity of ER values within the soil profile in investigated plots. The lowest values of ER were revealed for the upper solum of the soils investigated. There are notable sharp changes in ER values with soil depth, particularly in those layers, where the solum (active soil layer) is in contact with the permafrost table. This well corresponds to data, obtained previously (Ohashi et al. 2012, Abakumov et Tomashunas 2016, Gibas et al. 2005, Ikeda 2006), that the permafrost layers shows the ER values about hundreds - thousands Ωm, while the soil materials in borders of active layer characterizes by values about 10-100 Ωm. The data obtained show that the upper border of the permafrost layer coincides with that ER transition, which was identified in field on the base of soil profile morphology description.

There is general trend of increasing ER in all the soils investigated from the topsoil to the permafrost table. The interruption in these increasing of the lines are more expressed in soils of former WPs disposals and caused by they former mechanical soil disturbance and appearance of artificial materials in solum.

In general, there are two differences if ER curves between natural soil and soil of the former waste disposal. The first is the higher vertical heterogeneity of ER distribution in anthropogenically affected grounds than in natural soils. This reflects the mechanical heterogeneity of soil profile, where turbic processes appears not only as a result of cryogenic process, but also caused by admixing of solid technical hard remnants to the soil material. The last factor result in more pronounces turbation process. The second difference of soil on the former wastes disposal is the higher thickness of active layer – up to 1.3-1.4 m, instead of 0.3-0.7 m in natural soils. The higher thickness of the active layer related to more intensive thawing processes in soils, affected by waste disposal. Technical hard remnants, situated in soil material increase the soil thermal conductivity and provide penetration of air in deeper layers. In addition, the absence of organic layer in case of waste disposal leads to increasing of thawing process due to higher isolation and to the absence of thermic isolation of soil, provided by organic layer. The role of organic material in thermal isolation of Antarctic soils discussed previously (Abakumov et Andreev 2011), while soil temperature regime were compared for soil with organic layer and without. Previously, the VERS methodology were applied for assessment groundwater level in grounds (Samouëlian et al. 2005) and ground water contamination on the territory of waste disposals (Karlık et Kaya 2001). In addition, the electric resistivity was used for mapping of oil spills in Antarctic environment (Pettersson et Nobes 2003). But no combined evaluation of ER for wastes polygons on permafrost environments were applied. In case of permafrost affected soils, application of VERS became useful for evaluation of soil thawing depth. VERS methodology can be used also for monitoring of the station current activity impact on the grounds. Degradation of permafrost can affect the stability of buildings basement and construction stability (Chambers et al. 2006). The data presented in this study on ER values in permafrost-affected soil coincides with those, published by McGinins et Jensen (1971) and Kasprzak (2015) who have shown that increased values of ER related to the permafrost table. At the same time, ER values in anthropogenically-affected soils are lower that in natural ones. Anthropogenically-affected soils show the lower ER values throughout the vertical profile which is connected with changing of composition and stratification of the solum. This is normal for Technosols in of Boreal environments, without effect of permafrost (Pozdnyakov 2008). The higher ER values in soils of natural environments caused by natural fabric of the particles and aggregates as well as higher portion of the fine earth of clayely texture, which normally provides the higher measured ER values (Pozdnyakov 2008). Thus, the ER values can be used in field survey of polar soils with aim of identification of anthropic mechanical impact.

Conclusions

Soils of the Fildes Peninsula are various in terms of morphology, stratigraphy and active layer thickness. The main soil types in surroundings of the Bellingshausen station represented by Turbic Cryosols in natural landscapes and Turbic Cryic Technosols on the territory of reclaimed former waste disposals. Anthropogenic factor, namely waste disposition on the territory of polar station surroundings, results in changes in soil thermic regime. This is caused by the accumulation of technical hard remnants and by degradation of the upper solum organic layers. It was shown, that the active layer thickness were twice higher in Technosols than in natural soils, which provide evidence of permafrost thawing under the station activity.

The use of VERS methodology in the soil survey is useful for identification of the permafrost depth without digging of soil pit. This method allows the identification of soil heterogeneity, because the ER values are strongly affected by soil properties and intensively changes on the border of different geochemical regimes, *i.e.* on the border of the active layer and the permafrost. The lowest ER values were founded for topsoil organic horizons, the highest – for the permafrost table. Technosols showed normally lower electric resistivity values that natural ones, which is related to the disturbance of soil stratification and increasing of soil permeability to air and water.

It can be summarized, that VERS methodology is a useful tool for preliminary soil surveys in the regions with permafrost-affected soil cover. VERS can be applied also for the elucidation of soil-permafrost layer stratification in field soil pits and for the assessment of the levels and rate of permafrost degradation in zones of permanent stations impact.

References

ABAKUMOV, E. V. (2010): Particle-size distribution in soils of West Antarctica. *Eurasian Soil Science*, 43(3): 297-304.

ABAKUMOV, E. V. (2010): The sources and composition of humus in some soils of West Antarctica. *Eurasian Soil Science*, 43(5): 499-508.

ABAKUMOV, E. V., ANDREEV, M. P. (2011): Temperature regime of humus horizons of the King-George Island, Western Antarctica. *Biological Communications*, 2: 129-133.

ABAKUMOV, E. V., LODYGIN, E. D., GABOV, D. A. and KRYLENKOV, V. A. (2014): Polycyclic aromatic hydrocarbons content in Antarctica soils as exemplified by the Russian polar stations. *Gigiena i Sanitariia*, 1: 31-35.

ABAKUMOV, E. V., MUKHAMETOVA, N. (2014): Microbial biomass and basal respiration of selected Sub-Antarctic and Antarctic soils in the areas of some Russian polar stations. *Solid Earth*, 5: 705-712.

ABAKUMOV, E. V., POMELOV, V. N., VLASOV, D. Y. and KRYLENKOV, V. A. (2008): Morphological organization of soils in Western Antarctica. Vestn. St.-Peterb. Univ., Ser. 3: Biol., No. 3: 102-115.

ABAKUMOV, E. V., PARNIKOZA, I. Y., LUPACHEV, A. V., LODYGIN, E. D., GABOV, D. N. and KUNAKH, V. A. (2015): Content of polycyclic aromatic hydrocarbons in soils of Antarctic stations regions. *Gigiena i sanitaria*, 7: 20-25.

ABAKUMOV, E. V., TOMASHUNAS, V. (2016): Electric resistivity of soils and upper permafrost layer of the Gydan Peninsula. *Polarforschung*, 86(1): 27-34.

ABAKUMOV, E. V., TOMASHUNAS, V. and ALEKSEEV, I. (2017): Profiles of vertical electric resistivity of selected soils of Yamal autonomus region. *Eurasian Soil Science*. (accepted in press).

ABAKUMOV, E. V., TRUBETSKOJ, O., DEMIN, D. and TRUBETSKAYA, O. (2014): Electrophoretic evaluation of initial humification in organic horizons of soils of western Antarctica. *Polarforschung*, 83(2): 73-82.

ABRAMOV, A. A., SLETTEN, R. S., RIVKINA, E., MIRONOV, V. and GILICHINSKY, D. A. (2011): Geocryological conditions of Antarctica. *Earth Cryosphere*, 15(3): 3-19.

ALEKSEEV, I., ABAKUMOV, I. and SHAMILISHVILY, G. (2016): Vertical electric sounding of soil and permafrost layers of the Eastern macro slope of the Polar Urals and the surroundings of Erkuta river. *Agrophysics*, 3: 1-6.

AMARO, E., PADEIRO, A., DE FERRO, A. M., MOTA, A. M., LEPPE, M., VERKULICH, S., HUGHES, K. A, PETER, H. U. and CANÁRIO, J. (2016): Assessing trace element contamination in Fildes Peninsula (King George Island) and Ardley Island, Antarctic. *Marine Pollution Bulletin,* 97 (1-2): 523-527, http://dx.doi.org/10.1016/j.marpolbul.2015.05.018.

BALKS, M. R., PAETZOLD, R. F., KIMBLE, J. M., AISLABIE, J. and CAMPBELL, I. B. (2002): Effects of hydrocarbon spills on the temperature and moisture regimes of Cryosols in the Ross Sea region. *Antarctic Science*, 14(4): 319-326, doi: 10.1017/S0954102002000135.

BEYER, L., PINGPANK, K., WRIEDT, G. and BÖLTER, M. (2000): Soil formation in coastal continental Antarctica (Wilkes Lands). *Geoderma*, 95(3-4): 283-304.

BLUMME, H-P, SCHNEIDER, D. and BÖLTER, M. (1996): Organic matter accumulation in and podzolisation of Antarctic soils. *Journal of Plant Nutrition and Plant Science*, 159(4): 411-412.

BOCKHEIM, J. G. (ed). (2015): The Soils of Antarctica. Springer. 322 p., ISBN 978-3-319-05497-1.

BOCKHEIM, J. G., HALL, K. (2002): Permafrost, active-layer dynamics and periglacial environments of continental Antarctica. *South African Journal of Science*, 98: 82-90.

BÖLTER, M. (2011): Soil development and soil biology on King George Island, Maritime Antarctic. *Polish Polar Research*, 32(2): 105-116.

CAMPBELL, I. B., CLARIDGE, G.G.C. (1987): Antarctica: Soils, Weathering Processes, and Environment. Elsevier, Amsterdam. 368 p.

CASANOVA KATNY, A. M., CAVIERES, L. A. (2012): Antarctic moss carpets facilitate growth of *Deshampsia antarctica* but not its survival. *Polar Biology*, 35: 1869-1878.

CONVEY, P. (2003): Maritime Antarctic climate Change: Signals from terrestrial biology. *Antarctic Research Series*, 79: 145-158.

CHAMBERS, J. E., KURAS, O., MELDRUM, P. I., OGILVY, R. D. and HOLLANDS, J. (2006): Electrical resistivity tomography applied to geologic, hydrogeologic, and engineering investigations at a former waste-disposal site. *Geophysics*, 71(6): B231-B239. https://doi.org/10.1190/1.2360184.

GIBAS, J., RACHLEWICZ, G. and SZCZUCINSKI, W. (2005): Application of DC resistivity soundings and geomorphological surveys in studies of modern Arctic glacier marginal zones, Petuniabukta, Spitsbergen. *Polish Polar Research*, 26(4): 239-258.

GILICHINSKIY, D., ABAKUMOV, E., ABRAMOV, A., FYODOROV-DAVYDOV, D., GORYACHKIN, S., LUPACHEV, A., MERGELOV, N. and ZAZOVSKAYA, E. (2010): Soils of mid and low antarctic: Diversity, geography, temperature regime. Proceedings of the 19th World Congress of Soil Science; Soil Solutions for a Changing World; ISBN 978-0-646-53783-2; Published on DVD; http://www.iuss.org; Symposium WG. 1.4.; Cold soils in a changing world; 2010 Aug 1-6. Brisbane, Australia: IUSS; pp. 32-35.

GLAZOVSKAYA, M. A. (1958): Weathering and initial soil formation in Antarctica. *Nauch Dokl Vyssh Shkoly Geol Geogr Nauki*, 1: 63-76.

HAUCK, C., MÜHLL, D. V. and MAURER, H. (2003): Using DC resistivity tomography to detect and characterize mountain permafrost. *Geophysical Prospecting*, 51: 273-284, doi:10.1046/j.1365-2478.2003.00375.x.

ILIEVA, R., VERGILOV, Z. and GROSEVE, M. (2003): Micromorpology of organic matter in the Antarctic soils. *Bulgarian Journal of Ecological Science*, 304: 52-54.

IKEDA, A. (2006): Combination of conventional geophysical methods for sounding the composition of rock glaciers in the Swiss Alps. *Permafrost and Periglacial Processes*, 17: 35-48.

KARLIK, G., KAYA, M. A.(2001): Investigation of groundwater contamination using electric and electromagnetic methods at an open waste-disposal site: a case study from Isparta, Turkey. *Environmental Geology*, 40: 725-731.

KASPRZAK, M. (2015): High-resolution electrical resistivity tomography applied to patterned ground, Wedel Jarlsberg Land, south-west Spitsbergen. *Polar Research*, 34: 25678.

KIRTSIDELI, I. YU., VLASOV, D., ABAKUMOV, E. V. and GILICHINSKY, D. A. (2010): Diversity and enzyme activity of microfungi from Antarctic soils. *Mikologiya I Fitopatologiya*, 44(5): 387-397.

KUBIENA, W. L. (1970): Micro morphologic investigations of Antarctic soils. *Antarctic Journal*, 5: 105-106.

LEE, Y. II, LIM, H. S. and YOON, H. II (2004): Geochemistry of soils of King George Island, South Shetland Islands, West Antarctica: Implications for pedogenesis in cold polar regions. *Geochimica et Cosmochimica Acta*, 68(21): 4319-4333, https://doi.org/10.1016/j.gca.2004.01.020.

LU, Z., CAI, M., WANG, J., YANG, H. and HE, J. (2012): Baseline values for metals in soils on Fildes Peninsula, King George Island, Antarctica: the extent of anthropogenic pollution. *Environmental Monitoring and Assessment*, 184(11): 7013-7021.

MAGNIN, E., DELINE P., RAVANEL, L., NOETZLI, J. and POGLIOTTI, P. (2015): Thermal characteristics of permafrost in the steep alpine rock walls of the Aiguille du Midi (Mont Blanc Massif, 3 842 m a.s.l). *The Cryosphere*, 9: 109-121, https://doi.org/10.5194/tc-9-109-2015.

MARCHENKO, M. N. (ed). (2007): Manual on Vertical Electric Sounding. - Moscow, Moscow State University, pp. 1-30.

MCGINIS, L.D., JENSEN, T. E. (1971): Permafrost-hydrogeologic regimen in two ice-free valleys, antarctica, from electrical depth sounding. *Quaternary Research*, 1: 389-409.

MERGELOV, N. S., GORYACHKIN, S. V., SHORKUNOV, I. G., ZAZOVSKAYA, E. P. and CHERKINSKY, A. E. (2012): Endolithic pedogenesis and rock varnish on massive crystalline rocks in East Antarctica. *Eurasian Soil Science*, 45(10): 901-917, https://doi.org/10.1134/S1064229312100067.

MICHEL, R. F. M., SCHAEFER, C. E. G. R., SIMAS F. M. B., FRANCELINO, M. R., FERNANDES-FILHO, E. I., LYRA, G. B. and BOCKHEIM, J. G (2014): Active-layer thermal monitoring on the Fildes Peninsula, King George Island, maritime Antarctica. *Solid Earth*, 5: 1361-1374, https://doi.org/10.5194/se-5-1361-2014.

OHASHI, K., KOIKE, T., TAKENAKA, S. and UMEMURA, J. (2012): Study on Applicability of Electric Sounding for Interpretation of the Internal Structure of Glacial Moraines. *Global Environmental Research*, 16: 51-58.

PADEIRO, A., AMARO, E., DOS SANTOS, M. M. C., GOMES, M. S, LEPPE, M., VERKULICH, S., HUGHES, K. A., PETER, H-U and CANÁRIO, J. (2016): Trace element contamination and availability in the Fildes Peninsula, King George Island, Antarctica. *Environmental Science: Processes & Impacts*, 18: 648-657.

PARNIKOZA, I., KORSUN, S., KOZERETSKA, I. and KUNAKH, V. A (2011): Discussion Note on Soil Development under the Influence of Terrestrial Vegetation at two Distant Regions of the Maritime Antarctic. *Polarforschung,* 80(3): 181-185, hdl:10013/epic.38394.d001.

PETER, H.-U., BÜßER/BRAUN, CH., MUSTAFA, O. and PFEIFFER, S. (2008): Risk assessment for the Fildes Peninsula and Ardley Island and the development of management plans for designation as Antarctic Specially Protected or Managed Areas. Jena University, Jena, pp. 1-344.

PETTERSSON, J. K., NOBES, D. C. (2003): Environmental geophysics at Scott Base: ground penetrating radar and electromagnetic induction as tools for mapping contaminated ground at Antarctic research bases. *Cold Regions Science and Technology*, 37(2): 187-195, 00037-5.

POZDNYAKOV, A. I. (2008): Electrical parameters of soils and pedogenesis. *Eurasian Soil Science*, 10: 1050-1058.

POZDNYAKOV, A. I., POZDNYAKOVA, L. A. and POZDNYAKOVA, D. A. (1996): Constant Electric Fields in Soils. 1-360.

RAKUSA-SUSHEVSKIY, S. (1998): The past and present of King-George Island (South-Shetland Islands, Antartcica). *Polish Polar Research*, 19: 249-252.

SAMOUËLIAN, A., COUSIN, I., TABBAGH, A., BRUAND, A. and RICHARD G. (2005): Electrical resistivity survey in soil science: a review. *Soil and Tillage research*, 83: 173-193, https://doi.org/10.1016/j.still.2004.10.004

SCOTT, W., SELLMANN, P. and HUNTER, J. (1990): Geophysics in the study of permafrost.- Geotechnic. Environment. Geophys., ed. S.Ward (ed.) Soc. Explor. Geophys,Tulsa, 355-384.

SHAEFER, C. E. G. R., SIMAS, F. N. B., GILKES, R. J., MATHISON, CH., DA COSTA, L. M. and ALBUQUERQUE, M. A. (2008): Micromorphology and microchemistry of selected Cryosols from maritime Antarctica. *Geoderma*, 144: 104-115, https://doi.org/10.1016/j.geoderma.2007.10.018.

SMERNIKOV, S. A., POZDNYAKOV, A. I. and SHEIN, E. V. (2008): Assessment of soil flooding in cities by electrophysical methods. *Eurasian Soil Science*, 10: 1059-1065.

TURU I MICHELS V., ROS VISUS X. (2013): Geophysical survey carried out in the Hansbreen glacial front (Hornsund, SW Spitzbergen): Surface Nuclear Magnetic Resonance (SNMR), Magnetic susceptibility of rocks and Electrical Resistivity facies: Permafrost identification and subglacial aquifers.- IV Congreso Ibérico de la I.P.A. Núria (Vall de Ribes, Pirineo oriental), junio 2013.

VANHALA, H., LINTINEN, P. and OJALA, A. (2009): Electrical Resistivity Study of Permafrost on Ridnitšohkka Fell in Northwest Lapland, Finland. *Geophysica*, 45: 103-118.

VLASOV, D. Y., ABAKUMOV, E. V. (2005): Lithosols of King George Island. Western Antarctica. *Eurasian Soil Science*, 38(7): 681-687.

Web sources / Other sources

[1] World Reference Base of Soil Resources. (2014) World soil resources report, No 106, FAO, Rome.