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Distribution, genesis, and properties of Arctic soils: a case study from the Fuglebekken catchment, Spitsbergen

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Abstract: This paper presents distribution and properties of soils within the Fuglebekken catchment in neighbourhood of the Polish Polar Station in Hornsund, SW Spitsbergen (Svalbard Archipelago). The present study describes 8 representative soil profiles out of 34 profiles studied for the whole catchment. Soils of the Fuglebekken catchment show initial stage of their formation because of very slow rate of chemical and biological weathering in Arctic climate conditions. Uplifted marine terraces of the Fuglebekken catchment are characterized by domination of Haplic Cryosols which are related to stony and gravelly parent material (reworked marine sediments). Such soils constitute of 17% of the studied area. Turbic Cryosols forming characteristic micro-relief occur on flat surfaces and gentle slopes. Such soils (covering 7% of the catchment) are formed from loamy parent material. Along streams Hyperskeletic Cryosols (Reductaquic) and Turbic Histic Cryosols occur. The last two soil units (constituting 11% of the catchment) are mantled by continuous and dense vegetation cover (especially mosses) due to high content of water rich in nutrients flowing from colonies of sea birds located on slopes of Ariekammen and Fugleberget. The studied soils are generally characterized by shallow occurrence of permafrost (*i.e.* at 30–50 cm), high content of pebbles, sandy or sandy loam texture, and neutral or slightly alkaline reaction. Soils occurring along streams and near colonies of sea birds show higher content of nutrients (N and P) in comparison with other soils and are covered by more dense vegetation. This indicates important impact of bird guano on chemical composition of soil solution and fertility of such soils.

Key words: Arctic, Svalbard, Cryosols, cryoturbation, permafrost.

Introduction

Soil (so called pedosphere) is a result of interactions between lithosphere, atmosphere, hydrosphere, and biosphere (Brady and Weil 2004) and is a very important element of environment playing a key role in circulation of organic and mineral matters and energy in ecosystems (Skiba *et al.* 2002; Brady and Weil 2004). Soil accumulates water and nutrients making them accessible for plants and soil microorganisms (*e.g.* van Breemen and Finzi 1998; Brady and Weil 2004). In addition, soil plays a role in cycling of organic carbon (being on the one hand a source of carbon dioxide due to mineralization of soil organic matter and on the other hand being a sink of carbon dioxide due to accumulation of organic matter) which is especially important in context of global warming (*e.g.* Bockheim *et al.* 2006; Beier *et al.* 2008; Smith *et al.* 2008).

Despite that Spitsbergen is located in the High Arctic, its climate conditions are quite mild (when compared with other areas situated on the similar latitude) due to specific atmospheric circulation and warm ocean current flowing on the western part of the Svalbard Archipelago (Ziaja 2002). Such conditions are favourable for the development of vegetation and formation of soils. According to the literature (*e.g.* Bockheim and Tarnocai 1998; Ugolini *et al.* 2006; White *et al.* 2007) in the High Arctic cryoturbation is a dominant soil forming process leading to formation and development of patterned ground as well as soils without clear horizonation. However, mode of the formation and development of permafrost-affected soils depend on properties of their parent material (especially texture and mineralogy), geomorphological position, local climate (*i.e.* microclimate), soil moisture, and vegetation cover (Tedrow 1977; Washburn 1980; Bockheim and Tarnocai 1998; Ugolini *et al.* 2006).

Soils of the Spitsbergen are important subject of investigations because they are very sensitive for environmental changes connected with global warming. In addition, investigations of polar soils (from initial stage of their formation) allow to better understanding genesis and evolution of soil cover. Such issues have increasing number of studies in the last decade especially in Antarctica (*e.g.* Simas *et al.* 2006; Cannone *et al.* 2008; Navas *et al.* 2008; Schaefer *et al.* 2008). On the other hand, recent studies concerning Arctic soils are rare (Mann *et al.* 1986; Klimowicz and Uziak 1988, 1996; van Vliet-Lanoë 1988; Melke and Uziak 1989; Melke *et al.* 1990; Klimowicz *et al.* 1997; Skiba *et al.* 2002; Melke and Chodorowski 2006; Kabała and Zapart 2009, 2012; Walker 2012). This paper presents distribution, genesis, and properties of soils occurring within the Fuglebekken catchment which is located in neighbourhood of Polish Polar Station in Hornsund fjord (SW Spitsbergen). In spite of many environmental studies in this area since 1950s soil cover was not described and analyzed in details. The present studies are especially important due to the fact that a lot of other environmental studies (*i.e.* hydrological, geochemical, biological, and geological) are carrying out within the Fuglebekken catchment. Thus, the knowledge about soil cover should be helpful in better understanding of environmental processes in this Arctic catchment. In addition, the presented results could be used in comparison purposes with similar studies carrying out in small Arctic catchments located in other parts of Spitsbergen as well as in other polar areas characterized by more severe climate conditions.

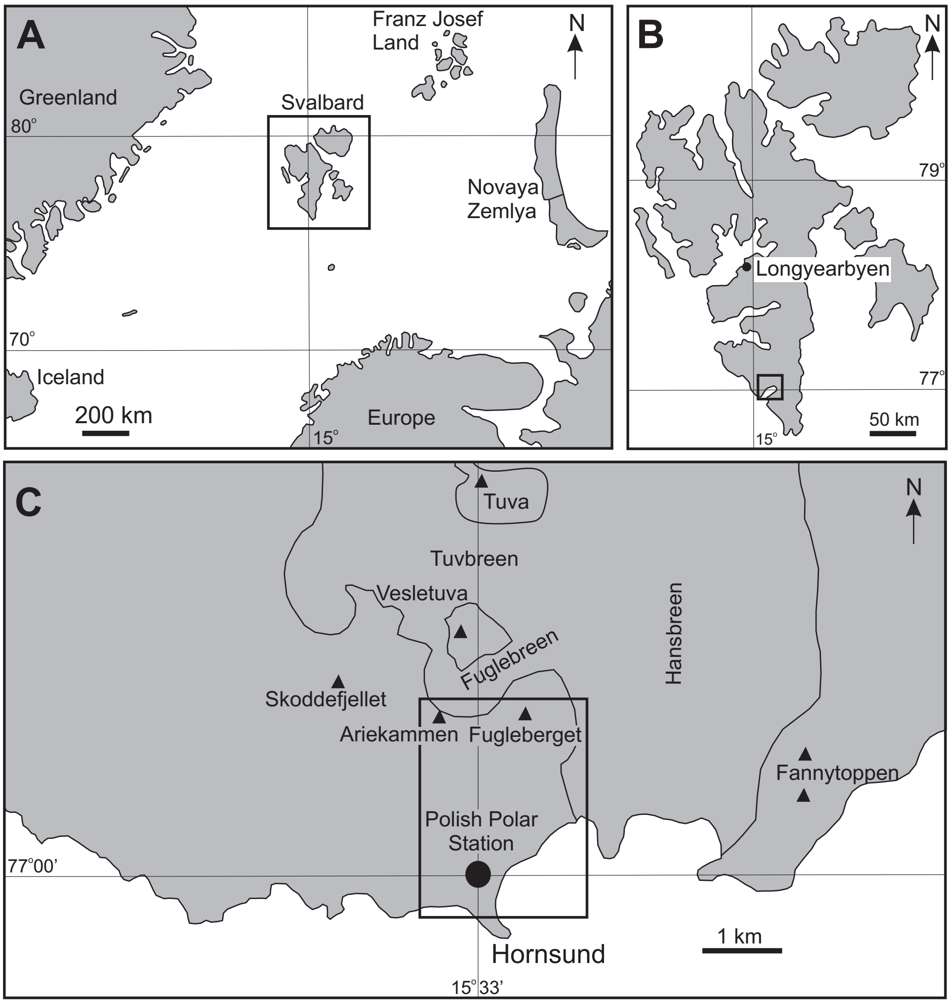

Fig. 1. Location of the Svalbard Archipelago (A), Hornsund fjord (B), and the Fuglebekken catchment (C).

The main aims of the present study were 1- to determine distribution, genesis, and properties of Arctic soils within the Fuglebekken catchment and 2- to determine relationships between soils and other elements of the Arctic environment.

Materials and methods

Study area. — The studies were carried out during summer 2011 along north coast of Hornsund fjord. Location of the studied area is presented in Fig. 1. The area is mainly built of metamorphic schists (containing mica, garnet, and calcite), paragneisses as well as marbles. In addition, in some places quartzites and amphibolites occur (Czerny *et al.* 1993). The crystalline bedrock is covered by marine deposits (stones, gravels and sands) which thickness is up to 4–5 m. The composition of clastic material corresponds to local geology. Majority of the investigated area is located on almost flat, uplifted marine terraces of Holocene age (Lindner *et al.* 1991) with few, low storm ridges and many small old skerries. East part of the studied area is occupied by lateral moraine of Hans glacier. The northern part of the Fuglebekken catchment constitutes steep slopes of Ariekammen and Fugleberget covered by coarse and angular rock debris. Climate of the Hornsund area is suboceanic with mean annual temperature -4.4°C and mean precipitation about 430 mm per year (Marsz and Styszyńska 2007).

The studied Fuglebekken catchment is characterized by high diversity of plant communities. The most common is lichen-heath tundra, which occurs on dry, flat and stable sites. Such communities are characterized by the dominance of lichens (mostly *Catrariella delisei* and *Ochrolechia frigida*), willow (*Salix polaris*), saxifrage (*Saxifraga oppositifolia*) and moss (*Polytrichastrum alpinum*). In contrast, in more loamy and wet habitats extensive moss carpets intermixed with cyanobacteria mats are formed (*e.g.* Richter and Matuła 2013). Wet moss tundra with *Sanionia uncinata*, *Warnstorfia sarmentosa*, *Starminergon stramineum*, and *Aulacomnium palustre* occurs in places with permanent supply of water. Small old skerries are covered by epilithic lichen-moss tundra with numerous lichens of genera *Cetraria*, *Cladonia*, *Alectoria*, *Usnea*, *Thamnolia* and *Rhizocarpon* as well as mosses with the most frequent species of genera *Racomitrium*. Geophytic initial tundra, characterized by sparse and floristically poor vegetation with a predominance of *Saxifraga oppositifolia* and *Sanionia uncinata*, is associated with the soils occurring on lateral moraine of Hans glacier and locally on slopes of Ariekammen and Fugleberget. At sites with a large numbers of birds, so called nitro-coprophilous tundra with the *Chrysosplenium tetrandrum* and *Cochlearia groenlandica* is present (Dubiel and Olech 1992) due to the influence of nutrients from their guano.

Field and laboratory methods. — The detailed study of soil cover of the Fuglebekken catchment was done after analysis of geological (Czerny *et al.* 1993) and geomorphological (Karczewski *et al.* 1990) maps. After reconnaissance of the study area, 34 soil pits in representative sites were excavated to the permafrost, ground water or hard bedrock and morphology of the soil profiles as well as vegetation cover was very carefully described. Each of the genetic horizons was sampled. In the laboratory, the samples were air dried, gently crushed using a wooden rolling pin and passed through a 2 mm sieve. Content of coarse rock fragments (fraction >2 mm) was determined by weighing and particle-size distribution of the fine earth material (fraction <2 mm) was determined using hydrometer method and wet sieving (Gee and Bauder 1986). Soil reaction was measured in distilled water and 1M KCl (1:2.5 ratio was used) (Thomas 1996). Modified Tiurin titration technique and volumetric Scheibler method were used to determined concentration of soil organic carbon (Nelson and Sommers 1996) and content of carbonates, respectively. Content of total soil nitrogen in the studied soils was determined using standard Kjeldahl technique. In order to determine chemical composition of the soil material, the samples were digested using lithium metaborate/tetraborate and dilute nitric acid and analyzed by Inductively Coupled Plasma – Emission Spectrometry (ICP-ES). The above mentioned geochemical analyses were done in AcmeLabs (Vancouver, BC, Canada). Soil color was described using Munsell Color Soil Charts (2000). Soil units were named according to WRB classification system (IUSS Working Group WRB 2006).

Results and discussion

Distribution of soil units within the study area is presented in Fig. 2. The most common soils of uplifted marine terraces within the studied area are Haplic Cryosols showing high content of coarse rock fragments (metamorphic schists, quartzities, paragneisses, and marbles) and sandy earth material. Only in some cases, texture of the Cryosols is sandy loam. Haplic Cryosols constitute of 17% of the studied area. Field description of exemplary Haplic Cryosol is presented in Table 1 (Profile 032). The Cryosols show shallow (*i.e.* at 30–50 cm) occurrence of permafrost. Most of them are characterized by neutral or alkaline reaction (pH from 6.8 to 8.1 in distilled water) what depends on presence or lack of carbonates in parent material. In turn, surface horizons of the soils containing higher amount of organic matter exhibit slightly acidic reaction (pH 5.5–6.3 in distilled water) (Table 2). Lower pH of the surface horizons indicates dissolution and leaching of carbonates. Content of soil organic carbon in Haplic Cryosols ranges from 0.7% to 4.3% and depends on vegetation coverage. Lower horizons contain distinct less soil organic carbon in comparison with superficial horizons. Haplic Cryosols containing high amounts of stones and gravels are covered by lichens. In turn, Haplic Cryosols showing higher amount of fine earth material are habitats for cyanobacteria, lichens (mainly *Cetrariella delisei*), saxifrages (*Saxifraga oppositifolia*, *S. caespitosa*), willow (*Salix polaris*), and sometimes mosses (most often *Sanionia uncinata*) because of longer accumulation of water and higher content of nutrients in comparison with more skeletal and permeable Cryosols.

In places where the parent material contains more silt and clay fractions Turbic Cryosols (Profile 003) were formed. Turbic Cryosols cover 7% of the studied area. Genesis of these soils is related to strong cryogenic processes which lead to swelling of soil material rich in fine fractions and subsequent lateral movement of frost-heaving stones to the vertical cracks formed by freezing. Such soils form micro-relief in the form of sorted circles, mud boils, cell forms, striped soils or polygons and are very characteristic for flat surfaces or gentle slopes (Fig. 3) (*e.g.* Washburn 1969; Klimowicz and Uziak 1996; van Vliet-Lanoë 1998; Skiba *et al.* 2002; Ugolini *et al.*

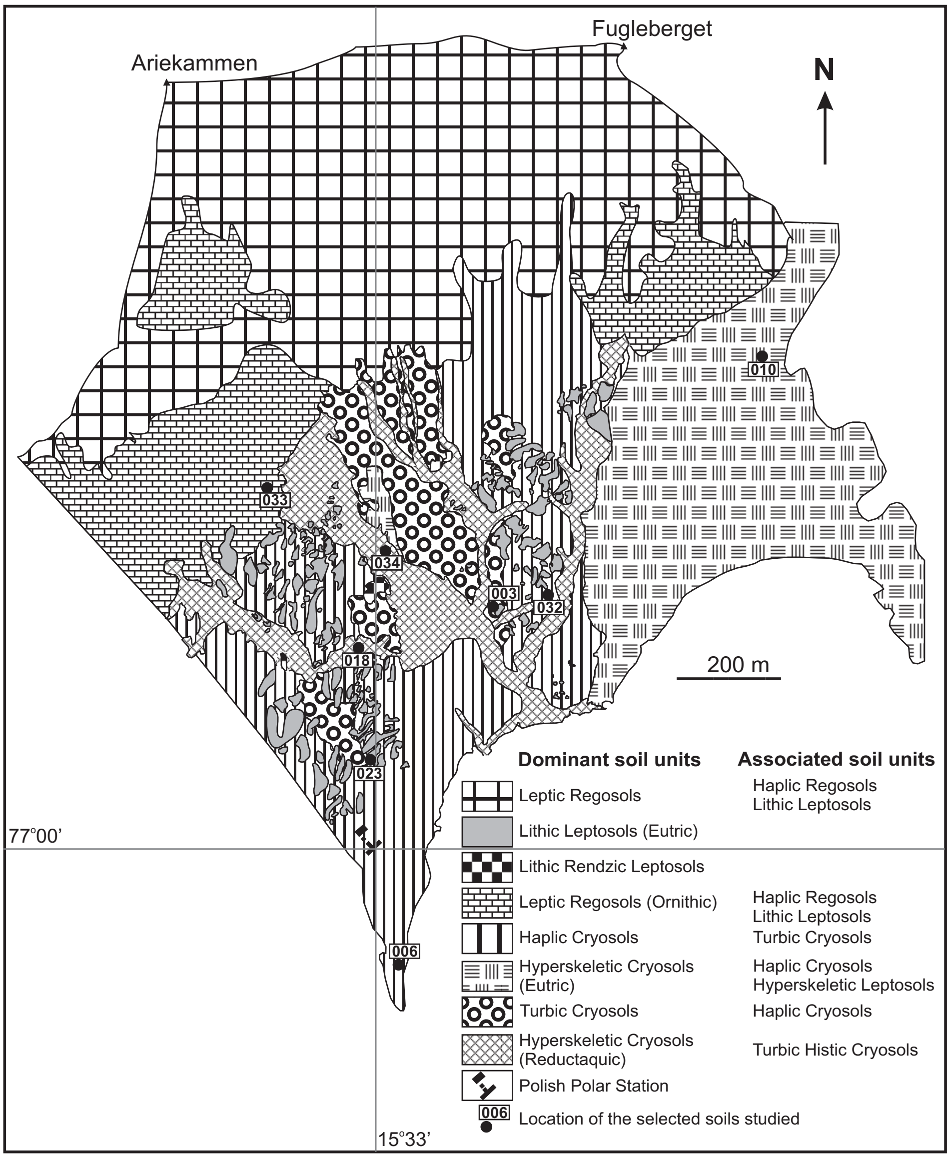

Fig. 2. Soil map of the Fuglebekken catchment, Spitsbergen (Svalbard Archipelago).

2006). Central part of such soils is composed of fine and moist mineral material but high amount of rock fragments (up to 73%) is also present. Particle-size distribution of the core part of Turbic Cryosols is usually sandy loam what is in agreement with results presented previously by Klimowicz and Uziak (1996), van Vliet-Lanoë (1998), Skiba *et al.* (2002), and Ugolini *et al.* (2006). The central part of Turbic Cryosols is covered by cyanobacteria, lichens, *Saxifraga oppositifolia*, and *Saxifraga caespitosa* (Table 1). The peripheral part of the Cryosols is formed from

Table 1

Field description of the selected soils studied; n.a., not analyzed.

Soil horizon	Depth (cm)	Color (moist)	Structure	Roots	Consistence	Moisture	Vegetation
Profile 032 Haplic Cryosol (Endoeutric, Endoskeletic); 77°00'43" N; 15°33'34" E; 10 m a.s.l.							
AC	0–9	2.5Y 3/1	single grain	many	soft	slightly moist	lichens, mosses, *Saxifraga oppositifolia*, *Salix polaris*
C1	9–20	2.5Y 3/2	single grain	common	loose	slightly moist	
2C2	20–(30)	10YR 3/3	single grain	few	slightly hard	slightly moist	
Profile 003 Turbic Cryosol (Eutric, Skeletic); 77°00'49" N; 15°33'03" E; 7 m a.s.l.							
AC	0–20	2.5Y 3/3	angular blocky	few	slightly hard	moist	cyanobacteria, lichens, *Saxifraga oppositifolia*
C1	20–30	2.5Y 3/3	sub- to angular blocky	few	slightly hard	moist	
C2	30–(40)	2.5Y 3/3	sub- to angular blocky	absence	slightly hard	moist	
Profile 018 Hyperskeletic Cryosol (Eutric, Reductaquic); 77°00'37" N; 15°32'43" E; 12 m a.s.l.							
Oi	0–2	n.a.	fibrous	many	soft	wet	mosses, *Saxifraga caespitosa*
ACg	2–(15)	2.5Y 3/3	ang- to subangular blocky	absence	loose	very wet	
Profile 006 Haplic Cryosol (Calcaric, Eutric); 76°60'00" N; 15°32'59" E; 4 m a.s.l.							
A	0–3	2.5Y 2/1	single grain	many	soft	slightly moist	cyanobacteria, *Saxifraga oppositifolia*
AC	3–9	2.5Y 3/1	single grain	common	loose	slightly moist	
2A	9–12	2.5Y 2/1	single grain	common	slightly hard	moist	
3AC	12–20	2.5Y 3/2	single grain	few	loose	moist	
4AC	20–(30)	10YR 2/2	single grain	few	loose	moist	
Profile 010 Hyperskeletic Cryosol (Eutric); 77°01'02" N; 15°35'07" E, 37 m a.s.l.							
AC	0–10	2.5Y 3/1	single grain	few	loose	moist	lichens, *Saxifraga oppositifolia*, *Saxifraga caespitosa*, *Cerastium arcticum*
C	<10	n.a.	n.a.	n.a.	n.a.	n.a.	
Profile 034 Turbic Histic Cryosol (Eutric); 77°00'56" N; 15°32'38" E; 14 m a.s.l.							
Oi	0–16	n.a.	fibrous	absence	soft	wet	mosses
C1	16–30	2.5Y 3/3	single grain to subangular blocky	absence	soft	wet	
C2	30–(40)	2.5Y 3/3	subangular blocky to platy	absence	soft	wet	
Profile 033 Leptic Regosol (Ornithic, Gelic, Endoskeletic); 77°00'59" N; 15°32'00" E; 42 m a.s.l.							
Ah	0–8	10YR 2/3	fibrous	common	soft	slightly moist	mosses, *Saxifraga oppositifolia*, *Cerastium arcticum*, *Poa alpina*
C	8–(30)	2.5Y 3/3	single grain to subangular blocky	few	slightly hard	slightly moist	
Profile 023 Lithic Leptosol (Eutric, Gelic); 77°00'22" N; 15°32'45" E; 10 m a.s.l.							
AC	0–(12)	2.5Y 3/2	single grain	few	loose	slightly moist	lichens, *Saxifraga oppositifolia*

Table 2

Some physical and chemical properties of the selected soils studied; n.a., not analyzed.

Soil horizon	Depth (cm)	pH		$CaCO_3$	Soil organic carbon	Soil organic matter	Total soil nitrogen	Skeleton	Sand	Silt	Clay
		H_2O	KCl	(%)							
Profile 032 Haplic Cryosol (Endoeutric, Endoskeletic)											
AC	0–9	6.2	4.8	0.0	1.44	2.49	0.32	13.9	70.0	24.0	6.0
C1	9–20	6.8	5.0	0.0	0.87	1.49	n.a.	32.7	83.0	12.0	5.0
2C2	20–(30)	7.1	4.9	0.0	0.68	1.17	n.a.	50.2	76.0	22.0	2.0
Profile 003 Turbic Cryosol (Eutric, Skeletic)											
AC	0–20	7.1	5.5	0.0	0.73	1.26	0.11	53.0	56.0	37.0	7.0
C1	20–30	7.2	5.6	0.0	0.70	1.20	n.a.	73.2	58.0	35.0	7.0
C2	30–(40)	7.3	5.7	0.0	0.60	1.03	n.a.	59.2	59.0	38.0	3.0
Profile 018 Hyperskeletic Cryosol (Eutric, Reductaquic)											
Oi	0–2	n.a.	n.a.	n.a.	n.a.	n.a.	1.81	n.a.	n.a.	n.a.	n.a.
ACg	2–(15)	7.1	5.6	0.0	1.08	1.86	n.a.	73.9	79.0	17.0	4.0
Profile 006 Haplic Cryosol (Calcaric, Eutric)											
A	0–3	7.4	7.0	14.0	1.50	2.59	n.a.	3.0	97.0	2.0	1.0
AC	3–9	7.7	7.4	14.6	1.32	2.28	n.a.	1.5	97.0	2.0	1.0
2A	9–12	7.6	7.0	3.3	2.41	4.16	n.a.	1.4	92.0	4.0	4.0
3AC	12–20	7.9	7.3	11.5	1.34	2.30	n.a.	18.0	90.0	9.0	1.0
4AC	20–(30)	7.9	7.3	2.1	1.46	2.52	n.a.	38.0	87.0	9.0	4.0
Profile 010 Hyperskeletic Cryosol (Eutric)											
AC	0–(10)	7.8	7.6	4.7	0.31	0.54	0.00	72.5	85.0	14.0	1.0
Profile 034 Turbic Histic Cryosol (Eutric)											
Oi	0–16	6.8	6.2	n.a.	n.a.	38.46	0.11	n.a.	n.a.	n.a.	n.a.
C1	16–30	7.4	6.0	0.0	0.55	0.94	n.a.	39.6	69.0	27.0	4.0
C2	30–(40)	7.3	5.5	0.0	0.63	1.09	n.a.	12.1	46.0	44.0	10.0
Profile 033 Leptic Regosol (Ornithic, Gelic, Endoskeletic)											
Ah	0–8	6.5	5.8	0.0	11.15	19.22	1.12	21.2	n.a.	n.a.	n.a.
C	8–(30)	7.1	5.9	0.5	1.06	1.83	n.a.	59.9	62.0	32.0	6.0
Profile 023 Lithic Leptosol (Eutric, Gelic)											
AC	0–(12)	6.7	5.0	0.0	1.20	2.06	n.a.	7.5	73.0	23.0	4.0

coarse and angular gravel without continuous vegetation cover (Fig. 3). The gravelly part of Turbic Cryosols is mantled by small patches of lichens occurring only in some places. Turbic Cryosols do not exhibit clear stratification due to cryoturbation and sometimes show indistinct, olive-green mottles indicating weak gleyic processes (Fig. 4). They are characterized by neutral reaction (pH 7.1–7.3 in distilled water) and lack of carbonates. Soil organic carbon is almost evenly distributed throughout the soil profile and its amount ranges between 0.5 and 0.8% (Table 2). The most probably such distribution of soil organic carbon is related to mixing of

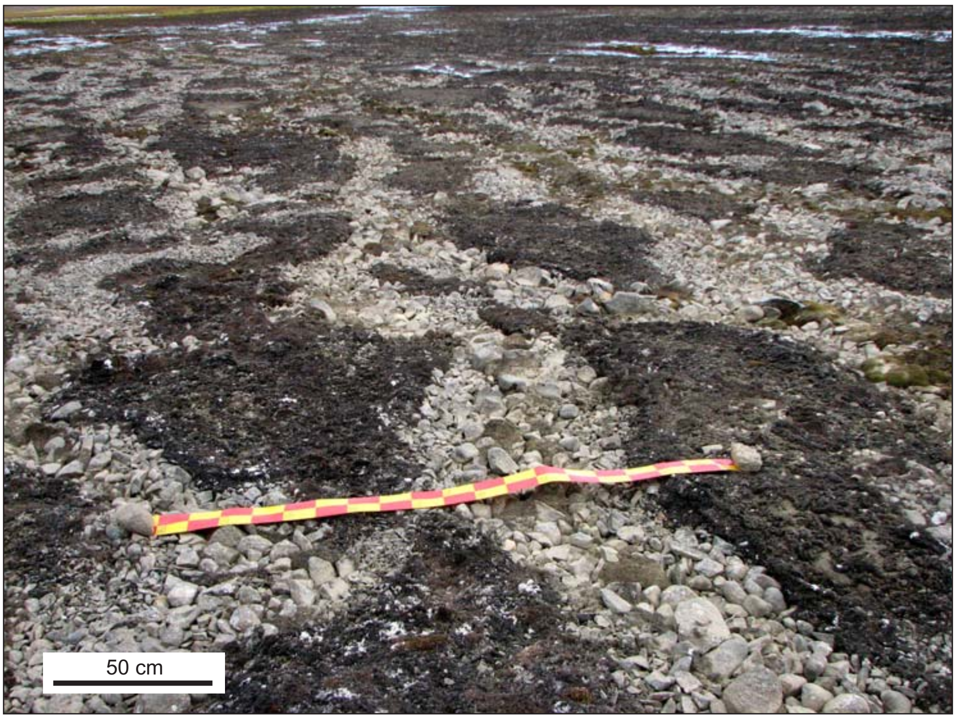

Fig. 3. Patterned ground showing clear segregation by frost.

soil material due to cryoturbation. Chemical composition of Turbic Cryosols is similar to the composition of Haplic Cryosols (Table 3). However, Turbic Cryosols contain lower amount of SiO_2 (63.7–65.9%) and higher amounts of Al_2O_3 (17.0–18.3%) and Fe_2O_3 (8.4–8.9%) than Haplic Cryosols, which is likely related to higher amounts of aluminosilicates (*i.e.* clay minerals) and lower amount of quartz in Turbic Cryosols than in Haplic Cryosols.

Hyperskeletic Cryosols (Reductaquic) together with Turbic Histic Cryosols along streams prevail. Such soils cover 11% of the studied area. Field descriptions of the soil units are presented in Table 1 (Profiles: 018 and 034). Hyperskeletic Cryosols (Reductaquic) (Profile 018) are characterized by coarse sandy texture and contain a lot of gravels (Fig. 5). These soils show slightly acidic or neutral reaction (pH 6.2–7.1 in distilled water) what is connected with lack of carbonates (Table 2). Characteristic feature of the Cryosols is quite high content of soil organic carbon (up to 6.9%) and total soil nitrogen (up to 1.8%) because of dense and continuous vegetation cover and high water content which leads to conservation of organic matter due to slowdown of mineralization (*e.g.* White *et al*. 2002, 2004). Chemical composition of Hyperskeletic Cryosols (Reductaquic) is almost the same as the composition of Haplic Cryosols (Table 3). However, Hyperskeletic Cryosols (Reductaquic) are characterized by higher amounts of P_2O_5 and nitrogen

Table 3

Chemical composition of the selected soils studied; n.a., not analyzed.

Soil horizon	Depth (cm)	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	P_2O_5	MnO
		(%)								
Profile 032 Haplic Cryosol (Endoeutric, Endoskeletic)										
AC	0–9	69.82	15.13	7.27	2.09	1.33	1.58	2.49	0.16	0.12
C1	9–20	73.94	12.88	6.37	1.62	1.40	1.65	1.89	0.15	0.11
2C2	20–(30)	67.79	15.55	7.50	2.62	1.86	1.94	2.44	0.16	0.14
Profile 003 Turbic Cryosol (Eutric, Skeletic)										
AC	0–20	63.66	18.30	8.89	2.62	1.35	1.41	3.46	0.15	0.16
C1	20–30	64.27	17.99	8.75	2.55	1.33	1.48	3.31	0.15	0.16
C2	30–(40)	65.87	16.95	8.39	2.56	1.31	1.52	3.10	0.16	0.14
Profile 018 Hyperskeletic Cryosol (Eutric, Reductaquic)										
Oi	0–2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
ACg	2–(15)	67.09	15.75	7.88	2.42	1.77	1.90	2.85	0.19	0.15
Profile 006 Haplic Cryosol (Calcaric, Eutric)										
A	0–3	69.79	8.82	7.20	3.78	7.65	0.96	1.45	0.22	0.14
AC	3–9	71.84	7.77	5.77	3.57	8.53	0.87	1.33	0.18	0.12
2A	9–12	78.67	9.12	5.43	1.78	2.10	1.07	1.53	0.20	0.10
3AC	12–20	69.60	10.05	5.57	4.03	7.59	1.17	1.71	0.18	0.09
4AC	20–(30)	69.41	14.58	6.93	2.44	2.08	1.62	2.62	0.19	0.13
Profile 010 Hyperskeletic Cryosol (Eutric)										
AC	0–(10)	64.90	16.62	7.50	2.60	3.41	1.90	2.82	0.17	0.08
Profile 034 Turbic Histic Cryosol (Eutric)										
Oi	0–16	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
C1	16–30	63.03	18.33	8.97	2.59	1.72	1.75	3.23	0.19	0.19
C2	30–(40)	59.54	19.62	10.59	2.99	1.74	1.61	3.54	0.20	0.19
Profile 033 Leptic Regosol (Ornithic, Gelic, Endoskeletic)										
Ah	0–8	52.09	21.63	11.98	4.12	4.05	1.30	3.92	0.67	0.24
C	8–(30)	59.19	19.98	9.83	3.51	1.37	1.68	4.00	0.21	0.22
Profile 023 Lithic Leptosol (Eutric, Gelic)										
AC	0–(12)	65.00	17.18	7.61	3.41	1.75	1.90	2.88	0.14	0.12

than Haplic Cryosols and Turbic Cryosols (Tables 2 and 3). This indicates that Hyperskeletic Cryosols (Reductaquic) show enrichment in nitrogen and phosphorus. Turbic Histic Cryosols (Profile 034) exhibit sandy loam or loamy texture and contain histic-like horizon (10–16 cm thick). Its genesis is related to slow decomposition of organic matter in severe, arctic climate conditions (*e.g.* Klimowicz *et al.* 1997; Lev and King 1999; Skiba *et al.* 2002; White *et al*. 2002). The histic-like horizons are characterized by slightly acidic reaction whereas the underlying mineral horizons exhibit neutral or slightly alkaline reaction (Table 2). The histic-like horizons contain high amount of organic matter (38.5–67.6%). In some places

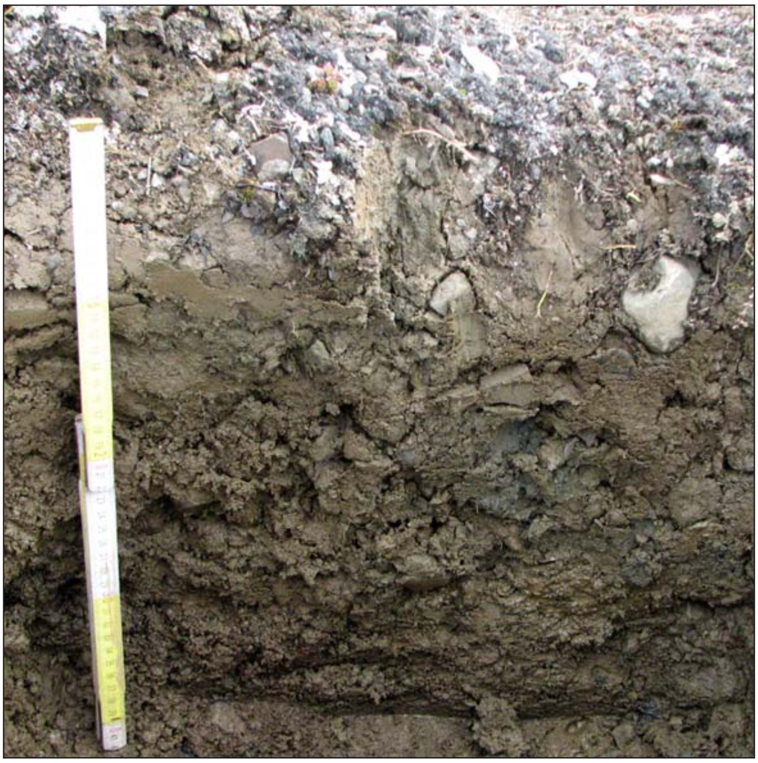

Fig. 4. Turbic Cryosol with permafrost occurring at 40 cm.

thufurs, *i.e.* small mounds which height is 30–40 cm and diameter 40–50 cm occur (Fig. 6). Turbic Histic Cryosols and thufurs are covered by moist carpet of mosses (Table 1, Fig. 6). Such carpet of mosses have strong insulating properties which lead to frequent presence of discontinuous ice lenses as well as shallow occurrence of permafrost (usually at 20–30 cm under soil surface) (Fig. 6). Hyperskeletic Cryosols (Reductaquic) and Turbic Histic Cryosols are habitats for wet moss tundra with *Sanionia uncinata*, *Warnstorfia sarmentosa*, *Starminergon stramineum*, *Aulacomnium palustre*, which cover 90–100% of soil surface. It is connected with high amount of water, which is enriched in nutrients (nitrogen and phosphorus) originating from bird colonies (*Alle alle*) located on slopes of Ariekammen and Fugleberget. The same close relationships between vegetation and soils rich in water and nutrients are indicated by Klimowicz *et al.* (1997) and Skiba *et al.* (2002) from other parts of the Spitsbergen (*i.e.* Bellsund region and Sørkappland, respectively). On small old skerries occurring within the study area very thin, initial Lithic Leptosols (Profile 023) are formed (Table 1). Genesis of such soils is connected with high resistant of crystalline rocks to physical weathering (Skiba *et al.* 2002). Such soils are characterized by sandy or sandy loam texture, slightly acidic or neutral reaction, lack of carbonates and low amount of soil organic carbon (up to

Fig. 5. Hyperskeletic Cryosol (Reductaquic) with thin histic-like horizon.

1.2%) (Table 2). Such soils cover 2.5% of the studied area and are habitats for lichens, *Saxifraga oppositifolia*, and *Cerastium arcticum* (Table 1). Rock outcrops forming from marbles are parent material for thin Lithic Rendzic Leptosols. The soils exhibit sandy texture, alkaline reaction and quite high content of carbonates. Content of soil organic carbon is similar to that of Lithic Leptosols (*i.e.* 1.0–1.5%). Lithic Rendzic Leptosols are covered by lichens, *Saxifraga oppositifolia*, *S. caespitosa* and *Polygonum viviparum*.

Soils occurring on lateral moraine of Hans glacier in the eastern part of the studied area contain a lot of angular rock fragments and show sandy or sandy loam texture. Such soils are classified as Hyperskeletic Cryosols (Eutric) (Profile 010), Haplic Cryosols or Hyperskeletic Leptosols and constitute 17% of the studied area. Quite high content of carbonates (4.7–10.5%) is a reason of alkaline reaction of these soils. Soil organic carbon content in the soils is low and ranges from 0.3 to 0.5% what is connected with sparse vegetation cover. *Sanionia uncinata*, *Racomitrium lanuginosum*, *Saxifraga oppositifolia*, *S. caespitosa*, and *Cerastium arcticum* are major species occurring on lateral moraine of Hans glacier (Table 1).

Slopes of Ariekammen and Fugleberget are covered by angular rock debris which is parent material for Leptic Regosols and Haplic Regosols showing high content of coarse rock fragments and very low amount of fine earth material. Leptic Regosols and Haplic Regosols constitute of 32% of the studied area. The soils are characterized by neutral reaction and sandy or sandy loam texture. Their

Fig. 6. Thufur containing ice lenses (visible in central part under moss carpet).

surface is often covered by sparse vegetation. In some places, with high influence of birds, Leptic Regosols (Ornithic) (Profile 033) are almost entirely covered by mosses (*Brachythecium turgidum*, *Sanionia uncinata*), Arctic mouse-ear (*Cerastium arcticum*), grass (*Poa alpina* var. *vivipara*) and *Chrysosplenium tetrandrum* being the most common species of vascular plant (Table 1). It is related to enrichment of surface horizon of the soils in nitrogen and phosphorus (Tables 2 and 3). Such soils (covering 6.5% of the catchment) show sandy loam texture, lack or very low amount of carbonates and slightly acidic or neutral reaction (Table 2). High content of soil organic carbon (up to 11.2%) in such soils is effect of dense vegetation cover which provides organic substrate. On the rock outcrops occurring close to Leptic and Haplic Regosols, very thin Lithic Leptosols are also present.

Conclusions

Arctic soils of the Fuglebekken catchment show initial stage of their formation because of very slow rate of chemical and biological weathering in Arctic climate conditions. Uplifted marine terraces of the studied Fuglebekken catchment are characterized by domination of Haplic Cryosols which are related to stony and gravelly parent material (reworked marine sediments). Haplic Cryosols cover 17% of the studied area. Turbic Cryosols forming characteristic micro-relief (*i.e.* sorted circles, mud boils, cell forms, striped soils or polygons) occur on flat surfaces and gentle slopes. Such soils (covering 7% of the studied area) are formed from loamy parent material. Along streams (Fuglebekken and its tributaries) Hyperskeletic Cryosols (Reductaquic) and Turbic Histic Cryosols occur. The soil units (constituting 11% of the studied area) are mantled by continuous and dense vegetation cover (especially mosses) due to high content of water and nutrients originating from bird colonies (*Alle alle*) located on slopes of Ariekammen and Fugleberget. Thin Lithic Leptosols are limited to rock outcrops on Ariekammen and Fugleberget ridges and old skerries occurring on uplifted marine terraces. The studied soils are generally characterized by shallow occurrence of permafrost (*i.e.* at 30–50 cm), high content of pebbles, sandy or sandy loam texture, and neutral or slightly alkaline reaction. Soils occurring along streams and near colonies of sea birds show higher content of nutrients (N and P) in comparison with other soils and are covered by more dense vegetation. This indicates important impact of bird guano on chemical composition of soil solution and fertility of such soils.

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