Zbigniew Klimowicz
Jerzy Melke
Jacek Chodorowski
Stanisław Uziak
Piotr Bartmiński

6. Soils

The western coast of Spitsbergen, despite its rather short distance from the pole and the dominion of mountain areas, is characterised by a comparatively moderate, subpolar marine climate. The petrographic composition of the lithosphere and the right humidity, particularly in the area of seaside planes and valley floors, were conducive to the development of the biosphere. This resulted in the intensification of soil formation processes, which in turn led to the formation of various soils on large areas of land: initial, weakly developed soil, gley soil, organic soil, or brown soil with a relatively high content of organic matter.

The characteristics of these soil types have been described in works by such authors as: Blümel *et al.* (1993ab), Forman & Miller (1984), Göttlich & Hornburg (1982), Hallet *et al.* (1988), Kabała & Zapart (2012), Klimowicz *et al.* (1993), Klimowicz *et al.* (2008), Låg (1988), Mann *et al.* (1986), Melke *et al.* (1990), Melke & Chodorowski (2006), Plichta & Kuczyńska (1991), Plichta (1993), Skiba & Kuczek (1993), Skiba *et al.* (2002), Szerszeń (1974), Thannheiner & Möller (1994), Ugolini & Sletten (1988), Weber & Blümel (1994).

Purpose and methods of study

The aim of this study is to present the characteristics of the soils of north-western section of Wedel Jarlsberg Land based on the key results of research carried out on Spitsbergen by the Department of Soil Science and Soil Protection of Maria Curie-Skłodowska University.

Soil profiles for study were located so as to cover all the main geomorphological forms, particularly the vast, raised marine terraces. The less accessible mountainous areas were also included. The selection of study sites was guided mostly by the lithology and relief of the area, its moisture content, type of vegetation, vicinity of bird colonies, etc. Particular attention has been paid to the relationship between the formation of soils with specific properties and the microrelief forms common in the area of study, e.g.: sorted circles, mud boils, cellular forms, striped forms (streaks), or tundra polygons (Fig. 6.1).

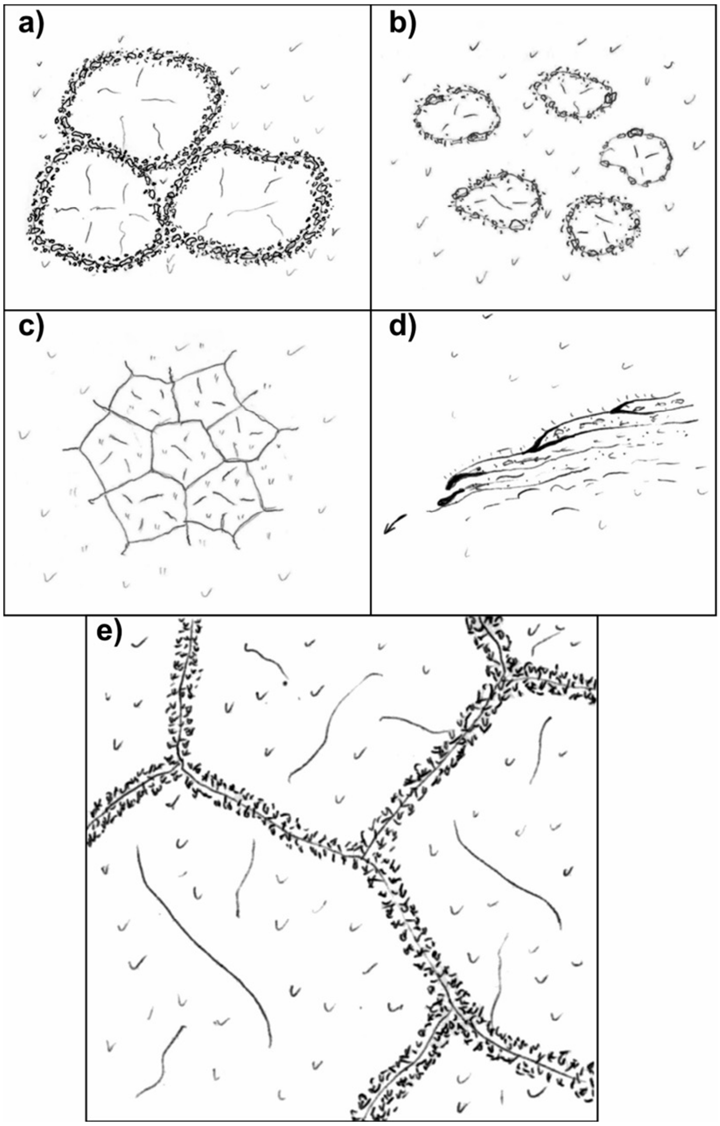

Fig. 6.1. Main micro-relief forms of study area: a- sorted circles, b- mud boils, c- cell forms, d- striped soils (streaks), e- tundra polygons.

During the field studies of numerous soil surfaces the researchers employed the method of intersecting levelling-soil sections, based on which they analysed the soil morphology as well as the type and degree of vegetation coverage. Additionally, a couple of longer (several hundred meters) levelling-soil transects were marked out and one that ran across the whole system of raised marine terraces all the way to the mountain summit. The studies also covered the peat soils along the defined sections. Punctual soil studies focused mainly on the soils of mountainous areas, a few peatlands and seaside plains.

The dynamic range of certain physical-chemical soil characteristics, such as the redox potential (Eh) or the oxygen diffusion rate (ODR) was analysed in the course of stationary studies conducted on brown soil (Gelic Cambisol) developed from silty lighty loamy sand, and in gley soil (Gelic Gleysol) developed from medium silty loam. The following properties of soils were determined in the lab: granulometric composition – using the Bouyoucos aerometric method modified by Casagrande and Prószyński; calcium carbonate converted into $CaCO_3$ – the Scheibler apparatus; pH – by joint electrode; organic matter content – loss on ignition method; organic carbon – the Tiurin method; total nitrogen – the Kjeldahl method, easily available phosphorus and potassium forms – the Egner-Riehm method; and exchangeable cations – the Mehlich method (Lityński *et al.* 1976). The color of selected soils was determined based on air-dry samples according to the color atlas.

Mineralogical analyses included microscopic examinations of fine-grained sand or coarse silt as well as roentgenographic examination of the clay fraction. The roentgenographic examination used a DRON diffractometer with a copper lamp and computer-based data recording.

Total content of iron, aluminum and manganese was determined after solving the samples in a mixture of hydrofluoric acid and perchloric acid (Lim & Jackson 1982). Also was an identified different form of iron, aluminum and manganese in the following solutions: sodium pyrophosphate 0.1 M (Mc Keague 1981), oxalate solution and citrate buffer. The composition of humic compounds was determined using the method of fractional analysis developed by Boratyński & Wilk (1963). The content of heavy metals in mineral soils was determined in a DTPA-TEA extraction solution using the Lindsay-Norvell method (1978). Macro- and microelements in organic soils were identified after combusting samples and solving them in a mixture of HF and $HClO_4$ acids. The elements were identified using the ASA method and the Perkin-Elmer 3300 apparatus (AMAAS - Analytical Methods for Atomic Absorption Spectrometry 1982). Soluble forms of Ca, Mg, K, Na and P were determined in a 0.03 M solution of CH_3COOH, phosphorus – using colorimetry, and the remaining elements using the ASA method. Iron compounds (Fe^{2+} and Fe^{3+}) were identified using the Kozarinova-Oknina method modified by Koptieva (1958).

The formation of soil cover in polar conditions

In the area of Spitsbergen's arctic tundra the dominant factors in terms of soil formation are the following: the climatic conditions and resulting water relations, the petrographic composition of lithosphere, and the biosphere. The relief of the land is also of significant importance, as even slight inclinations are subject to solifluction processes that modify the character of the soil cover. These processes mainly affect soils made from fine silt and clay fractions. They lead to the creation of solifluction streaks or various striped formations on the surface, and cause the round formations, usually sorted circles, to become stretched out.

The processes that result in the formation of various soil types are usually directly related to the vicinity of glaciers, very numerous in the area, which due to long-term interaction provide different types of sediments. The mineral composition of these sediments, including marine sediments, their mechanical composition and moisture content, determine the formation of different soil types. Of course, we should also bear in mind the thermal factors.

The soils of the north-western part of Wedel Jarlsberg Land were basically created as a result of the following soil-formation processes: initial soil formation, gleying, browning, humus accumulation and peat formation. All the soils are to a different extent affected by cryogenic processes.

Initial soils were created in the least favorable conditions, i.e. in mountainous areas or in areas that are less elevated but with layers of loose formations. The profile of initial soils is poorly developed (AC or AC-C). The transitional humus horizon is gray with a brownish or yellowish hue, not very different in color from the substratum rock. Initial character of these soils is also due to the high intensity of periglacial processes.

Particularly shallow soil types include initial soils, poorly developed soils in mountainous areas as well as initial rendzinas with a clay-silt composition (Rendzic Leptosols and Gelic Leptosols (FAO-UNESCO 1997). These usually occur in the vicinity of soilless regions. Regosols (Gelic Regosols) with a profile of A-C1, C2, C3 or A-C-Cgg are slightly better developed. They are formed from unconsolidated sedimentary rocks and are characterised by a rather non-distinct morphology and only slightly more marked and slightly more thick humus layer than the soils described above. The grain size distribution of these soils is varied and, in general they are without microrelief. The described group may also include alluvial soils, not presented on the map. These occur in areas of significantly less dynamic fluvial processes (Photo 6.1).

Common occurrence of gleying processes in the soils of the region resulting from permanent or periodic excessive moisture content is mostly related to the climatic conditions and the fineness of the solid phase. Shallow and frozen substratum and the relatively low evaporation level are all conducive to retention of moisture within the soil. It should, however, be mentioned that the strong and frequent winds lead to the drying of soil surface, which in turn leads to the creation of a network of small cracks in the clay or loam material.

The profile of gley soils is AC-G1-G2. Low thickness of the humus layer and its gray color is a result of the relatively low humus content. In the lower layers the color becomes gray-greenish. In terms of grain size distribution clay and loam material are dominant. Gley soils often accompany such microrelief forms as: mud boils, cellular forms, sorted circles, or – to a lesser extent – solifluction stripes (Photo 6.1).

The origins of the brown soils (Gelic Cambisols) from the studied area have not yet been identified in full. Many authors are inclined to believe that the 'B' layers of these soils might have been formed both due to illuviation of Fe, Al and – partially – organic matter, as well as due to *in situ* weathering of rocks containing iron. Some indicate that browning layers within the arctic region have certain relic-like features. The profiles of brown soils in the studied area are clearly distinct. The relatively deep profile is comprised of the following levels: either A-B-C or AB-BC-C. The gray-brown (10 YR 4/2) humus horizon clearly changes into the B enrichment layer with a brown or dark-brown color (10 YR 4/6 or 10 YR 3/4) and then into the bed-rock horizon with its yellowish-brown color (10YR 6/6) (Photo 6.1).

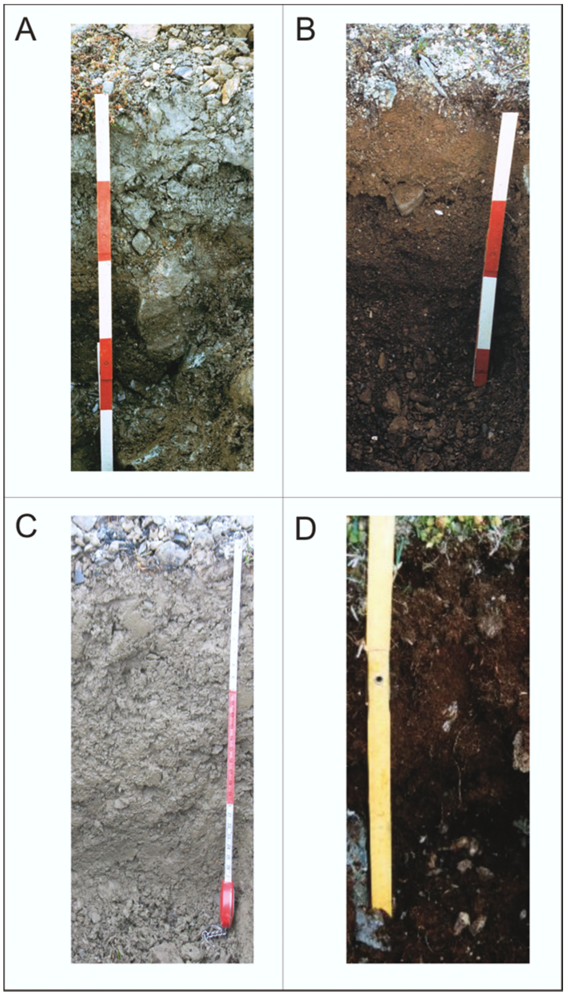

Photo 6.1. Profiles of main soil units: A- initial soil – Lithic Leptosol (Photo J. Melke), B- brown soil – Gelic Cambisol (Photo J. Chodorowski), C- gley soil – Gelic Gleysol (Photo P. Bartmiński), D- peat soil – Gelic Histosol (Photo J. Melke).

The brown soils of the studied area were mostly formed from loamy sands and light loam, often enriched with silt fractions, i.e. materials with a lighter granulometric composition than gley soils. They also have less moisture content than gley soils, so the cryoturbation processes taking place within them are less intensive. This results in the lack of surface diversity or the exclusive formation of vast tundra polygons. The comparatively good drainage system of these soils is due to their lighter granulometric composition and the fact they are located near deep chasm and sea-cliffs.

A portion of the soils, mostly brown soils, is relatively rich in organic matter. Admittedly, in polar conditions the growth of biomass is only slight, especially in areas more remote from the sea, but due to low biological activity of the soil, its decomposition is very slow. The soils of the western and south-western parts (west of Cape Lyell) in particular are affected by climatic conditions more conducive to the growth of vegetation than in the eastern part. This results in the humus content of these soils being nearly two times higher than that of the soils located to the east of Cape Lyell.

Conditions that are favorable to the developing of peatlands in the studied area occur mostly near the sections of marine terraces located at the foot of mountain slopes. Snow melt water and rainwater flows down these slopes. Because the slopes of mountain ridges in the vicinity of the sea coast often constitute nesting grounds for numerous bird colonies inhabiting the area, they are heavily fertilised by bird feces. High growth of biomass occurs in the lower parts of slopes and at the foot of the slopes.

The layer of peat soils (Gelic Histosols) is usually no thicker than 0.5 m. Their profile is: (PO)-O1-O2-D. The surface is covered with a several centimeter thick layer of moss, usually gray-greenish in color. It is undecomposed or decomposed to a very low degree. It lies directly on a layer of peat (O1) that is slightly more decomposed and light-brown in color. Below that the organic layer is black-brown and decomposed to a high degree (O2). The mineral layer (D) spread below the organic ones is varied in terms of granulometric composition and, but often rich in fine-grained fractions. It should be mentioned that organic-mineral and mineral-organic soils (categorised depending on their thickness and organic matter content) occur quite numerously within the studied area. These types of soils are created on low permeable substrata; they have high moisture content and are heavily affected by gleying processes (Photo 6.1).

Unique impact of frost processes on soil characteristics

The impact of cryogenic processes on the lands and soils of Spitsbergen is visible in the richness of surface formations (Prestrud-Anderson 1988; Van Vliet-Lanoë 1988). Vast areas are occupied by so-called patterned ground. The deciding factors in its creation are the low and near-zero temperatures. Other important aspects include the fineness of the mineral material and its moisture content (Fig. 6.1).

The researchers identified a direct relationship between the various microrelief forms, the characteristics of structural soils and the accompanying vegetation. The most easily distinguishable surface formations include stone and gravel circles, which constitute an almost decorative element of the generally monotonous arctic tundra. The diameter of these formations is usually between 1 and 3 m, and the height of the sorted circles rarely exceeds 20 cm. Some are level with the ground and there are even some that are below the ground level. In Dyrstaddalen, the researchers also found singular, large-diameter circles made of stones and rock blocks, and even some made entirely out of rock blocks, with the block diameter reaching 1 m (Photo 6. 2AB).

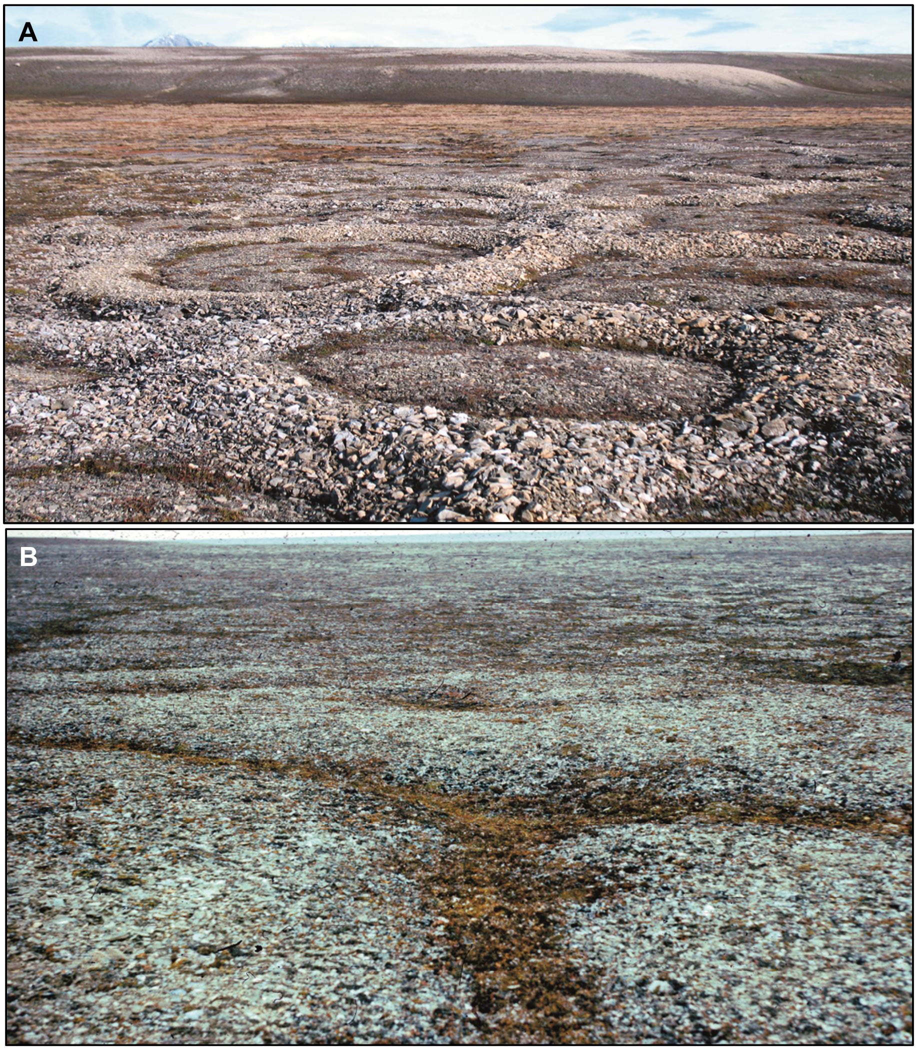

Photo 6.2. Micro-relief forms of study area: A- sorted circles (Photo P. Bartmiński), B- tundra polygons (Photo J. Chodorowski).

Within the area of sorted circles the most common soils include: gley soils (Gelic Gleysols), partially gleyed soils (from the bottom up) and certain regosols (Gelic Regosols). Scarce vegetation (approximately 20%) is present at the edges of the circles and between the circles; sporadically, plants can also be found in the center of a circle. Mosses are the dominant species; the vascular plants occurring in the area include: *Salix polaris L., Saxifraga oppositifolia L., Polygonum viviparum L., Equisetum Variegatum* L.; lichens are represented by *Cetraria hiascens* (Fr) Th.

Other surface formations, which occur in conditions similar to those described for sorted circles above, are mud boils. These are round or elliptical forms, slightly protruding, with a diameter of 50-70cm. Their light-gray color and almost complete lack of vegetation in the central area gives the impression of 'spots' on the ground. This is why these formations, as well as surfaces with scarce vegetation, are identified as spotted tundra. Mud boils often occur in the vicinity of sorted circles and are similarly related to gley soils. The edges of mud boils are covered with vegetation (up to 50%) in the following order (starting with the most common species): mosses; vascular plants: *Salix polaris L.* and *Saxifraga oppositifolia L.*; lichens: *Cetraria hiascens L.* and *Stereocaulon sp.* (Photo 6.3AB).

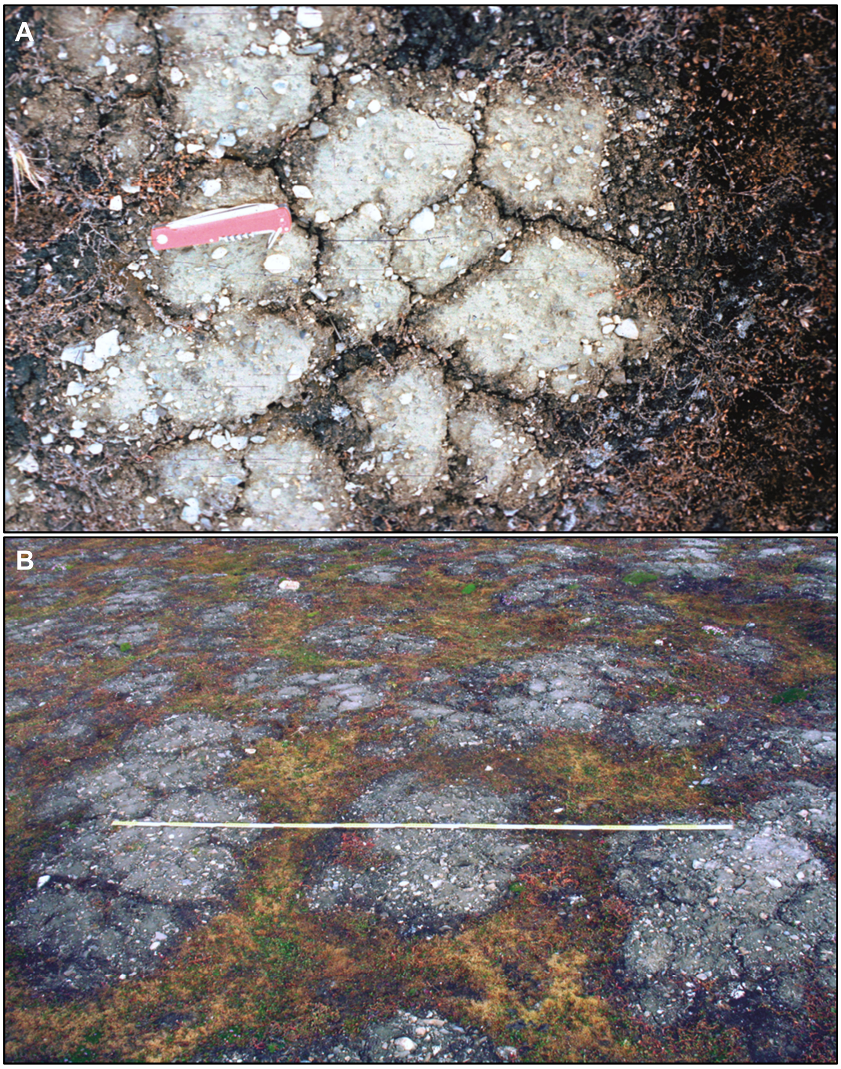

Photo 6.3. Micro-relief forms of study area: A- cell forms (Photo J. Chodorowski), B- mud boils (Photo P. Bartmiński).

Cellular soils are often found in the vicinity of sorted circles and mud boils; they are, however, less common than said formations. They take the form of polygons with a diameter of 0.5-1.0 m. Compared to mud boils they are flatter and more saturated with water. Cracks that separate the described formations may become deposits of crushed rock material, set into the substratum. Due to high moisture content, specifically near the small lakes that are characteristic of the area, the main processes here are gleying processes. The vegetation cover (around 40%) is markedly different than the flora of previously described formations. Algae are the dominant species, followed by mosses and grasses (Photo 6.3).

Striped soils, characteristic of periglacial environments, are a common feature on the slopes found throughout the studied area. Frequently distorted profiles of said soils, comprised of loam material or loam-silty material, are reminiscent of gley soils or poorly developed soils, sometimes brown soils. The vegetation layer is similar to that of cellular formations, with differences in the composition of species. In the case of striped soils the dominant species is *Polygonum viviparum L.,* followed by: *Salix polaris L.* and *Saxifraga oppositifolia* L.; lichens include: *Cetraria hiascens L.* and *Stereocaulon sp.*

Tundra polygons (large-sized) belong to the biggest types of soil surface formations. Their diameters range from several to a dozen or so meters. They are currently limited by lines of soil wedges (in the initial stage – ice wedges), described by Jahn (1982, 1983). After the ice has thawed, the cracks were filled with mineral material with a heavy admixture of organic matter. Tundra polygons are a prevalent feature in the area of lower marine terraces made of loamy sands and light loam (Photo 6.2).

Moderate moisture content and more favorable thermal conditions than the ones described above stimulated the growth of vegetation and the formation of relatively well-developed brown soils (arctic brown soils – Gelic Cambisols). The vegetation layer (with a width of up to 1 m) covers the whole area of frost cracks, and about 70% of the polygons themselves. The central part is covered in lichens (*Cetraria hiascens L.* and the light-gray *Stereocaulon sp.*), and vascular plants – *Salix polaris L., Saxifraga oppositifolia L.*, and *Silene acaulis* (L) Jacq. Along the cracks and at the top of the cracks mosses are the dominant species, but other species also occur: *Cetraria hiascens Fr., Salix polaris L.*, *Saxifraga oppositifolia L.,* and *Silene acaulis* (L) Jacq. In the vicinity of tundra polygons you can also find indistinct areas or areas with vaguely visible, irregular crackings. These areas occur on formations with a granulometric composition similar to that of the brown soil bedrock; they are also of a similar type. The indistinct microrelief or its complete lack is due to low mechanical activity of the soil, caused perhaps by e.g. lower moisture content as compared to tundra polygons. The vegetation coverage of these surfaces is around 60% and its species composition is reminiscent of plant types typical for central parts of tundra polygons (Klimowicz & Uziak 1996b).

The soil cover of valley floors and seaside plains

The locations of soils and areas without the soil cover have been presented on a schematic map (Fig. 6.2) which apart from the features of respective soil types accounts for petrographic features of the substratum, the relief of the land, the water relations and the character of the biosphere. The legend of the map also includes a list of soil units.

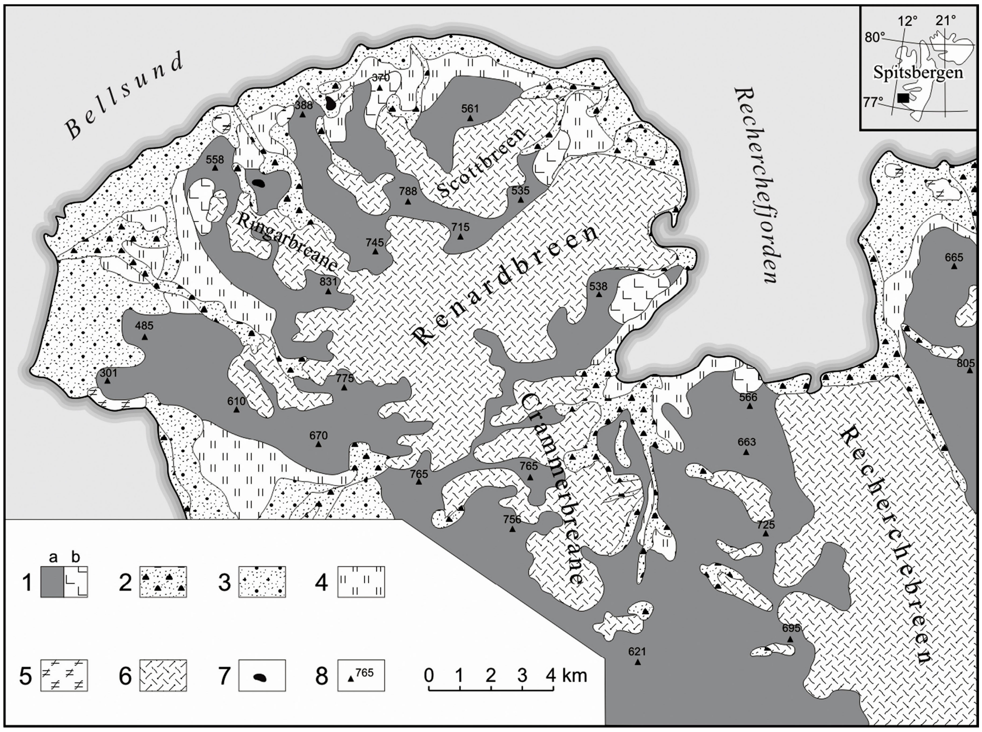

Fig. 6.2. Map of soils and formations without soil cover: 1a- formations without soil cover (massive rocks, rock debris) and locally initial and weakly developed soils, mainly mountains soils (Lithic Leptosols), 1b- rendzinas (Rendzic Leptosols), 2- formations without soil cover, mainly glacial and fluvioglacial deposits, locally initial and weakly developed loose soils (Gelic Regosols) and alluvial soils (Gelic Fluvisols), 3- brown soils (Gelic Cambisols), 4- gley soils (Gelic Gleysols), 5- organic soils (Gelic Histosols) and organic-mineral and mineral-organic soils; 6- glaciers, 7- lakes, 8- culminating points.

Initial and poorly developed soils including rendzinas take up large surfaces of land in the studied area. They developed on shallow deposits of massive rock waste mostly related to mountainous areas. Much less expansive areas of these soils, which were formed on loose rocks (Gelic Regosols), occur in the forefields and in the vicinity of glaciers, near watercourses and braided rivers.

Seaside plains, as well as the stretches of land found within large valleys, especially Dunderdalen and Lognedalen, are covered with brown soils. Large river valleys and areas adjoining slopes usually contain gley soils (Gelic Gleysols); these, however, rarely reach all the way to the seashore.

Small areas of peat soils (with a thickness of organic layers exceeding 0.4 m) occur in several locations only (Klimowicz *et al.* 1997). The largest and best-developed of these can be found in the lower regions of the Dundrabeisen massif and at its foot (Dunderbukta region) as well as (considerably smaller-sized) at the foot of the northern ridge of Klokkefjellet (Fig. 6.3). Additionally, in several areas of Calypsostranda the researchers found a specific type of peat soils, i.e. so-called crevasse soils. In general, the studied area includes numerous small-sized regions of organic-mineral and mineral-organic soils. These are formed under slopes, at the edges of minor lakes and at the bottoms of mostly small basin-like formations with a low-permeable substratum.

Within the area of seaside plains, apart from river valleys in which water flows continuously (during the summer season), there are also several smaller valleys in which minor amounts of water occur periodically. Depending mostly on the fineness of the soil material, the moisture content and the microclimatic conditions, the bottoms of these valleys and their slopes have a highly diverse soil and vegetation cover. The soil cover is basically non-existent on gravely-stony substrata, but in the case of the Calypsostranda station, where the substratum contains mostly silty-loamy sands with only a slight admixture of large-sized fractions, the land is extremely fertile – as evidenced by the vegetation coverage of over 50% (up to 100%), the well-developed brown soils on the slopes and highlands, as well as the alluvial-delluvial soils on the valley floors (Klimowicz & Uziak 1996a).

An inherent feature of the studied area's landscape is the occurrence of small shallow lakes and wetlands. In the vicinity of these formations the soils often form a specific toposequence, starting with gley cell soils in areas adjoining the water. These soils then change into poorly-developed soils or striped soils, and further on into brown soils. Similarly, one can observe changes in the granulometric composition, starting with clay formations in the lowest areas next to the water, which are eventually replace by light loam and medium silty loam in the brown soils found further up. Soils in the vicinity of these lakes are usually alkaline, rich in $CaCO_3$, have a high content of calcium, manganese and sodium soluble in 0.03 M CH_3COOH, and have small amounts of phosphorus and potassium. Places with the highest moisture content are covered in tufts of moss and grass (including the imposing *Deschampsia alpina*) and cell soils are dominated by black and brown algae (Klimowicz & Uziak 1995).

The researchers identified three types of sorted circles in the area of study: the most common gravel/stone type (a), the sporadically occurring stone type (b) and the unique stone/rock block type (c). They also discovered a surprising pattern with regard to the grain size distribution. In the soils that accompany the a, b and c formation types the sand fraction content was, respectively, 45, 14 and 4%, and the colloidal fraction content (<0.002 mm): 8, 11 and 22%. One noteworthy aspect is the large size of the skeleton fraction in the case of stone/rock block circles, reaching a diameter of 0.5-1.0 m. Different fraction diameters and the resulting fineness of material affects the size of the total specific surface area, so it also improves the sorption capacity, also with regard to water. This is due to high levels of stress resulting from freezing and thawing of such soils, which leads to one of the processes characteristic of polar regions, i.e. sorting of rock material, even of such large size. The aforementioned formations are usually surrounded by gley soils, which do not, however, demonstrate any regularity in terms of chemical characteristics (Klimowicz 1997, 1999).

Rocky outcrops, irregular hillocks several meters high, that jut out above the surface of seaside plains are quite common in certain regions of the arctic tundra. The summits have no soil cover or are covered with poorly-developed soils or, rarely, brown soils. In the lower regions these become striped soils of similar qualities to brown soils. Gleying processes sometimes take place at the foot of the elevations. Mechanical disintegration of the rock material (fineness level) is mild at the summits and grows in intensity the closer you get to the foot of the hillocks, where the soils are richer in organic matter (Fig. 6.4).

Soils of mountainous areas

Mountain ridges, quite common in the north-western part of Wedel Jarlsberg Land, do not, admittedly, have large absolute height values (up to approx. 800 m a.s.l.), but due to the vicinity of the sea their relative height values are quite significant. These ridges are characterised by a post-glacial relief of the surface and as such are reminiscent of an alpine landscape. The surface of mountain slopes is mostly occupied by formations lacking soil cover, i.e. massive rocks and rock debris. Only in a few locations can you find shallow and primitive soils, whose qualities are similar to those of initial rock soils, poorly developed soils or rendzinas (Lithic-Rendzic Leptosols and Gelic Leptosols). The bedrock is mainly comprised of loamy and silty formations with a very low content of colloidal particles, i.e. smaller than 0.002 mm.

Mountainous soils are rich in $CaCO_3$, usually alkaline and diverse in terms of organic matter content. The humus content is highest in soils located closer to the ocean, as compared to those located deep within the island. Slope exposure is also of significant importance. West-exposed slopes are generally covered in dense vegetation, and the average content of C-org is 2%, while in the case of east-facing slopes the same value is 4 times lower. In all cases the humus content value decreases with the height above the sea level. This is probably because of thermal and moisture-related factors that determine the growth of vegetation, which serves as substrate necessary for the creation of humus.

The described soil types usually have a high content of Ca and Mg and – less commonly – Na, and a low content of P and K. The high content of easily available calcium and magnesium may be explained by the prevalence of dolomites in the area. Large amounts of sodium can be found in sodium-calcium feldspars. Low content of available potassium stems from the fact that the substratum rocks are poor in this element, and low content of phosphorus – from low biological activity, typical of the Arctic.

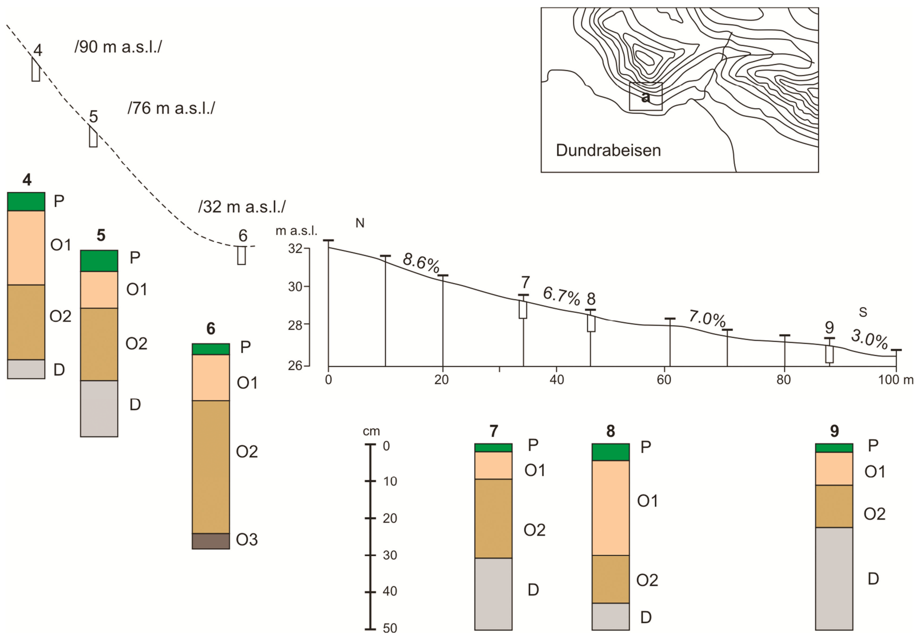

Fig. 6.3. Intersection catena of the peat soils in the Dundrabeisen region: a- location of the study area; 4-9- soil pits; T- examined sites; P- non decomposed or poorly decomposed organic horizon, O1- poorly (on terrace) and medium decomposed (on slopes) organic horizon, O2- medium or fairly well decomposed organic horizon, O3- frozen peat, D- underlying rock.

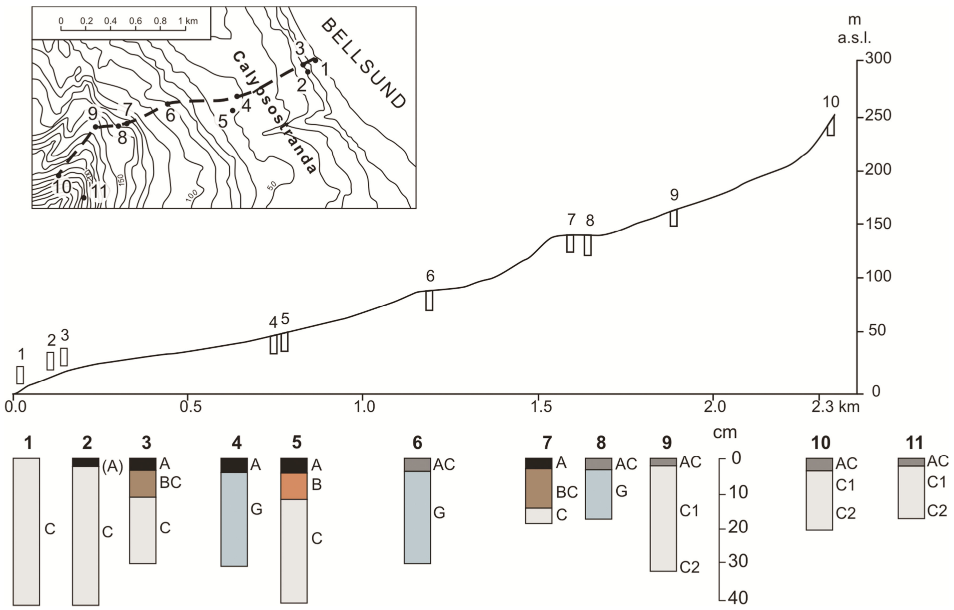

Fig. 6.4. Intersection catena of Calypsostranda – Bohlinryggen: 1-11- soil pits: 1- lack of soil cover, 2- weakly developed striped soil (Gelic Regosol), 3, 5, 7- brown soil (Gelic Cambisols), 4, 6, 8- gley soils (Gelic Gleysols), 9, 11- initial soils (Lithic Leptosols); (A)- humus horizon (initial), A- humus horizon, B- browned horizon, AC and BC- transitional horizons, G- gley horizon, C1, C2, C3- parent rock.

As was already mentioned, the mountainous areas of the studied region are largely devoid of both the vegetation layer and the soil cover. This is especially true of the eastern section. On the other hand, the areas closer to the sea, including the western-facing slopes, have more vegetation and better-developed soils. The flora is represented by the following species (vascular plants): *Salix polaris L.*, *Saxifraga oppositifolia L., Saxifraga caespitosa L.*, *Cerastium arcticum L.*, *Silene acaulis* (L.) Jacq. and, rarely, grasses. A large portion of the vegetation layer consists of mosses. In the eastern part, to the east of Cape Lyell, vegetation can only be found in selected locations in the form of: *Saxifraga oppositifolia L.*, *Cerastium arcticum L., Saxifraga Caespitosa L., Salix polaris L.* and its mountainous variety – *Salix recitulata L.,* less frequently: *Silene acaulis* (L.) Jacq. and *Dryas octopetala L.* These plants are accompanied by mosses and lichens, including saxicolous lichens (Klimowicz & Uziak 1996a; Klimowicz *et al.* 1996).

Mineral composition and physical characteristics of soils

The bedrock under the soils of the studied area consists mostly of diamictites, usually with clasts of dolomite or quartzite of different fineness, marine sediments (sand and loam), as well as alluvial silty sediments.

The dominant material in fine sands and the silt fraction is quartz and muscovite. Accessory minerals are mostly chlorites and feldspars. And as regards the clay fraction, the primary minerals – apart from muscovite – include chlorite, with an admixture of quartz and feldspar (Uziak *et al.* 1999) (Table 6.1).

The granulometric composition is highly diverse and unique for the arctic tundra regions. In the grain size distribution there is a large proportion of gravels and stones, i.e. the coarse fraction (soil skeleton). Sand and silt are the dominant material in finer fractions. Most soils have relatively small amounts of the finest – colloidal – fractions. This is due to the fact that physical weathering has more impact on the studied area than any other weathering process. Another characteristic feature of polar soils is that they are often silty, i.e. the average content of the silt fraction exceeds 25%. Apart from typical silty formations, this is particularly true of loam. And even in sandy formations the average content of the silt fraction can be as high as 19%.

The bulk density of soils is varied; the lowest value is found in the humus layer of brown soils: 1.3 $Mg \cdot m^{-3}$; the value is higher in the humus layer of gley soils: 1.9 $Mg \cdot m^{-3}$; and the highest value has been recorded in the CG layer of gley soils: 2.2 $Mg \cdot m^{-3}$. The bulk density increases the deeper down you go, as opposed to total porosity, which shows the highest values, i.e. within the range of 50-60 %, in brown soils. Bigger differences in the value of this indicator can be observed in gley soils – from 26% in the CG2 layer to 45% in the accumulation layer (A). In terms of non-capillary porosity, the largest differences (1-10%) have been recorded in loamy gley soil, characterised by intensive swell.

Table 6.1. Mineral composition of clay fractions.

Profile No.	Genetic horizon	Sampling depth (cm)	Dominant minerals	Accessory minerals
1	A	5-9	Mi>Ch	Q,Sk,Pl,Le
			↓	↑
	BC	22-30	Mi>Ch	Q,Sk,Pl,Le
2	Dl	9-13	Ch, Mi	Q, Sk, Pl, St, Ge, K
			↓ ↓	↓ ↓ ↓ ↑
	D3	30-40	Ch, Mi	Q, Sk, Pl, St, Ge
3	A	1-5	Mi>Ch	Q,Pl,Sk,Le
	AB	20-30	Mi>Ch	Q.Pl,Sk,Le
4	AC	2-7	Mi>Ch	Pl, Sk, Q
	Cl	15-25	Mi>Ch	Pl, Sk, Q
	C2g	35-45	Mi>Ch	Pl, Sk, Q
6	A	0-5	Ch>Mi	H, St, Sk, Pl, Q, S/I
				↓ ↑
	C2g	40-47	Ch>Mi	H, St, Sk, Pl, Q, S/I
7	AB	0-4	Mi>Ch	Pl, Q, Le, Ge
				↓ ↑
	BC	12-16	Mi>Ch	Pl, Sk, Q, Le, Ge
8	AC	0-5	Mi>Ch	Q, Ca, Pl, Sk
9	AC	0-7	Mi, Ch	Ca, Do, Q, Pl, Ge
10	AC	0-5	Mi, Ch	Ca, Q, Pl, Sk, Ge

Ch- chlorite, Mi- muscovite, S/I- smectite/illite, Q- quartz, Sk- orthoclase, Pl- plagioclase, K- kaolinite, G- goethite, H- hornblende, Le- lepidocrocite, St- stilpnomelane, Ca- calcite, Do- dolomite; arrows indicate directions of increasing contents.

Chemical and physical-chemical properties

Due to the fact that the rocky substratum of the studied soils is very rich in calcium-magnesium carbonates, the occurrence of $CaCO_3$ in soil profiles is quite common. Its content is highest in gley soils (over 10% on average) and in poorly-developed soils, and lowest in the top layers of brown soils. In the case of all soils the carbonate content increases markedly along with the depth. The dominant reaction of mineral soils is neutral and, to a lesser extent, alkaline. Slightly acidic reaction occurs only in certain accumulation layers of brown and initial soils. The pH value of all soils increases as we move deeper down, with alkaline being the dominant reaction in the bedrock layer. In respective granulometric groups the average values of pH (KCl approx. 7) are quite similar.

Mineral soils are, in general, quite rich in organic matter. This is particularly true of brown soils, with their average content of Corg being 2.34% in layer A and 1.37% in layer B. Poorly-developed soils (Gelic Regosols) and initial rocky soils (Lithic

Leptosols) have a similarly high content of humus. A significantly lower humic content is found in gley soils (Gelic Gleysols), with the average value being 1.74% C-org in the humus layer. Even though in the case of all soils the humus content decreases along with the depth, the resulting differences are not really that high. This is probably due to cryogenic disturbances that cause mechanical mixing of material within soil profiles.

The researchers found that soils consisting of formations with a high content of sand and silt fractions and low content of colloidal particles provide more favorable conditions for the growth of vegetation and, in consequence, have more possibilities to accumulate organic material. They are relatively warm and humid enough, which is conducive to the occurrence of plants. Different conditions can be found in gley soils, which are usually very humid and cold, and 'heavier' in terms of grain size distribution. It should be mentioned that sand formations in the studied area do not actually have the lowest content of nutrients, as these are usually loamy sands with a large admixture (19%) of silt particles and relatively small admixture of colloidal particles.

In the fractional humus composition there is a significantly high proportion of nonhydrolyzing substances and bitumens. They are characterised by a low level of humification and polymerisation. This leads to a high content of mobile forms, largely fulvic acids. The ratio of KH/KF in compounds more strongly bound with the soil mineral material is significantly lower than 1, and in permanently fixed compounds (after a hydrolysis of 0.5 N H_2SO_4) this ratio (KH/KF) is markedly higher. However, the latter compounds are few in the analysed soils. Harsh climatic conditions that limit the biological activity and inhibit the intensity of biochemical processes in soils clearly affect the character of humic compounds (Klimowicz & Uziak 1996c).

Within the defined granulometric groups, i.e. loamy sands, loam and silt formations the dominant cation is Ca^{2+}, followed by H^+ or Mg^{2+}. The number of Na^+ and K^+ is very small. The sum of alkaline cations is highest in loam and loamy sands (around 15 and 14 cmol $(+)\cdot kg^{-1}$, respectively) and in the case of silt formations it is, on average, around 11.5 $cmol(+)\cdot kg^{-1}$. Similar proportions have been observed with regard to the saturation of the sorption complex with alkaline ions, with the highest values being recorded in loamy formations, whose saturation exceeds 90 $cmol(+)\cdot kg^{-1}$. The highest sorption capacity was found in sand formations belonging to the loamy sand with a significant percentage of silt particles and relatively high content of organic matter – as opposed to, e.g. loamy (medium and heavy loam) gley soils (Melke *et al.* 1990). A complete analysis of chemical composition shows a high content of silica, aluminum and iron oxides in these soils, as well as large quantities of CaO and Na_2O. As regards available particles, there is a high number of calcium compounds, followed by sodium and magnesium compounds. There are only slight quantities of potassium, nitrogen (in the form of NO_3) and phosphorus.

The quantities of most of these compounds are dependent on the type of substratum rocks created from rock detritus rich in silicates and aluminum silicates. Sodium content may be linked to sea-related precipitation and phosphorus content to the places of frequent occurrence of animals – either reindeers or, on a wide scale, bird colonies. The studied soils show relatively high contents of microelements, e.g. manganese, copper, zinc, or lead, with the same values being different in the case of mineral and organic soils (Melke 1997; Melke & Chodorowski 2006).

Heavy metals extracted from top soil layers usually occur in the following order: Mn>Zn, Pb>Co>Cd. There is a clear positive correlation (mainly with regard to Pb and Zn) with the content of C-org. A positive correlation has also been found between fractions with a diameter of <0.02 mm and metals, particularly Cu and, partially, Mn. There is also a negative correlation between the amount of Pb and Cu, and the content of sand particles. The content of heavy metals in vascular plants typical for the studied area can be ranked as follows: Mn>Zn (sometimes Zn>Mn)>Cu>Co, Pb>Cd (and sometimes Pb>Co>Cd). There are, however, no regularities in the spatial distribution of these metals. Yet it should be mentioned that the content of heavy metals in the soils and plants of the studied area indicates that they are not polluted (Melke 2006; Melke & Uziak 2006).

Studies regarding the variability of the content of available soil elements were conducted during the growing season of 1987 based on soil profiles of accumulation layers of gley soils (loamy) and brown soils (sandy) located in Calypsostranda. It is worth noting that both loamy as well as sandy soils included, in general, high quantities of silt fractions. Research results show a high dynamic but a similar pattern of changes with regard to such elements as: Ca, Na, Fe, Mn and Cu. The researchers found a relationship between certain elements and the moisture content, e.g. higher moisture content relates to higher content of Mg, Fe, Mn and Cu; there is also a negative correlation between moisture content and Ca (Fig. 6.5AB).

Studies dealing with the variability of sorption qualities of the same soils were conducted in the summer season of 1999. The number of alkaline cations diminished during the studied season, together with the sorption capacity of soils. The decrease in soil temperature was accompanied by a clear decrease in the content of Ca^{2+} and an increase in the content of H^+, Mg^{2+}, Na^+ and K^+ (Melke & Uziak 1989, 1992; Melke *et al* 2003). The same sites were used to study the redox potential and oxygen diffusion rate. Concurrently, the researchers conducted measurements of soil moisture and temperature. The collected Eh values indicate a prevalence of redox – or even anaerobiotic – conditions, mainly in gley soils with a high moisture content. Both the measured redox values and the oxygen diffusion rate values were higher during the second half of polar summer, i.e. in the second half of July and in August. In general, it could be concluded that the study results confirm the high dynamics of properties of the arctic tundra soils (Melke 1999) (Fig. 6.5C).

The coastal strip of land, about 50 km long, stretching from Dunderdalen in the south-west to Reinsletta in the east is not uniform in terms of climate, vegetation or soil properties. The thermal and moisture-related conditions in its western half, to the west of Cape Lyell, are more favorable to plant growth. This is confirmed by a dense vegetation layer, seen both on flat areas as well as on western-facing slopes. This part of the studied area also includes peat soils, quite well-developed taking into account the polar conditions.

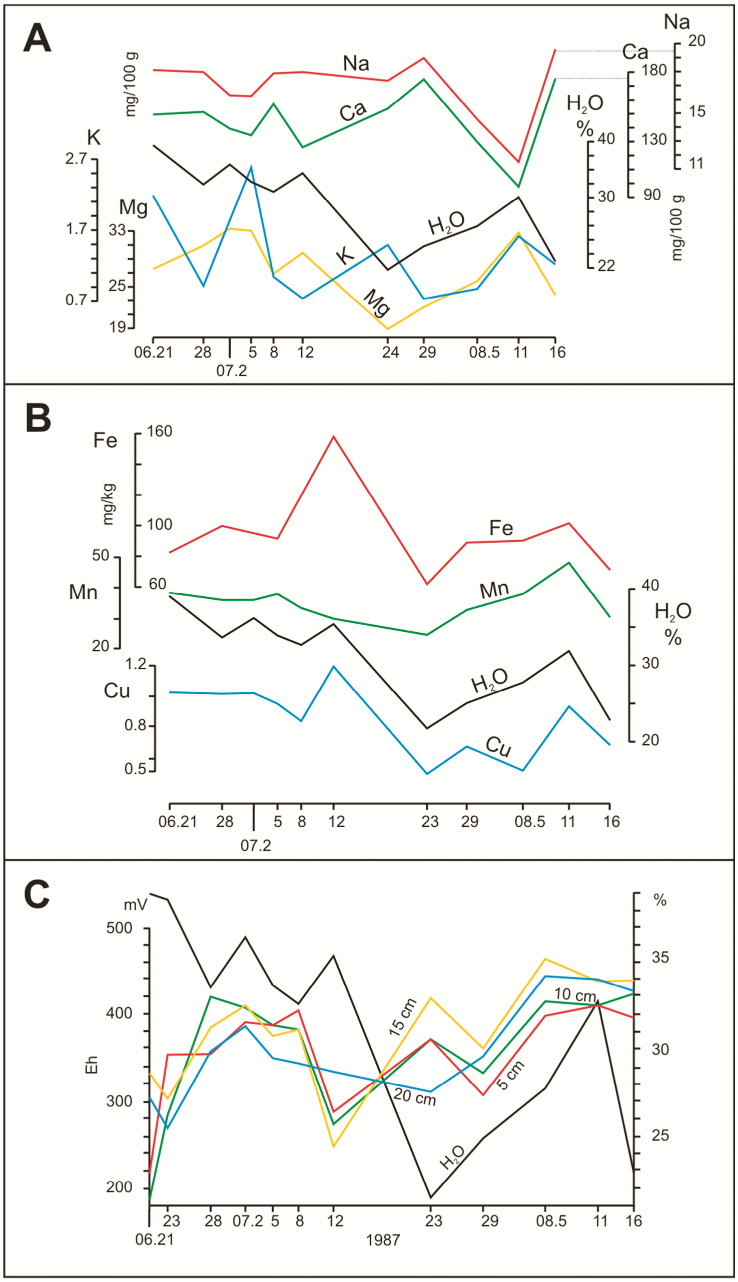

Fig. 6.5. A- dynamics of available Ca, Mg, Na and K (in mg·100g^{-1} of soil) and moisture content in brown soil (Gelic Cambisol); B- dynamics of available Fe, Mn and Cu (in mg·kg^{-1} of soil) and moisture content in brown soil (Gelic Cambisol); C- redox potential (Eh) of brown soil (Gelic Cambisol) at depths of 5, 10, 15 and 20 cm and soil moisture at depth of 5 cm.

Soils occurring to the SW of Cape Lyell have, on average, twice as much humus as those found to the east. With regard to composition of humic compounds the western soils have more active fulvic acids and are also more acidic. These qualities make it easier to leach carbonates and alkaline cations from the sorption complex, which decreases its saturation with these elements (Klimowicz & Uziak 2003).

The Polish and world literature of the subject is referred to in detail in our monograph dealing with the soils of the north-western part of Wedel Jarlsberg Land (Klimowicz *et al.* 2008). In this work, as was mentioned before, we will focus mostly on comprehensive monograph studies by Plichta (1993) dealing with the soils of Kaffiöyra and by Skiba *et al.* (2002) dealing with the soils of the western coast of Sørkappland. The soils analysed by these authors occur to the north and to the south of the ones described in this work.

The aforementioned authors agree about the importance of cryogenic processes in soil formation. It is particularly emphasised in the book by Skiba *et al.* (2002) with regard to the soils of western Sørkappland. In the global nomenclature system soils formed in such fashion are known as Cryosols. However, typical cryosols occur only sporadically in our studied area, because, if we take into account their definition, e.g. permafrost occurs too deep in the region of southern Bellsund (the authors of this work consider the southern Bellsund to be synonymous with the north-western part of Wedel Jarlsberg Land).

Within the studied area, in contrast to Sørkappland, there is a high proportion of well-developed brown soils (Gelic Cambisols). As was already stated, these were formed on material with a higher content of sand fractions and are related to large tundra polygons and surfaces lacking any distinctive micro-relief features. Known as 'arctic brown soils', they were studied, among others, by Drew & Tedrow (1962), or Ugolini & Sletten (1988). In the opinion of Bockheim (1980), due to the low moisture content of brown soils, the cryogenic processes affect them to a lesser extent. This is confirmed by our research related to brown soils (more on the subject in the monograph by Klimowicz *et al.* 2008).

Within the three listed regions of western Spitsbergen, only Skiba *et al.* (2002) identifies the occurrence of alluvial soils, but limited mostly to gravel-stone formations; the author classifies them as initial stony alluvial soils. In the case of our studied area alluvial soils were not marked on the soil map, because they occur in small patches in valley areas in the vicinity of initial and poorly-developed soils (regosols), as well as glacial and fluvioglacial formations.

The soils of the studied area are highly diverse in terms of mineral composition. In the opinion of Skiba *et al.* (2002) this is especially true of the moraine material and fluvioglacial or marine sediments, and is due to petrographic variety of different types of rock detritus. If we look at, e.g. the sandy-silty fraction, both in the area of Bellsund and Sørkappland this fraction has a high proportion of quartz, and in the clay parts – muscovite and chlorite. As regards the grain size distribution, there is a common consensus that most soils are characterised by a high content of skeleton, stone and gravel fractions, and in finer parts – sandy and silty fractions with a relatively low content of colloidal particles (Plichta 1993; Skiba *et al.* 2002; Klimowicz *et al.* 2008).

Most authors agree that carbonate compounds occur universally within the studied area. This view is further confirmed by Sletten (1988) with regard to other areas of Spitsbergen. The presence of carbonate compounds affects the reaction values, which seem to be higher when compared to the other two regions. Only in the area of Kaffiöyra and the north-western part of Wedel Jarlsberg Land did the researchers record lower pH values in brown soils than in gley soils. In the case of Kaffiøyra, Plichta (1993) believes that the specific brown soil reaction value is due to the supply of alkaline elements by sea spray, the content of carbonates in the bedrock and the intensity of leaching processes.

Our studies have shown that the content of organic matter in the soils is quite high for arctic conditions; these results are corroborated by the results of previous studies (Tedrow & Hill 1955; Douglas & Tedrow 1959; Szerszeń 1974; Plichta 1993). According to Plichta (1993), the slower rate of the organic matter mineralisation process results from the low temperature and high moisture content of soils. Organic compounds have more fulvic acids than humic acids. This is confirmed by Szerszeń (1974), who explains that the low content of humic acids is due to the specific bio-ecological conditions, which are unconducive to polymerisation. Moreover, the molecules of these acids in the soils of arctic areas have a lower carbon content and a higher content of hydrogen and oxygen when compared to other climatic zones. These qualities are typical for 'young' humic acids, similar rather to fulvic acids (Dziadowiec *et al.* 1994).

The sorption capacity of soils with regard to cations varies throughout the studied area, the highest values are found in brown soils formed from loamy sands with high content of silt fractions and humus. The soils of Kaffiøyra studied by Plichta (1993), including gley soils and brown soils, are characterised by low sorption capacity.

The studies regarding the presence of macro- and microelements and heavy metals in the soils of Spitsbergen only began 20 years ago (Plichta & Kuczyńska 1991; Plichta 1993; Ziaja *et al.* 1996; Melke 1997, 2006). Additionally, within the studied area the content of elements has also been determined with regard to plants (Jóźwik, Magierski 1992; Melke & Uziak 2006). There is a positive correlation between the metal content and the humus content of soils (Melke 2006). This is confirmed by the results of studies of Ziaja *et al.* (1996) with regard to copper, lead and cadmium. According to Plichta (1993) the source of the elements found in the soil, apart from the bedrock, could be the atmosphere, especially in the case of lead and cadmium. The values of respective elements' content calculated for the studied area indicate that the soils are not contaminated with heavy metals – this is corroborated by the results of studies of Ziaja *et al.* (1996), Skiba *et al.* (2002), Melke & Uziak (2006).

It is worth mentioning that analysing the content of Mn in *Dryas octopetala* L., and the content of Cu in *Saxifraga caespitosa L.* and *Saxifraga oppositifolia L.* allows us, according to Melke & Uziak (2006) to utilize these plants as bio-indicators for environmental pollution.

In the last couple of years, in cooperation with other scientific institutions in the country, studies were commenced focusing on the analysis of spatial and temporal variability of radionuclide activity in the soils and peatlands of Western Spitsbergen (Łokas *et al.*, 2009). The main goal is to study the correlation between the content of radionuclides and selected properties of soils. The European part of the Arctic, including the area of Spitsbergen, is particularly under the threat of being contaminated by radionuclides (e.g. due to nuclear tests carried out on Novaya Zemlya). The focus of other studies was the cellulolytic activity of arctic soils, i.e. brown soils and gley soils, which represent two types of bedrock – respectively, loamy sands with high admixture of gravel and stones, and loam formations with high silt content (Świtoniak *et al.* 2013).

Conclusions

The following formation types and soil types were identified within the studied area: 1) formations without soil cover (massive rocks, rock debris), as well as locally occurring initial and poorly developed soils, mainly of the mountainous type, including rendzinas (Rendzic Leptosols and Lithic Leptosols), 2) formations without soil cover, mainly glacial and fluvioglacial deposits, as well as locally occurring initial and poorly developed loose soils (Gelic Regosols), and alluvial soils (Gelic Fluvisols), 3) brown soils (Gelic Cambisols), 4) gley soils (Gelic Gleysols) and 5) organic soils (Gelic Histosols), as well as organic-mineral and mineral-organic soils (the distribution is shown on the attachment map).

The dominant factors affecting the soil formation processes were the following: climatic conditions, petrographic characteristics of the substratum, surface relief, and biosphere characteristics. One notable factor that is unique to the studied area and heavily affects the formation of soils is the frost-related (cryogenic) factor.

The researchers found distinct characteristics and regularities in terms of morphology and physical-chemical qualities of soils, depending on their location, e.g.: in mountain areas, peatlands, small valleys, in the vicinity of rocky outcrops, small lakes, or different types of sorted circles.

In terms of granulometric composition, a significant proportion of soils is comprised of skeleton fractions – stone and gravel, and in finer materials – sand and silt fractions with a slight admixture of colloidal fractions.

In general, soils are rich in $CaCO_3$ and their reaction (mostly mineral soils) is neutral or alkaline.

Brown soils have a relatively high content of organic matter as opposed to, e.g. gley soils. In terms of organic compounds, a large percentage of these include nonhydrolyzing substances and bitumens; there are also a considerable content of mobile forms, mainly fulvic acids.

Soil sorption capacity with regard to cations is rather low, with the exception of brown soils. The dominant exchangeable cation is Ca^{2+}, followed by H^{+} or Mg^{2+}.

Soils are characterised by a high content of silica, aluminum oxide and iron oxide. The frequency of microelement occurrences is the following: Mn>Zn,Pb>Co>Cd. Analysing the content of Mn and Cu in selected plants makes it possible to use them as bio-indicators for environmental pollution. The studied soils were found to be free of heavy metals. The study results have shown that the content of various elements in the soils is highly dynamic during the growing season.

The soils in the south-western part of the studied area, to the west of Cape Lyell, are formed in more favorable conditions, particularly in terms of thermal factors and humidity, than the soils in the east. On average, the western soils have a humus content that is almost two times higher, and they also have a higher level of active fulvic acids and a lower pH value, as compared to the eastern soils. Additionally, they are covered with dense vegetation (including the soils located on west-facing slopes).

Streszczenie

Gleby

W północno-zachodniej części Wedel Jarlsberg Land (Spitsbergen) wyodrębniono następujące grupy utworów: 1) utwory bezglebowe skaliste (skały lite, rumosz skalny) oraz miejscami gleby inicjalne skaliste i słabo wykształcone – głównie gleby górskie wraz z rędzinami (Rendzic Leptosols i Lithic Leptosols), 2) utwory bezglebowe luźne, w przewadze lodowcowe i wodnolodowcowe oraz lokalnie gleby inicjalne i słabo wykształcone luźne (Gelic Regosols), a ponadto gleby aluwialne (Gelic Fluvisols), 3) gleby brunatne (Gelic Cambisols), 4) gleby glejowe (Gelic Gleysols), 5) gleby organiczne (Gelic Histosols), a także organiczno-mineralne i mineralno-organiczne (ryc. 6.2, 6.4; fot. 6.1, 6.2, 6.3).

Decydujący wpływ na wytworzenie się gleb na omawianym obszarze wywarły warunki klimatyczne, cechy petrograficzne podłoża, ukształtowanie powierzchni, biosfera oraz czynnik mrozowy (kriogeniczny), w różny sposób modyfikujący obraz pokrywy glebowej w tym obszarze (ryc. 6.1). Dominacją utworów bezglebowych wykazują się grzbiety górskie, przedpola lodowców i niekiedy wychodnie skałek. Na powierzchniach podniesionych teras morskich i w dnach dużych dolin przeważają gleby brunatne. Z różnymi typami wieńców kamienistych, z wylewami gliniastymi i formami komórkowymi, związane są na ogół gleby glejowe. W niektórych miejscach podmokłych, użyźnianych przez kolonie ptasie, występują gleby torfowe (ryc. 6.3).

Znaczny udział w składzie granulometrycznym gleb zajmują frakcje szkieletowe – kamieniste i żwirowe, a w materiale drobniejszym – piaszczyste i pyłowe ze stosunkowo nieznaczną domieszką frakcji koloidalnych. Średnia zawartość pyłu w utworach gliniastych przekracza 25% i nawet w piaskach osiąga 19%. W składzie mineralogicznym gleb, we frakcjach piasku drobnego i pyłowej, dominują kwarc i muskowit, a jako minerały towarzyszące występują chloryty i skalenie. We frakcji ilastej natomiast przeważają: muskowit i chloryt z domieszką kwarcu i skaleni (tabela 6.1). Powszechnie występuje $CaCO_3$, a odczyn gleb jest na ogół obojętny lub alkaliczny. Względnie znaczną zasobnością w materię organiczną cechują się gleby brunatne (średnio w poziomie A – 2,34% C org.), zaś małą – gleby glejowe (odpowiednio – 1,74% C org.). W związkach organicznych duży udział mają substancje niehydrolizujące oraz bituminy – znaczna jest zawartość ich form ruchliwych, głównie kwasów fulwowych.

Pojemność sorpcyjna gleb względem kationów jest, poza glebami brunatnymi, niezbyt wysoka. W składzie kationów wymiennych dominuje Ca^{2+}, a w dalszej kolejności występują: H^+ lub Mg^{2+}. Gleby te cechuje znaczna zawartość krzemionki, tlenków glinu i żelaza. Kolejność występowania mikroelementów jest następująca: Mn>Zn,Pb>Co>Cd. Stwierdzono znaczną dynamikę zawartości pierwiastków w glebach w okresie wegetacyjnym oraz brak zanieczyszczeń gleb metalami ciężkimi (ryc. 6.5).

Gleby zachodniej części obszaru badań kształtowane są przez korzystniejsze warunki, głównie termiczno-wilgotnościowe, niż gleby części wschodniej. Na zachód od Kapp Lyell gleby wykazują średnio prawie 2-krotnie wyższą próchniczność, wyższą zawartość ruchliwych kwasów fulwowych oraz niższe pH, niż w części wschodniej. Porasta je dość zwarta pokrywa roślinna, zwłaszcza gleby na stokach eksponowanych w kierunku zachodnim.

Objaśnienia

Ryciny

Ryc. 6.1. Podstawowe formy mikroreliefu na badanym obszarze: a- wieńce kamieniste, b- wylewy gliniaste, c- grunty komórkowe, d- formy pasowe (smugi), e- poligony tundrowe.

Ryc. 6.2. Mapa gleb i utworów bezglebowych: 1a- utwory bezglebowe (skały masywne, rumosz skalny) oraz miejscami gleby inicjalne i słabo wykształcone, głównie górskie (Lithic Leptosols), 1b- rędziny (Rendzic Leptosols), 2- utwory bezglebowe, w przewadze lodowcowe i wodnolodowcowe oraz lokalnie gleby inicjalne i słabo wykształcone luźne (Gelic Regosols) a ponadto gleby aluwialne (Gelic Fluvisols), 3- gleby brunatne (Gelic Cambisols), 4- gleby glejowe (Gelic Gleysols), 5- gleby organiczne (Gelic Histosols) oraz gleby organiczno-mineralne i mineralno-organiczne, 6- lodowce, 7- jeziorka, 8- punkty wysokościowe.

Ryc. 6.3. Transekt niwelacyjno-glebowy przez powierzchnię gleb torfowych w rejonie Dundrabeisen: a- lokalizacja obiektu badań; 4-9- odkrywki glebowe; T- punkty badawcze; P- poziom organiczny nierozłożony lub słabo rozłożony, O1- poziom organiczny słabo rozłożony (tarasowy) i średnio rozłożony (na stoku), O2- poziom organiczny średnio lub dobrze rozłożony, O3- torf zmrożony, D- skała podścielająca.

Ryc. 6.4. Transekt niwelacyjno-glebowy Calypsostranda-Bohlinryggen: 1-11- odkrywki glebowe; 1- profil bezglebowy; 2- gleba słabo wykształcona pasowa (Gelic Regosol); 3,5,7- gleby brunatne (Gelic Cambisols); 4,6,8- gleby glejowe (Gelic Gleysols); 9,11- gleby inicjalne (Lithic Leptosols); (A)- poziom próchniczny inicjalny, A- poziom próchniczny, B- poziom brunatnienia, AC, BC- poziomy przejściowe, G- poziom glejowy, C, C1, C2- skała macierzysta.

Ryc. 6.5. A- dynamika zawartości przyswajalnych form Ca, Mg, Na i K (w mg·100 g^{-1} gleby) oraz wilgotności w glebie brunatnej (Gelic Cambisol); B- dynamika zawartości przyswajalnych form Fe, Mn i Cu (w mg·kg^{-1} gleby) oraz wilgotności w glebie brunatnej (Gelic Cambisol); C- potencjał redox (Eh) w profilu gleby brunatnej (Gelic Cambisol) na głębokości 5, 10, 15 i 20 cm oraz wilgotność na głębokości 5 cm.

Fotografie

Fot. 6.1. Profile głównych jednostek glebowych; a- gleba inicjalna – Lithic Leptosol (fot. J. Melke), b- gleba brunatna – Gelic Cambisol (fot. J. Chodorowski), c- gleba glejowa – Gelic Gleysol (fot. P. Bartmiński), d- gleba torfowa – Gelic Histosol (fot. J. Melke).

Fot. 6.2. Formy mikroreliefu; A- wieńce kamienisto-żwirowe (fot. P. Bartmiński), B- poligony tundrowe (fot. J. Chodorowski).

Fot. 6.3. Formy mikroreliefu; A- grunty komórkowe (fot. J. Chodorowski), B- wylewy gliniaste (fot. P. Bartmiński).

Tabele

Tabela 6.1. Skład mineralogiczny frakcji ilastej.