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Soils of the Argentine Islands, Antarctica: Diversity and Characteristics

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Abstract: The Argentine Islands is one of the relatively richly vegetated regions of the maritime Antarctic, with the most developed vegetation type being the Antarctic herb tundra formation. In the present study we address the soils of the central island of this archipelago, Galindez Island, to investigate their morphology, chemistry, trace element contents, microbiological characteristics in order to provide a complex description of the soils of central maritime Antarctica. We found the region to be characterised by ornithic soils (Ornithosols), Leptosols, Gleysols, and Histosols. Their distribution appeared to depend on a number of factors, such as the proximity and size of penguin rookeries, characteristics of the parent rocks, the resident plants communities, and hydrological conditions. The active layer of these soils is shallow (20-40 cm), but is significantly thicker than at King George Island (30-150 cm). The examined soils demonstrate substantial accumulation of carbon and nitrogen, which is not typical for the Antarctic barrens; therefore, they are classified as tundra-type soils. The current and former effects of zoogenic material have played a key role in the soils' enrichment with biogenic elements via both direct deposition and intensification of biological processes. The latter effect is weakest in ornithic soils, but all the other types of the regional soils have been strongly impacted by vegetation. The studied soils were found to be quite heterogeneous in regard to their trace element content, probably caused by both natural sources in the parent rocks and anthropogenic pollution. Ornithic soils were found to have highest abundances in microbiota. The soils of Galindez Island are exposed to ongoing climate changes and anthropogenic impacts; therefore, continued monitoring and conservation are important.

Zusammenfassung: Die Argentine Islands gehören zu den Gebieten der maritimen Antarktis, die reich an Vegetation sind. Hier dominiert die Antarktische Tundren-Formation. Die Böden der Zentralinsel des Archipels, Galindez Island, wurden im Hinblick auf Morphologie, Chemie, Spurenelemente und mikrobiologische Eigenschaften untersucht. Das Ziel war es, Informationen bezüglich der komplexen Eigenschaften der Böden des zentralen Teils der maritimen Antarktis zu liefern. Die in dieser Arbeit beschriebenen Hauptbodentypen sind ornithische Böden (Ornithosols), Leptosols, Gleysols und Histosols. Ihre Verteilung hängt mit der Abundanz von Pinguinkolonien, der Charakteristik des Ausgangsgesteins, der verschiedenen Pflanzengesellschaften und hydrologischen Bedingungen zusammen. Die Mächtigkeit der saisonalen Auftauschicht war gering (20-40 cm) aber mächtiger als auf King George Island. Es gibt deutliche Wechselbeziehungen zwischen den Böden und einigen Vegetationstypen. Die untersuchten Böden zeigen erhebliche Anreicherungen an Kohlenstoff und Stickstoff, was untypisch für antarktische Polarwüsten wäre. Aus diesem Grund wurden alle untersuchten Böden als Tundrenböden klassifiziert. Die Auswirkungen des zoogenen Materials spielen aktuell als auch in der Vergangenheit eine Schlüsselrolle für die Anreicherung von biogenen Elementen in Böden über zwei Prozesse, nämlich die direkte Zunahme des Feinerdeanteils durch die biogenen Elemente als auch durch eine Intensivierung der biogenen Prozesse. Dieser Effekt ist am schwächsten in den ornithischen Böden ausgeprägt. Somit sind die Eigen schaften der anderen Böden hauptsächlich vegetationsabhängig. Die heterogenen Gehalte an Spurenelementen sind wahrscheinlich das Ergebnis von Erosion natürlicher Substrate als auch der anthropogenen Verschmutzung. Mikrobiologische Untersuchungen zeigen die höchste Anreicherung von Mikrobiota in den ornithischen Böden. Die Böden von Galindez Island werden von den aktuellen Klimaänderungen und von anthropogenen Einwirkungen beeinflusst. Aus diesem Grund sind ein kontinuierliches Monitoring dieser Böden und ihr Schutz von großer Bedeutung.

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INTRODUCTION

Maritime Antarctica is an area of relatively advanced pedogenesis in comparison with the continental part of the Antarctic (Blume et al. 2002, Abakumov 2010, 2011, Parnikoza et al. 2011a). The morphological types of soil are quite variable, especially for the Antarctic Peninsula. Here, the main soil types are presented by undeveloped profiles (Leptosols, Lithosols, Entisols). Some Cryosols exhibit notable signs of cryoturbation in cases when relatively thick friable parent material layers are present. Likewise, Gleysols and gleyified soils exposed to excess of ground and surface moisture and ornithic soils formed on penguin rookeries show cryoturbation. Arctic soils are also very variable, and the active layer thickness can be also very small (Vlasow et al. 2005). In the Antarctic, soils are frequently separated from the permafrost by massive crystal rock, while in polar ecosystems in the northern hemisphere permafrost is typically in direct contact with the soil. Nevertheless, all of the Antarctic soils are Gelisols, with the permafrost appearing within one meter (Soil Survey Staff 2014).

The ecosystems of the western side of the Antarctic Peninsula are strongly influenced by both the periglacial conditions and the proximity to the ocean. The climate in this part is relatively warm and humid compared to the eastern side of the Peninsula and the continental parts of the Antarctic (Abakumov & Mukhametova 2014). Thus this region of the Antarctic Peninsula coastal zone is known as maritime Antarctica. Here, the terrestrial ecosystems are characterized by relatively high soil diversity and biodiversity. The biodiversity of the maritime Antarctic has been reported to be strongly affected by birds which play an active role in plant dispersal by using viable plant parts and seeds as nest building material and thus having impact on the distribution of some plant communities (Parnikoza et al. 2012). Another specific feature of this region's ecosystems is a relatively long period of soil-biological activity (Abakumov & Andreev 2011), which in some years reaches up to 100 days per year. The third pedological feature is the accumulation of guano and related compounds in proximity to penguin rookeries (Smykla et al. 2015) or near the feeding and nesting sites of other birds. All these factors lead to increased soil diversity, which in turn plays a key role for biodiversity.

From the pedological standpoint, only some areas of the maritime Antarctic have been well surveyed, with more attention having so far been paid to continental parts (Allen & Heal 1970, Campbell & Claridge 1987, Lupachev & Abakumov 2013, Abakumov et al. 2015, Bockheim 2015, Chukov et al. 2015). The lack of basic surveys of the Antarctic soils in many parts of the Antarctic impedes our understanding of their ability to support biotic communities and limits our ability to monitor and predict the impact of current environmental changes, such as regional warming, on Antarctic terrestrial ecosystems (Convey 2003, Day et al. 2008, Turner et al. 2013, Smykla et al. 2015). One of such understudied regions in the central part of the maritime Antarctic are the Argentine Islands. These islands are a relatively richly vegetated region of the maritime Antarctic covered with stretches of Antarctic herb tundra formation (Smith & Corner 1973). This rocky archipelago consists of 40 islands with a relatively short vegetating season of about three months and a high density of colonial birds, which creates a strong ornithogenic influence. The well-developed flora of the islands is represented by lichens, bryophytes, fungi, algae, and two vascular plants, *Deschampsia antarctica* Desv. and *Colobantus quitensis* (Kunth) Bartl. These vascular plants are the distinctive species of the Antarctic herb tundra formation (Smith & Corner 1973, Parnikoza et al. 2009). Birds play a crucial role in the distribution of the vegetation components and intensification of soil formation (Parnikoza et al. 2012, 2015). In the conditions of a regional warming in Western Antarctica, it is thus important to understand the regional soil diversity and the initial soil forming processes. In this study, we present an initial description of the soil diversity on the Argentine Islands by focusing primarily on five types of characteristics:

i) The thickness of the active layer and heterogeneity of parent material layers.

ii) The soil morphological diversity in different parts of the Argentine Islands.

iii) The organic matter accumulation in initial soils.

iv) The contents of trace elements.

v) The diversity of microorganisms in different types of soils.

MATERIALS AND METHODS

Description of study sites

The study was conducted during the 18th (2013/14) and 19th (2014/15) Ukrainian Antarctic Expeditions to Galindez Island (Argentine Islands) near the Ukrainian Vernadsky Antarctic station (western Galindez Island, Marina Point, 65°14.742' S, 64°15.407' W) (Fig. 1). The Argentine Islands Archipelago is located on the coastal shelf of the western part of the Antarctic Peninsula, 5-7 km from the continent (Graham Land, Kyiv Peninsula). Galindez Island is located in the central part of the archipelago. The climate of the maritime Antarctic is cold and is heavily influenced by the interaction of humid and relatively warm air masses from the Pacific sector of the South Ocean, cold and dry air masses from the continent, and oceanic circulations that influence the Peninsula's mountain chain. At the Vernadsky Station, the average annual temperature has been recorded to have increased by 2 ºC in the period from 1947 to 2007. The average annual precipitation is about 433 mm with a variation coefficient of 0.32 (Martazinova et al. 2010). A stable snow cover lasts from March until October-November (Timofeev 1997), and glacier occupies approximately 70 % of Galindez Island. The highest point of Galindez Island is Woozle Hill (51 m.a.s.l.) located in the northeast portion of the island ice cap.

Galindez Island and some of the surrounding islands (entirely or partially) consist primarily of breccias, andesites, and tuffs, which belong to the Upper Jurassic Volcanic Group (Elliot 1964, Govorucha 1997). The coast of the islands is abrupt and rocky without signs of abrasion and beaches (Govorucha 1997). Middle-scale ridges with average height about 10-15 m are a typical form of relief. The depressions between the ridges are filled with snow usually throughout the year. Some information about the soil formation conditions in the Argentine Islands region has already been reported in previous publications (Govorucha 1997, Korsun 2005, Korsun et al. 2008, Parnikoza et al. 2011, Nedogibchenko et al. 2013, Roshal et al. 2013, Kozeretska et al. 2015).

The regional vegetation communities were initially described in 1970 by Smith & Corner (1973). The vegetation cover is well developed on the slopes of high hills that are exposed to the north or northwest. Typical plant communities in current time according to our investigation are:

(1) Moss community *Polytrichum strictum Brid.-Chorisodontium aciphyllum* (Hook f. & Wilson) Broth. – most producer of peat;

(2) moss carpet communities with *Brachytecium astrosalebrosum* (Müll. Hal.) Kindb., *Sanionia uncinata* (Hedv.) Loeske, *S. georgicouncinata* (Müll. Hal.) Ochyra & Hedenäs;

(3) *Deschampsia antarctica* pure community;

(4) community of the lichens *Usnea antarctica* Du Rietz – *Umbilicaria antartica* Frey & I.M. Lamb. – moss *Andreaea regularis* Müll. Hall;

(5) Community of mosses and lichens of the rocky faces of the Northern aspect;

(6) Community of the crustose lichens on rocky surfaces and fragments of weathered erosion material;

(7) Community of microalgae.

The moss species names used are according to Ochyra et al. (2008), and the lichen species names are following Øvstedal & Smith (2001). Crustaceous lichens on the massive rock surfaces as well as bryophyte communities incorporating *Deschampsia antarctica* are typical for Galindez Island. *D. antarctica* rarely forms monospecific dominant communities and usually grows mixed with mosses on relatively small patches. Many localities of *D. antarctica* have been described for this island (Parnikoza et al. 2009, 2015). The communities dominated by vascular plants show the most notable accumulation of organic matter in soils. The microorganisms, fungi, and soil invertebrates take part in the processes of organic matter decomposition. The total area of declivous beaches in the littoral zone is relatively small. Algae remnants accumulate at these patches of the littoral, resulting in the formation of Organic Littoral Soils.

There are some penguin rookeries that strongly affect the soil formation directly or indirectly on Galindez Island (mainly, *Pygoscelis papua* (Forster 1781) colonies with sporadic individuals of other species). Ornithic soils are mainly located within the vicinity of penguin rookeries. The spatial distribution of the nitrophylous algae *Prasiola crispa* (Lightfoot) Kützingis is also connected with localities of guano accumula-

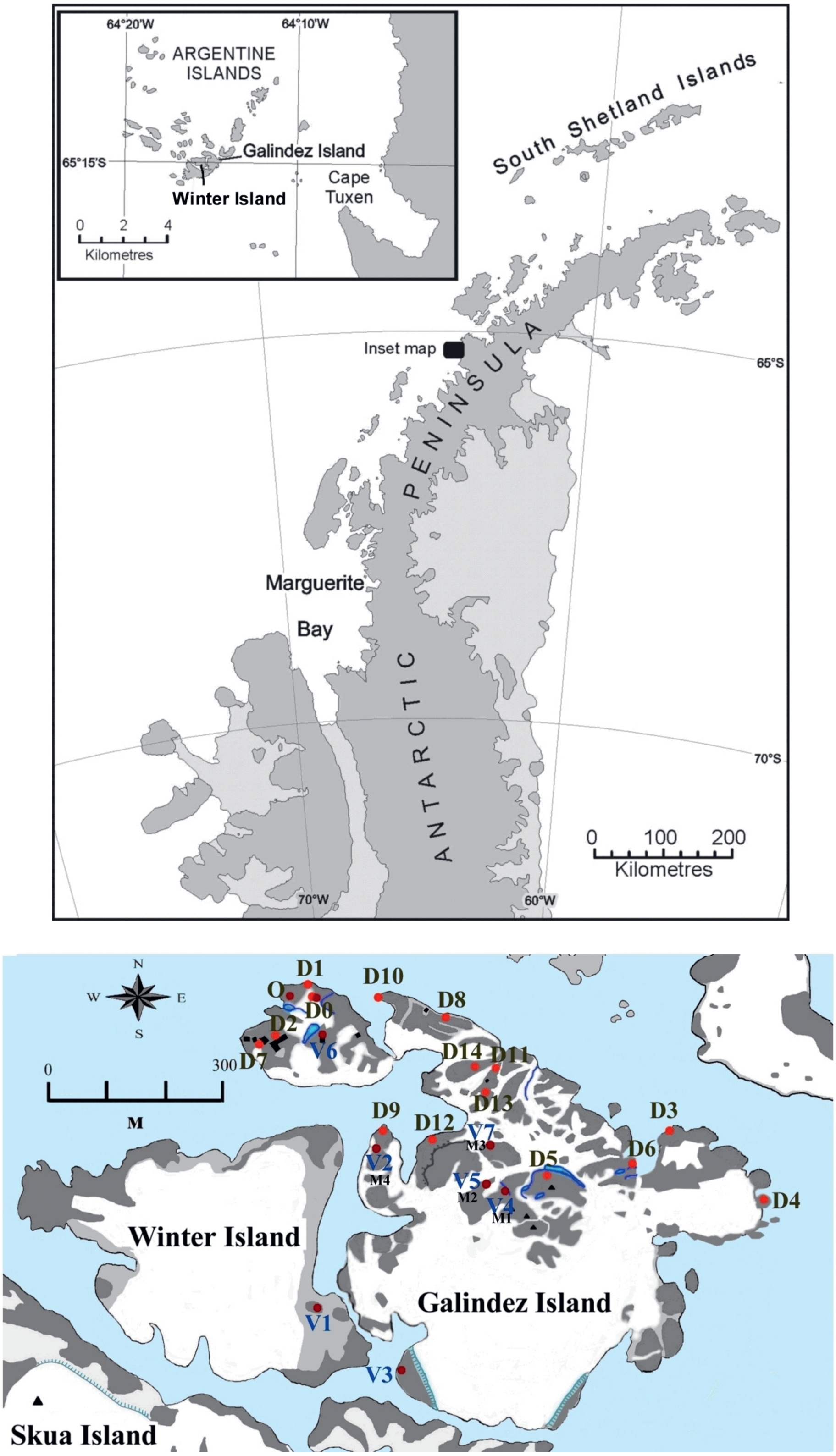

Fig. 1: Antarctic Peninsula with inset maps showing Argentine Islands and sampling locations on Galindez Island and Winter Island; for geographic coordinates see Table 2.

Abb. 1: Übersichtskarte der Antarktischen Halbinsel mit Detailkarten der Argentine Islands und Beprobungspunkten auf Galindez Island und Winter Island; geographische Koordinaten siehe Tabelle 2.

tion. The flying birds *Laurus dominicanus* Lichtenstein, 1823 and *Stercorarius maccormicki* H. Saunders, 1893, play a key role in the distribution of plant material into the inner parts of the island (Parnikoza et al. 2012, 2015). These and other birds, as well as seals, create a random influx of organic matter to soils that have formed under various vegetation types.

The main characteristic of the soils in the region is the low depth of textured friable gravel and weathering. Weathering products and organic material can accumulate only in relatively shallow cracks and crevices on the slopes and on the tops of rock ridges. At the same time, the vegetation and soil development on lowlands are prevented by snow even during the peak pinnacle part of the austral summer. In contrast to

Soil samples			
Sample Code	Location, vegetation description, Total vegetation cover (TVC) and individual cover of some plants, inclusions, coordinates, height m.a.s.l.	Profile (cm)	Soil type WRB
O	Sample of penguin *Pygoscelis papua* guano, Marina Point, 65°14.701' S, 64°15.378' W, 6 m.a.s.l.		Ornithic Leptosol
D0	Marina Point, near pavement for fuel hoses, lack of vegetation, 65°14.710' S, 64°15.295' W, 7 m.a.s.l.	12	Ornithic Leptosol
D1	On rocky coast of Marina Point near Meteorological station, *D. antarctica* population #6, (here and next see population # in PARNIKOZA et al. 2015), TVC 1 %, D. antarctica 0,5 %, *Sanionia sp*. 0,5 %, gravel, 65°14.686' S; 64°15.348' W, 13 m.a.s.l.	3	Leptosol
D2	Marina Point near main Station building, *D. antarctica* population #3, TVC 90 %, *D. antarctica* 25 %, bryophytes 65 %, gravel, 65°14.740' S; 64° 15.409' W, 12 m.a.s.l.	5	Leptosol
D3	Penguin Point, northern coast, in zone of limited guano input from nearest penguin colony *D. antarctica* population #43, TVC 5-20 %, *D. antarctica* 4-19 %, *Prasiola crispa*- 1 %, gravel, 65°14.849' S; 64°14.474' W, 7 m.a.s.l.	7	Ornithic Leptosol
D4	Penguin Point, eastern coast, in zone of limited guano input from nearest penguin colony, *D. antarctica* population #47, TVC 5 %, *D. antarctica* 5 %, *Sanionia sp*. + *Prasiola crispa* <1 %, limpet shells and gravel, 65°14.921' S, 64°14.307' W, 10 m.a.s.l.	16	Ornithic Leptosol
D5	Near Anna Hill, (Woozle Hill top), without visual guano input, *D. antarctica* population #67, TVC 50 %, *D. antarctica* 5 %, *Sanionia sp*. +*Polytrychum strictum* 45 %, gravel, 65°14.896' S, 64°14.714' W, 45 m.a.s.l.	7.5	Ornithic Leptosol
D6	Roztochia Ridge, *D. antarctica* population #40, TVC 50-60 %, *D. antarctica 3 %, bryophytes* 47-57 %, gravel, 65°14.880' S, 64°14.553' W, 19 m.a.s.l.	4	Leptosol
D7	Marina Point near Diesel station, *D. antarctica* population #1, TVC 3 %, *D. antarctica* 1 %, *bryophytes* 2 %, gravel, 65°14.751' S, 64°15.459' W, 3 m.a.s.l.	5	Gleysol
D8	Neck Ridge, coastal rocks, *D. antarctica* population #11, TVC 10-20 %, *D. antarctica* 1-10 %, *bryophytes* 9-10 %, gravel, 65°14.728' S, 64°14.992' W, 14 m.a.s.l.	19	Leptosol
D9	Stella Point, coastal rock - Gull Tower, *D. antarctica* population #53, TVC 5-50 %, *D. antarctica* 1-40 %, *bryophytes* 4-10 %, gravel and limpet shells, 65°14.847' S, 64°15.164' W, 10 m.a.s.l.	7	Leptosol
D10	Magnit Cape, top of the coastal rock, *D. antarctica* population #10, TVC 5-25 %, *D. antarctica* 4-24 %, *bryophytes* 1 %, on limpet shells, 65°14.704' S, 64°15.160' W, 6 m.a.s.l.	6.5	Leptosol
D11	Top of the Cemetery Ridge near WLF, *D. antarctica* population #16, TVC 5-40 %, *D. antarctica* 4-30 %, *bryophytes* 1-10 %, limpets, gravel, 65°14.779' S; 64°14.912' W, 17 m.a.s.l.	5	Leptosol
D12	Moss Valley, Smith *Polytr.-Chorisod*. moss bank, TVC 90 %, 65°14.862' S, 64°15.047' W, 16 m.a.s.l.	80	Histosol
D13	Cemetery Ridge, top of central part of ridge, not deep Polytr. moss bank, TVC 40 % with incurporation of *Sanionia sp*. and *D. antarctica* cushions, 65° 14.779' S, 64° 14.912' W, 17 m.a.s.l.	10	Histosol
D14	Karpaty Ridge, N slope of central part, Carpaty Polytr. moss bank, TVC 80 % with incorporation of *Sanionia sp*. chusions, 65°14.768' S, 64°14.959' W, 17 m.a.s.l.	6	Histosol
Vegetation samples			
L1	Lichen *Ramalina terebrata*, Fildes Peninsula, 62°12.658' S, 58°54.941' W, 2014/15		
L2	Lichen *Usnea aurantiacoatra*, Fildes Peninsula, 62°12.776' S, 58°55.900' W, 2013/14		
L3	Lichen *Usnea aurantiacoatra*, Fildes Peninsula, 62°10.572' S, 58°58.408' W, 2013/14		
M1	*Sanionia sp*. surface carpet, Galindez Island, rock terrace near Anna Hill (Woozle Hill top), 65°14.906' S, 64°14.797' W, 44 m.a.s.l.		
M2	*Sanionia sp*. surface carpet, Galindez Island, Died Moss Ravine, 65°14.897' S, 64°14.840' W, 28 m.a.s.l.		
M3	Zamok Ridge, Galindez Island, *Sanionia sp*. surface carpet, 65°14.863' S, 64°14.878' W, 34 m.a.s.l.		
M4	Stella Point, Galindez Island, *Polytrychum strictum* moss turf, 65°14.858' S, 64°15.180' W, 23 m.a.s.l.		

Tab. 2: Locations where soil and vegetation samples were collected, Galindez Islands, Argentine Islands and additional samples from Fildes Peninsula (King George Island).

Tab. 2: Standorte auf Galindez Island, Argentine Islands und Fildes Peninsula an denen Boden- und Vegetationsproben genommen wurden.

the oases of King George Island, there are no distinct catena formations of vegetation and soil in the direction toward the shoreline (Kozeretska et al. 2010, Parnikoza et al. 2011b).

Anthropogenic factors affect the soils by hydrocarbon pollution and outgassing of incineration products from the diesel station. There are no roads, but there is limited tourist recreational activity during the austral summer.

Measuring of the active layer thickness

Electric resistivity (ER) was measured directly in the soil profiles by the vertical electrical resistivity sounding (VERS) method, which provides data on the changes in electrical resistivity through the profile from the soil surface without invasive digging pits or drilling. This method allowed us to divide the soil layer vertically into genetic layers, which have different key properties and characteristics (Pozdnyakov et al. 1996, Pozdnyakov 2008). VERS using a Schlumberger array was carried out at four field stations, situated on Galindez Island. All experimental sites for VERS are shown in Table 1. Different soil layers have different ER values; therefore, the sharp changes in ER values in the soil profile can be interpreted as results of transition from one horizon to another (Pozdnyakov 2008). In our study, resistivity measurements were performed using four-electrode (AB + MN) arrays of the AMNB configuration and using Schlumberger geometry (Manual 2007). A Landmapper ERM-03 instrument (Landviser, USA) was used for the VERS measurements in this study. The resistance readings at every VERS point were automatically displayed on a digital readout screen and then written down in a field notebook. VERS was used to study the upper 0-5 m thick layer in greater detail. The distance between A and B electrodes ranged from 5 to 100 cm, while the distance between M and N electrodes was kept constant at 10 cm. The electrodes were positioned at the soil surface with a penetration depth in the soil of about 0.5 cm. A 1D layer model (ZonDIP program) 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), thickness of layers (h), and layer depth (z). The geometric factor, K, was first calculated for all the electrode spacings using the formula: $K = \pi\,(L2/2b - b/2)$, for Schlumberger array with MN = 2b and 1/2AB = L. The values obtained, were then multiplied with the resistance values to obtain the apparent resistivity, ϱa, values. As shown previously (Pozdnyakov 2008, Manual 2007), the depths of VERS coverage are almost the same as the distance between electrodes A and B.

Sampling strategy and procedure

Soil sampling was organized by taking into account the spatial pattern of vegetation cover, with special attention to patches of moss carpet *Sanionia sp*. Loeske communities with *Deschampsia antartica, and* Moss community: *Polytrichum strictum*, which were associated with *Chorisodontium aciphyllum*. Also, the localities of penguin rookeries (colonies of *Pygoscelis papua*) were investigated at Marina Point (65°14.713' S, 64° 15.335' W). Soil profiles were investigated in all of the mentioned types of vegetation. Characterizations of soils at the investigated localities are given in Table 2.

Three samples of lichens were used for chemical analyses (*Ramalina terebrata* (Hook. f. et Tayl. (1 sample); *Usnea aurantiacoatra* (Jacq.) Bory (2 samples). These samples were kindly presented for investigation by J. Esfeld (Fildes Peninsula, King George Island, season of 2014/15). To evaluate the N, P, and K contents, the following bryophyte samples were analysed from Galindez Island: *Sanionia sp*. (3 samples); *Polytrychum strictum* (1 sample) (Tab. 2). The samples of bryophytes were used as standard analytical samples for identification of trace elements in soils and vegetation materials.

Sample code	Location, vegetation description, Total vegetation cover (TVC) and individual cover of some plants, coordinates, height a.s.l.	Soil type WRB	VERS	Microbiol. study
D0	Marina Point, near pavement for fuel hoses, lack of vegetation, 65°14.710' S, 64°15.295' W, 7 m.a.s.l.	Ornithic soil	–	+
V1	Winter Island, Wordie House Point, Angelica Thumb, TVC 48 %, *D. antarctica* 1 %, *Sanionia sp*. 47 %, on limpet shells gravel, 65°15.013' S, 64°15.338' W, 8 m.a.s.l.;	Leptosol	+	+
V2	Galindez Island, Stella Point northern margin sparse lichen cover, 65°14.858' S, 64°15.180' W, 23 m.a.s.l.	Leptosol	+	+
V3	Galindez Island, Sterna Point, zone of Galindez glacier retreat, coarse ground of the moraine glacial genesis with sparse lichens and mosses cover, 65°15.074' S, 64°15.097' W, 9 m.a.s.l.	Leptosol	+	–
V4	Galindez Island, rock terrace near Anna Hill (the Woozle Hill dome), bryophytes cover and *Usnea antarctica* formation on rock, 65° 14.906' S, 64° 14.797' W, 44 m.a.s.l.	Leptosol	+	+
V5	Galindez Island, Died Moss Ravine, died *Polytrychum strictum* peat, 65°14.897' S, 64°14.840' W, 28 m.a.s.l.	Histosol	–	+
V6	Galindez Island, near Aerology building, 65°14.746' S, 64°15.286' W, sparse S*aniona-D. antartica* vegetation, 21 m.a.s.l.	Leptosol	–	+
V7	Galindez Island, Zamok Ridge near Fairy Meadow, lack of vegetation, 65° 14.849' S, 64°14.865— W, 23 m.a.s.l.	Leprosol	–	+

Tab. 1: Locations where VERS scanning was performed and samples for microbiological investigations were collected, Galindez and Winter Islands, the Argentine Islands.

Tab. 1: Standorte auf Winter Island und Galindez Island an denen VERS-Messungen und mikrobiologische Untersuchungendurchgeführt worden sind.

Chemical Methods

Soil material, penguin guano, seawater, and lichen and moss samples were analysed. Soil samples were taken for each soil horizon and bedrock material for analyses of chemical and microbiological characteristics, particle-size distribution, and micromorphological analyses (thin sections). Determination of the chemical characteristics was done in the certified Laboratory of Agroecology and Analytical research of the Institute of Agriculture of the National Academy of Agrarian Sciences of Ukraine and in the chemical laboratory of the Department of Applied Ecology, Saint-Petersburg State University, Russia. Soils were air-dried, grounded, and passed through a 1-mm sieve for separation of the fine earth fraction. Soils were analysed by the following methods: Active acidity (pH_{H2O}) and potential forms of acidity (pH_{KCl}) were determined by glass electrode using a suspension of 1:2.5 soil water and 1 mol/l KCl solution respectively. Organic carbon was analysed by the Tyurin method with potassium dichromate oxidation and next titration according to WALKEY (1935). The total concentrations of nitrogen, phosphorus, and potassium were determined after extraction by digestion with concentrated sulfuric and hydrochloric acids and further thermal destruction. Total nitrogen was determined using the titrimetric method after Kjeldahl digestion (KLUTE 1992). Total phosphorus was determined photometrically with blue phosphorus molybdenum complex forming. Potassium contents were evaluated by the method of flame photometry. Total contents of trace elements in soil, guano, and vegetation samples were analysed by atomic absorption spectrophotometer after digestion in nitric acid. The content of trace elements in seawater was determined by the atomic absorption method.

Microbiological studies

The total number of bacteria and the number and proportion of bacteria forms able to filtrate (FFB) in the total number of bacterial population were determined with the fluorescent dye acridine orange, in accordance with the producer's recommendations using a Zeiss Axioskop 2 Plus luminescence microscope equipped with the filter set type 09. The number of bacteria in 1 g of soil was calculated according to the manual (HANDBOOK 1991). A soil sample (1 g) was placed in 100 mL of sterile water and treated on an UDZN-1 ultrasonic disperser (Russia) at 22 kHz and 0.44 A for 2 h for desorption of cells from the surface of particles. Soil particles were precipitated by centrifugation at 2000 rpm for 10 min. The supernatant was taken in a sterile medical syringe and passed through a membrane filter (Sarstedt, pore size of 0.2 µm); the obtained filtrate was concentrated by centrifugation (10000 rpm, 10 min) (LYSAK et al. 2010, 2014). Most of the prepared cells were 120-200 nm in diameter and 300-400 nm in length, as we have reported earlier in the study of cell morphology and sizes under a transmission electron microscope (SONINA et al. 2012).

Saprotrophic bacterial complexes were quantified by inoculating water suspensions on a glucose-peptone-yeast culture medium (GPY) containing antibiotic nystatin in the following dilutions: 1:100, 1:1000, 1:10000, with 3-5 replicates. Registration of bacteria grown on the GPY medium was performed after 10–14 days by determining the total colony size and the number of specific taxonomic groups (LYSAK et al. 2003).

Statistics

All data were statistically analysed using the SIGMAPLOT 8.0 software (means, standard deviation, post hoc test for pH values, one-way ANOVA for carbon contents, C/N ratios, P_2O_5 and K_2O values).

RESULTS AND DISCUSSION

Vertical electric resistivity sections

Data on the active layer thickness and upper permafrost layer border thickness are important for pedogenic interpretation of all the data obtained. Data on modelled soil resistivity are shown in Table 3 and Figure 4. The substantial heterogeneity of soils appears to be caused by the massive rocks underlying the friable soil. The lowest values of ER are characteristic for the uppermost solum, which contains organic matter, fine earth, and friable matter. Down the soil profile, the layers with increased electric resistivity occur due to appearance of the frozen ground. On the base of electric resistivity measurements we found that on the Argentine Islands many of the soils did not face directly to the frozen layer but were isolated from the this part by unfrozen massive rocks. Therefore, they can be classified as Leptosols according to WRB system. In general such results for Galindez Island agree with data from the nearest regions of maritime Antarctica. Recent observations at Cierva Point and Anvers Island indicate that the occurrence of permafrost in the shallow soils may generally be rare in the maritime Antarctic HAUS et al. 2015).

Soil morphology and diagnostics, related vegetation communities and animal influence

The local diversity and classification of soils appear to be one of the main questions of the Antarctic soil science. All the soils investigated belong to the Cryosols according to WRB. Soils, formed of the massive crystallic rock can be also classified as

Plot No	P (apparent resistivity (Ω m)	Depth of layer (m)
1	270	0.00
	109	0.04
	2261	0.40
2	47	0.00
	6650	0.30
3	139	0.00
	184	0.10
	4812	0.20
	14535	0.40
4	489	0.00
	38220	0.40

Tab. 3: Apparent electric resistivity and estimated permafrost table depth of the studied soils of Galindez and Winter Islands, the Argentine Islands; 1, 2, 3, and 4 correspond to sample locations V1, V2, V3, and V4 in Table 1.

Tab. 3: Spezifischer elektrischer Widerstand und Tiefe des Permafrosts in den untersuchten Böden von Galindez Island und Winter Island, Argentine Islands; 1, 2, 3, und 4 bezeichnen die Probenstandorte V1, V2, V3 und V4 in Tabelle 1.

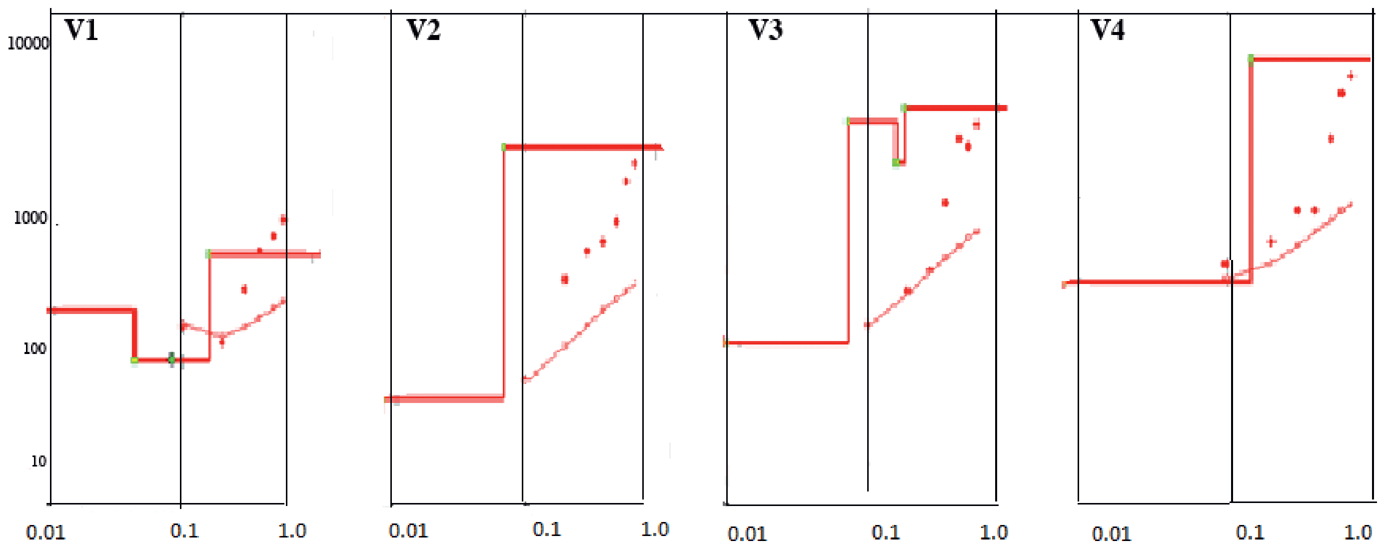

Fig. 4: Electric resistivity curves and models of soil profiles at investigated sites on Winter and Galindez Islands. Solid line denotes the layer model; dotted line denotes measured values; thin lines denotes calculated model curves. Vertical scale: ER values (Ωm); horizontal scale: AB/2 distance (m), V1, V2, V3, V4 denotes sample locations as in Table 1.

Abb. 4: Spezifische Widerstandskurven und Modelle der Bodenprofile an den Untersuchungsstandorten. Vertikale Skala = ER-Werte (in Ω m); horizontale Skala = AB/2 Abstand (in m); V1, V2, V3, V4 = Standorte der Bodenprofile wie in Tabelle 1.

Leptosols (soils with limitation for root growth and thin layer of solum), Gleysols (soils with a notable layer of redoxi-morphous features), and even Histosols in places where thick layers of raw humus material accumulate in small depressions of the landscape. The qualifier Histic can also be used for other soils with accumulations of raw humus. For example, some Histic Leptosols appeared in terrain with excess moisture.

Penguin colonies occupy the coastal parts of Galindez Island: Marina Point, Penguin Points, and Pigeon Point, where Ornithic soils (i.e., soils with evident features of guano accumulations) have formed. Initially, Ornithic soils form as guano-rich Leptosols, which have an upper horizon of fresh organic matter with relatively large C/N ratios and a lower horizon with lower C/N ratios. We analysed three samples of Ornithic soils. A fresh surface sample (O) was dark brown with a very sticky and greasy consistency. We also analysed two horizons on the peripheral edge of the colony on Marina Point (Fig. 2a, b): an upper C1 (0-5 cm) and a lower C2 (5-12 cm). Communities of the nitrophilous algae *Prasiola crispa* are associated with the margins of current and former penguin rookeries and points of local guano influx. Later, when the concentration of carbon and nitrates toxic contents decrease, other types of vegetation can colonize post-Ornithic soils. Ornithic soils are common throughout the maritime Antarctic due to sea bird activity, which does not seem to be limited to any particular latitude along the western Antarctic Peninsula (except for Alexander Island), and ornithogenic soils are common from Hope Bay (63°23.824' S, 56°59.923' W) to Marguerite Bay (68°17.423' S, 67°8.457' W) (Haus et al. 2015).

Other soils (beyond penguin colonies) are represented mainly by Leptosols and initial stages of humification on the slopes and tops of rocky ridges (Fig. 2c-f). This soil type is most common on Galindez Island and on other islands of the archipelago and probably reach 400 m a.s.l. in coastal oases (see also Parnikoza et al. 2011, Roshal et al. 2013). In conditions such as those on the Argentine Islands, these soils have an uppermost organic layer of about 2.0-3.5 cm thick and an organomineral solum with a high content of remnants of lichens and other plants and some incrustations of the limpet *Nacella* sp. shells. Where guano influx is limited, such Leptosols can be characterised as Ornithic, for instance at the D3 location (Fig. 2f).

In terms of thickness, more developed soils occurred at D4 and D8 locations due to the higher thickness of the friable parent materials (up to 19 cm, Fig. 3a). Those soils, according to WRB, can be classified as Leptosols. Plant communities of *D. antarctica* here cause intensive accumulation of humus (Vlasov et al. 2005, Abakumov 2010), which also leads to the formation of Humic Leptosols (location D8 in Fig. 1) with a conspicuous layer of organic matter residues succeeded by a layer with more humified organic matter (see Gajdosova et al. 2003). Some of the soils contain partially decomposed guano underlying a layer of vegetation-derived organic matter. These soils are identified as Ornithic Leptosols (Fig. 3b). Under conditions of low better drainage, Gleysols form. We found a typical Gleysol at location D7 (Fig. 3d). Gleyification and redoximorphism denote the reduction of ferric iron to ferrous iron under anoxic conditions. Aquic conditions and soils with redoximorphic features are found throughout the maritime Antarctic, although redoximorphic features are not very well expressed in most soils (Haus et al. 2015).

Accumulation of typical peat occurs under communities dominated by the mosses *Polytrichum strictum* and *Chorisodontium aciphyllum* (Fig. 3e). Peat layers in such places may reach up to 50 cm of thickness, mostly ranging from 15 to 40 cm (Fig. 3f). These peats are represented by stratified remnants of bryophytes, which show progressively higher decomposition grades with depth. These soils correspond to Histosols in the WRB soil classification.

Leptosols are typical for moss carpet *Sanionia* communities with *Deschampsia antarctica*, while *Polytrychum-Chorisodotium* communities lead to the formation of Histosols. Histo-

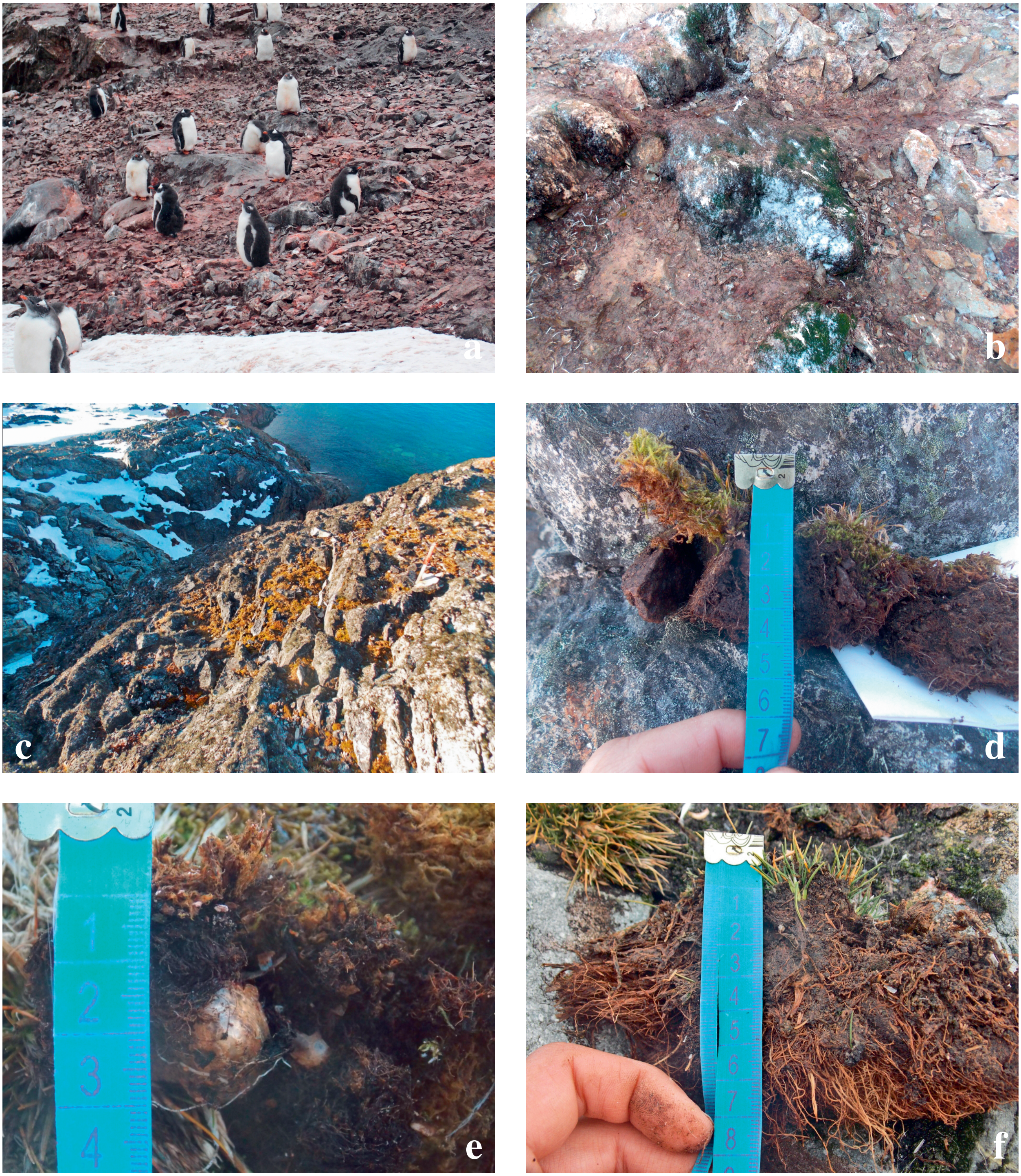

Fig. 2: Selected study locations and soil profiles from Galindez Island. For locations see Figure 1. **a** and **b**: sample location D0 at Marina Point at a *Pygoscelis papua colony* (left), a site of Ornithic soil formation; soil surface shown at right. **c** and **d**: sample location D11 at Cemetery Ridge as a typical locus of Leptosol formation under a *Sanionia-D. antarctica* community (left) showing Leptosol soil profile at the right. **e:** sample location D6 showing a Leptosol profile under a *Sanionia-D. antarctica* community at Roztochia Ridge with limpet shell deposits. **f**: sample location D3 at Penguin Point showing Ornithic Leptosol under a *D. antarctica* community.

Abb. 2: Ausgewählte Untersuchungsstandorte und Bodenprofile Galindez Island, Argentine Islands, maritime Antarktis; Lage der Standorte siehe Abbildung 1. **a** und **b** = Standort D0 mit einer *Pygoscelis papua* Kolonie am Marina Point (links) führt zur Bildung von ornithischen Böden; Oberfläche des ornithischen Bodens (rechts). **c** und **d** = Standort D11 am Cemetery Ridge zeigt einen typischen Standort der Leptosolbildung unter *Sanionia-D. antarctica* Gemeinschaft (links) und Detail des Leptosol Bodenprofils (rechts). **e** = Standort D6 am Stella Point zeigt ein Leptosol Profil unter *Sanionia-D. antarctica* Gemeinschaft mit Mollusken Ablagerungen. **f** = Standort D3 am Roztochia Ridge zeigt einen Ornithic Leptosol unter einer *D.antarctica* Gemeinschaft.

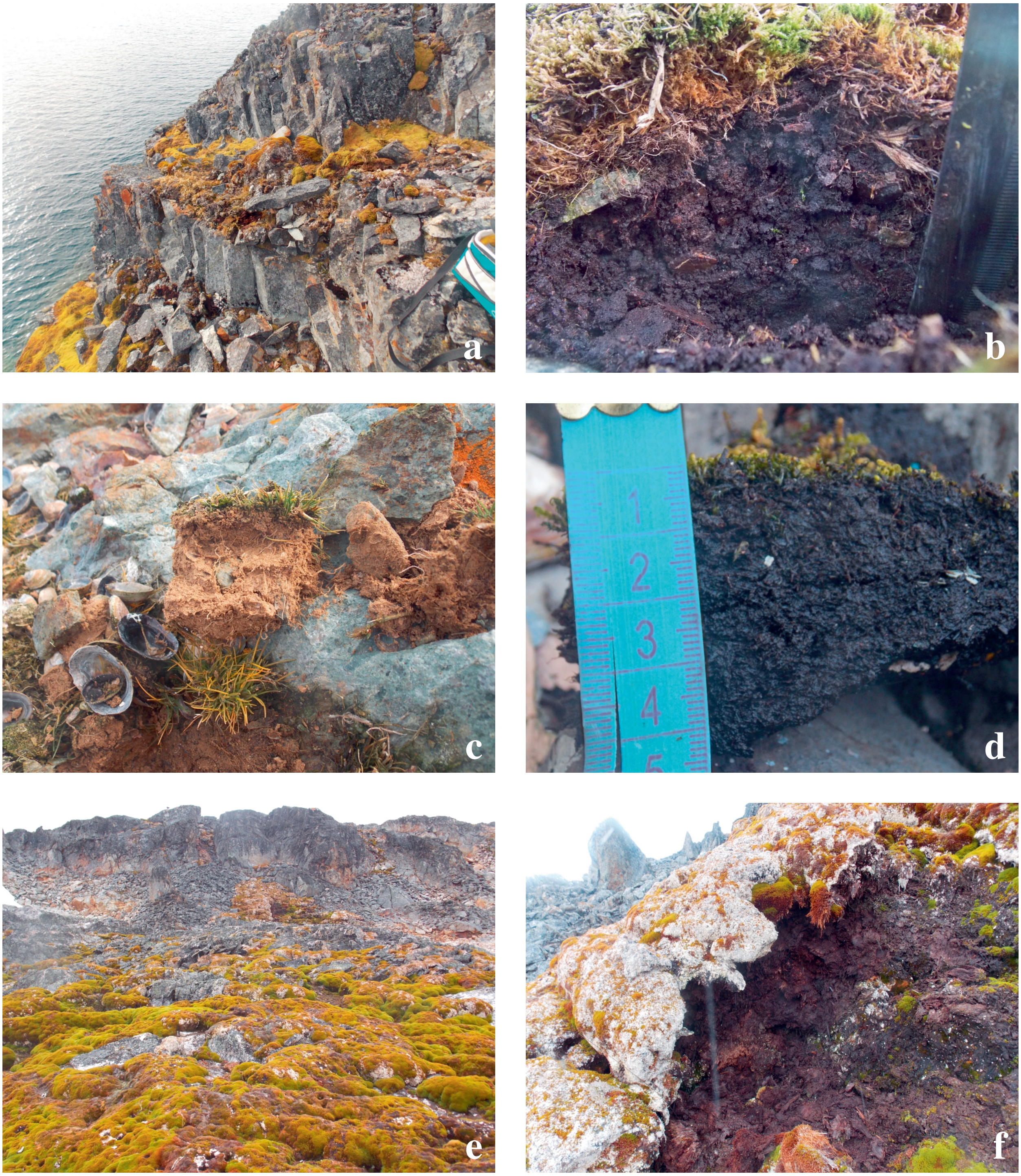

Fig. 3: Selected study locations and soil profiles from Galindez Island. For locations see Figure 1. **a** and **b**: sample location D8 at steep coastal rock (left) showing evolution of Histic Leptosol soils (right). **c**: sample location D4 at Penguin Point showing evolution of Ornithic Leptosol. **d**: sample location D7 near the Diesel station showing evolution of a Gleysol. **e** and **f**: sample location D12 shows an overview (left) of a *Polytrichum-Chorisodontium* Smith moss bank at Moss Valley and in detail a typical Histosol profile (f).

Abb. 3: Ausgewählte Untersuchungsstandorte und Bodenprofile von Galindez Island auf den Argentine Islands, maritime Antarktis; Lage der Standorte siehe Abbildung 1. **a** und **b** = Standort D8 auf steilen Felsklippen (links) zeigt eine Entwicklung zum Histic Leptosol. **c** = Standort D4 am Penguin Point zeigt eine Entwicklung zum Ornithic Leptosol. **d** = Standort D7 in der Nähe der Diesel-Station zeigt eine Entwickung zum Gleysol. **e** und **f** = Standort D12 beim Moss Valley zeigt einen Überblick über einen weiten *Polytrichum-Chorisodontium* Smith Moosbewuchs (links) und ein typisches Histosol Profil (f).

sols are essentially enriched by the presenter of invertebrates. (Trokhymets et al. 2014). Also, the south polar skua (*Stercorarius maccormicki*) use peatlands-Histosol fields for nest building. According to Haus et al. (2015), the soils of the other ice-free areas of the maritime Antarctic, such as Hope Bay, Cierva Point, Arthur Harbour, and Marguerite Bay, similarly to the Argentine Islands, are generally thin Leptosols formed in shallow till or frost-shattered rock. Larger areas of deeper and more developed soils occur on glaciofluvial plains, patterned ground, peat beds, moraines, raised beaches and solifluction terraces. However, soils at these places are usually poorly vegetated Haus et al. (2015).

Soil chemical characteristics

The analysed samples of different soil types are heterogeneous in regard to pH and biogenic element contents (Tab. 4). This results from two different types of organic matter sources in soils, i.e., zoo- and phytogenic (Abakumov et al. 2015b).

The best illustration of the animal source of organic material in soils are soils affected by birds activity. As mentioned above, guano has a profound effect on the soil quality. Galindez Island is populated with active penguin colonies, and the ground is covered with a compacted, dried layer of light brown guano (with its characteristic ammonia smell) and pebbles. These young soils are generally rich in carbon (C), nitrogen (N), phosphorus (P), and other biogenic elements (i.e., Ca, K, Mg, Na), have low C/N ratios and a large variation of pH. Their contents of inorganic micro- and macro-elements are also highly variable, with considerably higher levels (Smykla et al. 2015). The chemical characteristics of guano from sample O is presented in Table 3. These data show increased pH and total contents of nitrogen, phosphorrous, and potassium. These characteristics of guano also affect the soil (Ornithic Soils, location D0, Tab. 3), which shows increased pH (7.05 in the upper and 6.23 in the lower horizon) as well as organic matter highly enriched in nitrogen originating from guano. In such soils, the contents of N and C decline at comparable rates because the C/N values do not change with time, while phosphorus content increases. The high concentration of phosphorus is a good indicator of Ornithic origins of the soils, especially in areas where now such colonies are absent (Smykla et al. 2015).

Sample code	$C_{org.}$ (%)	C:N	pH_{H2O}	pH_{KCl}	Total content (%)		
					N	P_2O_5	K_2O
Ornithic soils							
O	22.3	6.5	7.0	–	3.45	11.38	0.43
D0, C1, 0-5 cm	41.63	12.53	7.07	–	3.32	–	–
D0, C2, 5-12 cm	16.85	4.46	6.23	–	3.77	–	–
Leptosols and Gleysols							
D1	47.0	18.1	5.0	4.1	2.60	1.67	0.21
D2	27.0	10.5	6.3	5.5	2.57	0.98	0.14
D3	49.9	16.3	6.3	6.1	3.07	3.38	0.35
D4	10.6	8.9	7.6	7.5	1.19	8.33	0.16
D5	21.3	10.5	7.4	7.4	2.02	7.10	0.20
D6	41.9	21.1	6.7	6.6	1.99	3.18	0.16
D7	32.8	21.4	6.8	5.9	1.53	1.04	0.15
D8	41.2	14.0	5.2	4.8	2.94	2.77	0.32
D9	63.0	22.8	5.5	5.0	2.76	1.56	0.21
D10	44.6	17.8	6.7	6.7	2.50	2.38	0.32
D11	45.1	18.0	6.2	6.0	2.50	2.01	0.46
Histosols							
D12	67.0	27.7	4.2	3.4	2.42	0.42	0.07
D13	51.7	22.6	6.1	5.7	2.29	1.45	0.32
D14	64.8	27.3	5.1	4.1	2.37	0.79	0.42
Lichens samples							
L1	32.2	20	–	–	1.62	0.18	0.53
L2	34.3	30	–	–	1.12	0.08	0.35
L3	33	7	–	–	0.82	0.09	0.24
Moss samples							
M1	–	–	–	–	1.56	0.50	0.59
M2	–	–	–	–	1.16	0.12	0.08
M3	–	–	–	–	1.74	0.72	0.36
M4	–	–	–	–	1.34	0.53	1.93

Tab. 4: Chemical characteristics of different types of soils from Galindez Islands, Argentine Islands and additional samples from Fildes Peninsula (King George Island).

Tab. 4: Chemische Eigenschaften der unterschiedlichen Bodentypen, Flechten und Moosproben von Galindez Island (Argentine Islands) und Fildes Peninsula (King George Island).

Leptosols, and Gleysols are characterized by more acidic pH values compared to Ornithic soils due to the accumulation of sufficient amounts of plant organic residues in the upper solum. The relatively high contents of carbon and nitrogen in the studied soils are consistent with earlier publications (Fabiszewski & Wojtun 2000, Juchnowicz-Bierbasz & Rakusa-Suszczewski 2002, Korsun 2005, Parnikoza et al. 2011). At the same time, some Leptosols from Cierva Point that had formed under a *Sanionia* sp. cover have been reported to contain 12.2 % total carbon (Haus et al. 2015), which corresponds to the carbon-poorest Leptosols from Galindez Island observed in our study (Tab. 3). The N (0.88 %) and P (0.49 %) contents, though, were comparable with the Galindez Island samples we examined.

Soils enriched with guano-derived compounds demonstrate lower C/N ratios (on average 8-10) compared to Leptosols and Gleysols (9-21). The differences in the N content, as well as C/N ratios, were significant for the following comparison pairs: Histosols – Leptosols, Lichens/Mosses – Ornithic soils, and Histosols – Ornithic soils ($p < 0.04$, $p < 0.03$, $p < 0.01$, respectively).

Accumulation of guano also affects the phosphorus content; this was revealed for both current Ornithic soils and post-ornithic places. All the soils affected by birds' geochemical influence show increased concentrations of phosphorous, which are consistent with previous publications (Smykla et al. 2015). As to potassium, its concentrations increased proportionally to the accumulation of plant remnants due to biological accumulation (Tab. 4).

Histosols show pH values between 4 and 6, low contents of phosphorous, and high contents of organic matter. These are due to the vegetation origins of the soil organic matter. This also results in higher C/N ratios (on average 22-27), as well as lower pH (3-6) compared to other soils. There is a significant difference between Histosols and Ornithic soils in organic carbon content ($p < 0.04$). We did not detect statistical differences in carbon content between Histosols and Leptosols. The low influx of zoogenic materials in Histosols is indicated by the low contents of phosphorous. There was a significant difference between Histosols and other soils in phosphorous content ($p < 0.03$), but not between Histosols and plant remnants of lichens and bryophytes ($p > 0.05$).

For comparison, the Histosol sample from Cierva Point (more northern location in the maritime Antarctic) from under a *Polytrychum strictum* community had comparable C (31.8 %) and P (0.30 %), but lower N (0.72 %) contents (HAUS et al. 2015).

The initial soils, sometimes with deep profiles, described from different points of the maritime Antarctic had low C, N and P due to the lack of vegetation cover, similar to soils at Cierva Point and Amsler Island (HAUS et al. 2015).

Trace element contents

The contents of the main trace elements (Tab. 5) differed in soils from various localities of Galindez Island. Previous studies (KORSUN 2005, PARNIKOZA et al. 2007) have shown a high iron content in soils from different points of the Argentine Islands region. Ferum levels were high in investigated soils of Galindez Island too. Manganese levels were high in most of the examined samples, with the exception of samples from locations D4 and D5 (with equal iron contents), which could be attributed to differences in the contents of Mn and Fe in the parent materials. Some additional accumulation is possible from guano (see ANDREEV et al. 2004). Significantly higher levels of Ni and Cd were revealed in samples D2 and D7, which are located in proximity to the Vernadsky Station and might be contaminated. However, high concentrations of Cd equal to the presumably polluted samples D2 were previously also observed on Great Yalour Island. The Cd contents in soils of all the other studied loci on Galindez Island were comparable to non-affected soils from other islands of the Argentine Islands region that had been studied previously (PARNIKOZA et al. 2007). According to NEDOGIBCHENKO et al. (2013) the Cd content in base rock is 0.1-0.3 mg/kg and in surface deposits of Woozle Hill slopes (Galindez Island) varied with a range of 0.04-33.3 mg/kg.

The contents of Cu, Pb, and Zn, just as Fe and partially Mn are low in samples from locations D4, D5 and D6, which represent more or less pristine soils. Other samples (except for the presumably polluted D2 and D7) demonstrated medium amounts of these elements, which might be caused by pollution from the station activity. The contents of Cu, Pb and Zn were high in guano, which is also rich in iron. Regarding Cu, influx from the base rock is possible. Previous studies have shown higher concentrations of Cu in a number of randomly chosen locations on the Argentine Islands compared to the polluted areas on Galindez Island (PARNIKOZA et al. 2007). According to NEDOGIBCHENKO et al. (2013), the content of Cu in surface deposits of the Woozle Hill slopes ranges between

Sample Code	Trace elements, mg/kg						
	Cu	Zn	Pb	Cd	Ni	Mn	Fe
0	122.5	215.5	26.3	3.2	7.2	20.6	863.3
D1	43.9	50.8	63.8	0.7	1.6	54.3	13242.5
D2	192.5	616.5	1760.0	29.8	11.4	252.5	15685.0
D3	49.2	101.4	9.5	12.7	2.4	49.9	69.3
D4	0.2	0.4	5.8	0.6	2.2	0.6	4.5
D5	0.3	0.5	5.5	1.0	2.5	1.0	5.5
D6	0.2	8.0	4.8	10.1	4.4	36.2	3.8
D7	1856.3	667.1	741.3	20.9	12.2	77.1	18623.8
D8	70.0	52.2	12.4	2.0	2.2	90.0	12197.5
D9	30.5	53.2	6.9	2.8	3.0	76.3	25.8
D10	52.9	105.1	49.6	1.3	3.6	123.4	11841.3
D11	18.0	55.4	6.3	2.8	1.5	104.3	14857.5
D12	5.4	19.9	7.6	0.3	1.8	42.9	2886.2
D13	20.7	104.1	8.5	2.6	3.1	495.0	10052.5
D14	13.0	14.5	3.1	0.5	2.1	29.3	66.6
Sea water	0.04	0.08	0.79	0.15	0.51	–	0.85
Littoral zone	1.8	4.6	3.7	0.1	–	–	–
M1	3.5	12.9	2.1	0.2	2.1	12.8	321.0
M2	2.5	16.0	2.1	0.3	1.1	40.8	5702.5
M3	4.7	13.8	1.1	0.3	3.5	15.2	3472.5
M4	5.5	10.0	1.3	0.2	4.7	14.0	1337.3

Tab. 5: Total contents of trace elements in different soil types, sea-water, and vegetation components of Galindez Island, the Argentine Islands (mg/kg).

Tab. 5: Gesamtgehalt an Spurenelementen in den unterschiedlichen Bodentypen, Seewasser und Vegetationskomponenten der Galindez Island, Argentine Islands (mg/kg).

1.9 and 28.3 mg/kg. The Zn and Pb low and middle contents from Galindez Island were comparable to data form randomly chosen locations of the region obtained previously (PARNIKOZA et al. 2007). According to NEDOGIBCHENKO et al. (2013), the content of Zn and Pb in surface deposits of the Woozle Hill slopes ranged between 2.4-262.1 and 2.4-10.6 mg/kg, respectively. It is interesting that location D4, which is extremely polluted with polycyclic aromatic compounds (ABAKUMOV et al. 2015a), does not show any unusual accumulation of trace elements. In general, the soils of Galindez Island are more polluted with trace elements compared to Point Thomas oasis (KORSUN et al. 2008). The difference between theses soil localities are caused by the effects of the thinner friable soil profile on Galindez Island compared to Point Tomas, while the station activity is similar at both locations (KORSUN et al. 2008, PARNIKOZA et al. 2010). The high content of Cu, Zn, Mn, and Fe in Histosols (D12, D13) is probably caused by the accumulation of these elements from moss. According to ZHOVINSKI et al. (2014), mosses appear to contribute large quantities of the mobile form of Fe (44.4 %), as the element is essential for their normal growth. As noticed by BARGAGLI (2005), the mobility of trace metals and other contaminants in soils is reduced in presence of organic material and clay. In Antarctic soils with relatively low amounts of organic matter, soluble and insoluble chemicals move very slowly due to the low moisture content, so the migration of pollutants from crushed batteries, scattered trash and buildings is not significant. Analyses of seawater and soil from the littoral zone showed that the accumulation of trace elements from the sea sprays is negligible.

Microbiological characteristics of soils.

The total number of bacteria in the studied soil samples varied from 3.95 to 0.22 billion in 1 g of soil. The highest abundances of microorganisms were found in Ornithic soils (D0), while in other samples this value was an order of magnitude lower (Tab. 6). These data are in good correspondence with previous results from other Antarctic regions (Abakumov 2010, Smykla et al. 2015). The total numbers of bacteria in Ornithic soils (D0) were comparable to those obtained for the earlier studied samples of zonal temperate soils, while in Leptosols they were orders of magnitude lower compared to temperate regions.

Many researchers argue that small forms of bacteria (filterable forms of bacteria: FFB, or nanobacteria, whose size usually does not exceed 200 nm) survive better in extreme environments. Such cells are detected by direct microscopic methods (Duda 2012, Lysak 2010).

In all of the studied samples, small forms of bacteria passing through membrane filters with pore size of 200 nm were identified. The number of such FFB cells varied from 0.13 to 0.002 billion cells per g soil. They accounted for 0.6 to 10 % of total bacteria, which was much lower than previously reported from primitive organo-mineral soils of East Antarctica, where in some horizons the FFB share reached 70-80 % (Kudinova 2015). Our measures are consistent with previous reports from "normal" zonal soils, where the FFB shares did not exceed 5-7 % (Lysak 2010, 2014).

The number of heterotrophic bacteria in the studied soils varied from 0.07 to 46.50 million CFU per 1 g of soil. Ornithic soils showed the highest numbers of heterotrophic bacteria, which indicates their role in decomposing zoogenic materials. An increased number of heterotrophic bacteria were found in front of the Aerology building, probably due anthropogenic impact. Low numbers of heterotrophic bacteria were found in the Leptosol samples with a sparse vegetation cover, the sample of the initial soil formation, and the Histosol sample.

Sample Code	Total number of bacteria, billion cells per 1 g of soil	Filterable forms of bacteria (FFB)		Number of heterotrophic bacteria, million CFU per 1 g of soil
		Number, billion cells per 1 g of soil	Fraction of FFB of total number of bacteria (%)	
D0	3.950±0.806	0.134±0.025	3.4	22.800±6.840
V1	0.946±0.283	0.016±0.005	1.7	2.850±0.855
V2	0.747±0.261	0.013±0.004	1.7	1.500±0.500
V4	0.597±0.178	0.060±0.04	10.2	9.810±1.962
V5	0.495±0.198	0.040±0.017	8.2	0.076±0.008
V6	0.223±0.093	0.013±0.004	6.0	46.500±6.975
V7	0.324±0.130	0.002±0.0008	0.6	0.129±0.026

Tab. 6: Microbiological characteristics of the soil samples from the Argentine Islands.

Tab. 6: Mikrobiologische Eigenschaften der Bodenproben, Galindez Island, Argentine Islands.

CONCLUSIONS

The soils of the Argentine Islands are formed on thick friable debris of the massive crystallic parent material on the rocky ridges surrounded by the glacier and snow accumulations in the conditions of guano and plant organic material influx.

The first application of the VERS methodology for the assessment of soil heterogeneity and identification of the permafrost upper boundary layer shows differentiation of the soil from the top down into the uppermost friable fine earth section, an unfrozen rock layer underlying it, and a permafrost rock layer. The active layer in these conditions varied between 20 and 40 cm.

The soils of Galindez Island are quite diverse in terms of their morphology and chemical properties. The Ornithic soils (Ornithosols) and post Ornithic soils exhibit signs of additional accumulation of carbon, nitrogen, and phosphorous. Soils with an undeveloped organic horizon underlain by a thick layer of friable debris, based on their profile thickness, are classified as Leptosols. In general, Leptosols seem to be the dominant type of soil in the region. The Gleysols are typical for over-moisted places the island. Another soil order present in association with moss turf *Polytrichum-Chorisodontium* communities is Histosols.

We found significant differences in the chemical composition of the investigated soils. Thus, the Ornithic soils demonstrated the largest differences from the other types regarding C and N contents and C/N ratios. These soils also turned out to harbour the highest numbers of bacteria. The increased content of nitrogen in some Leptosols indicates previous ornithogenic influence, even when the soils are not currently exposed to birds. The local Histic material deposits make a strong contribution to the accumulation of organic matter as a result of slow decomposition during the short periods of biological activity and the presence of permafrost.

The obtained data show some interrelationships between the spatial distribution of soils and vegetation cover. The post-ornithogenic stage of soil formation can be identified by the accumulation of an increased amount of organic carbon resulting from the increased biological productivity of these soil locations.

The distribution of trace elements in the soil cover of Galindez Island is heterogeneous. The soils demonstrate high contents of iron, which is caused by the characteristics of the local parent materials. The accumulation of other elements (e.g., Ni, Cd, Pb) mainly reflects human impact.

The soil cover on Galindez Island represents a polypedone of different lithogenic, organogenic, and ornithogenic soils, which is very well spatially differentiated in a landscape-dependent manner and impacts biodiversity and geochemical processes.

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