soil sequences atlas

edited by
Marcin Świtoniak
Przemysław Charzyński

WYDAWNICTWO NAUKOWE
UNIWERSYTETU MIKOŁAJA KOPERNIKA

Soil Sequences Atlas

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M. Świtoniak, P. Charzyński (Editors)
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FOREWORD

To understand the soil-landscape relation it is necessary to study the spatial diversity of soil cover. This variability is partly predictable due to the substantial repeatability of soil units. Depending on dominant soil-forming factor affecting the repeated soil patterns, different types of soil sequences can be distinguished. The influence of relief on the repeated variability of soil cover was first noticed by Milne in 1935 in East Africa. He proposed the term "catena" to describe a transect of soils that are related to the topography. Sommer and Schlichting in 1997 distinguished several archetypes of catenas depending on the mobilization processes and hydrological regimes. The impact of climate on the variability of soil cover is described as climosequences. The diversity of soils due to the different time of development - chronosequences are a suitable tool for investigating rates and directions of soil and landscape evolution.

This book provides an extensive database of soil sequences of various types from the following countries: Hungary, Latvia, Lithuania and Poland. The main objective of this study was to present a great diversity of soil-landscape/climate/hydrology relations and its effect on patterns in soil cover. Most recent edition of the World Reference Base classification system was used to classify presented soils (2014). Fourteen Reference Soil Groups are represented in this publication.

The collected data will be a useful tool in soil-science teaching, helping to understand reasons of variability of soil cover and influence of various soil-forming factors on directions and degree of development of 'Earth skin'. Presented data can also be used for comparison purposes.

Marcin Świtoniak

Przemysław Charzyński

List of Acronyms

Al_o – aluminium extracted by an acid ammonium oxalate solution
Al_t – iron extracted by solution of $HClO_4$–HF
BS – base saturation
CEC – cation exchange capacity
CEC_{clay} – CEC of the clay
$EC_{1:2}$ – electrical conductivity of a 1:2 soil-water extract
$EC_{1:2.5}$ – electrical conductivity of a 1:2.5 soil-water extract
EC_e – electrical conductivity of the soil saturation extract
Eh – redox potential related to the standard hydrogen electrode
ESP – exchangeable sodium percentage
FAO – Food and Agriculture Organization of the United Nations
Fe_d – iron extracted by a dithionite-citrate-bicarbonate solution
Fe_o – iron extracted by an acid ammonium oxalate solution
Fe_t – iron extracted by solution of $HClO_4$–HF
HA – potential (hydrolytic) acidity ($pH_{8.2}$) by the Kappen method
IUSS – International Union of Soil Science
N_t – total nitrogen
OC – organic carbon
pH_a – pH measurement referred to the actual soil moisture
pH_e – pH of saturation paste
pH_{ox} – pH measurement after incubation of soil samples under laboratory conditions within two months
pH_{pox} – pH measurement after oxidation with 30% H2O2
rH – the index used to assess redox conditions in water and soils calculated from pHa and Eh values (negative logarithm of the hydrogen partial pressure)
SAR – sodium adsorption ratio
SP – moisture content at saturation (saturation percentage)
S_t – total sulphur
TEB – total exchangeable bases

Methods

The soils were classified according to WRB 2014[1]. The soil morphology descriptions and symbols of soil horizons are given after Guidelines for Soil Description[2]. The samples were taken from selected soil horizons and after preparation (drying, separation of root and sand fraction >2 mm by sieving) it was analyzed in the laboratory. Texture was determined by (i) combining the Bouyoucos[3] hydrometer and sieve method or (ii) by pipette and sieve method. Organic carbon (OC) content was determined by the wet dichromate oxidation method, and total nitrogen (Nt) content by the Kjeldahl method. The reaction was measured in H_2O and 1 M KCl in 1:2.5 suspension for mineral samples, and 1:10 suspension for organic samples. Calcium carbonate ($CaCO_3$) content was determined by Scheibler volumetric method. Potential (hydrolythic) acidity (HA) was determined by Kappen method and exchangeable cation (bases) content was estimated by leaching with 1 M ammonium acetate with a buffer solution pH 8.2. Pedogenic forms of iron and aluminum were extracted: Fe_t and Fe_d by $HClO_4$–HF, Fe_d by sodium dithionite–citrate–bicarbonate[4] and Fe_o and Al_o by ammonium oxalate buffer solution[5]. Other soil analyses were performed according to the standard methods[6]. Color has been described according to Munsell[7]. It was recorded (i) in the moisture condition (single value) or (ii) in the dry and moisture condition (double values).

[1] IUSS Working Group WRB, 2014. World Reference Base for soil resources 2014. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Report No. 106. FAO, Rome.
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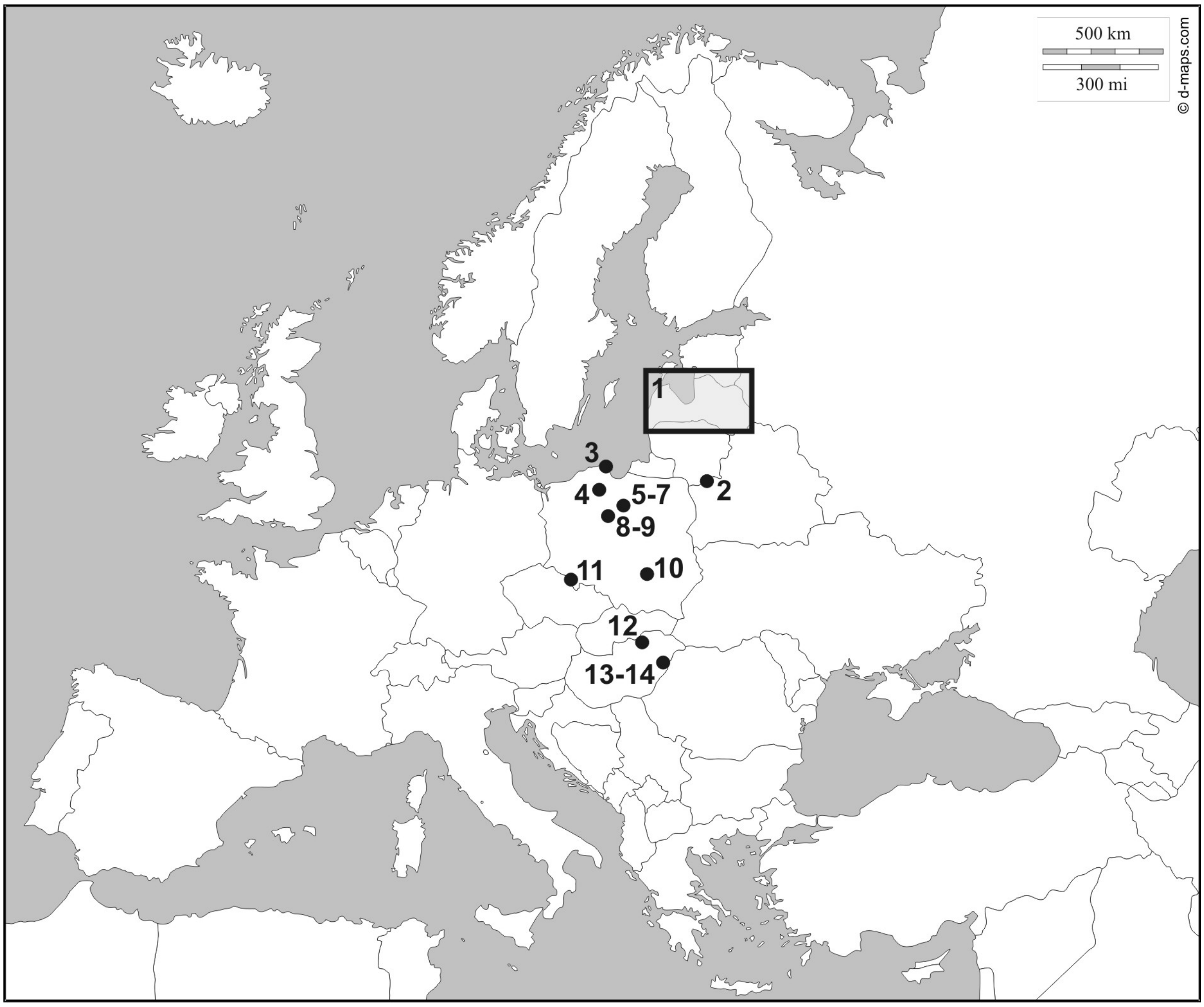
[4] Mehra, O.P., Jackson,M.L., 1960. Iron oxides removal fromsoils and clays. Dithionite–citrate systems buffered with sodium bicarbonate. Clays and Clay Minerals 7, 313–327.
[5] Mckeague, J.A., Day, J.H., 1966. Ammonium oxalate and DCB extraction of Fe and Al. Canada Journal of Soil Science 46, 13–22.
[6] Van Reeuwijk, L.P. 2002. Procedures for soil analysis. 6th Edition. Technical Papers 9. Wageningen, Netherlands, ISRIC – World Soil Information.
[7] Munsell Soil Colour Charts, 2009. Grand Rapids, Michigan USA.

STUDY AREAS



NUMBER OF CHAPTER - REGION AND COUNTRY:

1 - BOREO-NEMORAL ZONE, LATVIA

2 - DAINAVA GLACIOFLUVIAL LOWLAND, LITHUANIA

3 - PUCK LAGOON, POLAND

4 - TUCHOLA FOREST, POLAND

5–7 - BRODNICA LAKE DISTRICT, POLAND

8–9 - TORUŃ BASIN, POLAND

10 - ŚWIĘTOKRZYSKIE MOUNTAINS, POLAND

11 - STOŁOWE MOUNTAINS, POLAND

12 - BÜKKALJA FOOTHILL, HUNGARY

13–14 - SOUTH-NYÍRSÉG AND DEBRECEN, HUNGARY

Soils of *Quercus robur* L. stands on parent material with different genesis in the boreo-nemoral zone

Raimonds Kasparinskis, Vita Amatniece, Oļģerts Nikodemus

The distribution range of *Q. robur* L. covers all of Europe and extends to the Ural Mountains in Russia, reaching its northern distribution range in Scotland, Sweden and Estonia (Hytteborn et al., 2005). In the context of climate change, it is important to understand the limiting factors for the distribution of each tree species. Not only climate but also soil is one of the main limiting factors in the distribution of many tree species. Our research was conducted in Latvia, located in the boreo-nemoral transition region between the boreal and nemoral zones (Sjörs, 1963), near the northernmost distribution limit of oaks (*Quercus robur* L.). In Latvia, about 9734,38 hectares are covered by oak stands, i.e. 0.34% of the total area of forests (State Forest Service, 2011).

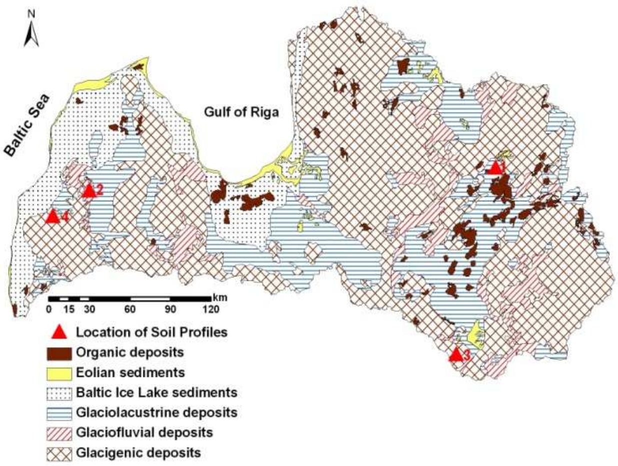


Fig. 1. Location of Soil profiles and Quaternary surface deposits in Latvia (after Geological map of Latvia, 1981)

In the boreo-nemoral transition region, *Q. robur* forms mixed stands on rich soils with nemoral tree species: linden (*Tilia cordata* Mill.), maple (*Acer platanoides* L.), elm (*Ulmus glabra* Huds.), white elm (*Ulmus laevis* Pall.) and common ash (*Fraxinus excelsior* L.), and boreal conifers − pine (*Pinus sylvestris* L.) and spruce (*Picea abies* (L.) H.) (Hytteborn et al., 2005).

Lithology and topography

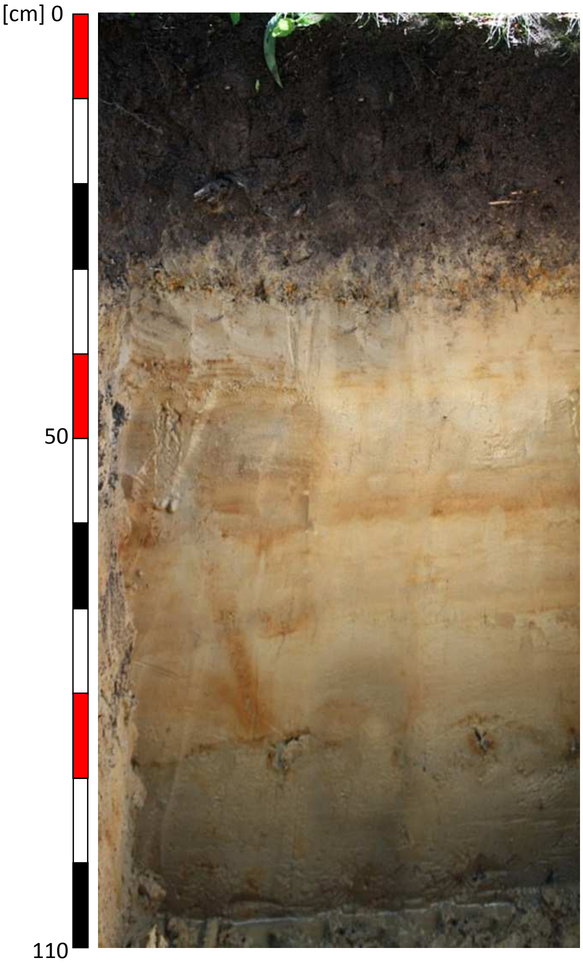
In Latvia, forests occur on soils of relativity high diversity, formed on different, mainly unconsolidated Quaternary deposits, in some places also on weakly consolidated pre-Quaternary terrigenous or hard carbonate sedimentary rocks (Kasparinskis, Nikodemus, 2012). The presented soils occur on a glaciolacustrine plain (Profile 1), glaciofluvial deposits (Profile 2), a glacigenic till hummock (Profile 3) and a glacigenic till plain (Profile 4) (Fig. 1).

Climate

Latvia is located in the transition zone of the nemoral and boreal zones (Ozenda, 1994), or the boreo-nemoral zone (Sjörs, 1963). The climate is between transitional maritime and continental with a mean temperature of -5.3°C in January and 14.8°C in July. Annual precipitation is 700–800 mm, of which about 500 mm falls in the warm period (data from the Central Statistical Bureau of Latvia, 2013). The climate is more continental towards the east. The forest area is about 55% and the dominant species are pine (*Pinus sylvestris L.*), birch (*Betula pendula L.*) and spruce (*Picea abies (L.) H.*), which represent 43%, 28% and 15% of the total growing stock volume, respectively (State Forest Service, 2008). Only about 1.1% of the forest area is dominated by nemoral tree species, such as oaks (*Quercus robur L*). An increase in the climate continentality from west to east is one of the main factors determining a decrease in the oak abundance with the increasing distance from the Baltic Sea (Krampis, 2010).

Profile 1 – Stagnic **Phaeozem** (Arenic, Ruptic)

Localization: East-Latvia lowland, glaciolacustrine plain, flat terrain 0–0.2%, oak forest, 111 m a.s.l.
N 60°09'10'', **E** 20°47'26''



Morphology:

Oi – 2–0 cm, slightly decomposed organic material;

Ah – 0–18 cm, *mollic* horizon, sandy loam, very dark gray (10YR 3/1), moist, moderate granular and subangular blocky fine, medium and coarse structure, diffuse and smooth boundary;

AEh – 18–28 cm, *mollic* horizon, sandy loam, very dark grayish brown (10YR 3/2), moist, strong granular and subangular blocky fine, medium and coarse structure, diffuse and wavy boundary;

EBsg – 28–44 cm, sand, pale brown (10YR 6/3), moist, weak subangular and angular blocky medium and coarse structure, *stagnic* properties, reducing conditions, common prominent sesquioxides coatings, diffuse and wavy boundary;

Bsg – 44–62 cm, sand, pale brown (10YR 6/3), wet, weak subangular and angular blocky medium and coarse structure, abundant prominent sesquioxides coatings, *stagnic* properties, reducing conditions, common reductimorphic mottles, diffuse and wavy boundary;

BCsg – 62–92 cm, sand, pale brown (2,5Y 7/3), wet, weak subangular and angular blocky medium and coarse structure, *stagnic* properties, reducing conditions, common prominent sesquioxides coatings, common reductimorphic mottles, clear and smooth boundary;

2Crk – 92–(109) cm, parent material, *lithic discontinuity*, loamy sand, greenish gray (GLEY2 5/5), very wet, weak subangular and angular blocky medium and coarse structure, reducing conditions, very few prominent reductimorphic mottles, moderately calcareous.

Table 1. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]			Textural class
		2.0–0.05	0.05–0.002	< 0.002	
Ah	0–18	55	44	1	SL
AEh	18–28	64	35	1	SL
EBsg	28–44	87	11	2	S
Bsg	44–62	92	3	5	S
BCsg	62–92	88	10	2	S
2Crk	92–(109)	72	25	3	LS

Table 2. Chemical and physicochemical properties

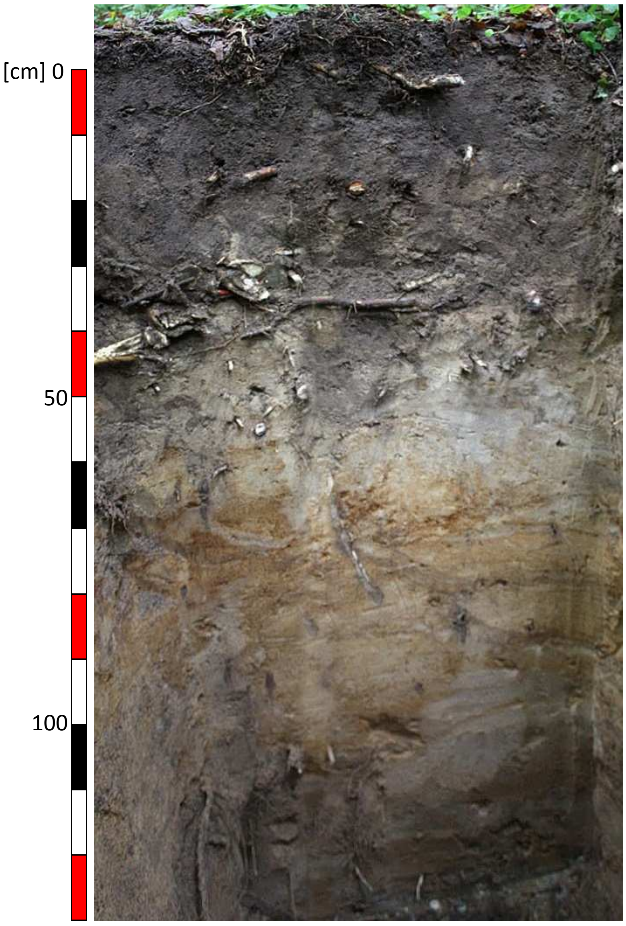
Horizon	Depth [cm]	OC [g·kg^{-1}]	Nt [g·kg^{-1}]	C/N	pH KCl	$CaCO_3$ [g·kg^{-1}]	Al^{3+}	Fe^{2+}	Mn^{2+}
							[mg·kg^{-1}]		
Oi	2–0	760	112	7	5.9	-	4.5	1.69	32.0
Ah	0–18	22.0	4.80	5	5.5	-	50.7	4.77	2.93
AEh	18–28	10.0	0.90	11	5.3	-	16.9	2.29	0.74
EBsg	28–44	-	-	-	4.8	-	2.9	0.97	0.22
Bsg	44–62	-	-	-	4.9	-	1.2	0.12	1.07
BCsg	62–92	-	-	-	6.0	-	1.4	0.37	0.23
2Crk	92–(109)	-	-	-	7.3	+	0.6	0.23	6.10

- $CaCO_3$ absent; + $CaCO_3$ present

Table 3. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	TA	CEC	CEC_{clay}	BS [%]
		[cmol(+)·kg^{-1}]								
Oi	2–0	35.6	4.56	0.350	0.083	40.6	0.050	40.6	-	100
Ah	0–18	9.38	1.07	0.102	0.053	10.6	0.563	11.2	350	95
AEh	18–28	5.73	0.74	0.018	0.032	6.52	0.188	6.71	321	97
EBsg	28–44	2.25	0.49	0.109	0.138	2.99	0.033	3.02	151	99
Bsg	44–62	4.30	0.75	0.077	0.154	5.28	0.013	5.29	106	100
BCsg	62–92	2.07	0.62	0.142	0.151	2.98	0.015	3.00	150	99
2Crk	92–(109)	4.22	1.00	0.076	0.039	5.33	0.007	5.34	178	100

Profile 2 – Haplic **Phaeozem** (Loamic)
Localization: West-Kursa upland, glaciofluvial terrace, gently sloping 2–5°, oak forest, 67 m a.s.l.
N 57°29'5'', **E** 20°52'10''



Morphology:

Oe – 6–0 cm, moderately decomposed organic material;

A – 0–10 cm, *mollic* horizon, loamy sand, dark brown (7.5YR 3/2), moderate granular coarse and very coarse structure, abrupt and wavy boundary;

AE – 10–33 cm, *mollic* horizon, loamy sand, very dark grayish brown (10YR 3/2), moderate subangular blocky medium and coarse structure, gradual and irregular boundary;

AEB – 33–53 cm, sandy loam, yellow light yellowish brown (2.5Y 6/3), strong subangular blocky very coarse structure, gradual and irregular boundary;

Bs – 53–94 cm, silt loam, yellowish brown (10YR 5/6), strong subangular blocky coarse and very coarse structure, common distinct sesquioxides coatings, gradual and irregular boundary;

BCg – 94–124 cm, sand, light yellowish brown (10YR 6/4), strong prismatic very coarse structure, *stagnic* properties, abrupt and smooth boundary;

2Cgk – 124–(134) cm, parent material, *lithic discontinuity*, sandy clay, grayish brown (10YR 5/2), weak subangular blocky coarse structure, *reducing* conditions, strongly calcareous.

Table 4. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]			Textural class
		2.0–0.05	0.05–0.002	< 0.002	
A	0–10	77	21	2	LS
AE	10–33	76	22	2	LS
AEB	33–53	65	33	2	SL
Bs	53–94	48	50	2	SiL
BCg	94–124	89	6	5	S
2Cgk	124–(134)	50	8	42	SC

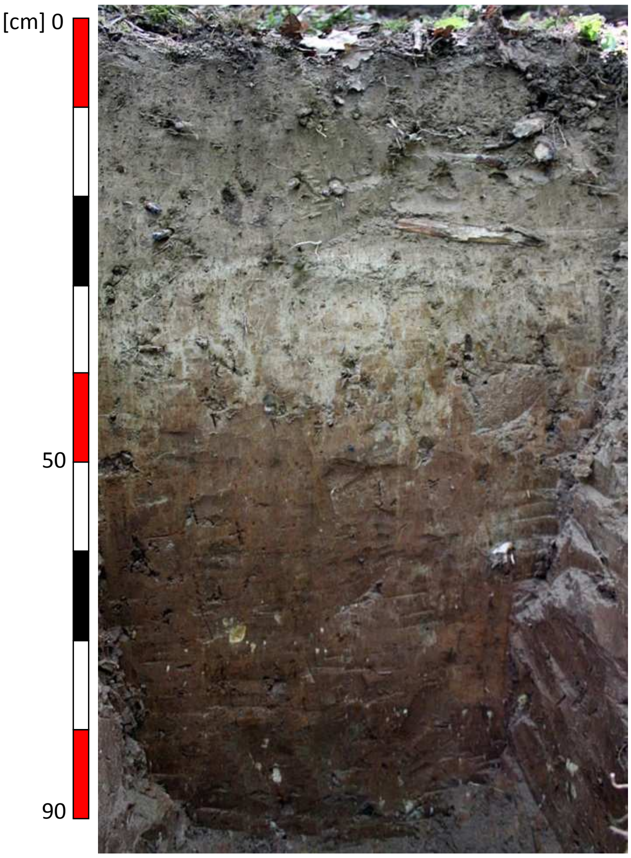
Table 5. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	C/N	pH KCl	$CaCO_3$ [g·kg^{-1}]	Al^{3+}	Fe^{2+}	Mn^{2+}
							[mg·kg^{-1}]		
Oe	6–0	560	180.0	3	5.7	-	3.0	0.80	69.5
A	0–10	20.0	3.51	6	4.3	-	52.4	0.61	6.16
AE	10–33	13.0	1.92	7	4.1	-	208	10.2	0.89
AEB	33–53	2.00	0.43	5	4.8	-	51.0	2.30	1.06
Bs	53–94	-	-	-	5.1	-	31.0	1.32	0.98
BCg	94–124	-	-	-	5.4	-	10.3	2.60	2.49
2Cgk	124–(134)	-	-	-	7.8	+	1.7	0.14	0.54

Table 6. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	TA	CEC	CEC_{clay}	BS [%]
		[cmol(+)·kg^{-1}]								
Oe	2–0	24.7	3.56	1.19	0.118	29.6	0.050	29.6	-	100
A	0–18	3.84	0.680	0.145	0.100	4.76	0.563	5.32	0	89
AE	18–28	1.34	0.381	0.095	0.259	2.07	0.188	2.26	0	92
AEB	28–44	1.01	0.234	0.031	0.034	1.31	0.033	1.34	32.0	98
Bs	44–62	0.71	0.185	0.024	0.025	0.944	0.013	0.957	47.9	99
BCg	62–92	2.27	0.566	0.052	0.028	2.92	0.015	2.94	58.8	99
2Cgk	92–(109)	8.22	0.909	0.079	0.043	9.25	0.007	9.26	22.0	100

Profile 3 – Eutric Stagnic Glossic **Retisol** (Abruptic, Siltic, Cutanic)
Localization: Augšzeme upland, glacigenic till hummock, slopping summit 5–10%, oak forest, 178 m a.s.l. **N** 59°48'57'', **E** 18°30'10''



Morphology:

Oi – 1–0 cm, slightly decomposed organic material;

Ah – 0–22 cm, sandy loam, brown (10YR 5/3), dry, moderate granular fine and medium structure, clear and wavy boundary;

EBg – 22–37 cm, transitional horizon, silt loam, pale brown (10YR 6/3), dry, moderate granular fine and medium structure, *stagnic* properties, clear and irregular boundary;

Btsg – 37–67 cm, *argic* horizon, clay loam, brown (7.5YR 5/4), slightly moist, strong prismatic medium and coarse structure, *stagnic* properties, reducing conditions, common distinct sesquioxides and clay coatings, diffuse and wavy boundary;

Bsgk – 67–(91) cm, *calcic* horizon, silt loam, strong brown (7.5YR 4/6), slightly moist, strong prismatic medium and coarse structure, *stagnic* properties, reducing conditions, common distinct sesquioxides and clay coatings, moderately calcareous.

Table 7. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]			Textural class
		2.0–0.05	0.05–0.002	< 0.002	
Ah	0–22	46	49	5	SL
EBg	22–37	19	62	19	SiL
Btsg	37–67	30	33	37	CL
Bsgk	67– (91)	23	52	25	SiL

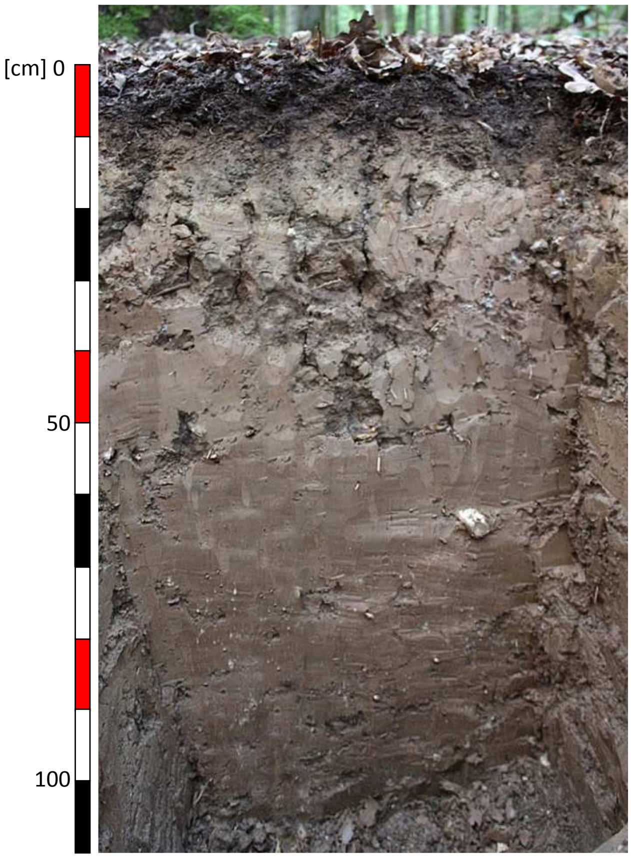
Table 8. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	C/N	pH KCl	$CaCO_3$ [g·kg^{-1}]	Al^{3+}	Fe^{2+}	Mn^{2+}
							[mg·kg^{-1}]		
Oi	1–0	830	344	2	5.9	-	4.40	1.98	127
Ah	0–22	19.0	4.00	5	4.5	-	80.8	2.84	34.7
EBg	22–37	-	-		4.5	-	87.7	0.67	4.31
Btsg	37–67	-	-		5.6	-	1.6	0.87	6.51
Bsgk	67– (91)	-	-		7.8	+	0.9	0.16	0.52

Table 9. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	TEB	TA	CEC	CEC_{clay}	BS [%]
		[cmol(+)·kg^{-1}]								
Oi	1–0	36.5	12.6	2.77	0.109	52.0	0.049	52.0	-	100
Ah	0–22	3.42	1.37	0.232	0.047	5.07	0.897	5.97	0.00	85
EBg	22–37	3.14	1.75	0.094	0.046	5.03	0.975	6.01	31.6	84
Btsg	37–67	9.42	4.91	0.185	0.067	14.6	0.018	14.6	39.5	100
Bsgk	67– (91)	9.82	3.48	0.125	0.053	13.5	0.010	13.5	54.0	100

Profile 4 – Endocalcaric Endostagnic **Luvisol** (Loamic, Cutanic, Hypereutric)
Localization: West-Kursa upland, glacigenic till plain, slope flat 0.2–0.5%, oak forest, 69.2 m a.s.l.
N 57°14’26’’, **E** 20°37’6’’



Morphology:

Oi – 1–0 cm, slightly decomposed organic material;

Ah – 0–11 cm, silty loam, dark grayish brown (10YR 4/2), strong subangular blocky fine and medium structure, clear and wavy boundary;

AhEBs – 11–25 cm, silty loam, grayish brown (10YR 5/2), strong angular blocky medium and coarse structure, very few faint sesquioxides coatings, gradual and irregular boundary;

Bts – 25–44 cm, *argic* horizon, silty clay loam, brown (10YR 4/3), strong subangular and angular blocky fine and medium structure, common faint sesquioxides coatings, clear and wavy boundary;

Btsg – 44–61 cm, *argic* horizon, silty clay loam, dark grayish brown (10YR 4/2), strong prismatic medium and coarse structure, *stagnic* properties, reducing conditions, many distinct clay-sesquioxides coatings, clear and wavy boundary;

Bsgk – 61–99 cm, *Calcaric* material, silty clay loam, dark grayish brown (10YR 4/2), strong prismatic coarse structure, *stagnic* properties, reducing conditions, many distinct clay-sesquioxides coatings, gradual and irregular boundary;

Ck – 99–(110) cm, *calcaric* material, parent material, silty clay loam, (GL15/10Y), weak prismatic medium and coarse structure, few faint sesquioxides coatings, extremely calcareous.

Table 10. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]			Textural class
		2.0–0.05	0.05–0.002	< 0.002	
Ah	0–11	2	82	16	SiL
AhEBs	11–25	12	63	25	SiL
Bts	25–44	5	62	33	SiCL
Btsg	44–61	0	67	33	SiCL
Bsgk	61–99	2	72	26	SiCL
Ck	99–(110)	1	63	36	SiCL

Table 11. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	C/N	pH KCl	$CaCO_3$ [g·kg^{-1}]	Al^{3+}	Fe^{2+}	Mn^{2+}
							[mg·kg^{-1}]		
Oi	1–0	222	13.4	17	5.3	-	6.40	1.50	158
Ah	0–11	21.0	4.5	5	4.3	-	168	0.32	21.5
AhEBs	11–25	9.00	1.8	5	4.8	-	69.9	0.84	19.5
Bts	25–44	-	-		5.7	-	1.40	0.45	4.61
Btsg	44–61	-	-		7.0	-	1.20	0.39	1.28
Bsgk	61–99	-	-		7.7	+	0.60	0.10	0.60
Ck	99–(110)	-	-		7.9	+	1.40	0.09	0.66

Table 12. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	TEB	TA	CEC	CEC_{clay}	BS [%]
		[cmol(+)·kg^{-1}]								
Oi	1–0	35.0	11.8	2.43	0.148	49.4	0.072	49.5	-	100
Ah	0–11	4.74	1.89	0.32	0.298	7.25	1.872	9.12	11.1	79
AhEBs	11–25	6.07	2.49	0.188	0.090	8.84	0.776	9.62	25.9	92
Bts	25–44	15.3	5.77	0.181	0.134	21.4	0.016	21.4	64.8	100
Btsg	44–61	17.3	6.83	0.155	0.131	24.4	0.014	24.4	73.9	100
Bsgk	61–99	16.2	3.74	0.158	0.103	20.2	0.007	20.2	77.7	100
Ck	99–(110)	13.8	3.82	0.180	0.132	17.9	0.015	17.9	49.7	100

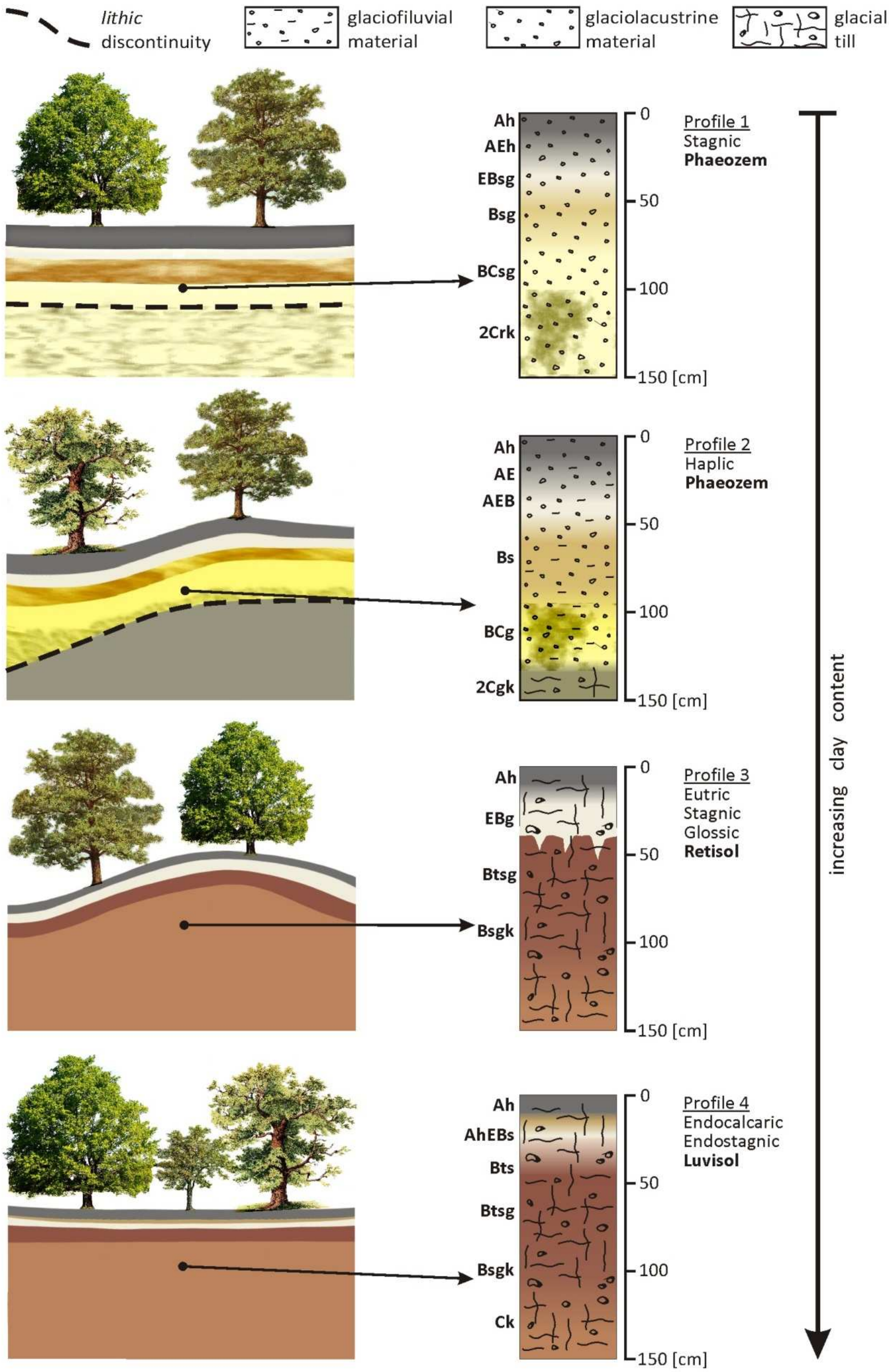


Fig. 2. Conceptual model of soils litosequence on Quaternary deposits under *Quercus robur L.* stands within Latvia

Influence of environmental factors on soil genesis and properties

Quaternary deposits, their granulometric and chemical composition have the strongest bearing on the spatial distribution of soil groups (according to FAO WRB classification (2014)) in Latvia. Furthermore, soil texture is the most important factor determining the forest soil diversity in the Late Weichselian glacial deposits and Holocene sediments (Kasparinskis, Nikodemus, 2012), and soil processes (e.g. accumulation of organic matter, podzolization and lessivage) may also be affected by different land-use changes (Nikodemus et al., 2013). Large-scale afforestation measures have been targeted at planting secondary *Q. robur* forests on former agricultural lands, and most of the *Q. robur* forest areas in many European countries are distributed on former agricultural lands (Brunet et al., 2011).

The most common soil groups in the *Q. robur* stands in Latvia are **Luvisols** (Ikauniece et al., 2013). Glaciolacustrine, glaciofluvial and glacigenic deposits (glacial till) are distributed on a relatively large area in Latvia (Fig. 1). The conceptual model of the soil **lithosequence** (Fig. 2) on Quaternary deposits under *Quercus robur L.* stands in Latvia shows the occurrence of Phaeozems on glaciolacustrine and glaciofluvial deposits formed by sandy material, but an increase in the clay content leads to the occurrence of Retisols in glacial tills related to an undulated topography, as well as Luvisols – in glacial till plains. The range of soil groups in the *Q. robur* stands indicates a fairly wide edaphic niche, which is typical in its range (Jones, 1959).

Previous studies of forest soils in Latvia according to FAO WRB (2007) showed a close correlation between Quaternary deposits, forest site types, dominant tree species and soil groups within nutrient-poor sandy sediments (e.g. **Arenosols**) and very rich deposits containing a relatively high content of clay, silt and free carbonates (e.g. **Luvisols** and **Albeluvisols**) (Kasparinskis and Nikodemus, 2012). Previous studies in Latvia indicated that mixed *Q. robur* stands with larger cover of the boreal conifers *P. abies* and *P. sylvestris* occurred on mesic habitats with a higher silt content. A typical nemoral herb layer with greater proportion of ant-dispersed species and hemicryptophytes was associated with soils that had a higher clay content (Ikauniece et al., 2013).

Typical features of the soils in this study include: reducing conditions, weakly expressed *stagnic* properties, free carbonates and relatively high base saturation (>50%) (Profiles 1–4).

Reducing conditions and *stagnic* properties were observed at a depth of 92 cm in Profile 1; in Profile 2, however, this is related to an increase in the clay content in subsoil (Table 4). Reducing conditions and *stagnic* properties were detected closer to the soil surface in the glacigenic till hummock (Profile 3) and the glacigenic till plain (Profile 4) where surface water filtration is disturbed by a relatively heavy soil texture (silt loam, clay loam and silty clay loam), resulting in *stagnic* and *gleyic* properties that morphologically indicate **Stagnic** and **Endostagnic** qualifiers.

Free carbonates and relatively high base saturation (>50%) are provided by soil parent material resulting in **Eutric** and **Hypereutric** qualifiers. Free carbonates and relatively high base saturation (>50%) were detected in deeper horizons of **Phaeozems** (Profiles 1, 2) – i.e. at a depth of 92 cm and 124 cm − than in **Retisol** (Profile 3) and **Luvisol** (Profile 4) – 67 cm and 99 cm, respectively.

pH_{KCl} of the mineral **soil** ranges from 4.1 to 7.9 in the studied soil profiles (1–4) (Table 2, 5, 8, 11). Lower pH_{KCl} values are detected in the mineral topsoil layers, thus indicating the edaphic role of oak *Q. robur* stands and possible initialization of the podzolization process (increase in exchangeable Al^{3+} concentration) (Profile 1–4, Table 2, 5, 8, 11).

Cation exchange capacity varies from 5.3 to 11.2 [cmol(+)·kg^{-1}] in mineral topsoil, in the O horizon − from 29.6 to 52.0 [cmol(+)·kg^{-1}] (Table 3, 6, 9, 12). These results showed that cation exchange capacity is higher in the O horizon of **Retisol** (Profile 3) in the glacigenic till hummock and **Luvisol** (Profile 4) in the glacigenic till plain. These properties in the topsoil could be explained by the influence of the root system and litter of oak *Q. robur* stands.

Depth of the organic matter accumulation horizon in mineral topsoil ranges between 28 cm (Profile 1 – Ah and AEh horizons) and 33 cm (Profile 2 – A and AE horizons) in glaciolacustrine and glaciofluvial deposits, to 22 cm (Profile 3 – Ah horizon) and 11 cm (Profile 4 – Ah horizon) in the glacigenic till hummock and the glacigenic till plain. This shows that the development of the organic matter accumulation horizon is disturbed in relatively heavy soils (silt loam, clay loam and silty clay loam).

Organic carbon content varies from 19 to 22 [$g{\cdot}kg^{-1}$] in mineral topsoil in all the studied soil profiles, however the highest content is detected in the O horizon (from 830 [$g{\cdot}kg^{-1}$] in **Retisol** formed on the glacigenic till hummock (Profile 3, Table 8) to 222 [$g{\cdot}kg^{-1}$] in **Luvisols** formed on the galcigenic till plain (Profile 4, Table 11).

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Forested areas within sandy lowlands and continental dunes of South-Eastern Lithuania

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The territory of South-Eastern Lithuania lies on the north-western edge of the East European plain (Soil Atlas of Europe, 2005). Its landscape has been smoothed by edge deposits of the Medininkai and Nemunas Glaciations (Fig. 1). The southern Lithuanian glaciation edge deposits stretch as a wide strip along the western edge of Aukštaičių and the northern edge of Sūduva Upland. The largest areas of South-Eastern Lithuania are occupied by glaciofluvial and glaciolacustrine formations (Eidukevičienė and Vasiliauskienė, 2001).

Fig. 1. Location

Lithology and topography

The presented soils are located in Dzūkijos dune hills and Ula-Katra glaciolacustrine plain areas of the Dainava glaciofluvial lowland (Guobytė, 2010). In terms of age, this is a fairly homogeneous territory associated with the Nemunas Glaciation Grūda phase formations (17,000 to 19,000 years old). Although the territory is covered by the same soil parent material of genetic origin, the diversity of its relief (abs. altitude 122–147 m) is largely associated with the epigenetic surface (aeolian processes) transformation and anthropogenic influences.

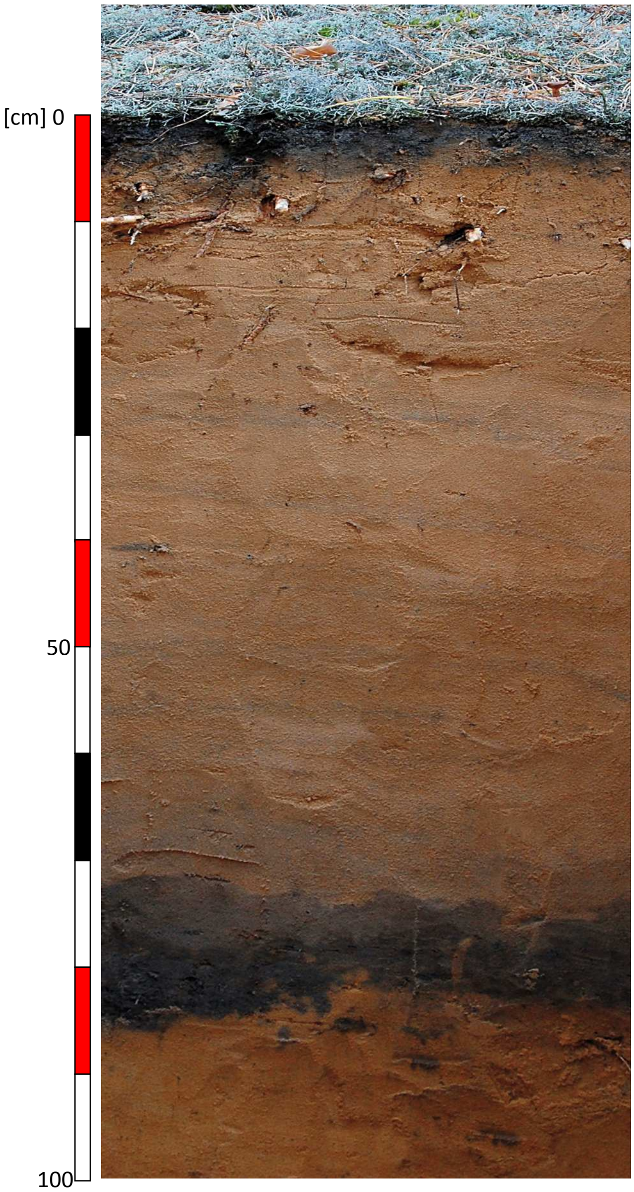
Land use

The majority of areas within the Dainava glaciofluvial lowland are covered with coniferous forests. The canopy layer is dominated by pine (*Pinus sylvestris*) and spruce (*Picea abies*). Because of the relatively low soil fertility, only the vast minority of lands are nowadays used for agricultural purposes.

Climate

The climate of South East Lithuania, which ranges between maritime and continental, is relatively mild. Average annual air temperature is +6.2 °C. Compared to other regions of Lithuania, however, the local climate is characterized by much larger seasonal temperature contrasts. Usually the wind is blowing unevenly but in gusts (Galvonaitė, 2013). Westerlies and south-westerlies dominate in the area throughout the year. The average annual amount of precipitation is 673 mm. Although the amount of precipitation can vary a lot in different years, the highest monthly amount occurs in July and August. Average annual relative humidity in the area does not vary much (from 80 to 81%).

Profile 1 – Dystric Protic **Arenosol** (Aeolic) over Brunic **Arenosol**
Localization: Dainava glaciofluvial lowland, back slope, pine monoculture
N 53°57'293", **E** 024°23'060"



Morphology:

Oi – 1–0 cm, slightly decomposed organic material;

Ah – 0–8 cm, humus horizon, fine sand, black (10YR 2/1), slightly moist, weak granular fine structure, fine and medium common roots, clear and wavy boundary;

Bw1 – 8–17 cm, fine sand, reddish yellow (7.5YR 6/6), slightly moist, weak granular very fine/single grain structure, coarse few roots, gradual and smooth boundary;

Bw2 – 17–31 cm, fine sand, light brown (7.5YR 6/4), slightly moist, single grain structure, clear and smooth boundary;

Bw3 – 31–45 cm, fine sand, light brown (7.5YR 6/3), slightly moist, single grain structure, clear and smooth boundary;

BC – 45–70 cm, transitional horizon, fine sand, light brown (7.5YR 6/3), slightly moist, single grain structure, abrupt and wavy boundary;

Ahb – 70–81 cm, buried humus horizon, fine sand, very dark gray (7.5YR 3/1), slightly moist, weak granular fine structure, fine few roots, abrupt and wavy boundary;

Bwb1 – 81–94 cm, fine sand, strong brown (7.5YR 5/8), slightly moist, single grain structure, gradual and smooth boundary;

Bwb2 – 94–(100/120) cm, fine sand, reddish yellow (7.5YR 6/8), slightly moist, single grain structure.

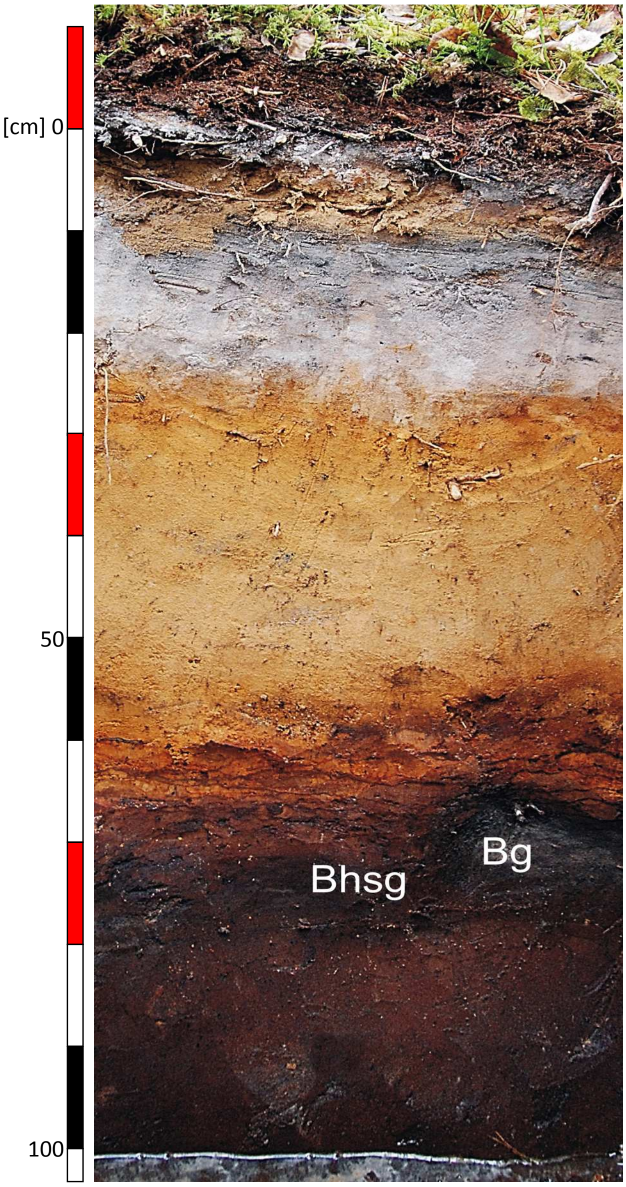
Table 1. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]								Textural class
		2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.106	0.106–0.053	0.053–0.038	0.038–0.002	<0.002	
Ah	0–8	1	2	28	60	9	0	0	0	FS
Bw1	8–17	0	0	24	67	9	0	0	0	FS
Bw2	17–31	0	0	29	64	7	0	0	0	FS
Bw3	31–45	0	0	22	68	10	0	0	0	FS
BC	45–70	0	0	26	66	8	0	0	0	FS
Ahb	70–81	0	0	15	67	16	0	2	0	FS
Bwb1	81–94	0	0	17	66	17	0	0	0	FS
Bwb2	94–100/120	0	0	12	70	18	0	0	0	FS

Table 2. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	pH KCl
Ah	0–8	9.91	3.9
Bw1	8–17	1.55	4.7
Bw2	17–31	0.88	4.9
Bw3	31–45	0.62	4.9
BC	45–70	0.93	4.8
Ahb	70–81	7.06	4.5
Bwb1	81–94	2.89	4.8
Bwb2	94–100/120	2.44	4.9

Profile 2 –Bathihypergleyic Folic Albic **Podzol** (Arenic)
Localization: Dainava glaciofluvial lowland, foot slope, pine monoculture,
N 53°57'21.3", **E** 024°22'47.6"



Morphology:

Oi – 10–0 cm, slightly decomposed organic material;

AE – 0–15 cm, humus horizon with features of eluviation process, fine sand, gray (10YR 5/1), slightly moist, weak granular fine structure, fine and medium common roots, gradual and smooth boundary;

E – 15–23 cm, eluvial horizon with *albic* material, fine sand, white (10YR 8/1), slightly moist, single grain structure, clear and smooth boundary;

Bs – 23–51 cm, illuvial horizon, fine sand, reddish yellow (7.5YR 6/8), slightly moist, single grain structure, medium very few roots in upper section, clear and smooth boundary;

Bsg – 51–67 cm, *spodic* horizon, fine sand, reddish brown (5YR 5/3), moist, single grain structure, clear and smooth boundary;

Bhsg – 67–81 cm, *spodic* horizon, fine sand, very dark gray (5YR 3/1), moist, single grain structure, platy weakly cemented by iron-manganese sesquioxides, many oximorphic mottles, clear and smooth boundary;

Bg – 70–80 cm, *spodic* horizon, fine sand, black (5YR 2.5/1), moist, single grain structure, platy moderately cemented by iron-manganese sesquioxides, many oximorphic mottles, clear and smooth boundary;

Bhsr – 81–103/110 cm, fine sand, dark reddish brown (5YR 2.5/2), wet, single grain structure, platy weakly cemented by iron-manganese sesquioxides, oximorphic conditions.

Table 3. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]								Textural class
		2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.106	0.106–0.053	0.053–0.038	0.038–0.002	<0.002	
AE	0–15	0	1	21	59	16	0	3	0	FS
E	15–23	0	0	14	68	16	0	2	0	FS
Bs	23–51	0	0	16	69	15	0	0	0	FS
Bsg	51–67	0	0	13	69	16	0	2	0	FS
Bhsg	67–81	0	0	28	61	8	0	3	0	FS
Bg	70–80	0	0	19	65	13	0	3	0	FS
Bhsr	81–(103/110)	7	20	27	27	9	3	7	0	FS

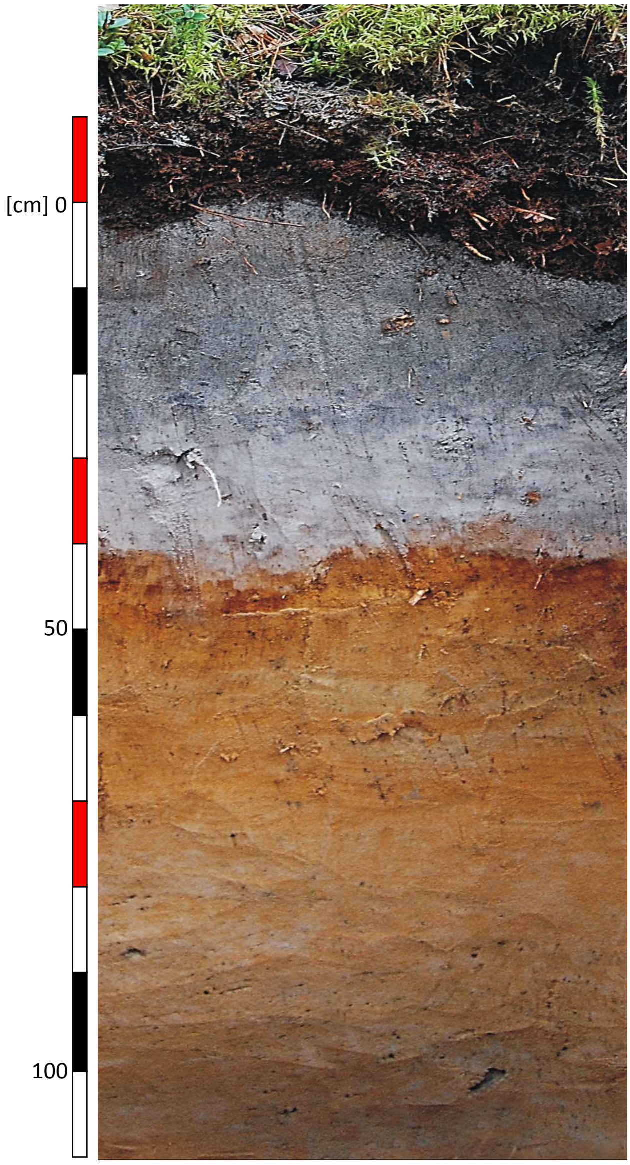
Table 4. Chemical and physicochemical properties

Horizon	Depth [cm]	OC	Fe	Al	pH KCl
		[g·kg^{-1}]			
O	10–0	272.1	-	-	-
AE	0–15	9.66	1.0	1.0	3.8
E	15–23	2.60	1.0	1.0	4.1
Bs	23–51	9.02	5.0	9.0	4.5
Bsg	51–67	5.28	2.0	5.0	4.7
Bhsg	67–81	3.58	1.0	7.0	3.6
Bg	70–80	4.78	0.0	1.0	3.5
Bhsr	81–(103/110)	105.0	-	-	4.0

Table 5. Chemical elements

Horizon	Depth [cm]	Hg [µg·kg^{-1}]	Co	Mn	Ba	Cr	Pb	V	Cu	Sc
			[mg·kg^{-1}]							
AE	0–15	4.0	5.5	8.0	9.4	1.3	5.2	1.0	0.5	0.2
E	15–23	7.0	2.8	6.0	8.2	0.9	2.7	1.0	0.2	0.1
Bs	23–51	35.0	12.7	17.0	9.1	3.9	4.9	7.0	0.7	0.5
Bsg	51–67	9.0	12.2	11.0	8.6	2.7	1.8	3.0	0.6	0.3
Bhsg	67–81	9.0	181	12.0	11.7	3.3	3.7	3.0	0.5	0.4
Bg	70–80	9.0	4.5	2.0	5.4	0.8	1.2	1.0	0.3	0.1

Profile 3 – Folic Albic **Podzol** (Arenic)
Localization: Dainava glaciofluvial lowland, upper slope (shoulder), pine monoculture,
N 53°57'22.8", **E** 024°22'44.1"



Morphology:

Oi – 16–0 cm, slightly decomposed organic material;

AE – 0–26 cm, humus horizon with features of eluviation process, fine sand, gray (7.5YR 5/1), slightly moist, weak granular fine structure, fine and medium very few roots, clear and smooth boundary;

E – 26–41 cm, eluvial horizon with *albic* material, fine sand, light gray (7.5YR 7/1), slightly moist, single grain structure, medium very few roots, clear and smooth boundary;

Bs1 – 41–49 cm, *spodic* horizon, fine sand, yellowish red (5YR 5/6), slightly moist, single grain structure, medium very few roots, gradual and smooth boundary;

Bs2 – 49–69 cm, fine sand, reddish yellow (5YR 6/6), slightly moist, single grain structure, fine very few roots, gradual and smooth boundary;

Bs3 – 69–98 cm, fine sand, reddish yellow (5YR 7/6), slightly moist, single grain structure, gradual and smooth boundary;

BC – 98–109 cm, transitional horizon, fine sand, pinkish gray (7.5YR 7/2), slightly moist, single grain structure.

Table 6. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]								Textural class
		2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.106	0.106–0.053	0.053–0.038	0.038–0.002	<0.002	
O	16–0	-	-	-	-	-	-	-	-	-
AE	0–26	0	0	13	70	15	0	2	0	FS
E	26–41	0	0	7	75	18	0	0	0	FS
Bs1	41–49	0	0	12	73	15	0	0	0	FS
Bs2	49–69	0	0	8	76	16	0	0	0	FS
Bs3	69–98	0	0	6	75	19	0	0	0	FS
BC	98–109	0	0	6	76	18	0	0	0	FS

Table 7. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	pH KCl
O	16–0	549.9	-
AE	0–26	14.0	3.4
E	26–41	3.28	4.0
Bs1	41–49	8.20	4.5
Bs2	49–69	2.70	4.7
Bs3	69–98	3.34	4.6
BC	98–109	1.90	4.8

Profile 4 – Gleyic Histic Albic **Podzol** (Arenic)
Localization: Dainava glaciofluvial lowland, foot slope, spruce monoculture,
N 53°57'32.9", **E** 024°19'16.1"

Morphology:

Oi – 10–0 cm, slightly decomposed organic material;

Ah – 0–8 cm, humus horizon, loamy fine sand, black (10YR 2/1), slightly moist, weak granular fine structure, fine and medium few roots, clear and smooth boundary;

AE – 8–17 cm, humus horizon with features of eluviation process, loamy fine sand, gray (10YR 5/1), slightly moist, weak granular fine /single grain structure, medium very few roots, gradual and smooth boundary;

E – 17–38 cm, eluvial horizon with *albic* material, fine sand, light gray (10YR 7/2), slightly moist, single grain structure, clear and wavy boundary;

Bsmg – 38–49 cm, *spodic* horizon, fine sand, brown (7.5YR 5/2), moist, single grain structure, strong induration, fine very few roots, clear and wavy boundary;

Bsg – 49–53 cm, *spodic* horizon, fine sand, yellowish red (5YR 4/6), moist, single grain structure, platy weakly cemented by iron-manganese sesquioxides, clear and smooth boundary;

2Cr – 53–75/110 cm, fine sand, light gray (5Y 7/2), wet, single grain structure, strong reducing conditions.

Table 8. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]								Textural class
		2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.106	0.106–0.053	0.053–0.038	0.038–0.002	<0.002	
O	10–0	-	-	-	-	-	-	-	-	-
Ah	0–8	4	13	18	31	19	5	10	0	LFS
AE	8–17	0	0	7	45	32	6	10	0	LFS
E	17–38	0	0	9	61	29	1	0	0	FS
Bsmg	38–49	0	0	7	62	27	1	3	0	FS
Bsg	49–53	0	0	2	54	39	3	2	0	FS
2Cr	53–(75/110)	0	0	17	61	19	1	2	0	FS

Table 9. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	pH KCl
O	10–0	612.3	-
Ah	0–8	90.9	3.1
AE	8–17	5.74	3.4
E	17–38	18.8	3.5
Bsmg	38–49	16.7	3.9
Bfrg	49–53	1.16	4.3
2Cr	53–(75/110)	1.80	4.2

Profile 5 – Dystric Drainic Hemic **Histosol**

Localization: Dainava glaciofluvial lowland, plain depression with biogenic deposits, **N** 53°57’11,51‘‘, **E** 24°19’03,68‘‘

Morphology:

Oi – 0–5 cm, slightly decomposed organic material;

Ha – 5–15 cm, *histic* horizon, highly decomposed organic material, black (10YR 2/1), moist, weak granular fine structure, fine common roots, clear and wavy boundary;

He1 – 15–25 cm, *histic* horizon, moderately decomposed organic material, black (10YR 2/1), moist, weak granular fine structure, fine few roots, clear and smooth boundary;

He2 – 25–50 cm, *histic* horizon, moderately decomposed organic material, black (10YR 2/1), wet, weak granular fine/ massive structure, fine very few roots, clear and smooth boundary;

He3 – 50–70 cm, *histic* horizon, moderately decomposed organic material, black (10YR 2/1), wet, massive structure, fine very few roots, clear and smooth boundary;

2Cr –70–85/120 cm, fine sand, light gray (5Y 7/2), wet, single grain structure, strong reducing conditions.

Table 10. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]								Textural class
		2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.106	0.106–0.053	0.053–0.038	0.038–0.002	<0.002	
Oi	0–5	5	25	29	22	12	7	0	0	FS
Ha	5–15	13	30	29	17	7	4	0	0	FS
He1	15–25	10	41	33	8	4	4	0	0	FS
He2	25–50	27	41	19	5	3	5	0	0	FS
He3	50–70	28	45	19	3	2	3	0	0	FS
2Cr	70–85/120	0	0	16	62	18	1	3	0	FS

Table 11. Organic carbon and pH

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	pH KCl
Oi	0–5	437.2	5.2
Ha	5–15	372.5	5.4
He1	15–25	489.6	5.5
He2	25–50	508.3	5.9
He3	50–70	513.7	5.8
2Cr	70–85/120	-	-

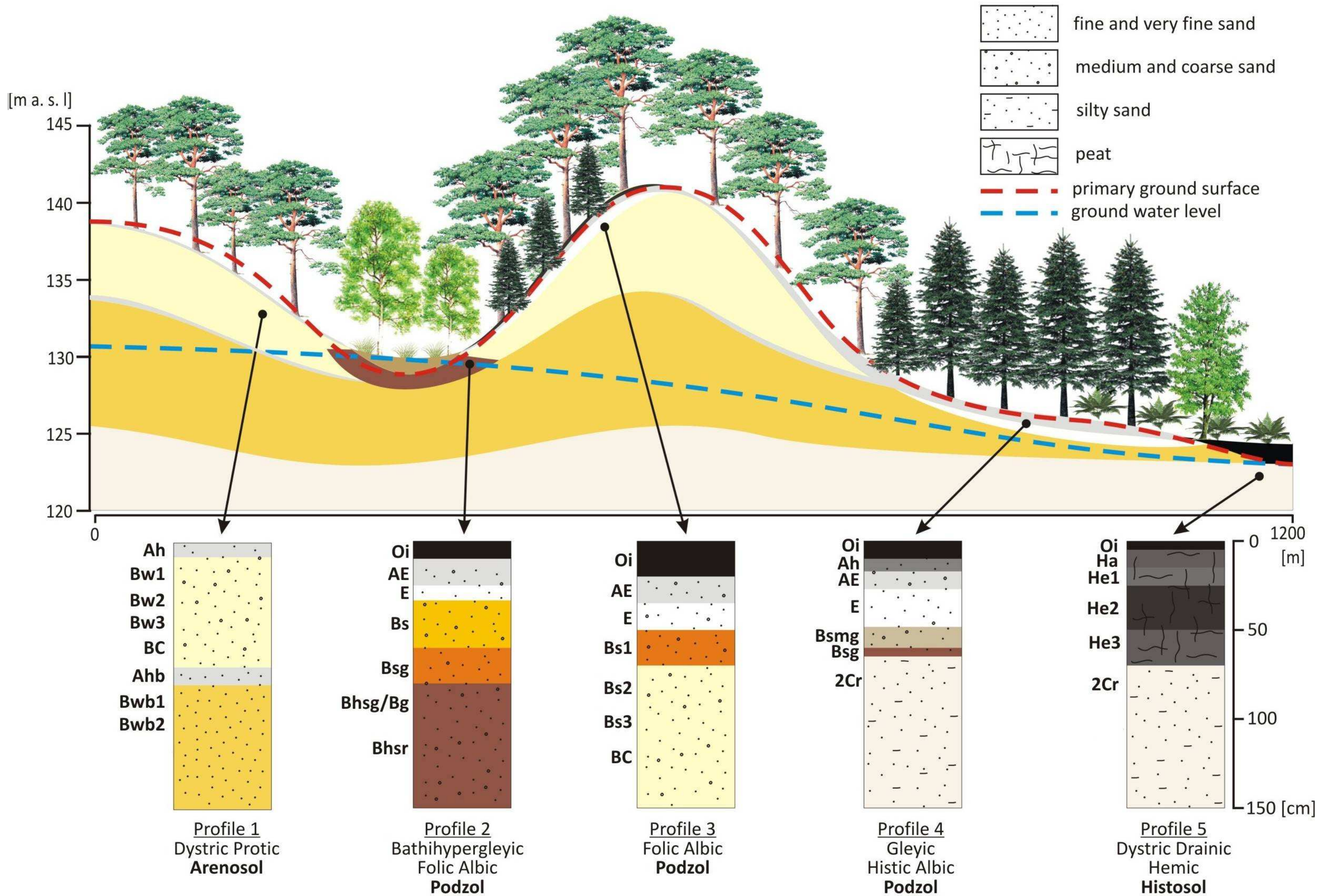


Fig. 2. Hydro-toposequence of soils within forested areas of sandy lowlands and continental dunes of South-Eastern Lithuania

Soil genesis and systematic position

The common feature of the south-eastern Lithuanian sandy lowlands is the extensive occurrence of *Arenosols* and *Podzols* − characteristic soils of the region (Motuzas et al., 2009). According to *WRB* 2014 (IUSS Working Group, 2014), *Arenosols* comprise sandy soils, including both soils developed in residual sands after *in situ w*eathering of usually quartz-rich sediments or rock, and soils developed in recently deposited sands (such as dunes and beach lands). According to the same *WRB* system, *Podzols* are soils with a typically ash-grey upper subsurface horizon, bleached by the loss of organic matter and iron oxides, on the top of a dark accumulation horizon with brown, reddish or black illuviated humus and/or reddish Fe compounds.

The predominance of *Arenosols* and *Podzols* in the studied area is determined by the abundance of sandy sediments (massifs of the continental aeolian sand dunes) covered with the forest stands. Three of five soil profiles were excavated in places with complex, but at the same time consistent soil structure that formed on the continental sand dunes. On the other hand, it was done in order to highlight both a genetic relationship between *Arenosols* and *Podzols* and the increasing problems with their classification in Lithuania (Vaisvalavičius et al., 2013). Primarily, there are different patterns in the formation of these soils depending on the exposition and on the slope of sandy dunes. It is obvious that the inhibited process of soil formation, and hence rather poorly developed soils occur on the southern slopes of the dunes due to microclimates that are much warmer compared to the northern slopes. In addition, due to the south-eastern/southern axis of the dunes, intensive deflation processes occurred in this area (even today in some isolated smaller sections) and layered soil profiles (buried soils) developed. ***Dystric Protic*** **Arenosol** (Aeolic) over ***Brunic*** **Arenosol** (Profile 1) with some weakly expressed features of the podzolization process is a characteristic example of such soil formation conditions on the local sands. The northern slopes of the dunes, particularly covered with old, mature and even premature forest stands, have deeper and much more strongly developed soil profiles. In general, while receiving a smaller amount of heat and at the same time having a higher moisture content, the soils undergo rather intensive formation processes. ***Folic Albic*** **Podzol** ***(Arenic)*** (Profile 3) are a significant example of such soil formation conditions. However, deeper spots between dunes are covered either with high moor soils (***Fibric*** **Histosols**) or ***Bathihypergleyic Folic Albic*** **Podzol** ***(Arenic)*** formed just on the footsteps of the dunes (Profile 2).

The place for the fourth profile was selected on the outskirts of the glaciolacustrine basin near the village of Kabeliai (Fig. 1). The soil here was classified as ***Gleyic Histic Albic*** **Podzol** ***(Arenic)*** (Profile 4). It well represents soils that have formed from aleurite sands on the glaciolacustrine plains under the conditions of wooded marshy landscape.

The central part of the glaciolacustrine basin is represented by ***Dystric Drainic Hemic*** **Histosol** (Profile 5). In the former wetlands (marshes), the deposits of organogenic origin occur directly on the shallow aleuritic sand sediments in the glaciolacustrine basin. However, the former wetlands have been intensively drained in the second half of the twenty century, thus the current *Histosols* are strongly mineralized.

Soil sequence

All presented soils are characterized by rather similar lithogenesis. They are developed from glaciolacustrine deposits covered by eolian material. The main differences responsible for different directions of soil-forming processes are associated with the topography and the influence of ground water. The spatial arrangement of pedons represent a typical **hydro-toposequence**. The slopes and the middle parts of dunes are covered by automorphic soils (Dystric *Arenosols* and Albic *Podzols*), developed in non-carbonaceous sands. In the lower parts of the dunes or depressions between dunes, the hydromorphic soils occur (Gleyic *Podzols* and *Histosols*). Although slightly eroded soils are quite common (16.6%) in the sandy south-eastern plain (Buivydaitė, 1999), nowadays the coniferous forest stands with some admixture of birch and alder species protect soils within the studied area against the erosion. This is the case even on steep slopes, as it has been observed in the undulating hilly topography of the Žemaičiai Uplands in Western Lithuania (Jankauskas and Fullen, 2002).

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Flat coastal plain of the Hel Peninsula (Puck Lagoon, Poland)

Piotr Hulisz

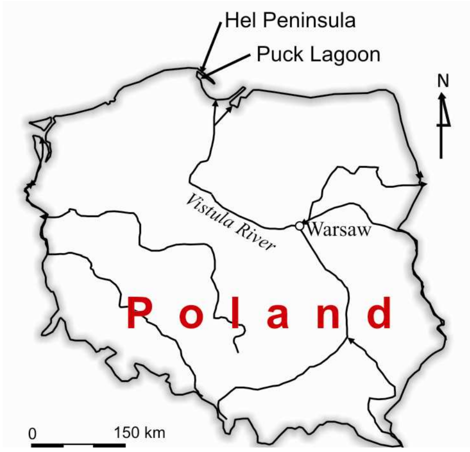


Fig. 1. Location

The Puck Lagoon is a north-western subregion of Gdańsk Bay (Northern Poland), separated from the waters of Puck Bay by a partly submerged sandy barrier (Rybitwia Mielizna – Seagull Shallows). The Hel Peninsula constitutes a borderline with the open waters of the Baltic Sea (Fig.1).

Lithology and topography

The Hel Peninsula is a narrow, 36 km long spit. Its width ranges from ca. 200 m to 3 km. The Holocene series of deposits are fully developed only in the eastern part of the Peninsula where its thickness reaches 100 m. In the western part there are Holocene deposits only of the Littorina period, forming a relatively thin cover of 10–12 m thickness (Tomczak, 1994). On the surface, there are marine and aeolian sands. The shores are mostly destroyed during storm surges. Sometimes, the inflow of seawaters from the open Baltic Sea into the Puck Lagoon is also observed (Wróblewski, 2008). Three soil profiles representing the coastal soils of the western part of the Hel Peninsula (Władysławowo) were selected (Hulisz, 2013). The first one was located within a very narrow beach zone, the second one - on the beach ridge and the third one - in the small wetland depression. The analysed section of the seashore is very flat (the altitude do not exceed 1 m a.s.l.).

Hydrology and climate

The coastal zone is affected mainly by the water level in the Puck Lagoon, with the average annual value of 502 cm for the period of 1951–2000. Extreme deviations from the mean sea level range from +1.5 to -1.0 m. Minimum values occur in March and April, and the maximum – during the autumn and winter storms (XI–II). The water salinity is on average ca. 7.0–7.5‰ (Majewski and Lauer, 1994). The region is located in the warm temperate, fully humid climate zone with warm summer (Kottek et al., 2006). The average annual air temperature for the period 1971–2000 is 8.7°C and the average annual precipitation is 515 mm (Filipiak et al., 2004). Winds from SW, W and NW directions prevail in the Lagoon. Strong winds (above 10 $m \cdot s^{-1}$) occur for ca. 70 days a year (Kwiecień, 1990).

Vegetation

The presented soils constituted an integral part of the unique habitats protected within the Natura 2000 network, including the dominant Atlantic salt meadows *Glauco-Puccinellietalia*, code 1330 (Herbich, 2004). In the surroundings of the soil profiles, two plant communities dominated, i.e. the rush community with *Schoenoplectus tabernaemontani* and *Bolboschoenus maritimus* (Profile 1 and 3) and saline meadow with *Juncus gerardi* (Profile 2). The former was characterized by a relatively high contribution of *Phragmites australis*. The rare occurrence of halophytes such as: *Atriplex prostrata* ssp. *prostrata* var. *salina*, *Aster tripolium*, *Spergularia salina*, *Glaux maritima* and *Triglochin maritimum* was observed in all locations.

Profile 1 – Fluvic **Gleysol** (Arenic, Humic, Protosalic, Sodic)

Location: Władysławowo, Puck Lagoon, Hel Peninsula, Poland, flat coastal plain (beach), rush community of *Schoenoplectus tabernaemontani* and *Bolboschoenus maritimus*, 0.1 m a.s.l., **N** 54°47’14.2”, **E** 18°25’39.1”

Morphology:

fluvic material:

Clnz1 – 0–2.5 cm, *gleyic* properties, medium sand with algae coat; greenish gray (10Y 5/1), wet, single grain structure, few shells, common reductimorphic mottles;

Hi – 2.5–9 cm, accumulation of allochthonous organic matter, black (10YR 2/1), very few shells;

Clnz2 – 9–(20) cm, *gleyic* properties, medium sand, greenish gray (10GY 6/1), wet, single grain structure, fine and medium common roots, common reductimorphic mottles.

Table 1. Properties related to the actual soil moisture

Horizon	Depth [cm]	Moisture [% w/w]	pH_a	pH_{pox}	Eh [mV]	rH	SO_4^{2-}	Cl^-
							[mg·100 g^{-1} of soil]	
Clnz1	0–2.5	21.5	7.3	4.7	291	24	13.8	49.6
Hi	2.5–9	490	7.1	4.4	237	22	340	1100
Clnz2	9–(20)	27.6	7.4	4.5	272	24	14.9	62.9

Table 2. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
Clnz1	0–2.5	0	1	18	74	7	0	0	0	0	0	MS
Clnz2	9–(20)	0	2	31	63	4	0	0	0	0	0	MS

Table 3. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	S_t [g·kg^{-1}]	C/N	C/S	pH		$CaCO_3$ [%]
							H_2O	KCl	
Clnz1	0–2.5	1.9	0.3	0.2	7	12	7.1	6.6	0.2
Hi	2.5–9	253	20.2	7.2	13	35	6.9	6.4	2.1
Clnz2	9–(20)	1.5	0.1	0.1	12	12	7.4	6.7	0.2

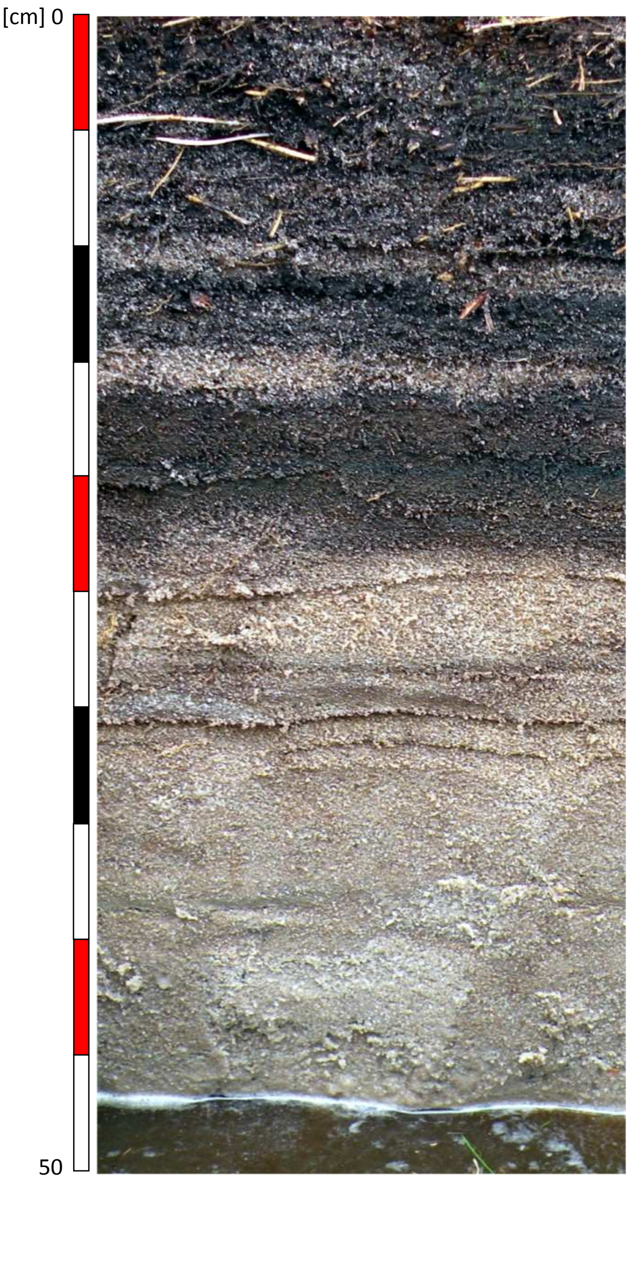
Table 4. Properties of the saturation extract

Horizon	Depth [cm]	pH_e	EC_e [dS·m^{-1}]	SP [%]	Salt content [%][1]		SAR	ESP[2] [%]
					extract	soil		
Clnz1	0–2.5	7.0	9.63	25.3	0.62	0.16	18	20
Hi	2.5–9	7.3	11.0	498	0.70	3.51	21	23
Clnz2	9–(20)	7.5	9.14	26.6	0.58	0.16	20	22

[1] calculations according to Soil Survey Laboratory Staff (1996):
salt content in extract = 0.064 · EC_e
salt content in soil = 0.064 · EC_e · SP/100
[2] estimated from SAR (van Reeuvijk, 2002)

Profile 2 – Fluvic **Gleysol** (Arenic, Humic, Protosalic, Sodic)

Location: Władysławowo, Puck Lagoon, Hel Peninsula, Poland, flat coastal plain (beach ridge), saline meadow with *Juncus gerardi*, 0.4 m a.s.l., **N** 54°47'14.6", **E** 18°25'39.2"



Morphology:

Ahn – 0–6 cm, humus horizon, medium sand; dark grayish brown (10YR 3/1), moist, single grain structure, very fine and fine common roots;

fluvic material:

A/C – 6–16 cm, layered soil material, medium sand and mud, moderately decomposed organic material, moist, very fine and fine common roots;

Ahnz – 16–23 cm, accumulation of allochthonous organic matter (highly decomposed peat and mud), admixture of sand, black (10YR 2/1), moist;

C – 23–28 cm, medium sand, light brown (10YR 6/3), moist, single grain structure;

Chn – 28–31 cm, accumulation of allochthonous organic matter, medium sand, grayish brown (2.5Y 5/2), moist, single grain structure;

Cl – below 31 cm, *gleyic* properties, medium sand, light greenish gray (10Y 8/1), wet, single grain structure, common reductimorphic mottles.

Table 5. Properties related to the actual soil moisture

Horizon	Depth [cm]	Moisture [% w/w]	pH_a	pH_{pox}	Eh [mV]	rH	SO_4^{2-} [mg·100 g^{-1} of soil]	Cl^- [mg·100 g^{-1} of soil]
Ahn	0–6	64.6	7.2	4.8	433	29	59.7	96.4
A/C	6–16	27.3	7.2	4.8	364	27	28.5	89.0
Ahnz	16–23	104	6.7	4.4	115	17	71.5	170
C	23–28	14.1	6.7	4.3	309	24	27.3	23.2
Chn	28–31	53.2	6.6	4.4	391	26	9.90	38.9
Cl	>31	16.0	7.2	4.5	237	22	5.50	27.9

Table 6. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
C	23–28	0	1	25	70	4	0	0	0	0	0	MS
Chn	28–31	0	2	17	68	11	1	1	0	0	0	MS
Cl	>31	0	2	15	73	10	0	0	0	0	0	MS

Table 7. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	S_t [g·kg^{-1}]	C/N	C/S	pH H_2O	pH KCl
Ahn	0–6	68.6	5.4	1.3	13	52	7.1	5.8
A/C	6–16	19.7	1.6	0.4	12	51	7.2	6.0
Ahnz	16–23	94.9	7.5	2.4	13	39	6.6	5.5
C	23–28	1.2	0.1	0.2	6	12	6.7	5.6
Chn	28–31	21.1	1.9	0.4	11	53	6.5	5.4
Cl	>31	1.0	0.1	0.1	10	15	7.1	6.0

Table 8. Properties of the saturation extract

Horizon	Depth [cm]	pH_e	EC_e [dS·m^{-1}]	SP [%]	Salt content [%][1] extract	Salt content [%][1] soil	SAR	ESP[2] [%]
Ahn	0–6	7.2	2.18	89.4	0.14	0.12	14	16
A/C	6–16	7.3	2.55	54.3	0.16	0.09	14	16
Ahnz	16–23	6.9	5.35	113	0.34	0.39	21	23
C	23–28	7.0	2.71	30.5	0.17	0.05	11	13
Chn	28–31	6.5	3.85	54.8	0.25	0.08	15	17
Cl	>31	7.4	3.21	25.9	0.21	0.05	12	14

[1] calculations according to Soil Survey Laboratory Staff (1996):
salt content in extract = $0.064 \cdot EC_e$
salt content in soil = $0.064 \cdot EC_e \cdot SP/100$
[2] estimated from SAR (van Reeuvijk, 2002)

Profile 3 – Histic **Gleysol** (Arenic, Protosalic, Sodic, Hypersulfidic)

Location: Władysławowo, Puck Lagoon, Hel Peninsula, Poland, flat coastal plain (small wetland depression), rush community with *Schoenoplectus tabernaemontani* and *Bolboschoenus maritimus*, 0.3 m a.s.l., **N** 54°47’14.5”, **E** 18°25’41.1”

Morphology:

Hanz – 0–6 cm, *organic* material, highly decomposed low-moor peat (sapric), muddy, dark grayish brown (10YR 3/2), wet, fine and medium common roots;

Hinz – 6–30 cm, *histic* horizon, slightly decomposed low-moor peat (fibric), muddy, brown (10YR 4/3), very wet, very fine and very few roots;

Crz ↓ – below 30 cm, *gleyic* properties, *hypersulfidic* material, medium sand, greenish gray (10Y 5/1), very wet, single grain structure, common reductimorphic mottles.

Table 9. Properties related to the actual soil moisture

Horizon	Depth [cm]	Moisture [% w/w]	pH_a	pH_{pox}	Eh [mV]	rH	SO_4^{2-}	Cl^-
							[mg·100 g^{-1} of soil]	
Hanz	0–6	547	6.3	4.2	85	15	379	1040
Hinz	6–30	295	6.0	1.6	20	13	487	530
Crz	>30	20.8	6.2	1.5	15	13	38.6	56.6

Table 10. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
Crz	>30	1	2	14	60	20	2	2	0	0	0	MS

Table 11. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	S_t [g·kg^{-1}]	C/N	C/S	pH_{ox}	
							H_2O	KCl
Hanz	0–6	339	241	116	14	29	6.3	5.3
Hinz	6–30	237	160	156	15	15	4.7	4.2
Crz	>30	2.5	0.2	0.4	11	7	3.9	3.4

Table 12. Properties of the saturation extract

Horizon	Depth [cm]	pH_e	EC_e [dS·m^{-1}]	SP [%]	Salt content [%][1]		SAR	ESP[2] [%]
					extract	soil		
Hanz	0–6	5.3	16.5	552	1.04	5.83	24	25
Hinz	6–30	4.5	11.8	301	0.76	2.27	15	17
Crz	>30	3.4	6.52	25.2	0.42	0.11	10	12

[1] calculations according to Soil Survey Laboratory Staff (1996):
salt content in extract = 0.064 · EC_e
salt content in soil = 0.064 · EC_e · SP/100
[2] estimated from SAR (van Reeuvijk, 2002)

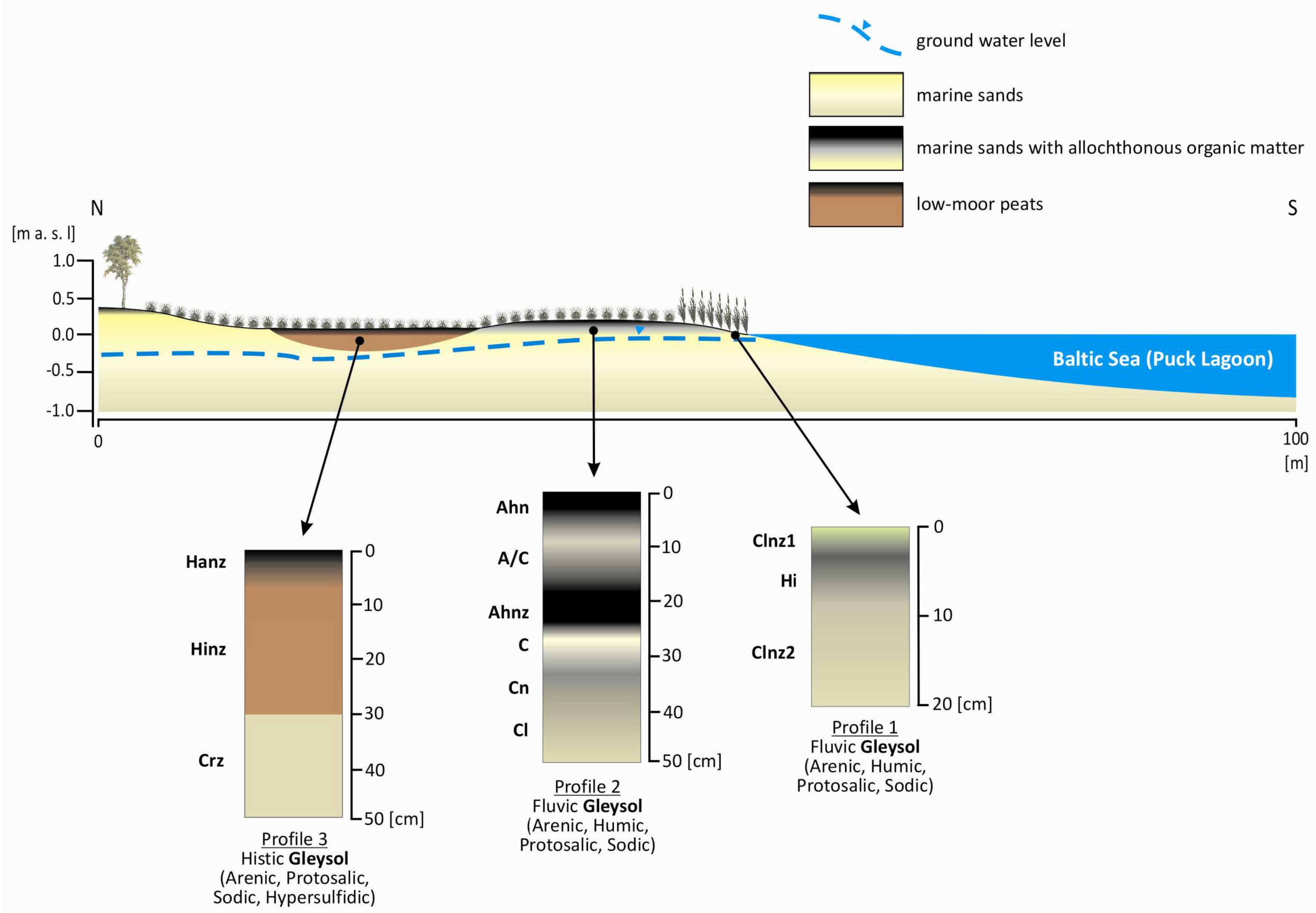


Fig. 2. Hydro-toposequence of soils of the flat coastal plain (Hel Peninsula, Puck Lagoon, Poland)

Soil genesis and systematic position

Coastal marsh soils in the Baltic zone have unique characteristics that result mainly from a brackish and heterogeneous salinity gradient of waters, climate conditions, land relief and minimal tides (Dijkema, 1990; Majewski and Lauer, 1994; Feistel et al., 2010; Hulisz, 2013). The presented soils are very shallow (up to several tens of cm) and affected both by surface and ground water (*gleyic* properties). They developed from stratified deposits (*fluvic* material – Profiles 1–2), which reflected the changing conditions of mineral and organic matter sedimentation (both geogenetic and pedogenetic processes). Accumulation of soil organic matter in those soils could have occurred in different environments: autochthonous (*histic* horizon – Profile 3) and allochthonous (***Humic*** supplementary qualifier – Profiles 1–2). The rate and the nature of soil formation processes was dependent on landscape positions. The soil located along the beach stretch (within the zone of the most dynamic seawater – Profile 1) was defined as an initial soil. The others were classified as semi-mature (Hulisz et al., 2012; Hulisz, 2013).

The salinity (ECe 6.5–16.5 $dS \cdot m^{-1}$) and sodicity level (ESP 12–25%) of the analysed soils reflected the brackish nature of the Baltic waters (***Protosalic*** and ***Sodic*** supplementary qualifiers). It was also significantly affected by other environmental factors (i.a. distance from the sea, seawater flooding frequency, microrelief) and basic soil properties (texture and the content of organic matter). The relatively large differences between pH values measured in Profile 3 (Hinz and Cgz horizons): (i) under field conditions (pHa), (ii) after two months of incubation of samples and (iii) after treatment with H_2O_2 can suggest that this soil is particularly susceptible to acidification (*hypersulfidic* material).

According to the WRB system (IUSS Working Group WRB, 2014), the studied coastal soils were classified as follows: Profiles 1 and 2 – ***Fluvic*** **Gleysol** ***(Arenic, Humic, Protosalic, Sodic)***, Profile 3– ***Histic*** **Gleysol** ***(Arenic, Protosalic, Sodic, Hypersulfidic)***.

Soil sequence

The analysed soils were characterized by small-scale diversity of morphology and other properties, depending on local geomorphological and hydrological conditions. They presented a specific spatial distribution pattern within the selected transect, which can be referred to as a **hydro-toposequence**. The narrow section of the beach and the beach ridge are covered by ***Fluvic*** **Gleysols,** while ***Histic*** **Gleysols** can be found in the small depression farthest from the waterline (30–40 m) – Fig. 2. Such a spatial arrangement of pedons is typical of soils in the South Baltic coastal zone (Hulisz, 2013). In accordance with the concept of Huggett (1975), it can also be called 'soil-landscape system' where soil properties vary along a specific gradient, conditioned by a combination of local environmental factors. The soil salinity level and sulphur dynamics were mainly affected by the recharge of the coastal areas with seawater during high water levels or storms, and seawater intrusions into shallow groundwater. That is why those soils can be considered as a geochemically independent. It should be noted, however, that the lack of regular sea transgressions (tides) and the presence of small depressions filled with organic sediments (reservoirs of the saline water) contributed to the fact that salinity of the studied soils in the narrow zone increased with the distance from the waterline (Table 4, 8 and 12). Under the conditions of the study, this pattern was observed within a limited area (up to about 50 m from the sea). It should be assumed that under other conditions of a local environment in the sequences of coastal soils, the direction of the salinity changes may be reversed. This was evidenced by, among others, the results obtained by Giani (1992) and Hulisz et al. (2013) for the clayey salt marsh soils exposed to regular tidal flooding in the North Sea area.

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Forested areas within the outwash plain in Poland (Tuchola Forest)

Piotr Hulisz, Marta Kowalczyk, M. Tomasz Karasiewicz

The Tuchola Forest (Bory Tucholskie) is one of the largest forest complexes in Poland which lies between the Brda and Wda Rivers (north-central Poland). It covers the vast outwash plain of over 3.000 km^2 area located in front of the Pomeranian phase of the Vistulian glaciation (Marks, 2012; Fig.1). The relief in this part of the Polish Lowland is very diverse. Other landforms occurring in that area are flat and undulated moraine remnants, kames, eskers, subglacial tunnels, kettle-holes, dunes, river valleys and peat plains (Galon, 1953 and 1958).

Fig. 1. Location

Lithology and topography

The presented soil sequence is located in the northeastern part of the Tuchola Forest (Popówka site) within the small kettle-hole (0.23 ha) formed in the outwash plain. The site lies on the edge of the intersection of the subglacial tunnels and therefore there are significant height differences in the immediate vicinity (154 m a.s.l. on the northern side, 144 m a.s.l. in the central part of the kettle-hole and about 149 m a.s.l. on the southern side). The maximum inclinations of slopes reach about 7°. The slope deposits are represented by sands and fine gravels. The bottom of the kettle-hole is covered by the ombrogenous (highmoor) peat bog.

Vegetation

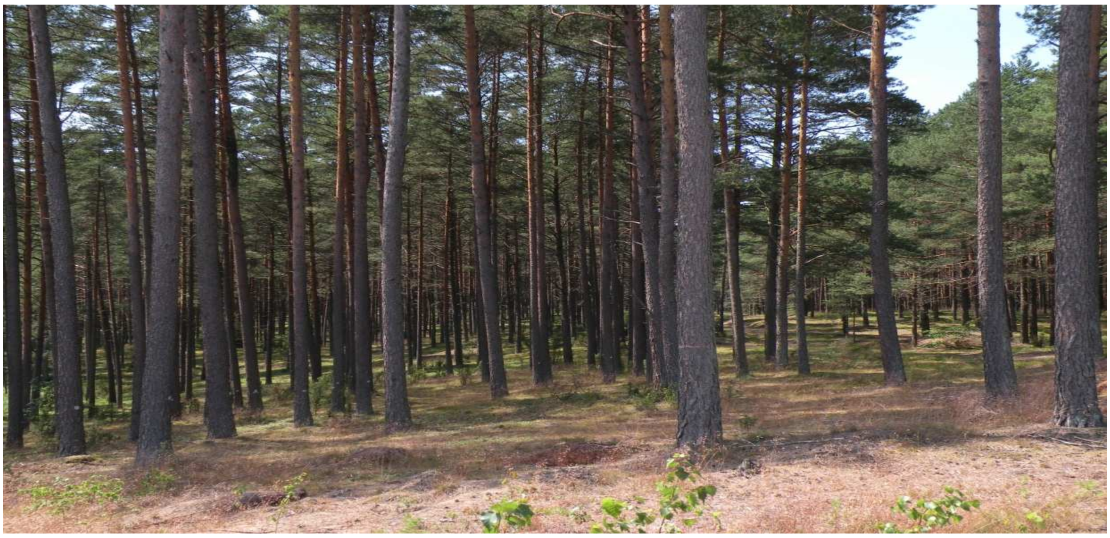
The current vegetation cover of the Tuchola Forest is a result of changes and transformations taking place over many centuries (Filbrandt-Czaja, 2009). The forest cover in the region is as much as 64% and represents 96% of the coniferous forest habitats (Kliczkowska and Zielony, 2012). The slopes of the kettle-hole were overgrown with Scots pines (*Pinus sylvestris*) and the most common forest floor species were: *Entodon schreberi*, *Dicranum polysetum*, *Vaccinium vitis-idaea*, *Vaccinium myrtillus, Festuca ovina.* However, the bog vegetation included *Sphagnum* sp., *Vaccinium uliginosum*, *Oxycoccus palustris*, *Polytrichum strictum*, *Eriophorum vaginatum* with an admixture of *Pinus sylvestris* and *Betula pubescens*.

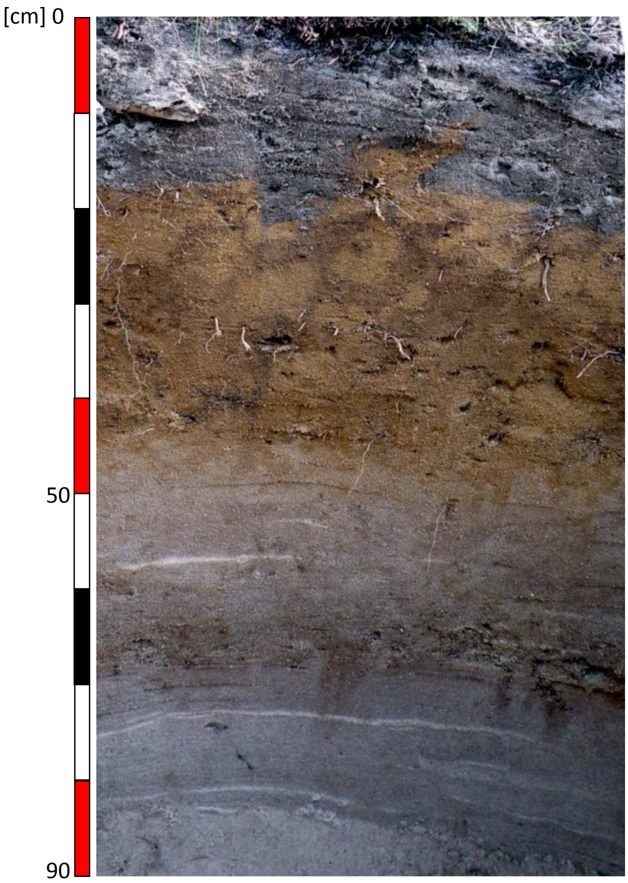
Climate

The region is located in the warm temperate, fully humid climate zone with warm summer (Kottek et al., 2006). The average annual air temperature for the period of 1951–1970 is about 7°C. The average temperature of the warmest month (July) is 16.6°C, while the coldest month is January (-2.2°C). The average annual precipitation is 580 mm. As much as 375 mm of precipitation falls in the period from April to September (Wójcik, Marciniak, 1987a, b). Westerlies prevail in the region and average annual wind speed is 4 m·s^{-1} (Atlas of the climate of Poland, 2005).

Profile 1 – Dystric Albic Brunic **Arenosol**

Location: Popówka (Tuchola Forest), outwash plain, kettle-hole, upper slope (shoulder), fresh coniferous forest, 147 m a.s.l; **N** 53°56'22.86'', **E** 17°48'5.82''





Morphology:

Oi – 8–6 cm, slightly decomposed organic material;

Oe – 6–2 cm, moderately decomposed organic material;

Oa – 2–0 cm, highly decomposed organic material;

AE(p) – 0–18 cm, features of ploughing disturbance in the past, discontinuous *albic* material in the upper part, fine sand, dark gray (10YR 5/1; 10YR 4/1), dry, single grain structure, fine and common roots, abrupt and wavy boundary;

Bw – 18–40 cm, fine sand, yellowish brown (10YR 6/6; 10YR 5/6), dry, single grain structure, fine and few roots, gradual and wavy boundary;

BC – 40–49 cm, fine sand, brownish yellow (10YR 7/6; 10YR 6/6), dry, single grain structure, very fine and very few roots, abrupt and wavy boundary;

C1 – 49–65 cm, fine sand, light gray (10YR 8/2; 10YR 7/2), dry, single grain structure, clear and smooth boundary;

C2 – 65–71 cm, fine sand with admixture of gravel, light yellowish brown (10YR 7/4; 10YR 6/4), dry, single grain structure, abrupt and irregular boundary;

C3 – 71–(90) cm, fine sand, light brownish gray (10YR 7/2; 10YR 6/2), dry, single grain structure.

Table 1. Texture

Horizon	Depth [cm]	Percentage of fraction [mm]							Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	< 0.05	
AEp	0–18	1	3	21	43	27	4	2	MS
Bw	18–40	3	5	25	44	20	4	2	MS
BC	40–49	1	2	10	56	31	1	0	MS
C1	49–65	1	1	8	60	30	1	0	MS
C2	65–71	9	7	16	48	28	1	0	MS
C3	71–(90)	0	0	2	58	39	1	0	MS

Table 2. Chemical and physicochemical properties

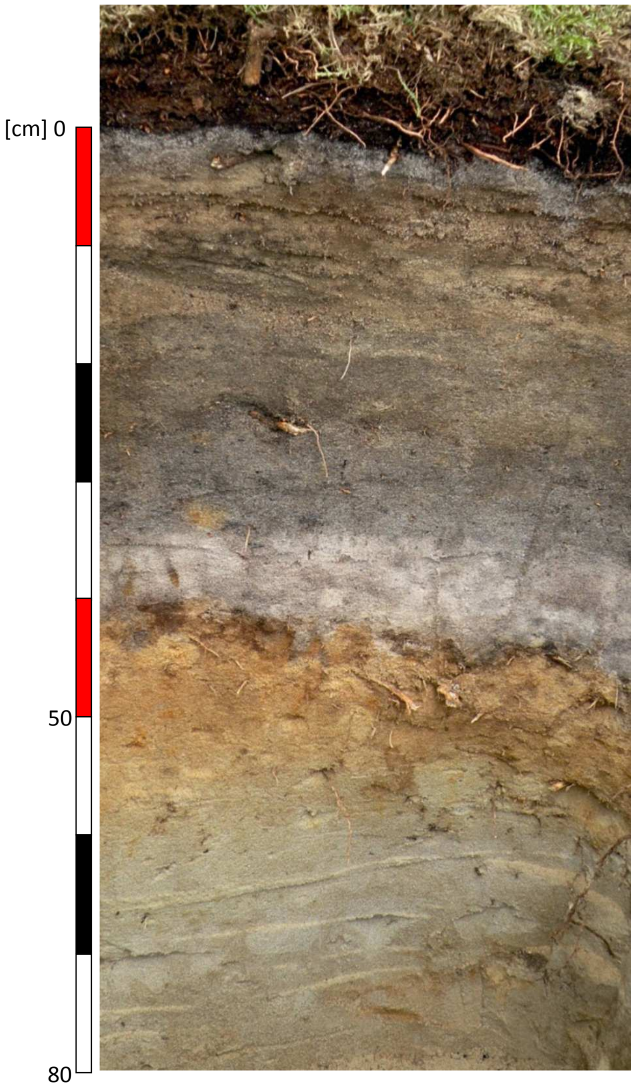
Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	N_t [$g \cdot kg^{-1}$]	C/N	pH	
					H_2O	KCl
Oe	6–2	348	10.2	34	3.9	2.8
Oa	2–0	338	9.75	35	3.2	2.2
AEp	0–18	7.90	0.20	40	5.0	4.2
Bw	18–40	2.20	0.10	16	4.9	4.6
BC	40–49	-	-	-	4.8	4.7
C1	49–65	-	-	-	5.0	4.9
C2	65–71	-	-	-	5.1	4.8
C3	71–(90)	-	-	-	5.3	4.9

Table 3. Content of selected forms of iron and aluminium

Horizon	Depth [cm]	Fe_o	Fe_t	Al_o	Al_t
		[$g \cdot kg^{-1}$]			
AEp	0–18	1.19	4.15	0.73	11.1
Bw	18–40	1.06	6.20	2.13	16.2
BC	40–49	0.62	4.99	0.96	10.3
C1	49–65	0.42	4.04	0.27	11.2
C2	65–71	0.85	7.56	0.55	14.0
C3	71–(90)	0.35	4.69	0.45	11.9

Profile 2 – Dystric Brunic Albic Folic **Arenosol** over Gleyic Albic **Podzol** (Arenic)

Location: Popówka (Bory Tucholskie), outwash plain, kettle-hole, middle slope (back slope), fresh coniferous forest, 145 m a.s.l.; **N** 53°56′23.94′′, **E** 17°48′5.1′′



Morphology:

Oi – 12–6 cm, slightly decomposed organic material;

Oe – 6–1 cm, moderately decomposed organic material;

Oa – 1–0 cm, highly decomposed organic material;

EA – 0–3 cm, *albic* material, fine sand, light brownish gray (10YR 7/2; 10YR 6/2), dry, single grain structure, fine and medium common roots, abrupt and smooth boundary;

BA – 3–25 cm, fine sand, brown (10YR 6/3; 10YR 5/3), dry, single grain structure, very fine and few roots, abrupt and smooth boundary;

Ab – 25–34 cm, fine sand, gray (10YR 6/1; 10YR 5/1), dry, single grain structure, fine and few roots, abrupt and smooth boundary;

Eb – 34–40 cm, *albic* material, fine sand, light gray (10YR 8/1; 10YR 7/1), dry, single grain structure, abrupt and smooth boundary;

Bsb1 – 40–43 cm, *spodic* horizon, fine sand, dark brown (10YR 4/3; 10YR 3/3), dry, single grain structure, very fine and few roots, abrupt and smooth boundary;

Bsb2 – 43–58 cm, *spodic* horizon, fine sand, brownish yellow (10YR 7/6; 10YR 6/6), dry, single grain structure, medium and few roots, gradual and smooth boundary;

Cl – 58–(80) cm, fine sand, pale yellow (2.5Y 8/3; 2.5Y 7/3), slightly moist, single grain structure, few oximorphic mottles.

Table 4. Texture

Horizon	Depth [cm]	Percentage of fraction [mm]							Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	< 0.05	
EA	0–3	2	4	27	51	13	2	1	MS
BA	3–25	>1	5	24	50	16	2	3	MS
Ab	25–34	>1	3	21	50	21	2	3	MS
Eb	34–40	>1	3	13	60	22	2	0	MS
Bsb1	40–43	>1	2	16	59	20	2	1	MS
Bsb2	43–58	1	3	14	57	24	2	0	MS
Cl	58–(80)	>1	1	8	71	19	1	0	MS

Table 5. Chemical and physicochemical properties

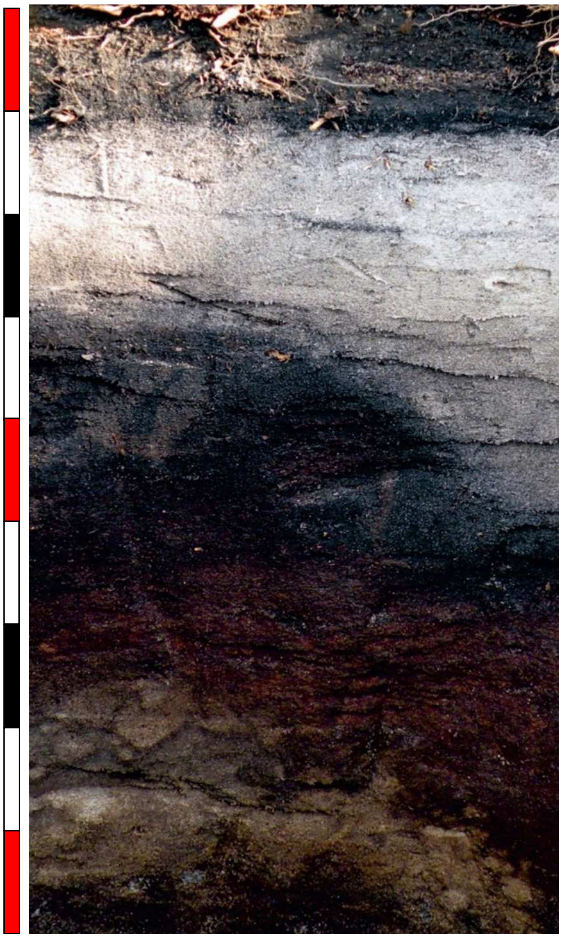
Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	N_t [$g \cdot kg^{-1}$]	C/N	pH	
					H_2O	KCl
Oi2	10–6	420	11.3	37	3.5	2.4
Oe	6–1	412	11.3	37	3.2	2.1
Oa	1–0	-	-	-	3.7	2.4
EA	0–3	9.4	0.32	29	4.2	3.1
BA	3–25	9.2	0.28	33	4.9	4.0
Ab	25–34	8.7	0.22	40	4.8	3.9
Eb	34–40	-	-	-	5.2	4.2
Bsb2	43–58	3.9	0.15	-	4.9	4.8
Cl	58–(80)	-	-	-	4.9	4.8

Table 6. Content of selected forms of iron and aluminium

Horizon	Depth [cm]	Fe_o	Fe_t	Al_o	Al_t
		[$g \cdot kg^{-1}$]			
EA	0–3	0.36	1.99	0.16	8.24
BA	3–25	0.83	3.09	0.66	10.8
Ab	25–34	0.48	2.88	0.56	13.3
Eb	34–40	0.16	1.03	0.22	6.28
Bsb2	43–58	1.56	4.91	6.58	16.4
Cl	58–(80)	0.11	3.12	0.78	13.2

Profile 3 – Gleyic Albic Orsteinic **Podzol** (Arenic)

Location: Popówka (Bory Tucholskie), outwash plain, kettle-hole, lower slope (foot slope), wet coniferous forest, 144 m a.s.l., **N** 53°56’24.00’’, **E** 17°48’4.8’’



Morphology:

Oi – 8–6 cm, slightly decomposed organic material;

Oe – 6–2 cm, moderately decomposed organic material;

Oa – 2–0 cm, highly decomposed organic material;

O/A – 0–11 cm, fine loamy sand, very dark gray (10YR 4/1; 10YR 3/1), dry, single grain structure, medium and coarse roots, abrupt and smooth boundary;

E – 11–30/44, *albic* material, fine sand, light gray (10YR 8/1; 10YR 7/1), dry, single grain structure, diffuse and irregular boundary;

Bsm1 – 30/44–55 cm, *spodic* horizon, fine sand, very dark brown (10YR 4/2; 10YR 2/2), dry, moderate massive (coherent) structure, clear and smooth boundary;

Bsm2 – 55–66 cm, *spodic* horizon, fine sand, very dark brown (7.5YR 4/3; 7.5YR 2,5/3), dry, moderate massive (coherent) structure, gradual and smooth boundary;

Bslm1 – 66–84 cm, *spodic* horizon, fine sand, dark yellowish brown (10YR 5/4; 10YR 4/4), dry, moderate massive (coherent) structure, many oximorphic mottles, clear and smooth boundary;

Bslm2 – below 84 cm, *spodic* horizon, medium sand, very dark brown (10YR 4/4; 10YR 2/2), dry, moderate massive (coherent) structure, many oximorphic mottles.

Table 7. Texture

Horizon	Depth [cm]	Percentage of fraction [mm]							Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	< 0.05	
O/A	0–11	0	12	20	32	20	8	8	LS
E	11–30/44	2	3	20	48	23	3	3	MS
Bsm1	30/44–55	>1	6	19	48	22	3	2	MS
Bsm2	55–66	>1	4	13	48	33	1	1	MS
Bslm1	66–84	>1	2	15	48	33	2	0	MS
Bslm2	>84	2	8	45	19	26	1	1	CS

Table 8. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	C/N	pH	
					H_2O	KCl
Oe	5–1	429	145	30	3.9	2.8
Oa	1–0	426	129	33	3.0	2.2
O/A	0–11	136	4.06	34	3.9	3.1
E	11–30/44	2.4	0.15	16	5.3	3.9
Bsm1	30/44–55	37.1	1.21	31	4.1	3.2
Bsm2	55–66	19.4	0.48	40	4.8	4.1
Bslm1	66–84	7.8	0.23	34	4.7	4.2
Bslm2	>84	9.0	0.22	41	4.7	4.1

Table 9. Content of selected forms of iron and aluminium

Horizon	Depth [cm]	Fe_o	Fe_t	Al_o	Al_t
		[g·kg^{-1}]			
O/A	0–11	6.00	10.0	4.50	27.6
E	11–30/44	0.06	0.88	0.06	3.73
Bsm1	30/44–55	0.43	1.64	1.90	10.3
Bsm2	55–66	0.18	4.97	5.20	14.2
Bslm1	66–84	0.04	2.89	1.31	9.56
Bslm2	>84	0.09	2.01	1.93	13.8

Profile 4 – Dystric Ombric Hemic **Histosol**

Location: Popówka (Bory Tucholskie), boundary between the outwash plain and the kettle-hole, lower slope (foot slope), ombrogenous peat bog (the lagg zone), 143 m a.s.l.;
N 53°56’23.94’’, **E** 17°48’4.98’’

Morphology:

histic horizon:

Hi1 – 0–4 cm, olive yellow (2.5Y 8/6; 2.5Y 6/6), slightly decomposed organic material (D1), muddy, wet;

Hi2 – 4–15 cm, olive brown (2.5Y 5/3; 2.5Y 4/3), slightly decomposed organic material (D2), muddy, wet;

He1 – 15–45 cm, very dark grayish brown (2.5Y 5/2; 2.5Y 3/2), moderately decomposed organic material (D5), wet;

↓He2 – 45–65 cm, very dark grayish brown (2.5Y 4/2; 2.5Y 3/2), moderately decomposed organic material (D5), wet;

↓Cl – below 65 cm, fine sand, light greenish gray (10Y 8/1; 10Y 7/1), wet, single grain structure, *gleyic* properties.

Table 10. Texture

Horizon	Depth [cm]	Percentage of fraction [mm]							Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	< 0.05	
Cl	>65	>1	5	30	48	14	2	1	MS

Table 11. Chemical and physicochemical properties

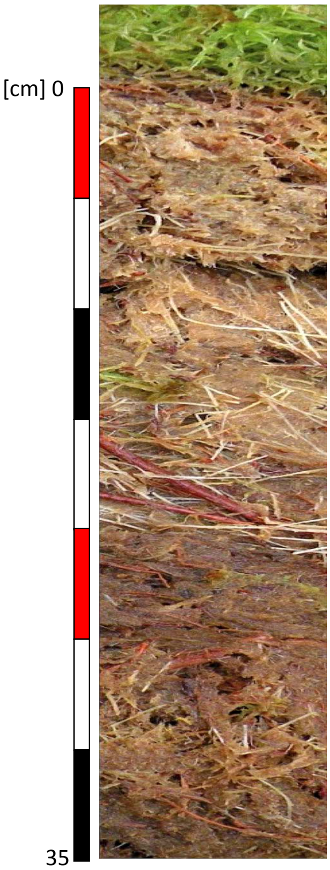
Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	C/N	pH	
					H_2O	KCl
Hi1	0–4	424	9.0	47	4.3	3.0
Hi2	4–15	452	10.8	42	4.0	2.8
He1	15–45	445	11.6	39	3.8	2.7
He2	45–65	402	7.5	54	3.8	2.5
Cl	>65	2.5	0.1	28	4.8	3.2

Table 12. Content of total iron and aluminium

Horizon	Depth [cm]	Fe_t	Al_t
		[g·kg^{-1}]	
Hi1	0–4	2.42	13.0
Hi2	4–15	2.64	4.53
He1	15–45	0.98	1.30
He2	45–65	0.44	0.84
Cl	>65	0.50	2.50

Profile 5 – Dystric Ombric Fibric **Histosol**

Location: Popówka (Bory Tucholskie), kettle-hole, bottom, ombrogenous peat bog, 142.5 m a.s.l., **N** 53°56′25.13′′, **E** 17°48′4.48′′



Morphology:

histic horizon:

Hi1 – 0–3 cm, light yellowish brown (2.5Y 7/4; 2.5Y 6/4), very slightly decomposed organic material (D1), wet;

Hi2 – 3–12 cm, light olive brown (2.5Y 6/4; 2.5Y 5/4), slightly decomposed organic material (D1), wet;

Hi3 – 12 cm, olive brown (2.5Y 5/3; 2.5Y 4/3), slightly decomposed organic material (D2), wet.

Table 13. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	C/N	pH	
					H_2O	KCl
Hi1	0–3	425	8.7	49	4.2	2.9
Hi2	3–12	424	8.2	52	3.6	2.4
Hi3	12–35	422	11.5	37	3.5	2.3

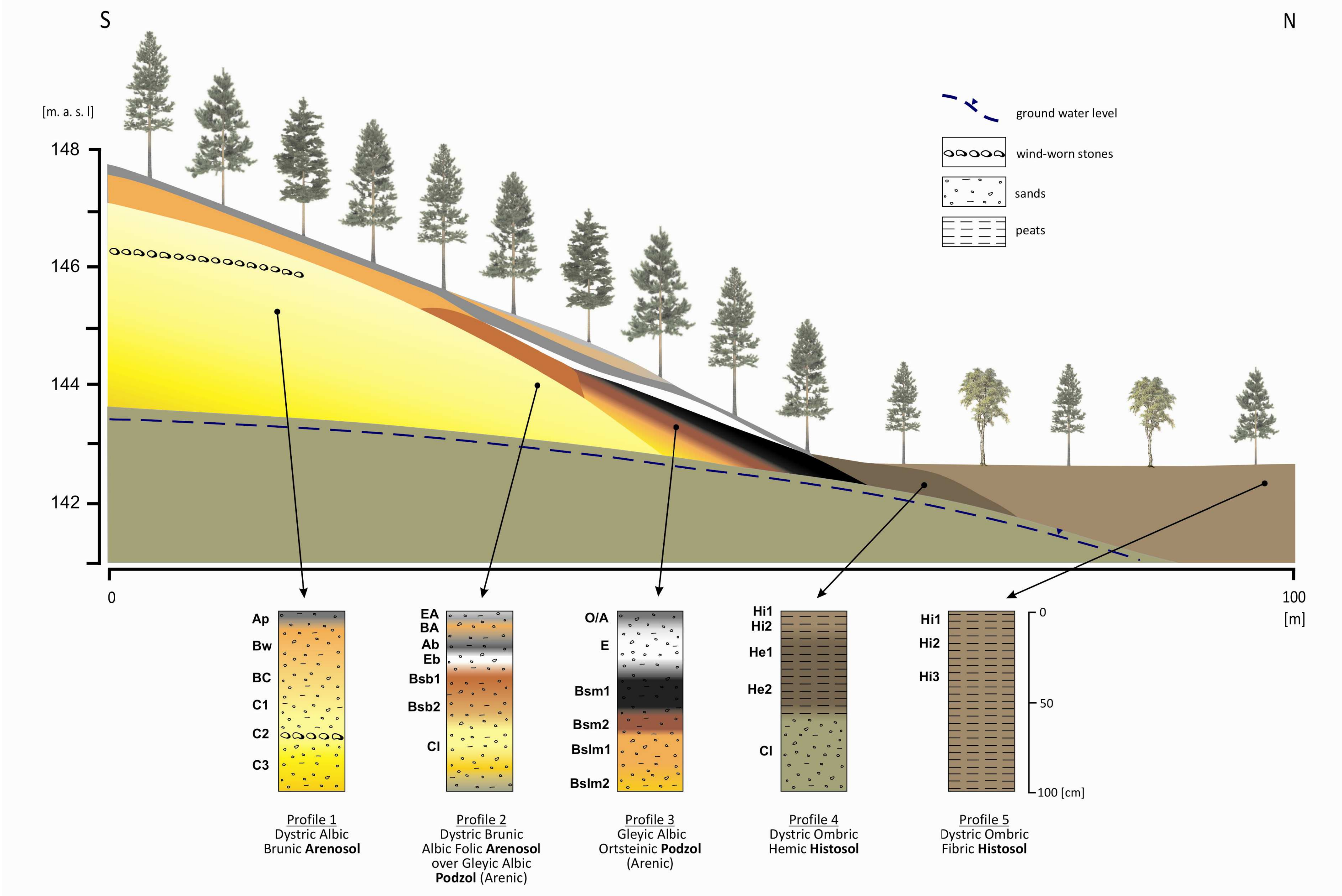


Fig. 2. Hydro-toposequence of soils in the forested areas within the outwash plain in Poland (Tuchola Forest)

Soil genesis and systematic position

Soil properties of outwash plains were affected by processes of morpho- and lithogenesis at the end of Pleistocene. Holocene erosion phenomena initiated the denudation of land surface, and processes of lithogenesis were replaced by pedogenesis, which largely modified the initial properties of the rock material (Bieniek, 2013). Most of the soils occurring in the outwash areas were characterized by the sandy texture. ***Dystric Albic Brunic*** **Arenosols** – IUSS Working Group WRB (2014), represented by Profile 1, was the dominant soil unit in this landscape. The Bw horizon of these acid soils had specific, yellowish brown colour resulting from the presence of humus complexes containing sesquioxides which form coatings around mineral grains. Properties of this horizon met most of the criteria for the *cambic* horizon except for the texture criterion, and therefore the ***Brunic*** principal qualifier was applied. In the topsoil (transformed as a result of agricultural treatments), the ***albic*** material (few cm thick, discontinuous horizon) was present as a consequence of the podzolization process commonly occurring in these soils. This process is affected by pine monocultures introduced in place of coniferous or mixed forests (Sewerniak et al., 2009). Furthermore, the described soil was characterized by the occurrence of a few cm thick sandy horizon with an admixture of gravels (wind-worn stones; 65–71 cm) – Fig 2.

Two other soils (Profile 2, 3) were described as **Podzols.** This RSG was distinguished based on the presence of the ***spodic*** horizon, in the formation of which ground water contributed. The groundwater level in the past could be much higher than today (e.g. 2 m below the surface level). The soils had a well-developed horizons which met the criteria for the ***albic*** material. The genesis of the first soil was significantly affected by slope processes, which resulted in the presence of a 25 cm layer of colluvia. The presence of these sediments could provide evidence of periods with intensified erosion processes in the past, induced by human activity (Sinkiewicz 1998; Kowalkowski 1999). Surface sediments were transformed by pedogenetic processes and consequently, a sequence of two soils developed, which according to the WRB classification (IUSS Working Group WRB, 2014) can be defined as ***Dystric Brunic Albic Folic*** **Arenosol** over ***Gleyic Albic*** **Podzol** ***(Arenic)***.

The latter pedon (Profile 3) was classified as ***Gleyic Albic Ortsteinic*** **Podzol** ***(Arenic).*** This soil had a mixed surface horizon (O/A), which was a primeval organic horizon developed as a result of mixing between the former organic horizon and deluvia during the soil preparation for pine planting. A distinguishing feature of this soil was ortstein (***Ortsteinic*** principal qualifier) occurring from a depth of 30 cm – strongly cemented soil material enriched with humus, iron and aluminium compounds, building the illuvial horizon (B). The formation of ortstein can be associated with an intensive process of podzolization in cooler and more humid climate compared to climate today (Prusinkiewicz, Noryśkiewicz, 1966), or with a relatively shallow groundwater level (Wang et al., 1978; Chodorowski, 2000 and 2009). On the one hand this process at the studied site should be related to an intensive podzolization process, which covers upper genetic horizons, but on the other – with a ground-gleyic process covering the middle and the lower part of the profile. On the borderline between the two zones, elements eluted from the upper genetic horizons through infiltrating rainwater are precipitated together with elements uplifted by the capillary water from the lower endopedons, covered by the gleyic process (***Gleyic*** principal qualifier).

The last profiles (4, 5) were represented by organic soils (**Histosols)** and recharged mainly by precipitation waters (***Ombric*** principal qualifier). Profile 4 was defined as ***Dystric Ombric Hemic*** **Histosol** according to WRB criteria. The total thickness of organic sediments was 65 cm, and organic matter (slightly decomposed peat, D1) occurred from this depth up to 15 cm. Peat located at a depth of 15–65 cm was highly decomposed (D5, ***Hemic*** principal qualifier). This sequence of peat deposits with a varying degree of decomposition could indicate a relatively high groundwater level fluctuations, typical of the lagg zone. Profile 5 was classified as ***Dystric Ombric Fibric*** **Histosol**. The decomposition rate of organic matter in this soil is very slow, therefore it is characterized by the presence of poorly and very poorly decomposed plant remnants (D1 and D2, ***Fibric*** principal qualifier). *Sphagnum* sp. was the dominant peat-forming species.

Soil sequence

Spatial variability of the soil properties along the analysed transect was determined mainly by such factors as relief, rainwater and groundwater. Nowadays, due to the presence of dense vegetation cover (pine forest), the impact of denudation processes on the soil cover is rather very small. The spatial arrangement of pedons located on the slope and within the kettle-hole represents **hydrotoposequence** (Fig. 2). The ***Albic Brunic*** **Arenosols** were typical of the relatively flat upper parts of the slopes, whereas the semi-hydrogenic soils occurred in the lower slope locations (***Gleyic Albic*** **Podzols)**. In some places they were covered by colluvial deposits **(*Brunic* Arenosols)**, the thickness of which decreased towards the footslope. The soils in that part of the slope also had a strongly cemented ***spodic*** horizon (***Gleyic Albic Ortsteinic*** **Podzols**). The kettle-hole was filled with the peat deposits characterized by a different degree of decomposition. The soils there were classified as ***Dystric Ombric Hemic*** **Histosols** and ***Dystric Ombric Fibric*** **Histosols.**

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Forested areas within hummocky moraine plateaus of Poland (Brodnica Lake District)

Marcin Świtoniak, Przemysław Charzyński, Łukasz Mendyk

The young morainic area of North Poland is part of the North European Plain and lies within the maximum range of the Vistulian Glaciation (Fig. 1) defined as the Leszno Phase in western Poland and the Poznań Phase in the central and eastern part of the country (Marks, 2012). The Brodnica Lake District represents typical young glacial landscapes and is located between the limits of the two major Vistulian glacial phases: Poznań and Pomeranian Phases. The general outline of the relief was formed during the late glacial period, i.e. ca. 16–17 ka CE (Niewiarowski, 1986; Niewiarowski and Wysota, 1986). The Brodnica moraine plateau is cut by longitudinal subglacial channels filled by numerous lakes and two sandy outwash plains (West and East Brodnica; Niewiarowski, 1986).

Fig. 1. Location

Lithology and topography

The presented soils were located in the south-eastern part of the Brodnica Lake District within a typical hummocky moraine plateau. The differences in terrain altitudes are associated with numerous kettles, irregular and elongate or roundish in shape. Among the surface sediments, ablation sands dominate with a thickness of tens of centimeters on glacial till. Slopes with an inclination > 10° represent about 16% of the total surface. The maximum inclinations of slopes reach about 30°. The denivelations are relatively high and in many places range up to 20 m.

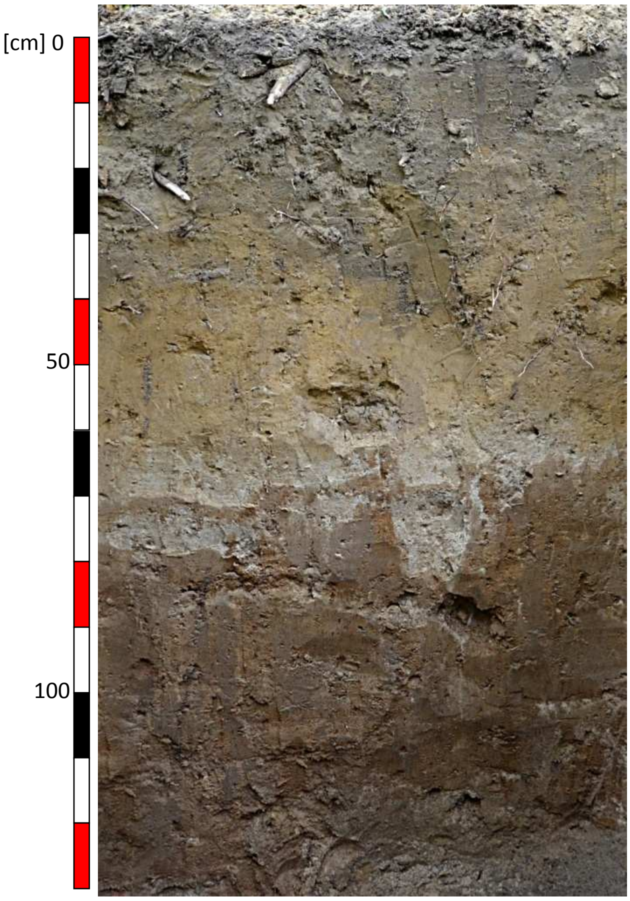
Land use

Only small areas of moraine plateaus within the Brodnica Lake District are covered by mixed forest. Because of a relatively high fertility of soils, the vast majority of them was converted into arable lands. Lack of profitability of agricultural production in currently forested areas is associated with intensive relief. The canopy layer is dominated by pines (*Pinus sylvestris*). Species typical of hornbeam forest (*Carpinus betulus, Tilia cordata,* and *Quercus sp*) dominate in the understory, the herb layer and the forest floor.

Climate

The region is located in the zone of moist and cool temperate climate (IPCC, 2006). According to Köppen–Geiger Climate Classification, the region is located in the fully humid zone with temperate and warm summer (Kottek et al., 2006). The average annual air temperature is about 7°C. The warmest month is July (17.6°C). The mean air temperature during January (coldest winter month) is about -4°C. The average annual precipitation is 552 mm. July is the wettest month with average precipitation around 90 mm (Wójcik and Marciniak, 1987a, b, 1993).

Profile 1 – Epidystric Albic Neocambic Glossic **Retisol** (Abruptic, Cutanic, Ruptic)
Localization: hummocky morainic plateau, flat terrain with slopes < 1°, mixed forest, 121 m a.s.l.
N 53°20'12", **E** 19°27'18"



Morphology:

Oi – 2–1 cm, slightly decomposed organic material;

Oe – 1–0 cm, moderately decomposed organic material;

A – 0–20 cm, humus horizon, sandy loam, dark brown (10YR 5/3; 10YR 3/3), dry, moderate granular medium structure, fine and medium common roots, diffuse and broken boundary;

Bw – 20–55 cm, *cambic* horizon, sandy loam, dark yellowish brown (10YR 6/4; 10YR 4/5), dry, weak subangular very fine structure, very fine and very few roots, clear and smooth boundary;

E – 55–70/65 cm, eluvial horizon with *albic* material, sandy loam, light yellowish brown (10YR 7,5/3; 10YR 6/4), dry, weak subangular very fine structure, abrupt and broken boundary;

E/B – 70/65–80 cm, transitional horizon, interfingering of *albic* material into *argic* horizon;

2Bt – 80–115 cm, *argic* horizon, sandy clay loam, strong brown (7.5YR 6/6; 7.5YR 4/6), slightly moist, strong angular coarse structure, common faint clay coatings, gradual and smooth boundary;

2C – 115–(130) cm, parent material, sandy loam, dark yellowish brown (10YR 5/6; 10YR 4/6), slightly moist, moderate angular coarse structure.

Table 1. Texture

Horizon	Depth [cm]	Percentage of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
A	0–20	4	3	6	14	25	26	12	6	3	5	SL
Bw	20–55	3	2	5	11	27	24	15	7	5	4	SL
E	55–70/65	3	2	4	9	26	26	14	8	5	6	SL
E/B	70/65–80	2	2	8	5	27	24	11	4	9	10	SL
2Bt	80–115	2	3	8	7	21	20	8	5	6	22	SCL
2C	115–(130)	2	1	5	4	28	22	10	7	5	18	SL

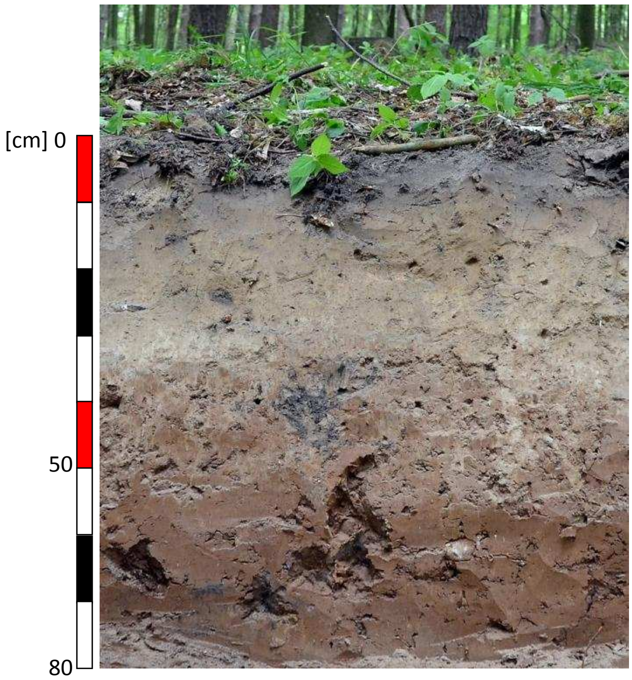
Table 2. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	C/N	pH		$CaCO_3$ [g·kg^{-1}]
					H_2O	KCl	
Oi	2–1	492	21.1	23	5.8	5.3	-
Oe	1–0	325	16.2	20	5.2	4.7	-
A	0–20	18.2	0.92	20	4.9	3.8	-
Bw	20–55	3.4	0.20	17	5.3	4.5	-
E	55–70/65	1.0	0.09	11	5.9	5.2	-
E/B	70/65–80	1.0	0.10	10	6.0	5.1	-
2Bt	80–115	1.4	0.16	9	6.2	5.3	-
2C	115–(130)	-	-	-	6.4	5.6	trace

Table 3. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	CEC_{clay}	BS [%]
		[cmol(+)·kg^{-1}]								
Oi	2–1	52.4	13.8	0.820	0.421	67.4	84.3	151.7	-	44
Oe	1–0	49.7	8.21	0.661	0.409	59.0	60.1	119.1	-	49
A	0–20	0.632	0.084	0.110	0.032	0.858	6.29	7.15	15.6	12
Bw	20–55	0.329	0.043	0.062	0.081	0.515	4.20	4.71	88.0	11
E	55–70/65	0.448	0.080	0.076	0.046	0.650	3.28	3.93	59.7	16
E/B	70/65–80	1.29	0.544	0.288	0.087	2.21	1.98	4.19	38.4	53
2Bt	80–115	6.21	1.34	0.305	0.090	7.94	2.65	10.6	45.9	75
2C	115–(130)	8.20	1.87	0.322	0.033	10.4	2.03	12.4	68.9	84

Profile 2 – Endocalcaric Albic Abruptic **Luvisol** (Epiarenic, Endoloamic, Cutanic, Epidystric, Ruptic, Inclinic)
Localization: hummocky morainic plateau, upper slope (shoulder), 11°, mixed forest, 117 m a.s.l.
N 53°20'6", **E** 19°27'9"



Morphology:

Oi – 3–1 cm, slightly decomposed organic material;

Oe – 1–0 cm, moderately decomposed organic material;

A – 0–10 cm, humus horizon, loamy fine sand, dark grayish brown (10YR 5/2; 10YR 4/2), dry, moderate granular medium structure, fine and medium common roots, clear and smooth boundary;

Bw – 10–20 cm, loamy fine sand, dark yellowish brown (10YR 6/4; 10YR 4/4), dry, weak subangular very fine structure, very fine and very few roots, gradual and smooth boundary;

E – 20–35 cm, eluvial horizon with *albic* material, loamy fine sand, light yellowish brown (10YR 7.5/3; 10YR 6/4), dry, weak subangular very fine structure, clear and irregular boundary;

2Bt – 35–90 cm, *argic* horizon, sandy clay loam, dark yellowish brown (10YR 4/4; 10YR 3/4), dry, strong angular coarse structure, common faint clay coatings, gradual and smooth boundary;

2Ck – 90–(150) cm, parent material, sandy loam, yellowish brown (10YR 6/3; 10YR 5/4), dry, moderate angular coarse structure, fine rounded and soft secondary carbonates.

Comments: parent material was taken from drill. Hard consistence of Bt horizon prevent to dig deeper soil pit.

Table 4. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
A	0–10	5	5	8	16	24	24	9	9	2	3	LFS
Bw	10–20	2	7	8	18	22	22	10	7	4	2	LFS
E	20–35	6	6	6	14	26	27	8	5	4	4	LFS
2Bt	35–90	3	2	5	11	20	17	7	9	6	23	SCL
2Ck	90–(150)	4	4	6	10	18	18	10	8	10	16	SL

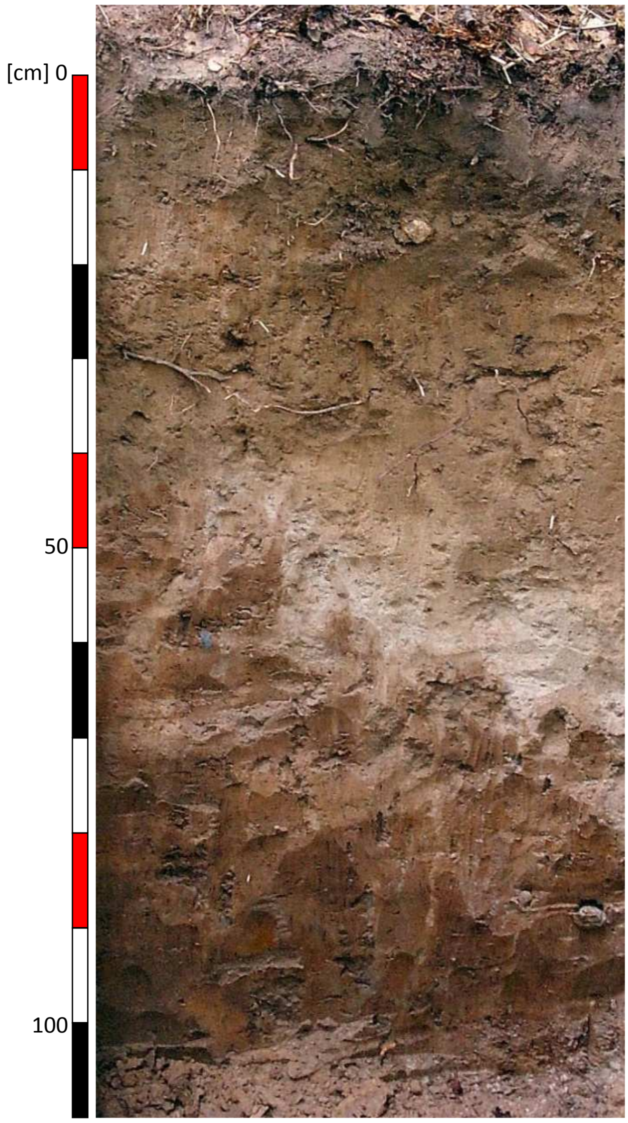
Table 5. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	C/N	pH		$CaCO_3$ [g·kg^{-1}]
					H_2O	KCl	
Oi	3–1	451	19.4	23	5.7	5.1	-
Oe	1–0	407	18.9	22	5.3	4.7	-
A	0–10	13.8	0.83	17	5.1	4.2	-
Bw	10–20	3.1	0.08	39	5.6	4.9	-
E	20–35	2.0	0.07	29	6.0	5.1	-
2Bt	35–90	2.2	0.10	22	6.3	5.6	trace
2Ck	90–(150)	-	-	-	8.0	7.1	35

Table 6. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	CEC_{clay}	BS [%]
		[cmol(+)·kg^{-1}]								
Oi	3–1	49.1	12.7	0.738	0.475	63.0	78.2	141.2	-	45
Oe	1–0	46.3	7.45	0.623	0.429	54.8	66.3	121.1	-	45
A	0–10	0.532	0.054	0.206	0.051	0.843	7.14	7.98	105.0	11
Bw	10–20	0.487	0.127	0.279	0.063	0.956	3.26	4.22	156.8	23
E	20–35	0.438	0.176	0.244	0.055	0.913	2.16	3.07	59.3	30
2Bt	35–90	9.27	0.922	0.415	0.113	10.7	2.21	12.9	52.7	83
2Ck	90–(150)	12.0	2.20	0.629	0.281	15.1	-	15.1	94.4	100

Profile 3 – Albic Abruptic **Luvisol** (Epiarenic, Endoloamic, Cutanic, Epidystric, Ruptic, Neocambic, Inclinic)
Localization: hummocky morainic plateau, middle slope, 6°, mixed forest, 107 m a.s.l.
N 53°20’1”, **E** 19°24’83”



Morphology:

Oi – 1–0.5 cm, slightly decomposed organic material;

Oe – 0.5–0 cm, moderately decomposed organic material;

A – 0–10 cm, humus horizon, loamy fine sand, dark brown (10YR 5/3; 10YR 3/3), dry, moderate granular medium structure, fine and medium common roots, clear and smooth boundary;

Bw – 10–40/45 cm, *cambic* horizon, loamy fine sand, dark yellowish brown (10YR 6/4; 10YR 4/4), dry, weak subangular very fine structure, fine and few roots, gradual and irregular boundary;

Eg – 40/45–45/60 cm, eluvial horizon with *albic* material, sandy loam, pale brown (10YR 8/2; 10YR 6/3), dry, weak subangular very fine structure, few reductimorphic mottles, clear and irregular boundary;

2Btg – 45/60–90 *argic* horizon, strong brown (7.5YR 6/6; 7.5YR 4/6), slightly moist, sandy loam, strong angular coarse structure, common faint clay coatings, few reductimorphic mottles, gradual and smooth boundary;

2C – 90–(110) cm, parent material, sandy loam, strong brown (10YR 5.5/6; 10YR 3.5/6), slightly moist, strong angular coarse structure.

Table 7. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
A	0–10	3	5	8	16	30	18	10	6	4	3	LFS
Bw	10–40/45	2	5	8	16	31	16	11	6	4	3	LFS
Eg	40/45–45/60	8	5	7	17	29	15	12	6	3	6	SL
2Btg	45/60–90	1	3	7	15	24	14	6	9	5	17	SL
2C	90–(110)	6	1	5	17	27	11	9	9	6	15	SL

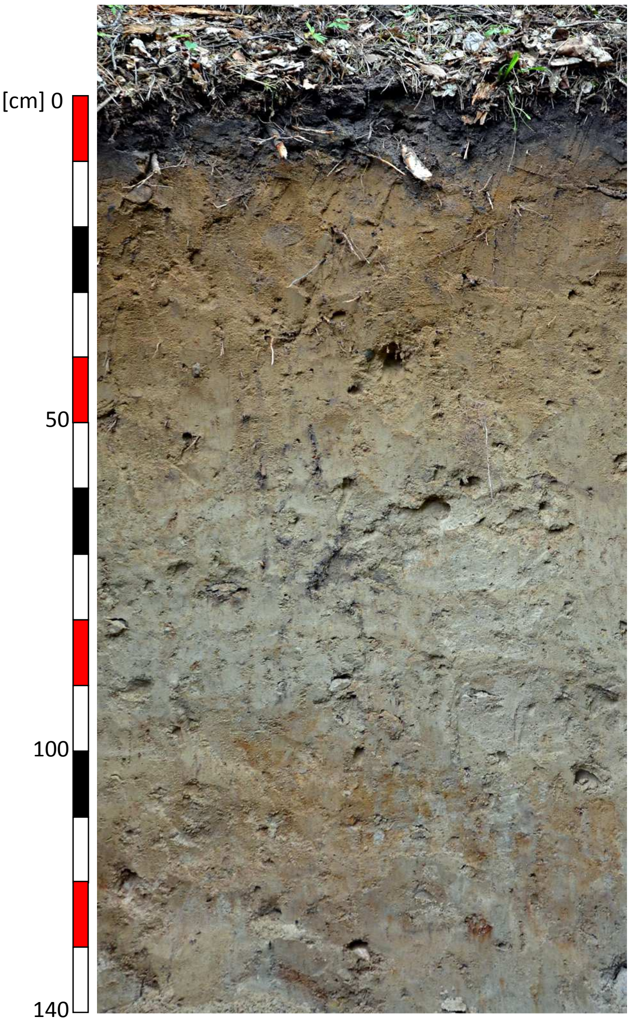
Table 8. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	C/N	pH	
					H_2O	KCl
Oi	1–0.5	426	21.6	20	5.2	4.6
Oe	0.5–0	312	15.0	21	5.0	4.4
A	0–10	12.5	1.01	12	4.9	3.7
Bw	10–40/45	4.3	0.28	15	5.2	4.1
Eg	40/45–45/60	0.9	0.08	11	5.9	4.1
2Btg	45/60–90	1.5	0.16	9	6.1	4.7
2C	90–(110)	-	-	-	6.2	4.4

Table 9. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	CEC_{clay}	BS [%]
		[cmol(+)·kg^{-1}]								
Oi	1–0.5	49.5	11.0	0.543	0.556	61.6	82.4	144	-	43
Oe	0.5–0	50.1	7.56	0.356	0.491	58.5	70.2	129	-	45
A	0–10	0.613	0.076	0.203	0.040	0.932	9.11	10.0	188	9
Bw	10–40/45	0.643	0.116	0.246	0.067	1.07	4.87	5.94	153	18
Eg	40/45–45/60	0.810	0.299	0.307	0.070	1.49	3.59	5.08	83.6	29
2Btg	45/60–90	2.02	0.478	0.527	0.105	3.13	2.67	5.80	30.5	54
2C	90–(110)	3.71	0.519	0.298	0.131	4.66	2.19	6.85	44.5	68

Profile 4 – Dystric Brunic Sideralic **Arenosol** (Geoabruptic, Bathygleyic, Inclinic)
Localization: hummocky morainic plateau, lower slope, 13°, mixed forest, 100 m a.s.l.
N 53°20'6", **E** 19°27'0"



Morphology:

Oi – 5–1 cm, slightly decomposed organic material;

Oe – 1–0 cm, moderately decomposed organic material;

A – 0–12 cm, humus horizon, loamy fine sand, very dark gray (7.5YR 4/1; 7.5YR 3/1), slightly moist, moderate granular medium structure, fine and medium common roots, clear and wavy boundary;

Bw – 12–55 cm, pedogenetic *in situ* accumulation of sesquioxides, loamy fine sand, dark yellowish brown (10YR 5/8; 10YR 4/6), slightly moist, single grain structure, very fine and very few roots, gradual and wavy boundary;

C – 55–100 cm, parent material, loamy fine sand, light yellowish brown (2.5Y 7/2; 2.5Y 6/3), slightly moist, single grain structure, few reductimorphic mottles, clear and broken boundary;

2Cl – 100–(130) cm, glacial till, sandy loam, light olive brown (2.5Y 6/6; 2.5Y 5/6), moist, moderate angular medium structure, common reductimorphic mottles;

Table 10. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
A	0–12	4	4	5	20	36	17	13	3	1	1	LFS
Bw	12–55	4	2	6	17	39	23	7	2	2	2	FS
C	55–100	3	3	5	18	38	25	6	1	1	3	FS
2Cl	100–(130)	10	5	11	24	27	12	4	2	3	12	SL

Table 11. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	N_t [$g \cdot kg^{-1}$]	C/N	pH	
					H_2O	KCl
Oi	5–1	478	17.2	28	5.0	4.4
Oe	1–0	326	15.2	21	4.5	3.8
A	0–12	18.7	1.18	16	4.4	3.6
Bw	12–55	4.9	0.29	17	4.6	4.0
C	55–100	-	-	-	5.1	4.1
2Cl	100–(130)	-	-	-	5.8	4.2

Table 12. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	TEB	HA	CEC	CEC_{clay}	BS [%]
		[cmol(+)$\cdot kg^{-1}$]								
Oi	5–1	32.8	12.5	0.421	0.092	45.8	94.2	140	-	33
Oe	1–0	41.5	4.18	0.394	0.174	46.2	82.5	128.7	-	36
A	0–12	0.604	0.027	0.045	0.049	0.725	7.41	8.13	159	9
Bw	12–55	0.273	0.021	0.020	0.038	0.352	3.20	3.55	91.9	10
C	55–100	0.326	0.144	0.073	0.066	0.609	1.72	2.32	77.6	26
2Cl	100–(130)	2.58	0.564	0.128	0.082	3.35	1.99	5.34	44.5	63

Profile 5 – Gleyic **Umbrisol** (Geoabruptic, Endoeutric, Epiarenic, Endoloamic)
Localization: hummocky morainic plateau, toe slope (bottom), 1°, deciduous moist forest, 94 m a.s.l.
N 53°20’06”, **E** 19°27’4”

Morphology:

Oi – 2–0 cm, slightly decomposed organic material;

Ah – 0–25 cm, *umbric* horizon, loamy sand, very dark grayish brown (10YR 4/2; 10YR 3/2), slightly moist, moderate granular medium structure, medium and coarse common roots, clear and smooth boundary;

2Ab – 25–35 cm, buried humus horizon, loamy sand, dark brown (7.5YR 4/1; 7.5YR 3/2), moist, moderate granular medium structure, medium and coarse few roots, clear and smooth boundary;

3Bl – 35–(70) cm, sandy loam, dark bluish gray (GLEY 2 5/10BG; GLEY 2 4/10B), moist, strong angular medium structure, common reductimorphic mottles, many fine and soft iron concentrations, residual rock fragments.

Table 13. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
Ah	0–25	1	1	8	19	31	11	7	9	6	8	SL
2Ab	25–35	1	2	10	16	32	13	9	6	5	7	SL
3Bl	35–(70)	2	5	9	13	25	8	6	6	8	20	SCL

Table 14. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	C/N	pH		$CaCO_3$ [g·kg^{-1}]
					H_2O	KCl	
Oi	2–0	493	18.8	26	4.9	4.2	-
Ah	0–25	28.3	2.45	12	4.8	3.5	-
2Ab	25–35	34.8	3.08	11	5.0	3.8	-
3Bl	35–(70)	9.22	0.77	12	6.6	6.0	trace

Table 15. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	CEC_{clay}	BS [%]
		[cmol(+)·kg^{-1}]								
Oi	2–0	55.2	18.3	0.511	0.580	74.6	92.3	166.9	-	44.7
Ah	0–25	0.714	0.086	0.103	0.044	0.947	11.4	12.3	29.9	7.7
2Ab	25–35	0.936	0.240	0.082	0.051	1.31	12.5	13.8	23.1	9.5
3Bl	35–(70)	4.02	1.33	0.212	0.059	5.62	3.94	9.56	31.7	58.8

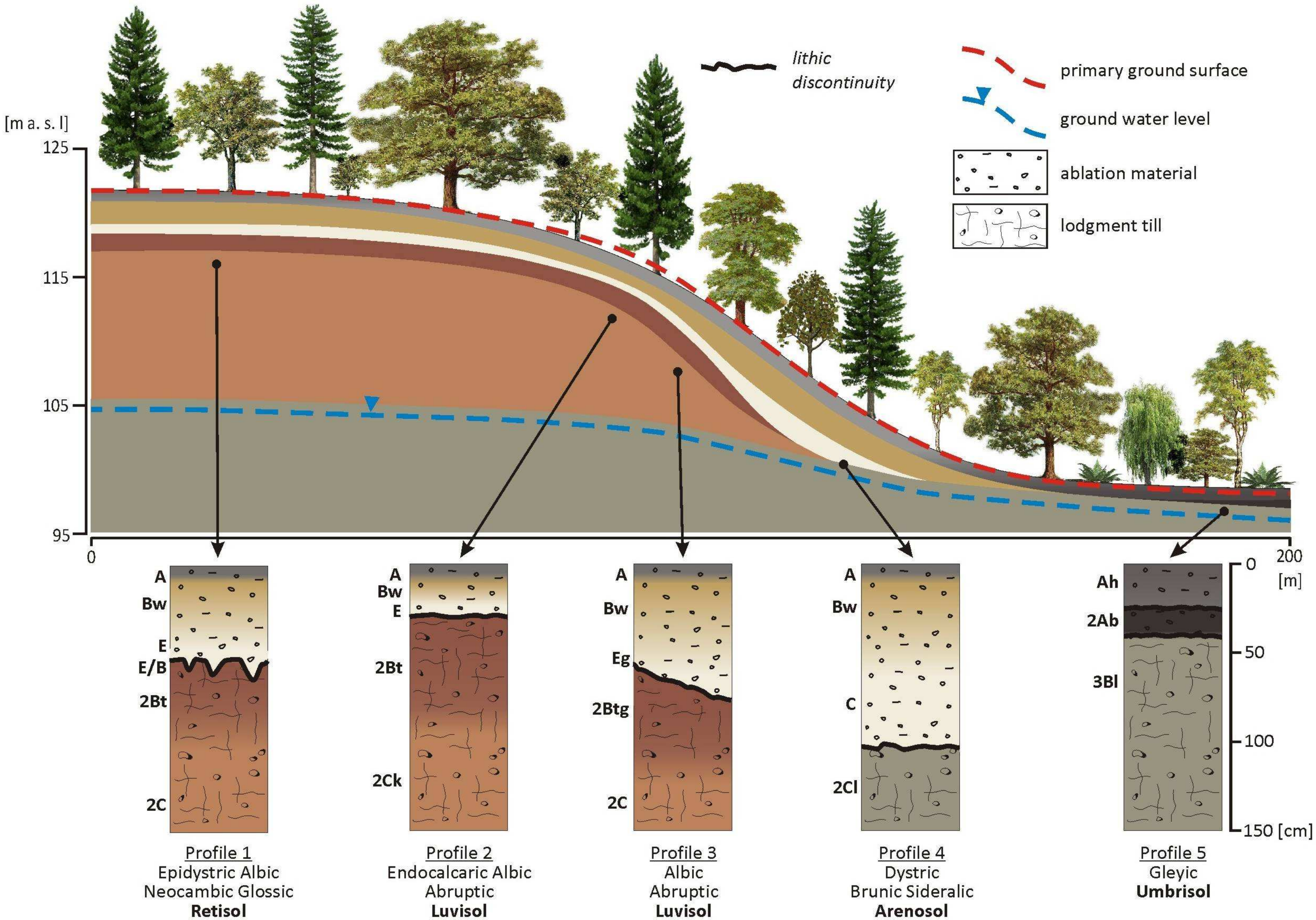


Fig. 2. Hydro-toposequence of soils within forested areas of hummocky moraine plateau

Soil genesis and systematic position

A characteristic feature of most of the soils in the studied area is a clear textural differentiation (all pedons) with the surface clay-depleted E horizons and with pedogenic accumulation of fraction <0.002 mm in the subsurface Bt horizon (Profiles 1–3, Table 1, 4, 7). The soils with a clay-enriched subsoil cover flat areas of vast summits and almost all parts of slopes. The presence of clay films on the surface of soil aggregates confirms the illuvial nature of Bt horizons. Abundant illuvial clay coatings and infillings were easily visible already at the stage of field work. This was also verified by micromorphological examination – oriented clay bodies represent more than 5% of the thin sections (Świtoniak, 2014). Illuvial genesis of *argic* Bt was expressed by the ***Cutanic*** supplementary qualifier. The prevalence of the *lessivage* process in young morainic deposits has already been described by several researchers (Dąbkowska-Naskręt and Jaworska, 1994a, b; Frielinghaus and Vahrson, 1998; Kühn, 2003; Marcinek and Komisarek, 2004; Kobierski, 2013; Podlasiński, 2013). Humid climate and mild average air temperatures of the investigated region favour the downward transport of clay particles (Quénard et al., 2011). The mean annual effective rainfall (precipitation minus evapotranspiration) is approximately 300 mm (Merot et al., 2003), which positively influences the development of clay eluviation (Arkley, 1967). Unconsolidated glacial deposits are highly suitable for the vertical flux of water (Quénard et al., 2011; Cornu et al., 2014). The majority of investigated soils with a clay-enriched subsoil were classified as **Luvisols** (Profile 2 and 3). Only one profile (No. 1) has the interfingering of the *albic* material into the *argic* horizon and was classified as **Retisol** (IUSS Working Group WRB, 2014). The basis for distinction of **Luvisol** RSG (in addition to the presence of the Bt horizon) were: (i) high base status – base saturation is more than 50% in the major part, between 50 and 100 cm and (ii) high activity of the clay fraction − the CEC values in Bt horizons are higher than 30 $cmol_c \cdot kg^{-1}$ of clay. In Profile 4 sandy cover primarily contained a low amount of clay fraction and the features characteristic for clay illuviation were not present. The vertical texture contrasted pedon (No. 4) without *argic* horizon was classified as **Arenosol**.

The subsequent effect of the eluviation process is the eluvial zone present above the Bt horizons from which the clay fraction has been partially removed (Profile 1–3). In the upper part of this eluvial zone, pedogenic accumulation of oxidized iron compounds is clearly visible by their brownish colorization. Because this part of the profile has a texture of loamy, very fine sand and shows evidence of alterations relative to the underlying E horizons, it was defined as the *cambic* horizon. In Profile 2 Bw material does not meet the criterion of *cambic* minimal thickness (15 cm). The newly added ***Neocambic*** qualifier makes it possible to emphasise the importance of this process for soils belonging to **Retisol** RSG. The qualifier ***Neoambic*** was added last as supplementary in Profile 3 because it is not included on the list of qualifiers assigned to the Luvisols. In Profile 4 presence of Bw horizon allowed to use ***Brunic*** qualifier. It is not designed as *cambic* because it has fine sand texture. The amount of uncoated silt and sand grains increases with depth, which is observed in the form of a light-coloured, subsurface zone. In three cases (Profile 1–3), there is a bleached eluvial horizon present with *albic* material characterized by a complete lack of iron coatings.

The criterion of a vertical increase in the clay content was not regarded as critical to distinguish Bt horizons due to the presence of *lithic discontinuity* in the above-mentioned profiles. All investigated profiles are developed from lodgement tills covered by ablation materials with sandy loam or loamy sand texture. In described **Luvisols** and **Retisol**, the primary, geological vertical texture contrast was only increased by the *lessivage* process. The presence of *lithic discontinuity* was identified by (i) an abrupt change in the particle-size distribution which may not only be caused by lessivage, (ii) a clear or abrupt boundary between ablation materials and lodgement tills, (iii) the occurrence of rounded pebbles in sandy ablation material, while the underlying lodgement till has angular rock fragments.

Differences in lithology occur within the upper 100 cm of all the described soils, which allowed the use of the ***Ruptic*** (Profile 1–3) supplementary qualifier. In Profile 4 and 5 these differnces are associated with *abrupt textural difference* that are not influenced by lessivage (***Geoabruptic***). Another frequently used qualifier ***Abruptic*,** reflects an abrupt textural change (a twofold increase in the clay content within 7.5 cm) caused by litho- and pedogenesis. Lodgement tills, which are the parent materials of **Luvisols** and **Retisol,** represent mostly sandy loam or loam textural classes. In one case (Profile 2), concentrations of secondary carbonates (Table 5) occur in the form of soft nodules (principal qualifier ***Endocalcic***). Parent material in another Luvisol is decalcified. The coarse texture of the ablation layer (A, E and Bw horizons) results from a primarily low amount of clay fraction compounded by eluvial depletion. This feature was expressed in the examined Luvisols (Profile 2, 3) by adding the ***Epiarenic*** supplementary qualifier. The exception among soils with the *argic* horizon is Profile 1 – **Retisol** with sandy loam texture in the upper part of the solum (Table 1). On the other hand, sandy cover primarily contained very low amount of clay fraction which prevented the development of *argic* horizon in Profile 4. The reason for this is a natural heterogeneity of ablation sediments. The low base saturation in the upper part of pedons is caused by the leaching process of basic compounds superimposed on the primarily acidic ablation cover. In all types of soils with (Profile 1 and 4), the extremely low base saturation meets the requirements of the ***Epidystric*** or ***Dystric*** qualifier.

Luvisol and Arenosol covering the middle slope position (Profile 3 and 4) have some properties of *reducing* conditions. In Profile 3, few reductimorphic mottles occur in the contact zone between E and Bt horizons. These mottles can be associated with periodic water stagnation on the poorly permeable *argic* horizon. Reductimorphic features, however, were too poorly expressed to use ***Stagnic*** qualifier. Pedon 4 has a faintly expressed gleyic colour pattern which in turn may result from seasonal saturation with groundwater (***Bathygleyic***). This soil is in fact close to the bottom part of the depression.

To express that Profile 2, 3 and 4 were located on the slope with an high inclination, the ***Inclinic*** supplementary qualifier was added.

The bottom part of the depression (Profile 5) is covered by soil, the properties of which evolved in the conditions of a strong influence by ground water. Soil material is saturated with water which obstruct the downward percolation and the eluviation process. High moisture leads to a slow decomposition of organic matter and accumulation of a significant amount of humus (Table 14) in the Ah and Ab horizon. A slightly lower content of humus in the uppermost (Ah) horizon (compared with the Ab horizon) can be associated with a supply of the less humus colluvial material from the higher parts of soils. In view of a high content of organic matter (OC > 28,3 $g{\cdot}kg^{-1}$), dark colour, well developed soil structure, significant thickness and low base saturation, the humus horizon has been classified as *umbric*. Because no other diagnostic horizons were present, the soil was classified as **Umbrisols**. The described soil has strong *reducing conditions* and *gleyic* properties below 35 cm from the surface (***Gleyic*** principal qualifier) and is exceptionally rich in organic carbon. Horizon B, in addition to reducing colours caused by ascending groundwater (l), includes illuvial concentrations of humus on aggregates surfaces. High base saturation (>50%) of this horizon is indicated by the ***Endoeutric*** qualifier. The presented **Umbrisol** is derived from the shallow ablation material covering the glacial till. Two *lithic discontinuities* occur in this pedon. The first one lies between the surface humus horizon enriched with the colluvial material and the Ab horizon. The second one is more clearly visible at a depth of 35 cm as an abrupt change in the particle-size distribution (Table 13). The qualifier ***Abruptic*** expresses textural differentiation caused by lithogenesis. ***Ruptic*** was not use because it is not on the list assigned to **Umbrisols**.

Soil sequence

All described pedons are characterized by a rather similar lithogenesis. They are developed from lodgement tills covered by ablation material. The main differences responsible for a different direction of the soil-forming processes are associated with the topography and the influence of ground water. The spatial arrangement of pedons represents a **litho-hydro-toposequence**. Flat surfaces of summits and slopes are covered by well developed vertical textural contrasted **Luvisols, Retisols** or **Arenosols**. Furthermore, in the middle parts of the slopes, these soils very often undergo a weakly expressed gleying process associated with both stagnation of rainwater in horizons Bt, and a capillary rise of ground waters. The soils found in the bottom of depressions are strongly influenced by ground water (***Gleyic* Umbrisol**). The described forest area is characterized by a minimal influence of erosion processes on the soil cover. The colluvium accumulated in the bottom part of the depression has a minimal thickness. Soils located on slopes have a fully developed sequence of genetic horizons (A-Bw-E-2Bt-2C or A-Bw-C-2C). The soil with such a morphology has already been described in young glacial regions of Germany (Kühn, 2003) and Poland (Świtoniak, 2008; Podlasiński, 2013). The only sign of truncation is a distinctly smaller thickness of the ablation layer in Profile 2 located in the upper, convex part of the slope. The rate of denudation is slow because the soil contains all genetic horizons (Świtoniak, 2014). Mixed forests covering soils within the studied area, almost completely prevent the accelerated erosion even on slopes of 10–15°. Similar conclusions about the protective role of dense vegetation were reached in the United Kingdom (Fullen, 1998), Lithuania (Jankauskas and Fullen, 2002), the Lublin Upland (Zgłobicki, 2013) or other Lake Districts in North-Eastern Poland (Smolska, 2002).

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Agricultural areas within hummocky moraine plateaus of Poland (Brodnica Lake District)

Marcin Świtoniak, Przemysław Charzyński, Łukasz Mendyk

The young morainic area of North Poland is part of the North European Plain and lies within the maximum extend of the Vistulian Glaciation (Fig. 1) defined as the Leszno Phase in western Poland and as the Poznań Phase in central and eastern part of the country (Marks, 2012). The Brodnica Lake District represents typical young glacial landscapes and is located between the limits of the two major Vistulian glacial phases: Poznań and Pomeranian Phase. The general outline of the relief was formed during the late glacial period, ca. 16–17 ka CE (Niewiarowski, 1986; Niewiarowski and Wysota, 1986). The Brodnica moraine plateau is cut by longitudinally extending subglacial channels filled by numerous lakes and two sandy outwash plains (West and East Brodnica; Niewiarowski, 1986).

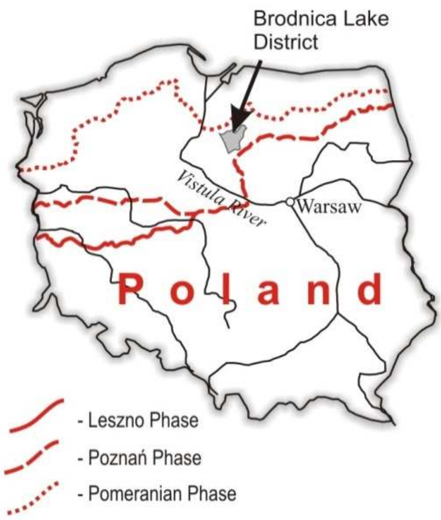


Fig. 1. Location

Lithology and topography

The presented soils were located in the south-eastern part of the Brodnica Lake District within a typical hummocky moraine plateau. The differences in terrain altitudes are associated with numerous kettles, irregular and elongate or roundish in shape. Among the surface sediments, ablation sands dominate, with a thickness of tens of centimetres on glacial till. Slopes with an inclination > 10° represent about 20% of the total surface. The maximum inclinations of slopes reach about 30°. The denivelations are relatively high and in many places range up to 20 m.

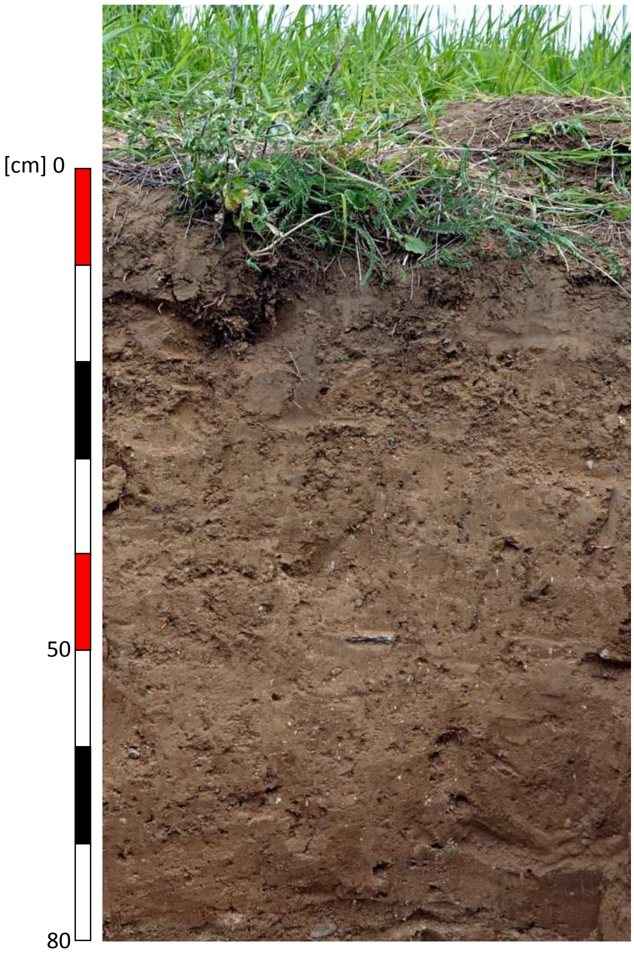
Land use

Agriculture is the main way of land use within the investigated hummocky moraine plateaus. The time of the earliest cultivation is still unknown. The oldest Neolithic sites were found only in the south-western part of the morainic Brodnica Plateau near Sumowo Lake. This archaeological sites are related to the origin of the late Linear Pottery culture, 4800–4700 BCE (Kukawka et al., 2002). The agricultural land has the largest range in the first half of the 20th century. After the Second World War, the steepest slopes were reforestated and converted into recreational areas or fallows (grass vegetation).

Climate

According to Köppen–Geiger Climate Classification, the region is located in the warm temperate, fully humid with a warm summer zone (Kottek et al., 2006). The average annual air temperature is about 7°C. The warmest month is July (17,6°C). The mean air temperature during January (the coldest winter month) is about -4°C. The average annual precipitation is 552 mm. July is the wettest month with average precipitation of ca. 90 mm (Wójcik and Marciniak, 1987a, b, 1993).

Profile 1 – Pantoeutric Calcaric **Regosol** (Loamic, Protocalcic, Aric, Inclinic)
Localization: hummocky morainic plateau, summit, 14°, boundary between arable field and fallow, 109,5 m a.s.l., N 53° 20'25", E 19°26'35"



Morphology:

ACkp – 0–20 cm, plough humus horizon, sandy loam, dark brown (10YR 5/3; 10YR 3/3), dry, moderate blocky/angular medium structure, very fine or fine roots, few carbonates, clear/abrupt smooth boundary;

Ck – 20–80 cm, parent material with *protocalcic properties*, sandy loam, dark yellowish brown (10YR 5/4; 10YR 3/4), dry, strong blocky coarse structure, very fine and very few roots, common fine rounded soft concretions and pseudomycelium of secondary carbonates.

Table 1. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
ACkp	0–20	6	3	4	10	17	27	18	5	6	10	SL
Ckp	20–(80)	8	1	5	12	19	25	15	7	4	12	SL

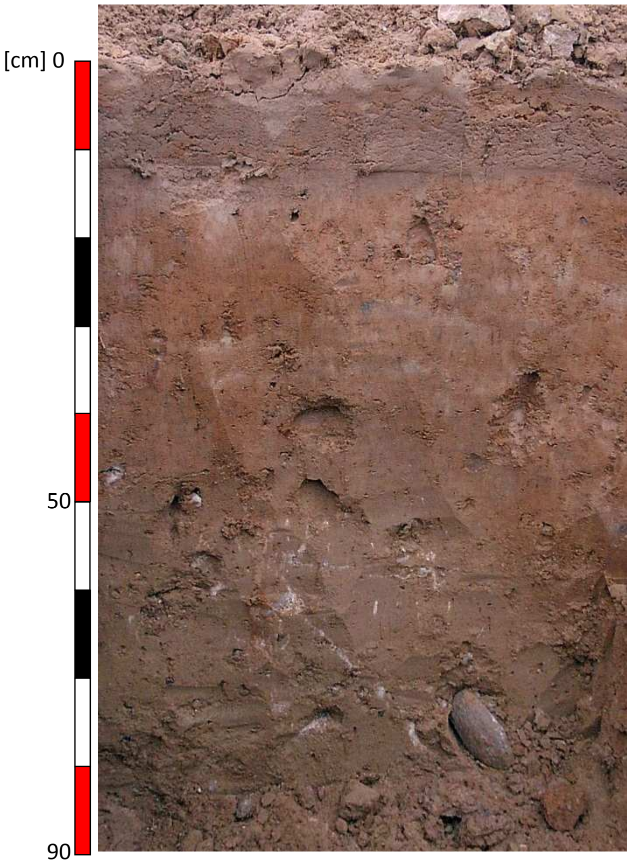
Table 2. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	C/N	pH		$CaCO_3$ [g·kg^{-1}]
					H_2O	KCl	
ACkp	0–20	6.4	0.81	8	7.1	5.4	34.0
Ckp	20–(80)	-	-	-	7.5	6.1	82.0

Table 3. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	CEC_{clay}	BS [%]
		[cmol(+)·kg^{-1}]								
ACkp	0–20	12.4	0.833	0.438	0.210	13.9	1.28	15.2	129.6	92
Ckp	20–(80)	20.5	1.820	0.592	0.253	23.2	-	23.2	193.3	100

Profile 2 – Endocalcaric Nudiargic **Luvisol** (Loamic, Cutanic, Hypereutric, Ochric, Inclinic);
Localization: hummocky morainic plateau, summit of hill/upper slope, 11°, arable field, 109 m a.s.l.
N 53°20’25”, **E** 19°26’35”



Morphology:

ABp – 0–15 cm, humus and *argic* plough horizon, sandy loam, dark yellowish brown (10YR 6/5; 10YR 4/5), dry, moderate blocky/angular medium structure, fine very few roots, pockets of Bt material, abrupt and smooth boundary;

Bt – 15–45 cm, *argic* horizon, sandy loam, dark yellowish brown (10YR 6/6; 10YR 4/6), slightly moist, strong subangular coarse structure, very fine and very few roots, gradual and wavy boundary;

Ck – 45–(90) cm, *calcaric* parent material, loamy sand, dark yellowish brown (10YR 6/4; 10YR 4/4), dry, moderate angular coarse structure, common fine rounded soft concretions and pseudomycelium of secondary carbonates.

Table 4. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
ABp	0–15	2	2	4	15	33	19	8	4	4	11	SL
Bt	15–45	2	2	5	16	31	16	9	3	4	14	SL
Ck	45–(90)	11	4	11	22	29	12	5	8	2	7	LS

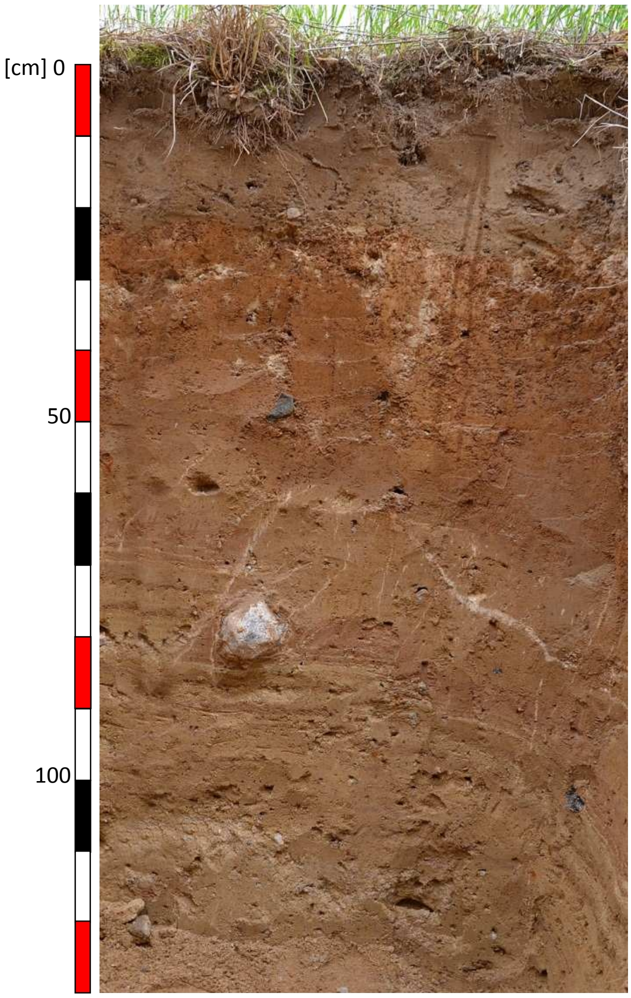
Table 5. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	N_t [$g \cdot kg^{-1}$]	C/N	pH		$CaCO_3$ [$g \cdot kg^{-1}$]
					H_2O	KCl	
ABp	0–15	3.5	0.38	9	6.1	4.7	-
Bt	15–45	1.3	0.18	7	6.8	5.0	1
Ck	45–(90)	-	-	-	8.7	8.0	61

Table 6. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	CEC_{clay}	BS [%]
		[$cmol(+) \cdot kg^{-1}$]								
ABp	0–15	3.45	0.035	0.083	0.044	3.61	3.58	7.19	54.2	50
Bt	15–45	8.32	0.717	0.323	0.195	9.56	0.00	9.55	65.0	100
Ck	45–(90)	19.8	1.783	0.513	0.229	22.3	0.00	22.3	319	100

Profile 3 – Endocalcaric Abruptic **Luvisol** (Cutanic, Hypereutric, Ochric, Ruptic, Aric, Inclinic);
Localization: hummocky morainic plateau, middle slope (back slope) 7°, fallow land, 105 m a.s.l.
N 53°20’30”, **E** 19°26’27”



Morphology:

Ap – 0–20 cm, plough humus horizon, loamy fine sand, brown (10YR 5/2; 10YR 4/3), dry, moderate granular medium structure, fine and medium common roots, abrupt and smooth boundary;

2Bt – 20–60 cm, sandy loam, strong brown (7.5YR 6/6; 7.5YR 4/6), slightly moist, strong angular coarse structure, common faint clay coatings, very fine and very few roots, few rocks, clear and wavy boundary;

2Ck – 60–(150) cm, *calcaric* parent material with, loamy fine sand, dark yellowish brown (10YR 5/6; 10YR 4/5), dry, weak subangular fine structure, common rocks, common fine rounded soft concretions and pseudomycelium of secondary carbonates.

Table 7. Texture

Horizon	Depth [cm]	Percentage of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
Ap	0–20	2	5	7	13	27	26	7	3	5	7	LFS
2Bt	20–60	4	2	8	17	28	12	4	3	7	19	SL
2Ck	60–(150)	9	5	7	20	32	12	8	7	4	5	LFS

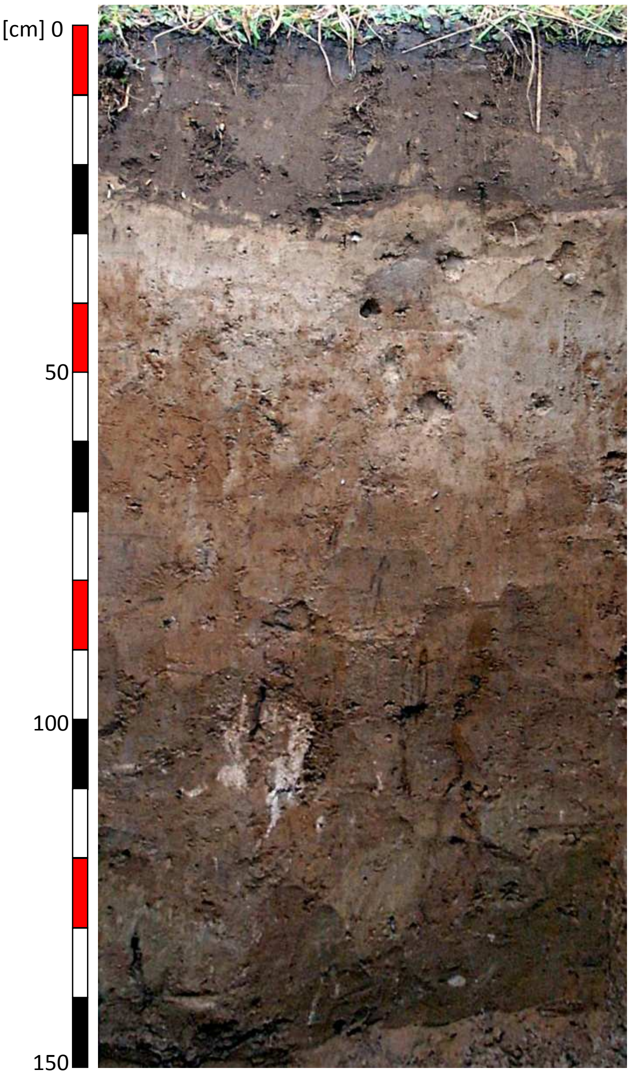
Table 8. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	C/N	pH		$CaCO_3$ [g·kg^{-1}]
					H_2O	KCl	
Ap	0–20	4.4	0.48	9	5.5	4.8	-
2Bt	20–60	1.6	0.23	7	7.1	6.4	2
2Ck	60–(150)	-	-	-	8.6	7.8	78

Table 9. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	CEC_{clay}	BS [%]
		[cmol(+)·kg^{-1}]								
Ap	0–20	2.09	0.059	0.157	0.051	2.36	2.07	4.43	41.3	53
2Bt	20–60	10.2	0.872	0.306	0.122	11.5	-	11.5	57.6	100
2Ck	60–(150)	20.1	1.854	0.355	0.269	22.6	-	22.6	452.0	100

Profile 4 – Endocalcaric Abruptic **Luvisol** (Epiarenic, Endoloamic, Cutanic, Epidystric, Ruptic, Aric, Inclinic)
Localization: hummocky morainic plateau, middle slope 5°, reforested recreational area, 94 m a.s.l.
N 53°20’42”, **E** 19°26’28”



Morphology:

Ap – 0–25 cm, plough humus horizon, loamy fine sand, dark brown (10YR 5/3; 10YR 3/3), slightly moist, moderate granular medium structure, fine and medium common roots, abrupt and smooth boundary;

E – 25–35 cm, eluvial horizon, loamy fine sand, yellowish brown (10YR 7/3; 10YR 5/4), slightly moist, weak subangular very fine structure, fine and few roots, clear and irregular boundary;

E/B – 35–55 cm, transitional horizon;

2Btk – 55–90 *argic* horizon, strong brown (10YR 5/4; 7.5YR 4/6), slightly moist, sandy loam, strong angular coarse structure, common faint clay coatings, very few and fine rounded soft concretions of secondary carbonates, gradual and smooth boundary;

2BCgk – 90–(150) cm, parent material with few faint clay coatings, sandy loam, strong brown (10YR 5.5/4; 7.5YR 4/6), moist, strong angular coarse structure; common medium reductimorphic mottles; common soft concretions and pseudomycelium of secondary carbonates.

Table 10. Texture

Horizon	Depth [cm]	Percentage of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
Ap	0–25	2	2	5	19	39	21	6	6	0	3	LFS
E	25–35	2	2	6	20	34	17	6	7	2	6	LFS
E/B	35–55	3	1	5	17	31	16	8	5	4	14	SL
2Btk	55–90	2	3	5	16	27	13	7	9	2	18	SL
2BCgk	90–(150)	3	2	6	18	29	19	8	5	3	10	SL

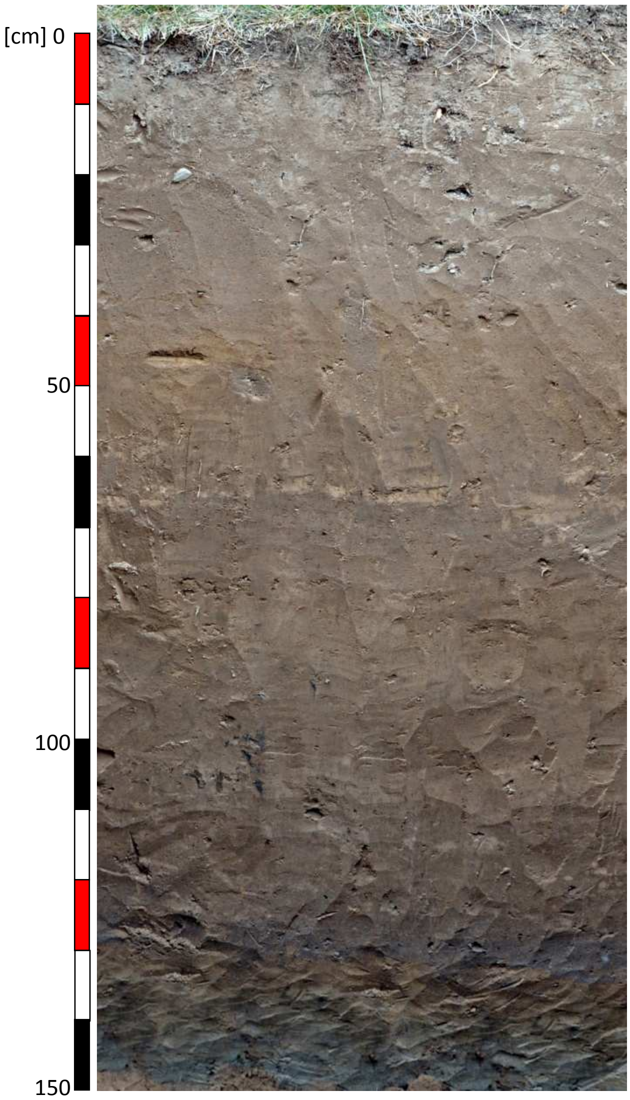
Table 11. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	C/N	pH		$CaCO_3$ [g·kg^{-1}]
					H_2O	KCl	
Ap	0–25	6.1	0.61	10	5.3	4.4	-
E	25–35	0.9	0.11	8	6.7	5.8	-
E/B	35–55	1.1	0.21	5	6.9	6.1	1
2Btk	55–90	1.4	0.35	4	7.7	6.7	1
2BCgk	90–(150)	-	-	-	8.5	7.8	30

Table 12. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	CEC_{clay}	BS [%]
		[cmol(+)·kg^{-1}]								
Ap	0–25	1.38	0.026	0.094	0.035	1.54	3.02	4.55	97	34
E	25–35	0.490	0.137	0.077	0.031	0.735	0.980	1.72	23.0	43
E/B	35–55	6.17	0.519	0.271	0.103	7.06	0.00	7.06	47.7	100
2Btk	55–90	10.3	0.810	0.247	0.147	11.5	0.00	11.5	60.5	100
2BCgk	90–(150)	15.9	0.489	0.234	0.152	16.8	0.00	16.8	171	100

Profile 5 – Dystric Sideralic **Arenosol** (Colluvic, Ochric)
Localization: hummocky morainic plateau, toe slope 4°, reforested recreational area, 90 m a.s.l.
N 53°20’24”, **E** 19°26’28”



Morphology:

A1 – 0–40 cm, colluvic material, humus horizon, loamy fine sand, grayish brown (10YR 6/2; 10YR 5/2), very dry, weak subangular very fine structure, fine and common roots, clear and smooth boundary;

A2 – 40–65 cm, colluvic material, humus horizon, loamy fine sand, brown (10YR 6/2; 10YR 5/3), dry, weak subangular very fine structure, very fine and very few roots, clear and smooth boundary;

A3 – 65–125 cm, colluvic material, humus horizon, loamy fine sand, grayish brown (10YR 6/2; 10YR 5/2), dry, weak subangular very fine structure, few charcoals, very fine and very few roots, clear and smooth boundary;

2Ab – 125–130 cm, buried humus horizon, loamy fine sand, dark gray (10YR 6/1; 10YR 4/1), slightly moist, weak subangular very fine structure, clear and smooth boundary;

2Bw – 130–140 cm, pedogenetic *in situ* accumulation of sesquioxides, loamy fine sand, brownish yellow (10YR 7/4; 10YR 6/6), slightly moist, weak subangular very fine structure, gradual and smooth boundary;

2Cl – 140–(150) cm, parent material, sand, greenish grey (GLEY 2 8/5BG; GLEY 2 6/5BG), moist, single grain structure, common medium reductimorphic mottles.

Table 13. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
A1	0–40	5	6	9	18	27	15	11	7	4	3	LFS
A2	40–65	3	5	8	25	30	17	6	4	3	2	LFS
A3	65–125	1	2	5	28	28	22	2	5	3	5	LFS
2Ab	125–130	3	5	12	16	29	14	5	10	6	3	LFS
2Bw	130–140	4	8	9	20	34	16	4	3	4	2	LFS
2Cl	140–(150)	7	4	7	16	30	31	6	2	3	1	FS

Table 14. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	C/N	pH		$CaCO_3$ [g·kg^{-1}]
					H_2O	KCl	
A1	0–40	5.2	0.36	14	5.1	4.5	-
A2	40–65	4.3	0.27	16	5.3	4.9	-
A3	65–125	4.8	0.29	17	5.3	4.8	-
2Ab	125–130	8.4	0.60	14	5.0	4.3	-
2Bw	130–140	-	-	-	5.9	5.2	-
2Cl	140–(150)	-	-	-	6.8	5.6	4

Table 15. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	CEC_{clay}	BS [%]
		[cmol(+)·kg^{-1}]								
A1	0–40	0.359	0.054	0.059	0.025	0.497	2.56	3.06	41.2	16
A2	40–65	0.397	0.067	0.050	0.034	0.548	2.03	2.58	53.7	21
A3	65–125	0.258	0.074	0.048	0.030	0.410	2.33	2.74	21.2	15
2Ab	125–130	0.327	0.085	0.051	0.028	0.491	3.94	4.43	49.7	11
2Bw	130–140	0.428	0.066	0.063	0.012	0.569	2.11	2.68	134	21
2Cl	140–(150)	0.894	0.085	0.072	0.043	1.094	1.78	2.87	287	38

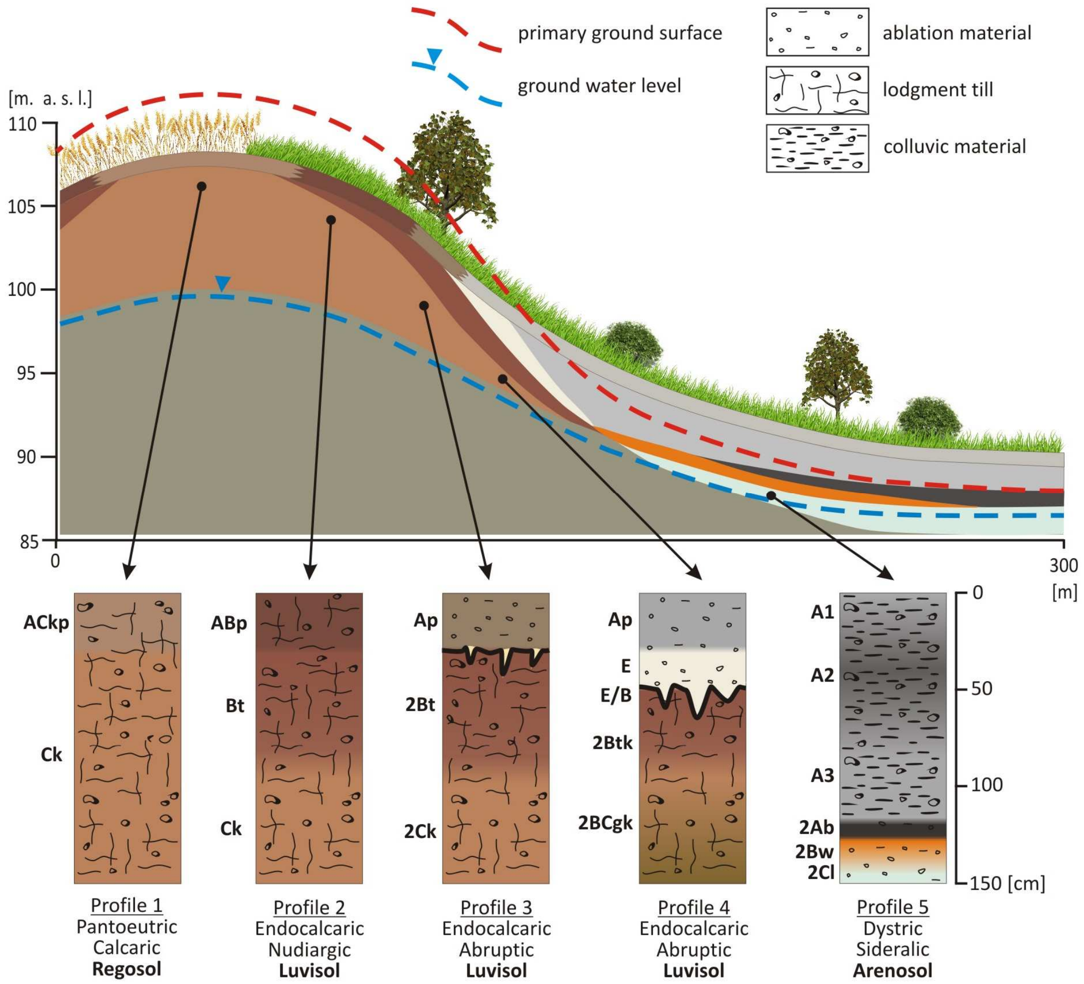


Fig. 2. Lithotoposequence of soils within agricultural areas of hummocky moraine plateau

Soil genesis and systematic position

Almost all of the investigated soils are developed on ground moraine deposits and they are morphologically very diverse. The summits of hills are covered by weakly developed pedons classified as **Regosols** (IUSS Working Group WRB, 2014). These soils are entirely built from glacial deposits slightly transformed by pedogenesis (Fig. 2., Profile 1). The texture in the entire soil profile is typical of bottom glacial sediments; these are mainly loams (Table 1). The solum of the discussed soils is limited to a poorly distinguished humus ploughing horizon ACkp. The colour of this horizon is similar to the colour of the parent material. This results from the low organic matter content (Table 2). Directly below the plough layer, there is *calcaric* parent material Ck. Total erosion of original soil horizons is evidenced by the presence of a significant quantity of calcium carbonates in most of the described pedons, even at their surface. Both materials from ACkp and Ck horizons effervescences strongly with 1 M HCl (contains more than 2% of calcium carbonates), which permits the use of the ***Calcaric*** supplementary qualifier. Extremely high base saturation, even in the surface horizon, was indicated by the ***Pantoeutric*** qualifier. Some carbonates produce formations of secondary accumulation – concretions, pseudomycelium, coatings on the soil aggregates (***Protocalcic*** qualifier). Forms of this type could have originated only in the parent material of primarily occurring, fully developed soils – probably **Luvisols**.

In the upper slope topographical positions, **Luvisols** dominate with the sequence ABp-Bt-Ck. Lack of eluvial horizons resulted from the partial truncation of these soils. Morphologically, they are very similar to **Cambisols**. The previous studies carried out within the Brodnica Lake District (Świtoniak et al., 2013, Świtoniak, 2014) confirmed the illuvial nature of B horizons. The occurrence of eroded **Luvisols,** morphologically similar to **Cambisols,** was also described by Józefaciuk et al. (1996), Sinkiewicz (1998) Phillips et al. (1999) or Marcinek and Komisarek (2004). Ploughing humus horizons ABtp of the described pedons contain mainly material forming original illuvial *argic* horizons and due to erosion, have a low content of organic carbon (***Ochric*** qualifier) (Table 5). The exposure on the surface Bt horizon was expressed by the ***Nudiargic*** qualifier. The presence of common fine rounded soft concretions and pseudomycelium of secondary carbonates was noted by the ***Endocalcaric*** qualifier. High base saturation in the whole soil, as in the case of the first profile, allows the use of the ***Hypereutric*** supplementary qualifier.

Profile 3 represents moderately eroded **Luvisol** (Świtoniak, 2014) with Ap horizons directly overlaying 2Bt horizons. The *lithic discontinuity* (***Ruptic***) and the related *abrupt textural difference* occurs at a depth of 20 cm (***Abruptic***) and contemporaneously delimits the lower boundary of Ap horizons. Surface humus horizons contain ablation sandy material (loamy sand – Table 7) from the primarily eluvial E horizon, which were completely mixed by ploughing with the Ap horizon. Residues of the eluvial horizon are also visible in the form of bleached and sandy tongues in the upper part of the 2Bt horizon. Clay coatings occur already at a depth of 20 cm (***Cutanic***), which is yet another sign of soil truncation. The concentrations of secondary carbonates (2Ck – calcaric material) occur from 60 cm below the soil surface (***Endocalcaric*** qualifier).

The middle slopes are covered with slightly eroded **Luvisols** (Profile 4). The dominant feature is a clear textural differentiation (***Abruptic***) with the surface clay-depleted horizons and with pedogenic accumulation of clay fraction in the subsurface Bt *argic* horizon in the form of clay coatings (***Cutanic***). The *abrupt textural difference* is inherited mainly from the parent material (ablation sandy cover on lodgement till) and was only reinforced by the eluviation-illuviation (lessivage) process (Świtoniak, 2008). The presence of *lithic discontinuity* was expressed by the ***Ruptic*** qualifier. **Luvisols** occupying the middle slope position have some properties of *reducing conditions*. Reductimorphic mottles occur in the lower section of the profile and can be associated with periodic water stagnation on poorly permeable loams.

The ***Inclinic*** qualifier was used in Profiles 1–4 due to the location of pedons within the slope with an high inclination. The qualifier ***Aric*** was applied in soils ploughed to a depth of ≥ 20 cm (Profile 1, 3 and 4).

Strong erosion processes led to accumulation of thick colluvium on foot-slope and toe-slope positions (***Colluvic***). The sandy texture of slope deposits, the low amount of organic carbon and lack of well-developed soil horizons allows only classification of the soil as **Arenosol**. The texture of slope sediments is similar to the granulometric composition of eluvial material in Luvisols occurring in the higher parts of the slopes. Therefore, the pre-existing E-horizons of nowadays eroded Luvisols can be regarded as the source of colluvium. Very low base saturation (less than 20% almost throughout the whole profile) was indicated by the ***Dystric*** and ***Sideralic*** qualifiers.

Soil sequence

The accelerated erosion triggered by agricultural activities have significantly affected the structure of soil cover and soil profile morphology in the described area. All investigated profiles showed strong transformations connected with slope processes. The development stage and the properties of particular pedons are strongly associated with the topographic position. The presented profiles form a kind of soil **lithotoposequence**. The most intensive erosion zone occurs on the upper, convex parts of slopes and within the tops of hills. The soil degradation led to complete (**Regosol** – Profile 1) or strong truncation (**Luvisol** – Profile 2) of primarily well-developed pedons. **Luvisols** with a well-preserved sequence of genetic horizons occupy only the middle slope positions. Several classes of Luvisol truncation was defined in previous studies (Świtoniak, 2014). The widespread occurrence of highly eroded Luvisols within young morainic agricultural landscapes of Poland was recently pointed out by Podlasiński (2013) and Kobierski (2013). **Arenosols** developed from the colluvial deposits in the toe-slope position are also important evidence of the high intensity of soil erosion in the past. Sinkiewicz (1998) assumed that the rate of aggradation on the morainic depressions in the middle part of North Poland is about 2–2.5 mm yr^{-1} during the last 150–300 years. The contemporary rate of slope processes is significantly lower. The steepest slopes within arable lands were reforested and converted into recreational areas or fallows (grass vegetation).

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Catchments of disappearing lakes in glacial meltwater landscapes (Brodnica Lake District)

Łukasz Mendyk, Maciej Markiewicz, Marcin Świtoniak

The young morainic area of North Poland is part of the North European Plain and lies within the maximum range of the Vistulian Glaciation (Fig. 1) defined as the Leszno Phase in western Poland and the Poznań Phase in the central and eastern part of the country (Marks, 2012). The Brodnica Lake District represents typical young glacial landscapes and is located between the limits of the two major Vistulian glacial phases: Poznań and Pomeranian Phases. The general outline of the relief was formed during the late glacial period ca. 16–17 ka CE (Niewiarowski, 1986; Niewiarowski and Wysota, 1986). The land relief of the Brodnica Lake District is very diverse. It comprises forms related to: the glacial accumulation − ground moraines, the effect of the glacial melt waters – esker and areal deglaciation, and melting of dead ice blocks, such as kame hills as well as vast kettle holes (Niewiarowski, 1995).

Fig. 1. Location

Lithology and topography

The presented soil sequence is located in the western part of the Brodnica Lake District within the southern part of the former Sumowskie Lake bottom (86 m a.s.l.) in a vast kettle hole and an adjacent kame plateau (about 92 m a.s.l.). Organic materials, such as gyttja, dominate among the surface sediments of the former lake bottom. Melt water deposits of the kame plateau are represented by sands and loams. The denivelations are relatively high and in many places range up to 20 m.

Land use and vegetation

The direct surroundings of Sumowskie Lakes are mainly covered by natural vegetation like a mosaic of rush communities (*Phragmitetum australis)* and willow shrubs (*Salicetum pentandro-cinereae*). The largest part of the former lake bottom is used as meadows (*Arrhenatheretum elatioris* and *Lolio-Cynosuretum).* The kame hills are occupied by communities typical of field cultivation (*Lamio-Veronicetum* and *Vicietum tetrasperme*).

Climate

According to Köppen–Geiger Climate Classification, the region is located in the warm temperate, fully humid zone with warm summer (Kottek et al., 2006). The average annual air temperature is about 7°C. The warmest month is July (17.6°C). The mean air temperature during January (the coldest winter month) is about -4°C. The average annual precipitation is 552 mm. July is the wettest month with average precipitation around 90 mm (Wójcik and Marciniak, 1987a, b, 1993).

Profile 1 – Endocalcaric Histic **Gleysol** (Epiarenic, Bathyloamic, Drainic, Hyperhumic, Endolimnic, Nechic, Novic)

Localization: former lake bottom, flat terrain, meadow, 86 m a.s.l.; **N** 53°20'14", **E** 19°17'04"

Morphology:

Ah – 0–40 cm, highly decomposed organic material mixed with sand, humus horizon, sand, black (10YR 2/1; 10YR 2/1), moist, moderate granular fine structure, fine common roots, diffuse and smooth boundary;

Ha – 40–60 cm, *histic* horizon, highly decomposed organic material, black (10YR 2/2; 10YR 2/2, wet, weak granular fine structure, fine common roots, clear and smooth boundary;

Lm – 60–120 cm, *limnic material*, dark gray (10YR 5/1; 10YR 4/1), very wet, layered structure, fine few roots, diffuse and smooth boundary;

C – 120–(140) cm, loam, dark gray (5Y 6/1; 5Y 4/1), very wet, massive structure.

Comments: due to high ground water level (45 cm) material from C horizon was taken from drill.

Table 1. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
Ah	0–40	1	3	7	26	31	21	6	3	1	2	S
C	120–(140)	5	3	3	7	20	15	12	11	9	20	L

Table 2. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g\cdot kg^{-1}$]	N_t [$g\cdot kg^{-1}$]	C/N	pH		$CaCO_3$ [$g\cdot kg^{-1}$]
					H_2O	KCl	
Ah	0–40	96.6	5.62	17	6.3	6.1	-
Ha	40–60	423	26.8	16	6.0	5.7	-
Lm	60–120	144	10.2	14	8.0	7.8	490
C	120–(140)	6.59	0.44	15	7.8	7.3	125

Table 3. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	CEC_{clay}	BS [%]
		[$cmol(+)\cdot kg^{-1}$]								
Ah	0–40	32.0	1.34	0.064	0.049	33.4	5.24	38.6	239	86
Ha	40–60	127	6.26	0.338	0.198	134	52.4	187	-	72
Lm	60–120	66.0	2.08	0.396	0.260	68.8	1.62	70.4	-	98
C	120–(140)	20.9	0.391	0.534	0.106	21.9	0.50	22.4	101	98

Profile 2 – Calcaric Histic **Gleysol** (Loamic, Drainic, Hyperhumic, Limnic)
Localization: former lake bottom, flat terrain, meadow, 86 m a.s.l.; **N** 53°20’14”, **E** 19°17’04”

Morphology:

Ha – 0–30 cm, *histic* horizon, highly decomposed organic material, black (10YR 2/1; 10YR 2/1), moist, weak granular fine structure, fine common roots, clear and wavy boundary;

L – 30–100 cm, *limnic material,* silt loam, dark greyish brown (2.5Y 5/2; 2.5Y 4/2), very wet, layered structure, fine few roots, clear and smooth boundary;

C1 – 100–120 cm, sand, very wet, single grain structure, clear and smooth boundary

C2 – 120–(140) cm, silty clay loam, dark grey (2.5Y 6/1; 2.5YR 4/1), very wet, massive structure.

Comments: due to high ground water level (40 cm) material from C1 and C2 horizons was taken from drill.

Table 4. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
L	30–100	0	0	2	8	10	14	18	25	14	9	SiL
C2	120–(140)	2	1	1	2	2	7	12	21	16	38	SiCL

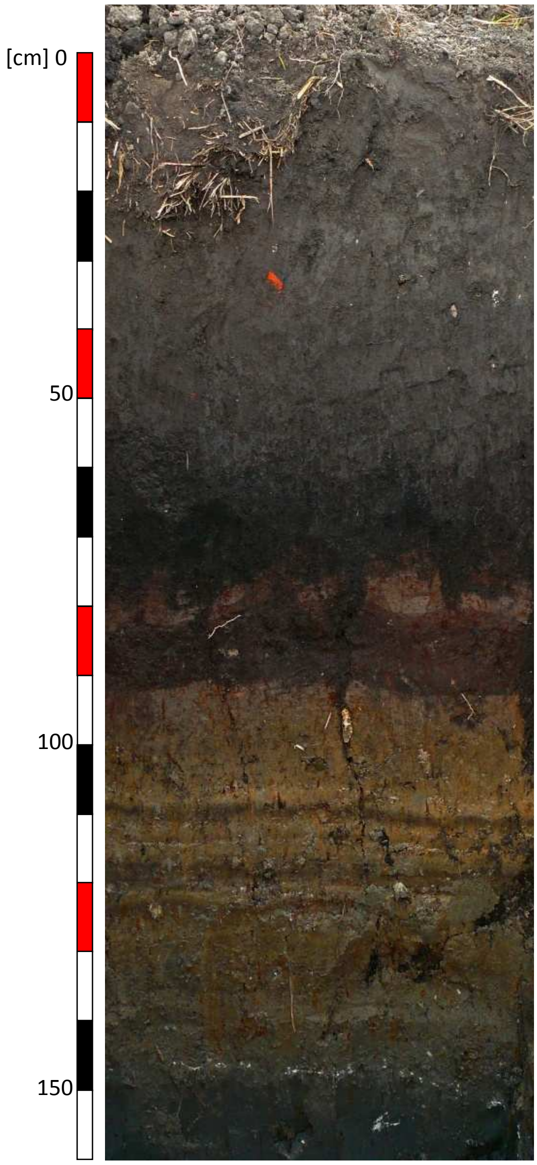
Table 5. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	C/N	pH		$CaCO_3$ [g·kg^{-1}]
					H_2O	KCl	
Ha	0–30	255	17.1	15	6.4	6.2	-
L	30–100	53.4	3.99	13	7.9	7.6	225
C2	120–(140)	13.3	0.91	15	7.8	7.3	164

Table 6. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	CEC_{clay}	BS [%]
		[cmol(+)·kg^{-1}]								
Ha	0–30	77.8	3.10	0.339	0.231	81.4	11.0	92.4	-	88
L	30–100	49.3	1.54	1.83	0.292	52.9	0.71	53.6	388	99
C2	120–(140)	42.5	0.903	1.35	0.177	44.9	-	-	-	-

Profile 3 – Epicalcaric Colluvic **Regosol** (Loamic, Aric, Humic, Greyic)
over Calcaric Histic **Gleysol** (Drainic, Hyperhumic, Limnic)
Localization: kame hill, foot slope, arable land, 87 m a.s.l.; **N** 53°20'13", **E** 19°17'02"



Morphology:

Ap1 – 0–30 cm, humus horizon, colluvic material, sandy loam, black (2.5Y 4/1; 2.5Y 2.5/1), slightly moist, moderate granular medium structure, few artefacts – brick pieces, clear and smooth boudary;

Ap2 – 30–60 cm, colluvic material, sandy loam, black (2.5Y 3/1; 2.5Y 2.5/1), slightly moist, moderate granular medium structure, few artefacts – brick pieces, diffuse and smooth boudary;

Hab – 60–75 cm, *histic* horizon, highly decomposed organic material, black (10YR 2/1; 10YR 2/1), moist, weak granular fine structure, fine common roots, clear and irregular boundary;

Lc1 – 75–80 cm, *limnic material*, very dark grayish brown (10YR 4/3; 10YR 3/2), moist, layered structure, fine and coarse few roots, common iron concretions, common cracks with material from Ha horizon, clear and wavy boundary;

Lc2 – 80–90 cm, *histic* horizon, *limnic material*, black (10YR 2/2; 10YR 2/1), moist, layered structure, fine very few roots, few cracks with material from Ha horizon, clear and wavy boundary;

Lm1 – 90–102 cm, *limnic material*, silt loam, olive brown (2.5Y 6/3; 2.5Y 4/3), moist, layered structure, fine very few roots, rusty roots channels, cracks with material from Ha horizon, clear and smooth boundary;

Lm2 – 102–125 cm, *limnic material*, silt loam, dark greyish brown (2.5Y 5/2; 2.5Y 4/2), wet, layered structure, common reductimorphic mottles, coarse very few roots, few cracks, clear and smooth boundary;

C1 – 125–140 cm, loamy sand, olive grey (5Y 6/2; 5Y 4/2), very wet, single grain structure, common reductimorphic mottles, occur few cracks, clear and smooth boundary;

C2 – 140–(160) cm, silty clay loam, very dark grey (5Y 5/1; 5Y 3/1), very wet, massive structure.

Table 7. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
Ap1	0–30	2	2	3	10	21	21	9	9	7	18	SL
Ap2	30–60	1	1	3	12	21	23	10	10	7	13	SL
Lm1	90–102	2	0	0	3	5	10	16	23	21	22	SiL
Lm2	102–125	0	0	3	7	5	12	17	24	17	15	SiL
C1	125–140	3	2	6	27	38	12	6	4	2	3	LS
C2	140–(160)	0	0	0	1	1	6	12	23	18	39	SiCL

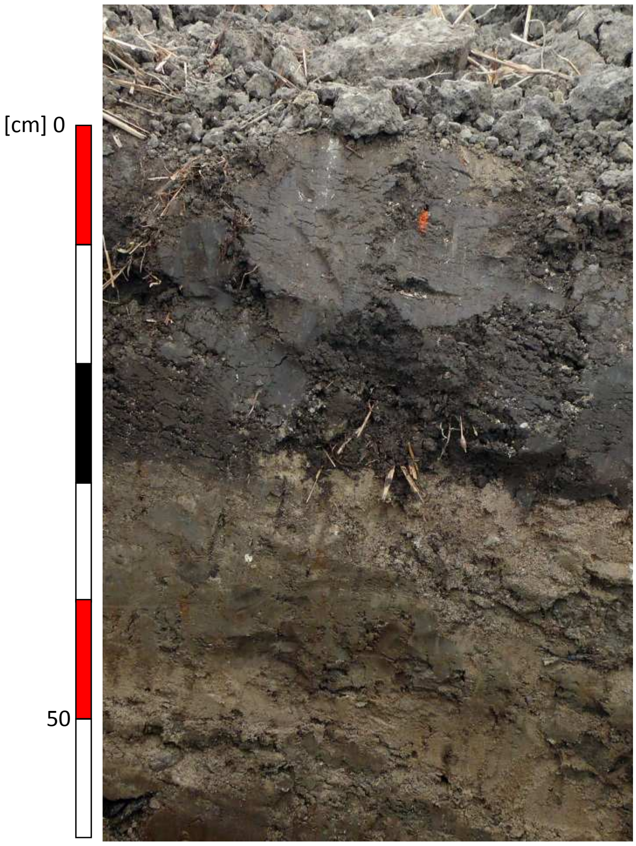
Table 8. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	C/N	pH		$CaCO_3$ [g·kg^{-1}]
					H_2O	KCl	
Ap1	0–30	34.4	2.85	12	7.5	7.0	164
Ap2	30–60	47.6	3.72	13	7.4	6.9	16
Hab	60–75	243	15.7	15	7.6	7.2	4
Lc1	75–80	347	21.5	16	7.5	7.0	3
Lc2	80–90	365	23.9	15	7.4	6.9	8
Lm1	90–102	51.7	3.58	14	8.6	7.4	241
Lm2	102–125	53.0	3.72	14	7.8	7.4	394
C1	125–140	13.6	0.87	16	8.0	7.8	131
C2	140–(160)	14.4	0.94	15	7.5	7.2	95

Table 9. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	CEC_{clay}	BS [%]
		[cmol(+)·kg^{-1}]								
Ap1	0–30	25.4	1.45	0.358	0.049	27.3	0.81	28.1	89.2	97
Ap2	30–60	33.6	1.82	0.178	0.057	35.6	1.52	37.1	157	96
Hab	60–75	122	5.32	0.089	0.090	127.2	14.4	142	-	90
Lc1	75–80	127	5.47	0.234	0.125	133.2	10.9	144	-	92
Lc2	80–90	134	0.061	0.171	0.182	134.1	14.5	149	-	90
Lm1	90–102	62.5	1.89	0.556	0.293	65.2	0.690	65.9	217	99
Lm2	102–125	57.9	1.71	0.612	0.283	60.5	0.671	61.2	284	99
C1	125–140	21.2	0.343	0.128	0.056	21.7	0.364	22.1	578	98
C2	140–(160)	33.9	0.879	2.00	0.228	37.0	0.739	37.7	83.7	98

Profile 4 – Calcaric Gleyic **Phaeozem** (Geoabruptic, Aric)
Localization: kame hill, middle slope, arable land, 87,5 m a.s.l.; **N** 53°20’12”, **E** 19°17’02”



Morphology:

Ap – 0–28 cm, *mollic* horizon, humus horizon, sandy loam, dark gray (5Y 4/1; 5Y 3/1), slightly moist, weak subangular medium structure, few artefacts – brick pieces, clear and smooth boundary;

Bl – 28–(60) cm, parent material, (I) loam and (II) sand insertions, (I) olive gray (5Y 6/2; 5Y 4/2) or (II) olive (5Y 6/1; 5Y 5/3), slightly moist, (I) weak subangular medium structure or (II) single grain structure, few iron concretions;

Table 10. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
Ap	0–28	3	2	3	10	24	20	10	8	6	17	SL
Bl (loam)	28–(60)	14	2	2	6	18	13	12	14	8	25	L
Bl (sand)	28–(60)	3	8	13	23	34	12	1	2	1	6	S

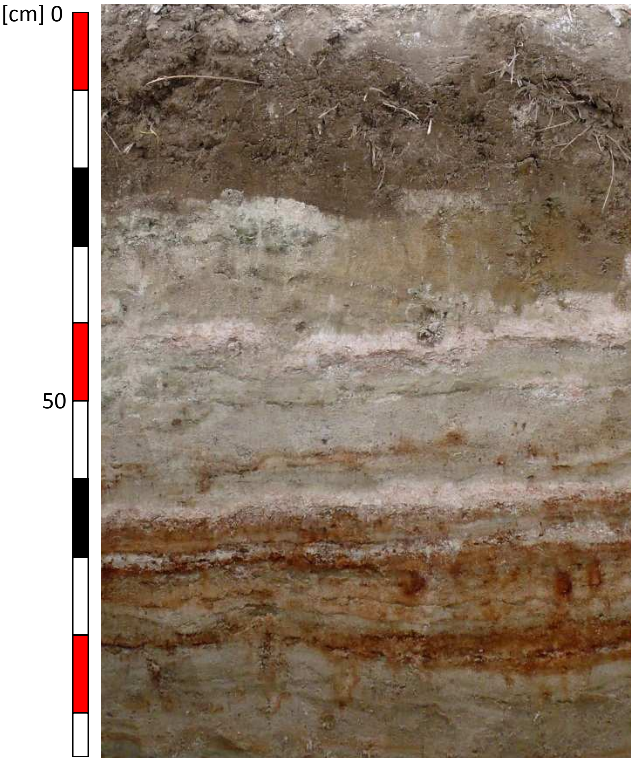
Table 11. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	C/N	pH		$CaCO_3$ [g·kg^{-1}]
					H_2O	KCl	
Ap	0–28	19.7	1.63	12	7.8	7.2	59
Bl (loam)	28–(60)	4.45	0.36	12	7.3	7.3	96
Bl (sand)	28–(60)	1.19	0.11	11	8.0	8.0	132

Table 12. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	CEC_{clay}	BS [%]
		[cmol(+)·kg^{-1}]								
Ap	0–28	22.1	0.940	0.411	0.024	23.5	0.530	24.0	101	98
Bl (loam)	28–(60)	21.9	0.963	0.224	0.050	23.2	0.311	23.5	87.8	99
Bl (sand)	28–(60)	7.37	0.144	0.064	0.012	7.59	0.187	7.8	123	98

Profile 5 – Calcaric **Stagnosol** (Endoarenic, Aric, Inclinic, Nechic, Ochric)
Localization: kame plateau, upper slope, arable land, 90 m a.s.l.; **N** 53°20’12”, **E** 19°17’02”



Morphology:

Ap – 0–24 cm, humus horizon, sandy loam, grayish brown (10YR 6/2; 10YR 5/2), slightly moist, moderate granular medium structure, clear and wavy boundary;

C1 – 24–40 cm, loamy sand, light brownish gray (10YR 7/2; 10YR 6/2), slightly moist, massive structure, discontinuous platy carbonate cementation, clear and wavy boundary;

C2 – 40–45 cm, sandy loam, light gray (10YR 8/1; 10YR 7/2), slightly moist, massive structure, continuous platy carbonate cementation, clear and wavy boundary;

Cg1 – 45–65 cm, loamy sand, dark yellowish brown (10YR 6/6; 10YR 4/6), slightly moist, single grain structure, continuous carbonate cemented layer in horizons bottom, few fine and soft iron concretions, clear and wavy boundary;

Cg2 – 65–80 cm, loamy sand, light olive brown (2.5Y 7/4; 2.5Y 5/4), slightly moist, single grain structure, continuous carbonate cemented layer in top section, many fine and soft iron concretions, clear and wavy boundary;

Cg3 – 80–(95) cm, sand, light brownish gray (2.5Y 7/3; 2.5Y 6/2), slightly moist, single grain structure, few fine and soft iron concretions, clear and wavy boundary.

Table 13. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
Ap	0–24	2	2	4	17	40	17	4	1	3	12	SL
C1	24–40	1	4	6	22	46	8	2	3	1	8	LS
C2	40–45	0	5	15	14	28	13	8	5	3	9	SL
Cg1	45–65	1	4	9	16	40	18	3	3	1	6	LS
Cg2	65–80	1	2	5	21	46	13	4	2	1	6	LS
Cg3	80–(95)	2	2	5	20	58	13	2	0	0	0	S

Table 14. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	Nt [g·kg^{-1}]	C/N	pH		$CaCO_3$ [g·kg^{-1}]
					H_2O	KCl	
Ap	0–24	4.30	0.45	10	8.1	7.6	78
C1	24–40	0.73	0.06	12	8.7	7.9	94
C2	40–45	2.53	0.14	18	8.5	8.1	456
Cg1	45–65	0.64	0.07	9	8.6	7.9	159
Cg2	65–80	0.86	0.05	17	8.4	7.9	104
Cg3	80–(95)	0.30	0.02	15	8.8	8.1	62

Table 15. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	CEC_{clay}	BS [%]
		[cmol(+)·kg^{-1}]								
Ap	0–24	111	0.021	1.11	0.098	112	0.294	112	920	100
C1	24–40	11.9	0.016	0.063	0.017	12	0.209	12	146	98
C2	40–45	42.5	0.012	0.058	0.021	43	-	-	-	-
Cg1	45–65	12.5	0.185	0.068	0.013	13	0.187	13.0	213	99
Cg2	65–80	10.0	0.024	0.058	0.009	10	0.228	10.3	167	98
Cg3	80–(95)	7.02	0.011	0.053	0.009	7	0.146	7.15	-	98

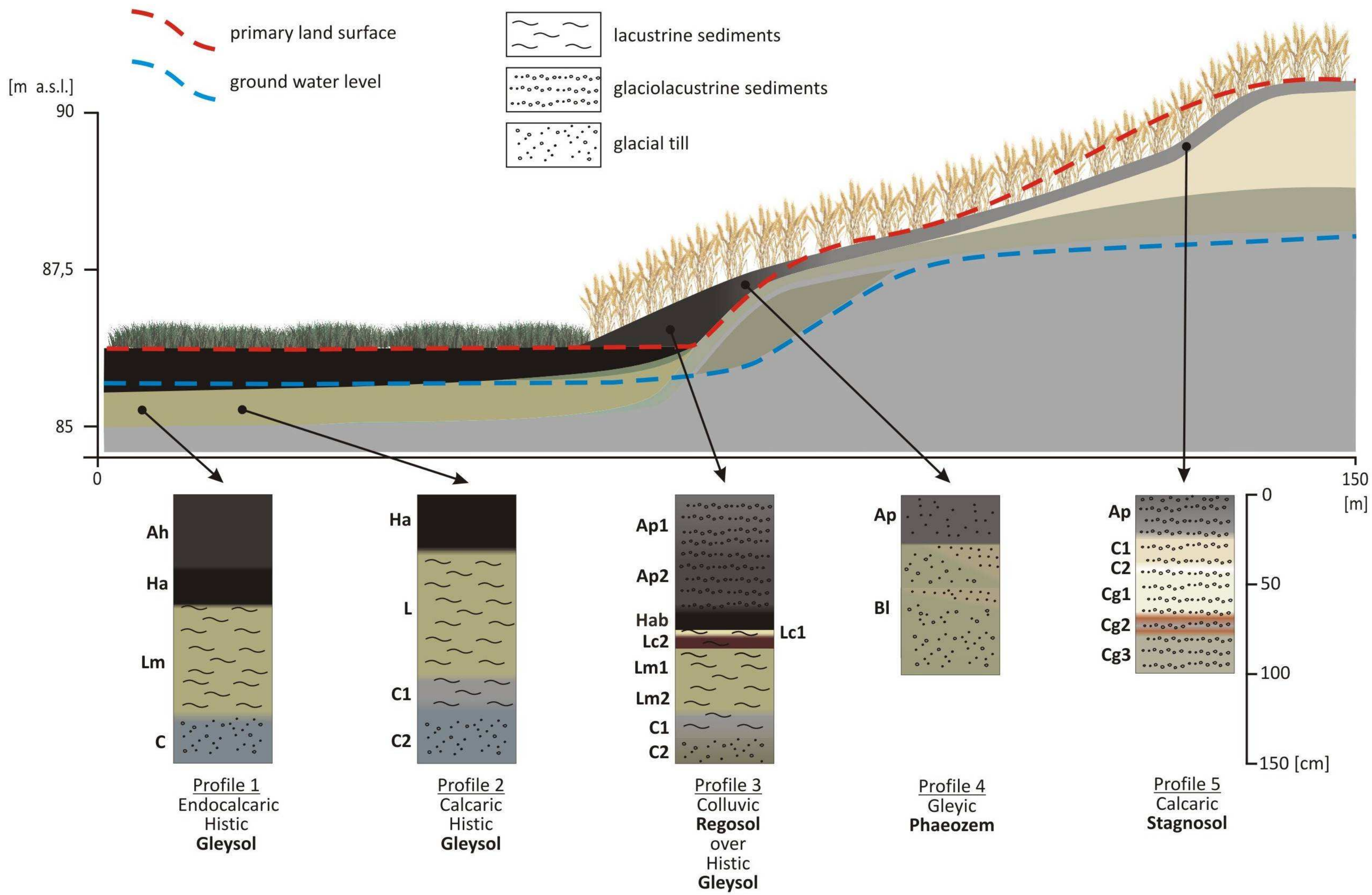


Fig. 2. Litho-hydrotoposequence of soils within disappearing lakes catchments

Soil genesis and systematic position

The environment in the studied area, including the soil cover, is affected mainly by the human impact. The water level of the former Sumowskie Lake has lowered due to natural and anthropogenic processes and now there are two separate water bodies (Churski, 1988; Marszelewski, 2005). Human activity in this area is manifested in the drainage network and in the human-induced erosion taking place especially on the surrounding hillsides of the kame used for agricultural purposes. Formation of new, characteristic soils due to drainage of shallow lakes in northern Poland and Germany was described by several researches (Uggla, 1964; Chmieleski and Zeitz, 2008; Łachacz et al., 2009; Gonet et al., 2010; Mendyk and Markiewicz, 2013).

The whole area of the former Sumowskie Lake bottom is covered with organic soils originated from lacustrine sediments as gyttja with shallow peat layers on the surface. Those sediments are characterized by a high content of organic matter and calcium carbonates. Soils developed from those materials are mostly classified as **Histosols** or **Gleysols** (Profiles 1–3) depending on the thickness of organic horizons (IUSS Working Group WRB, 2014). The qualifier ***Histic*** is applied to indicate the occurrence of horizons dominated by the organic matter in mineral soils (Profiles 1–3). Furthermore, the lacustrine origin of these sediments is expressed with the ***Limnic*** supplementary qualifier (Profiles 1–3). Organic matter in surface organic horizons of these soils is highly decomposed due to the fact of artificial drainage, that is why the qualifier ***Drainic*** was used (Profiles 1–3). A high content of the second main component of lacustrine sediments, i.e. calcium carbonates, is indicated by using ***Calcaric*** principle qualifiers (Profiles 1–3). In Profile 1, the specifier ***Endo*** was used to create the subqualifier ***Endocalcaric***. This means that this characteristic was present at a depth between 50 and 100 cm from the (mineral) soil surface. The supplementary qualifier ***Nechic*** indicates the occurrence of uncoated mineral grains of sand in a darker matrix within ≤ 5 cm of the mineral soil surface (Profile 1). Because of a high content of $CaCO_3$, all these soils have high base saturation (up to 99%), which allows the use of the ***Eutric*** qualifier. However we cannot use those two qualifiers together because there are connected with the same property of the soil.

All of the mineral soils in profiles located on the kame hill slope developed from the limnoglacial material. These sediments are characterized by sand and loam layers of varying thickness and particle size distribution, with a high content of calcium carbonates, which is clearly noticeable in the morphology of soil profiles. In Profile 3 and 4, thick humus horizons rich in organic matter with base saturation over 50% were observed. They meet the criteria of the ***mollic*** diagnostic horizon in Profile 4. Since there were no secondary carbonates, this profile was classified as **Phaeozem.** However, it did not meet the criteria of a colour and organic carbon content change when comparing with the underlying horizon in Profile 3, that is why it was classified as **Regosol**. Hard, impermeable calcium carbonate cemented horizons (Profile 5) cause the stagnation of water within the profiles, which is reflected as a *stagnic colour pattern.* Therefore the soil from the upper part of the slope was classified as **Stagnosol** (Profile 5). Two additional qualifiers in **Stagnosol** indicate a high content of primary calcium carbonate – ***Calcaric*** and the occurrence of a 30 cm layer or thicker within the upper 100 cm with a texture of loamy fine sand or coarser – ***Endoarenic*** (below 50 cm from the soil surface − ***Endo***). The main process that modifies the morphology of soils on the kame slope is human-induced erosion. Humus horizons of soils located on the foot slope are built of a colluvium from the upper parts. It is indicated by the qualifier ***Colluvic*** (Profile 3). To express that Profile 3 and 4 were located on the slope with an inclination over 5 degrees, the ***Inclinic*** qualifier was used. The qualifier ***Aric*** is applied in Profiles 3–4 because of ploughing.

Soil sequence

A relatively large variability of pedons is determined by different lithology, position in the relief and water conditions. The analyzed pedons could be divided into two main groups: soils developed from the exposed, drained mineral-organic lake sediments (**Histosols** and **Gleysols**) and mineral soils originated from glaciolacustrine sediments on the slope of the kame hill (**Phaeozems** and **Stagnosols**, also the occurrence of **Arenosols** is possible). Thus, we can say that it is a **litho-topohydrosequence**. It has to be stressed that anthropic pressure is still strongly modifying the soil processes. The soils (often organic ones) covering the foot slopes with *colluvic material*, and the newly forming soils form a colluvium of a considerable thickness while soils from the upper parts are strongly eroded, which is a common situation in young glacial landscapes (Frielinghaus and Vahrson, 1998; Smolska, 2002; Smólczyński S., and Orzechowski M., 2010, Świtoniak, 2014).This is related to the intensification of the agricultural use of the early post-glacial areas in northern Poland from the Middle Ages (at most 1000 years ago) (Karasiewicz et al., 2014).

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Chronosequence of soils on inland dunes in Poland

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Fig. 1 Location

Inland dunes are a typical feature of the Polish landscape (Galon 1958). The whole lowland and upland part of the country belongs to the so-called 'European aeolian sand belt' (Zeeberg 1998, Koster 2009). The Toruń Basin situated in Northern Poland represents a classical aeolian landscape and it is one of the largest inland dune fields in Europe (Mrózek 1958). Dunes were formed mostly on glaciofluvial outwash plains and ice-marginal stream terraces during the Late Glacial period, in periglacial conditions of an arctic desert and tundra (Jankowski 2002, 2007). During the Eo- and Mesoholocene, the area was covered by dense forests. Humans activity in the Neoholocene caused damage to vegetation cover, and initiated erosion and deflation processes that modified the relief of dunes, and truncated or destroyed the primary soils. In such conditions, initial psammophilous vegetation occurs starting a new line of vegetation succession and soil development (Rahmonov 1999, Jankowski and Bednarek 2000, 2002).

Landforms and lithology

The Toruń Basin is an extension of the Toruń-Eberswalde ice-marginal stream valley formed during the Pomeranian Phase of the last glaciation (Weichselian/Würm; Galon 1958, Weckwerth 2010). It is built of eleven glaciofluvial and fluvial terraces formed from sandy/sandy-gravely deposits. Dunes covering the terraces are mostly bow-shaped, but also parabolic, longitudinal and complex forms. They form a regular pattern, indicating Westerlies as the main aerodynamic factor shaping the landscape. The biggest dune forms are 30–45 m high and some km long. They are built from loose, permeable, extremely poor and very well sorted aeolian sand, dominated by fine and very fine sand fraction in the grain-size distribution (ca. 85–95%) and by quartz in the mineral composition (ca. 85–95).

Land use

Due to extremely low fertility of soils developed on dunes, the area is mostly covered with pine (*Pinus sylvestris*) woodlands. However, woodlands are planted by man and their botanical character is consistent with the primary natural vegetation, i.e. a continental middle pine forest (*Peucedano-Pinetum*; Matuszkiewicz 1995). In places devoid of vegetation cover, mosaics of bare sands and sod vegetation representing consecutive stages of succession occur. The dry grassland (*Spergulo-corynephoretum*) is the initial plant community. Later, more dense grasslands (with *Festuca* sp. and *Calamagrostis epigejos*) and heathlands (with *Calluna vulgaris*) appear, finally giving place to single pine (*Pinus sylvestris*) and birch (*Betula pendula*) trees. The last stage of succession is again a pine forest.

Profile 1 – Protic Dystric **Arenosol** (on buried truncated Dystric Brunic Arenosol)
Localization: aeolian cover, undulated surface, 54 m a.s.l. **N** 52°59’05”, **E** 18°38’58”
Age, developmental stage, vegetation: 0–5 years, initial, *Spergulo-corynephoretum*

Morphology:

(A) – 0–1 cm, initial humus horizon, sand, brown (10YR 5/3; 10YR 4/3), dry, single grain structure, fine common roots of grasses and lichen crusts, single fine charcoals (<1%) transitional boundary;

C – 1–110 cm, parent material, sand, yellowish brown (10YR 6/4; 10YR 5/3), dry, single grain structure, fine single roots, lamination of discontinuous initial humus horizons, fine single charcoals (<1%);

2Bwb – 110–(150) cm, buried Bw horizon, sand, yellowish brown (10YR 6/6; 10YR 5/6), dry, single grain structure, palaeolithic artefacts (flints).

Table 1. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]								Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.002	<0.002	
(A)	0–1	0	0	5	28	55	7	4	1	S
C	1–110	0	0	3	26	64	5	2	0	S

Table 2. Chemical and physicochemical properties

Horizon	Depth [cm]	OC	N_t	C/N	pH	
		$[g \cdot kg^{-1}]$			H_2O	KCl
(A)	0–1	0.24	0.02	12	5.3	4.3
C	1–110	-	-	-	4.8	4.3

Table 3. Contents of various forms of iron and aluminum

Horizon	Depth [cm]	Fe_t	Fe_d	Fe_o	Fe_t-Fe_d	Fe_d-Fe_o	Al_o
		$[g \cdot kg^{-1}]$					
(A)	0–1	1.88	0.62	0.29	1.26	0.33	0.33
C	1–110	1.16	0.50	0.23	0.66	0.27	0.31

Profile 2 – Protic Dystric **Arenosol** (on buried truncated Dystric Brunic Arenosol)
Localization: aeolian cover, undulated surface, 52 m a.s.l. **N** 52°59’09”, **E** 18°38’55”
Age, developmental stage, vegetation: 20–30 years, intermediate, *Pinus sylvestris* bio-groups

Morphology:

Oi – 8–6 cm, organic horizon, fresh litter of pine (mostly needles);

Oe – 6–0 cm, organic horizon, partly decomposed litter of pine;

A – 0–6 cm, humus horizon, sand, dark brown (10YR 4/2; 10YR 2/2), dry, single grain structure, fine common roots, fine single charcoals (<1%), transitional boundary;

C – 6–56 cm, parent material, sand, brown (10YR 6/3; 10YR 4/3), dry, single grain structure, fine and coarse common roots, traces of lamination, fine single charcoals (<1%), clear boundary;

2Bwb – 56–(90) cm, buried Bw horizon, sand, yellowish brown (10YR 6/6; 10YR 5/6), dry, single grain structure, medium single roots;

Table 4. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]								Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.002	<0.002	
A	0–6	0	0	2	9	73	11	4	1	S
C	6–56	0	0	1	16	73	7	3	0	S

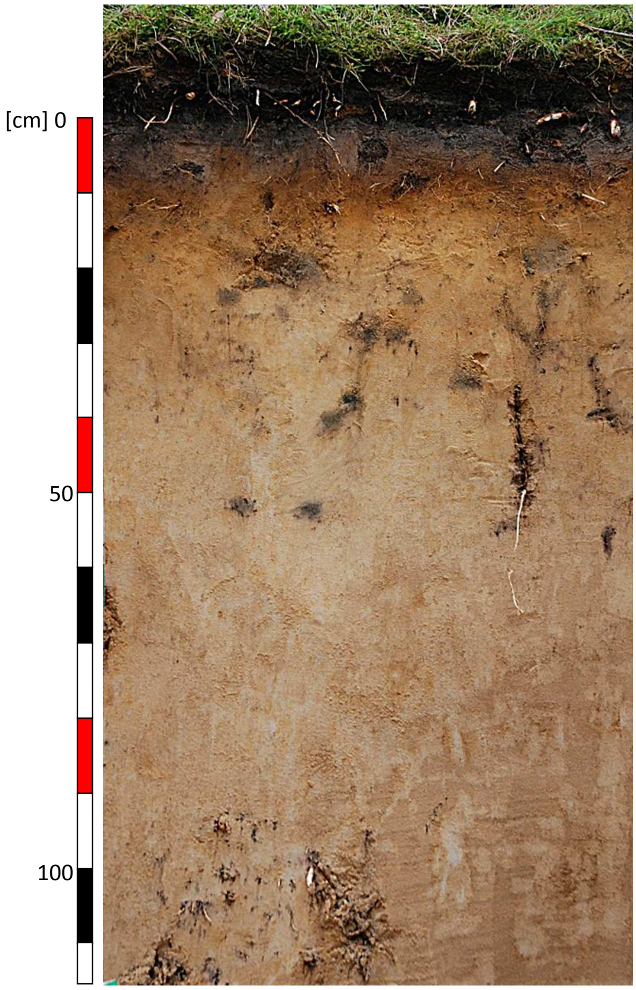
Table 5. Chemical and physicochemical properties

Horizon	Depth [cm]	OC	N_t	C/N	pH	
		$[g \cdot kg^{-1}]$			H_2O	KCl
Oi	8–6	46.7	0.60	78	4.2	3.7
Oe	6–0	20.5	0.74	28	4.5	3.7
A	0–6	2.27	0.07	17	4.6	3.6
C	6–56	-	-	-	4.5	4.2

Table 6. Contents of various forms of iron and aluminum

Horizon	Depth [cm]	Fe_t	Fe_d	Fe_o	Fe_t-Fe_d	Fe_d-Fe_o	Al_o
		$[g \cdot kg^{-1}]$					
A	0–6	2.92	1.44	0.73	1.48	0.71	0.50
C	6–56	2.01	0.81	0.36	0.12	0.45	0.48

Profile 3 – Dystric Albic **Arenosol**
Localization: inland dune N slope, 78 m a.s.l., **N** 52°54’48”, **E** 18°40’44”
Age, developmental stage, vegetation: 52 years old forest, semimature, *Peucedano-Pinetum*



Morphology:

Oi – 8–7.5 cm, slightly decomposed organic material;

Oe – 7.5–0 cm, moderately decomposed organic material;

AE – 0–7 cm, eluvial horizon with *albic* material, sand, grayish brown (10YR 5/2; 7,5YR 5/1), dry, single grain structure, fine and common roots, gradual and smooth boundary;

Bs – 7–30 cm, illuvial horizon, sand, yellowish brown (10YR 6/6; 10YR 4/6), dry, single grain structure, fine and common roots, gradual and smooth boundary;

C – 30–(120) cm, parent material, sand, brownish yellow (10YR 8/4; 10YR 6/6), dry, single grain structure.

Table 7. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
AE	0–7	0	0	1	9	69	16	0	4	1	0	S
Bs	7–30	0	0	0	7	68	20	2	1	0	2	S
C	30–(120)	0	0	0	8	72	17	1	1	0	1	S

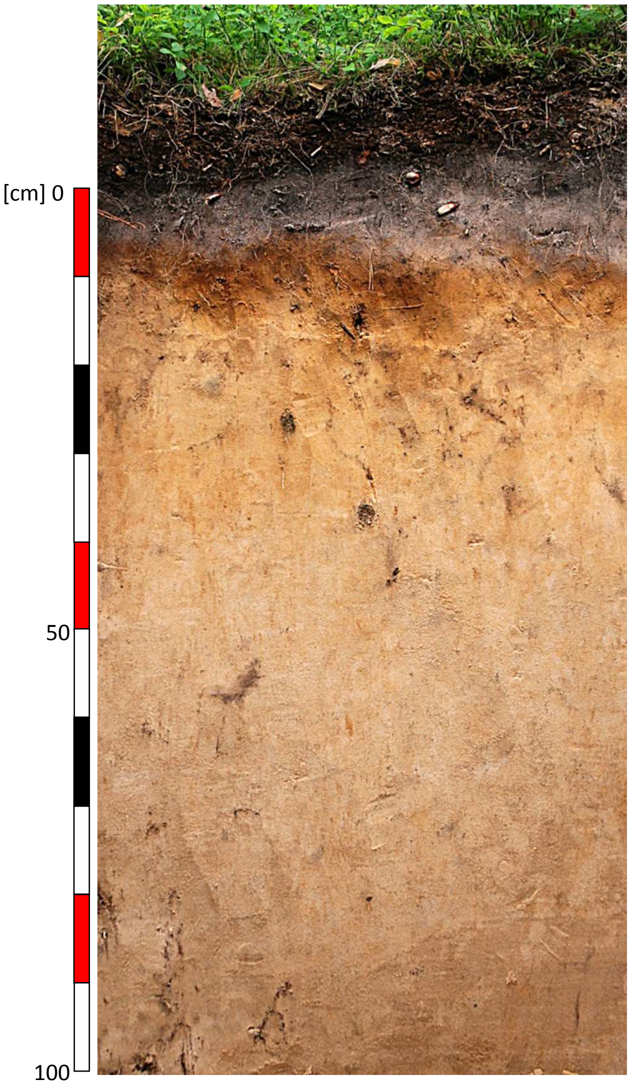
Table 8. Chemical and physicochemical properties

Horizon	Depth [cm]	OC	N_t	C/N	pH	
		[g·kg^{-1}]			H_2O	KCl
Oi	8–7.5	483	6.92	70	4.2	3.5
Oe	7.5–0	357	12.1	30	4.1	2.9
AE	0–7	13.3	0.63	21	3.9	3.3
Bs	7–30	4.32	0.23	19	4.6	4.5
C	30–(120)	-	-	-	4.9	4.6

Table 9. Contents of various forms of iron and aluminum

Horizon	Depth [cm]	Fe_t	Fe_d	Fe_o	Fe_t-Fe_d	Fe_d-Fe_o	Al_o
		[g·kg^{-1}]					
AE	0–7	4.45	1.27	0.68	3.18	0.59	0.37
Bs	7–30	5.90	2.14	1.13	3.76	1.01	2.04
C	30–(120)	4.24	0.66	0.22	3.58	0.44	0.23

Profile 4 – Folic Albic **Podzol** (Arenic)
Localization: inland dune N slope, 82 m a.s.l. **N** 52°54’53”, **E** 18°40’52”
Age, developmental stage, vegetation: 105 years old forest, mature, *Peucedano-Pinetum*



Morphology:

Oi – 11–10.5 cm, slightly decomposed organic material;

Oe – 10.5–2 cm, moderately decomposed organic material;

Oa – 2–0 cm, decomposed organic material;

E – 0–9 cm, eluvial horizon with *albic* material, sand, dark grayish brown (10YR 6/2; 10YR 4/2), dry, single grain structure, fine and common roots, clear and wavy boundary;

Bhs – 9–13 cm, *spodic* horizon, sand, dark brown (10YR 5/6; 7.5YR 4/6), dry, single grain structure, fine and common roots, gradual and wavy boundary;

BC – 13–44 cm, transitional horizon, sand, yellowish brown (10YR 7/6; 10YR 5/8), dry, single grain structure, fine and very few roots, diffuse and smooth boundary;

C – 44–(110) cm, parent material, sand, yelow (10YR 8/4; 10YR 7/6), dry, single grain structure.

Table 10. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
EA	0–9	0	0	0	7	71	18	1	1	0	2	S
Bhs	9–13	0	0	0	4	71	21	1	0	0	3	S
BC	13–44	0	0	1	5	76	16	0	1	1	0	S
C	44–(110)	0	0	1	8	74	16	1	0	0	0	S

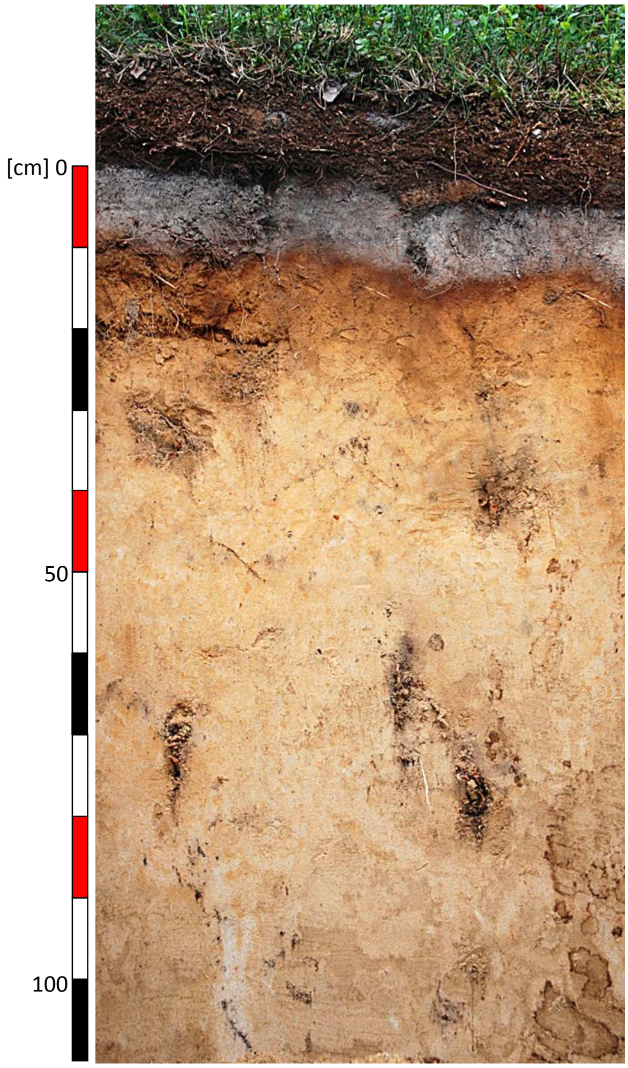
Table 11. Chemical and physicochemical properties

Horizon	Depth [cm]	OC	N_t	C/N	pH	
		$[g \cdot kg^{-1}]$			H_2O	KCl
Oi	11–10.5	487	8.28	59	4.3	3.6
Oe	10.5–2	397	15.3	26	3.8	3.0
Oa	2–0	234	10.3	23	3.7	2.9
EA	0–9	7.71	0.38	20	4.2	3.5
Bhs	9–13	9.83	0.53	19	4.7	4.3
BC	13–44	2.25	0.15	-	4.8	4.6
C	44–(110)	-	-	-	4.9	4.7

Table 12. Contents of various forms of iron and aluminum

Horizon	Depth [cm]	Fe_t	Fe_d	Fe_o	Fe_t-Fe_d	Fe_d-Fe_o	Al_o
		$[g \cdot kg^{-1}]$					
EA	0–9	3.15	0.68	0.39	2.47	0.29	0.29
Bhs	9–13	6.04	3.27	2.00	2.77	1.27	1.49
BC	13–44	5.98	1.20	0.50	4.78	0.70	1.34
C	44–(110)	6.06	0.75	0.18	5.31	0.57	0.67

Profile 5 – Folic Albic **Podzol** (Arenic)
Localization: inland dune N slope, 92 m a.s.l., **N** 52°54'24", **E** 18°40'45"
Age, developmental stage, vegetation: 150 years old forest, mature, *Peucedano-Pinetum*



Morphology:

Oi – 14–13 cm, slightly decomposed organic material;

Oe – 13–3 cm, moderately decomposed organic material;

Oa – 3–0 cm, decomposed organic material;

E – 0–10 cm, eluvial horizon with *albic* material, sand, yellowish brown (10YR 6/2; 10YR 5/5), dry, single grain structure, fine and few roots, abrupt and wavy boundary;

Bhs – 10–13 cm, *spodic* horizon, sand, dark yellowish brown (7,5YR 4/6; 7,5YR 3/4), dry, single grain structure, clear and wavy boundary;

Bs – 13–35 cm, illuvial horizon, sand, brown (10YR 6/6; 10YR 4/3), dry, single grain structure, fine and few roots, gradual and smooth boundary;

BC – 35–90 cm, transitional horizon, sand, brown (10YR 7/6; 10YR 5/3), dry, single grain structure, medium and very few roots, diffuse and smooth boundary;

C – 90–(110) cm, parent material, sand, very pale brown (10YR 8/4; 10YR 7/3,5), dry, single grain structure.

Table 13. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
E	0–10	0	0	2	4	69	16	3	1	4	1	S
Bhs	10–13	0	0	0	6	71	20	1	0	0	2	S
Bs	13–35	0	0	0	4	72	22	0	0	0	2	S
BC	35–90	0	0	0	4	76	19	1	0	0	0	S
C	90–(110)	0	0	0	4	75	19	1	0	0	1	S

Table 14. Chemical and physicochemical properties

Horizon	Depth [cm]	OC	N_t	C/N	pH	
		$[g \cdot kg^{-1}]$			H_2O	KCl
Oi	14–13	493	12.1	41	4.3	3.5
Oe	13–3	394	15.8	25	3.7	2.9
Oa	3–0	341	13.2	26	3.5	2.6
E	0–10	7.49	0.41	18	4.2	3.4
Bhs	10–13	13.5	0.73	19	4.5	4.1
Bs	13–35	2.95	0.15	19	4.8	4.6
BC	35–90	-	-	-	4.8	4.6
C	90–(110)	-	-	-	5.0	4.6

Table 15. Contents of various forms of iron and aluminum

Horizon	Depth [cm]	Fe_t	Fe_d	Fe_o	Fe_t-Fe_d	Fe_d-Fe_o	Al_o
		$[g \cdot kg^{-1}]$					
E	0–10	3,47	0.62	0.36	2.85	0.26	0.21
Bhs	10–13	7.62	4.44	3.03	3.18	1.41	3.53
Bs	13–35	5.96	1.48	0.75	4.48	0.73	1.69
BC	35–90	4.86	0.88	0.30	3.98	0.58	0.97
C	90–(110)	5.35	0.68	0.23	4.67	0.45	0.15

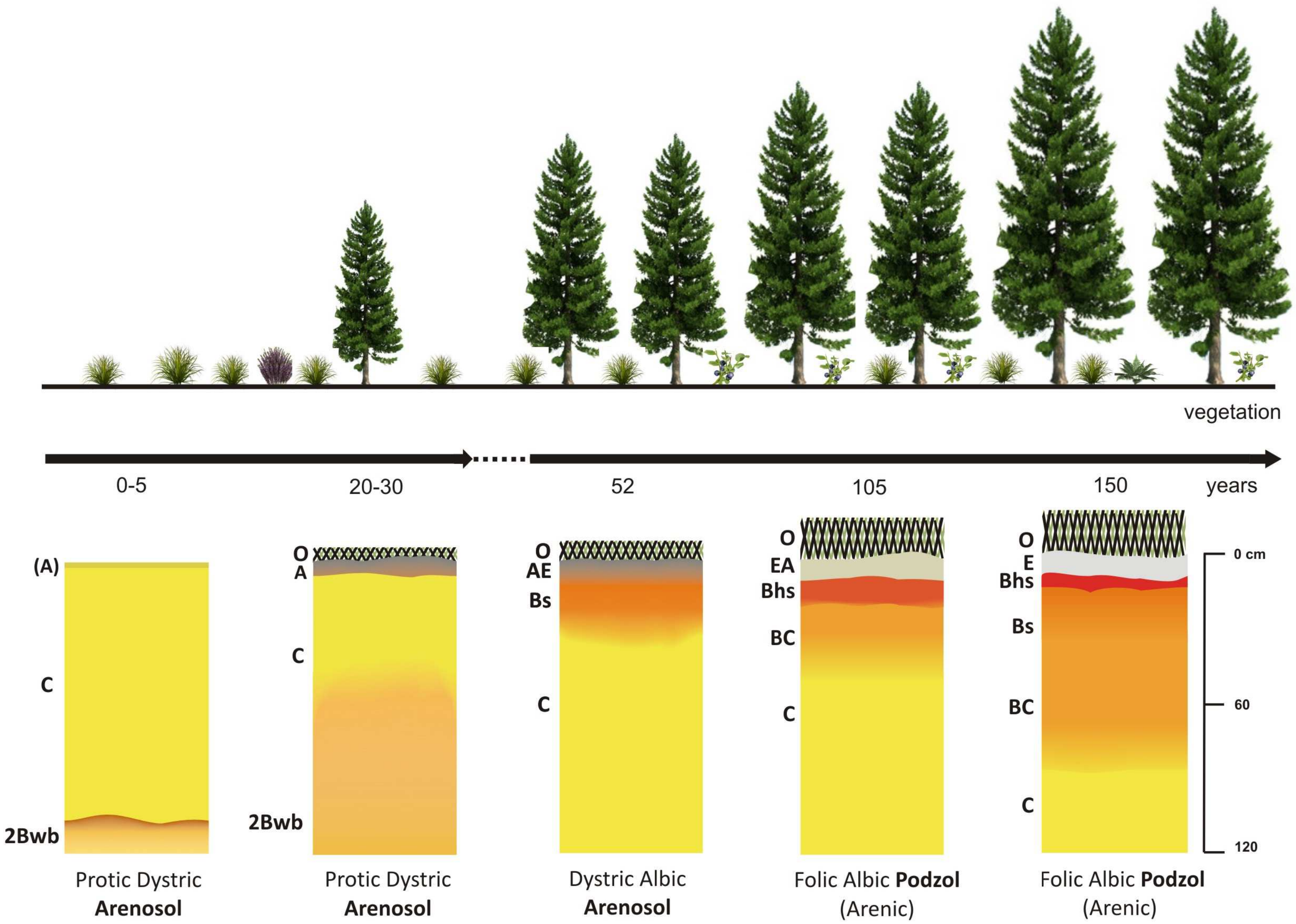


Fig. 2. Chronosequence of soils on inland dunes

Climate

The climate is of humid, temperate type. The average annual air temperature is 7.9°C. The warmest month is July (18.1 °C) and the coldest month is January (-2.2 °C). The average annual precipitation is 522.5 mm with the maximum in the summer half of the year (April-September 65%; Wójcik and Marciniak, 2006).

Soil genesis and systematic position

Extremely poor and permeable parent material, humid climate and the character of vegetation succession determine the direction of soil development. The beginning of soil formation is associated with the appearance of pioneer psammophilous plants, which gradually spread and are able to cover the entire soil surface after ca. 20 years (Jankowski and Bednarek, 2000, 2002). At this stage, under *Algae*, clusters of xerothermic grass (e.g. *Corynephorus canescens*) and drought-resistant mosses (*Polytrichum piliferum*), organic matter accumulates in the top few centimetres of mineral soil, resulting in the formation of the initial humus horizon (A). Together with organic matter also other elements (e.g. aluminium and iron) accumulate. New plant species (e.g. *Festuca* sp., *Calamagrostis epigejos* and *Calluna vulgaris*) encroach on the already stabilized surface. Soil properties change along with vegetation succession. After ca. 20–30 years of sod vegetation development, pine trees encroach on the area, forming biogroups (Rahmonov, 1999) with associated boreal plants. The formation of the organic horizon (O) starts under the tree canopies. Under ca. 30-year-old pine, the Oi-Oe sequence of horizons is already developed, indicating the ***mor*** type of humus formation (Plichta 1981).

Successive stages of soil and vegetation development are observed in timber forests planted by man. However, the even-aged monocultural pine tree stands are uniform, the undergrowth vegetation still changes along the succession line. For example, a typical boreal species − blueberry (*Vaccinium myrtillus*) − occurs in the forest floor only after 70 years of tree growth (Rutkowska and Jankowski, in press). Slowly decomposing litter of pine and other associated boreal plants determines further development of the organic horizon. Under 105-year-old pines, a full sequence of subhorizons (Oi-Oe-Oa) is present. The intensive production of fulvic acids as a result of plant debris decomposition causes an increase in acidification and mobilization of aluminium, iron and organic carbon and their leaching from the top to the deeper part of the soil. The direction of the soil forming process changes from the initial process to podzolization. After ca. 50–70 years of forest growth, eluvial (E) and illuvial (B) horizons are clearly visible in the soil. Their morphological and chemical contrast increases with time resulting in the formation of mature soil, i.e. Podzol. Due to the system of pine plantation, trees are cut down at the age of 100–150 years and the soil is ploughed before planting the new generation of young trees.

All the soils in the sequence have sandy texture (Tables 1, 4, 7, 10 and 13). Soil horizons in Profile 1 are very poorly developed (Tables 2 and 3) and do not meet the criteria of any diagnostic horizon or material. Thus, that soil was classified as **Arenosol**. Its initial character is additionally emphasized by the ***Protic*** principal qualifier. Acid reaction in all horizons corresponding to low base saturation is expressed by the ***Dystric*** principal qualifier. Although A and O horizons in Profile 2 are better developed, they are still not diagnostic, mostly because of insufficient thickness (Table 5 and 6). Both soils in Profile 1 and 2 are classified as ***Protic Dystric*** **Arenosols**. In the soil under 52-year-old pine forest (Profile 3), a shallow eluvial horizon is quite well developed. That zone meets the criteria of ***albic*** diagnostic material, which has been expressed by the use of the ***Albic*** principal qualifier. The illuvial horizon in that soil is morphologically distinguishable, although accumulation of organic carbon, iron and aluminium, as well as morphological features are too indistinguishable for the ***spodic*** diagnostic horizon (Tables 8, 9). Based on such features, the soil in Profile 3 cannot be classified as **Podzol** but instead as ***Dystric Albic*** **Arenosol**. Soils in Profile 4 (under 105-year-old pine forest) and Profile 5 (under 150-year-old pine forest) have a well-developed sequence of organic, eluvial and illuvial horizons (Tables 11, 12, 14 and 15). Since the illuvial Bhs-Bs horizons of both soils meet the criteria of the ***spodic*** diagnostic horizon, they belong to the Soil Reference Group (SRG) of **Podzols**. The presence of more than 10 cm thick organic horizon is indicated by the ***Folic*** principal qualifier. The presence of the eluvial horizon is recorded in the ***Albic*** principal qualifier. The supplementary qualifier (***Arenic***) shows a sandy texture of Podzols. Finally, soils in Profile 4 and 5 are classified as ***Folic Albic*** **Podzols** ***(Arenic)***.

Soil sequence

The described profiles represent the developmental sequence of soils forming in one climatic zone, in extremely homogenous parent material and similar relief position, without the influence of ground water. The only factors diversifying the soils are: 1. time, and 2. stage of vegetation succession. Thus, the sequence represents a **chronosequence** (Prusinkiewicz, 1965) and more precisely can be defined as a **chrono-vegesequence**. Although the studied soils are observed at the same moment, which shows the actual stage of their development, they differ in the duration of the soil-forming process. According to Vreeken (1975), the described pattern represents the post-incisive type of chronosequence.

The presented chronosequence does not appear in a complete form in nature. It consists of two parts: 1. the natural, younger one including ***Protic Dystric*** **Arenosols** developing under natural vegetation succession, from the starting point of the initial soil-forming process until the encroachment of pines and change in the soil evolution direction to podzolization (0 to ca. 50 years), and 2. the man-forced, older one consisting of ***Dystric Albic*** **Arenosols** evolving as the effect of podzolization to ***Folic Albic*** **Podzols** ***(Arenic)*** under vegetation of planted pine woods until cutting of trees (ca. 50 to 100-150-year old).

In the conditions of humid temperate climate of Poland, the rate of vegetation succession and soil development is relatively fast. The first effects of the initial soil-forming process are visible only after a few (0–5) years. However, low fertility of the parent material (dune sand) is, to some extent, a limiting factor in these processes. Especially in the early stages of vegetation succession, unstable soil surface is highly susceptible to degradation, and if vegetation cover is damaged by man or severe atmospheric conditions (strong winter), it can easily become affected by deflation and erosion again. In such a situation, a developing soil undergoes rejuvenation (Prusinkiewicz, 1969). Results of podzolization appear just after the first decades of soil development under pine forest vegetation (Jankowski and Bednarek, 2000, 2002). Formation of mature Podzol, however, takes at least 100 years of pine forest dominance and one can expect that even after 150 years its development is still not finished.

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Pleistocene terraces of the Toruń Basin on the border of the urban area

Przemysław Charzyński, Marcin Świtoniak

The city of Toruń is located in the centre of the Kujawy-Pomerania Province and covers an area of 116 km^2. The city is situated within several physico-geographical regions: Toruń Basin in the central part, Chełmno Lakeland, Drwęca Valley and Dobrzyń Lakeland in the north and north-east and Inowrocław Plain in the south-west (Andrzejewski and Kot, 2006). The Toruń Basin is the dominant geographical unit in the city and one of the largest widenings of the eastern part of the Noteć-Warta ice-marginal valley. Several glacio-fluvial and fluvial Pleistocene terraces were distinguished within the basin (Galon, 1961). The Vistula River floodplain is the axis of the Toruń Basin.

Fig. 1. Location

Lithology and topography

The dominant sediments of the erosive-accumulative terraces are sand and gravel-sand thick series (Weckwerth et al., 2011) deposited during the Late Pleistocene period, after the Pomeranian phase of the last Weischselian glaciation (Niewiarowski and Weckwerth, 2006). The thickness of these deposits varied from some to approximately 10 m. The sandy sediments of the terraces were repeatedly remodelled by aeolian processes in the Younger Dryas, Older Dryas and in the Preboreal. The intensity of these processes also increased during the settlement phases, e.g. in the Hallstatt – La Tené periods (Niewiarowski and Weckwerth, 2006). As a result of these processes, one of the biggest dune complexes in Poland were formed.

Land use

The immediate surroundings of the town is dominated by pine (*Pinus sylvestris* L.) monocultures. The main reason for forest use of the region is the occurrence of low-fertility soils developed from sandy aeolian and fluvial deposits. The semi natural mixed forest with a large contribution of deciduous species (oak, lime, hornbeam) was preserved in some natural reserves (Rutkowski, 2006). The biggest transformation of soil cover took place in the central part of the city (Charzyński et al., 2013a). The intensive human activities go back to the 13th century. The large areas were flattened during constructions – positive forms were levelled, while depressions were filled with deposits taken from nearest hills. The anthropogenic transformations are evidenced by embankments with a thickness of up to 4 m in the downtown area or even more than 8 m in places of medieval moats (Fedorowicz, 1993). Apart from typical built-up areas with the strongest anthropogenic transformations, there are forests and parks covering about 23%, meadows – 7% and arable lands − about 18% of Toruń (Kozłowski, 1998).

Profile 1 – Entic **Podzol** (Arenic)

Localization: dune within Pleistocene terrace, gently sloping 3°, pine monoculture, 48 m a.s.l.,
N 53°01’48”, **E** 18°31’41”

Morphology:

Oi – 5–4 cm, slightly decomposed organic material;

Oe – 4–0 cm, moderately decomposed organic material;

AE – 0–7 cm, humus horizon, fine sand, gray (10YR 6/2; 10YR 5/1), dry, weak granular fine structure, fine and medium common roots, clear and smooth boundary;

Bs – 7–15 cm, *spodic* horizon, fine sand, yellowish red (5YR 6/6; 5YR 5/6), slightly moist, weak granular fine structure/single grain structure, fine and medium few roots, gradual and wavy boundary;

C – 15–(80) cm, parent material, fine sand, very pale brown (10YR 8/4; 10YR 7/4), slightly moist, single grain structure, medium very few roots.

Table 1. Texture

Horizon	Depth [cm]	Percentage of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
AE	0–7	0	0	2	15	71	4	6	0	1	1	FS
Bs	7–15	0	0	1	14	75	5	3	2	0	0	FS
C	15–(80)	2	1	5	22	66	2	1	2	0	1	FS

Table 2. Chemical and physicochemical properties

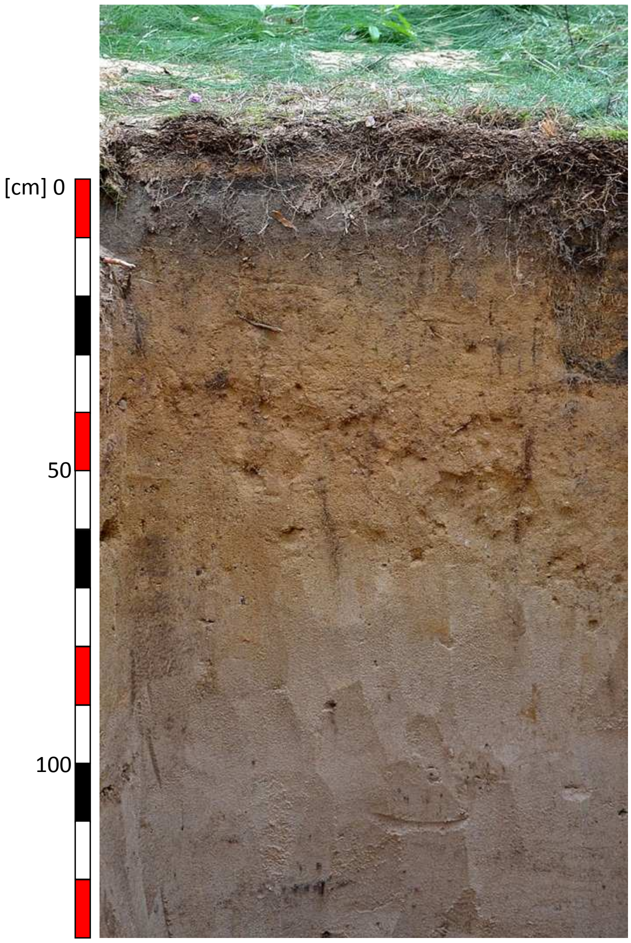
Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	C/N	pH		Fe_t	Fe_d	Fe_o
					H_2O	KCl	[g·kg^{-1}]		
Oi	5–4	433	13.6	32	4.8	4.1	-	-	-
Oe	4–0	476	15.2	31	3.7	3.1	-	-	-
AE	0–7	8.2	0.30	27	3.9	3.2	3.98	2.21	0.95
Bs	7–15	-	-	-	4.5	3.9	4.87	2.52	1.33
C	15–(80)	-	-	-	4.8	4.4	2.76	0.93	0.48

Table 3. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	BS [%]
		[cmol(+)·kg^{-1}]							
Oi	5–4	18.7	3.10	1.87	0.31	24.0	88.3	112	21
Oe	4–0	12.9	2.17	2.44	0.63	18.1	124	142	13
AE	0–7	0.074	0.021	0.038	0.016	0.149	7.56	7.71	2
Bs	7–15	0.043	0.016	0.013	0.019	0.091	2.21	2.30	4
C	15–(80)	0.012	0.013	0.016	0.004	0.045	1.37	1.41	3

Profile 2 – Hyperdystric Brunic Sideralic **Arenosol**

Localization: Pleistocene terrace, flat terrain with slopes < 1°, mixed forest with dominant pines in first floor, 44 m a.s.l., **N** 53°01′49″, **E** 18°31′59″



Morphology:

Oi – 6–5 cm, slightly decomposed organic material;

Oe – 5–0 cm, moderately decomposed organic material;

A – 0–13 cm, humus horizon, fine sand, brown (10YR 5/2; 10YR 4/3), dry, weak granular fine structure, fine and medium common roots, clear and smooth boundary;

AB – 13–30 cm, transitional horizon, fine sand, yellowish brown (10YR 6/3; 10YR 5/4), slightly moist, weak granular fine structure, fine and medium few roots, gradual and wavy boundary;

Bw – 30–60 cm, pedogenetic *in situ* concentration of sesquioxides, fine sand, brownish yellow (10YR 7/6; 10YR 6/8), slightly moist, weak granular very fine/single grain structure, few stones, diffuse and wavy boundary;

C – 60–(130) cm, parent material, fine sand, very pale brown (10YR 8/3; 10YR 7/3), slightly moist, single grain structure.

Table 4. Texture

Horizon	Depth [cm]	Percentage of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
A	0–13	1	2	12	53	28	2	1	1	0	1	FS
AB	13–30	2	1	13	56	24	4	1	0	0	1	FS
Bw	30–60	8	6	20	51	19	3	0	0	1	0	FS
C	60–(130)	1	5	21	48	22	2	1	1	0	0	FS

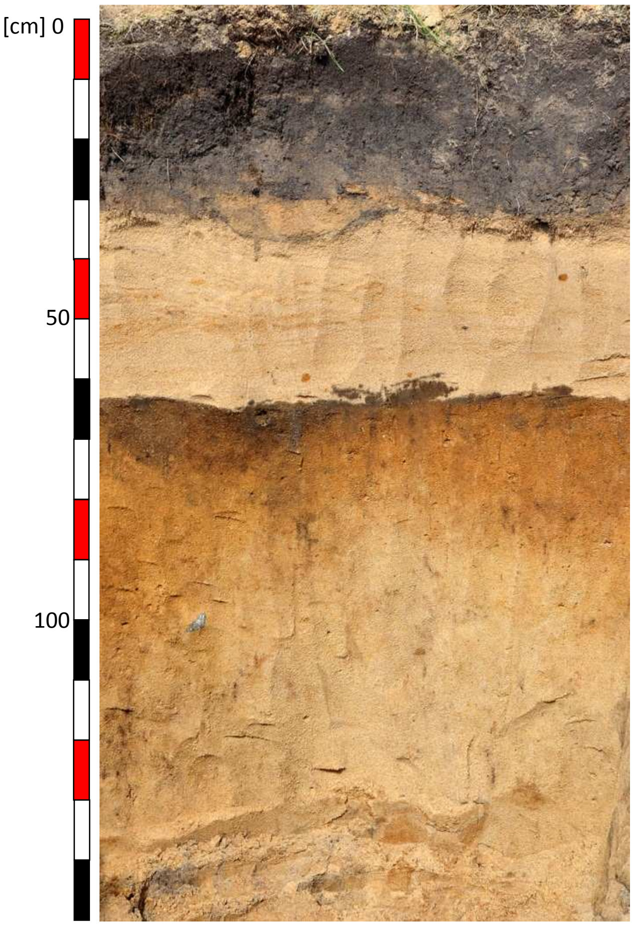
Table 5. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	C/N	pH		Fe_t	Fe_d	Fe_o
					H_2O	KCl	[g·kg^{-1}]		
Oi	2–1	429	16.4	26	4.8	4.2	-	-	-
Oe	1–0	465	17.8	26	4.2	3.5	-	-	-
A	0–13	9.30	0.48	19	4.2	3.8	4.11	1.97	0.90
AB	13–30	4.20	0.24	18	4.5	4.0	4.23	1.92	0.96
Bw	30–60	-	-	-	4.9	4.4	4.36	2.05	0.84
C	60–(130)	-	-	-	5.5	4.9	2.29	0.94	0.35

Table 6. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	BS [%]
		[cmol(+)·kg^{-1}]							
Oi	2–1	22.9	3.05	2.24	0.540	28.7	75.2	103	28
Oe	1–0	16.2	1.94	2.35	0.630	21.2	89.4	110	19
A	0–13	0.120	0.077	0.053	0.026	0.276	9.04	9.32	3
AB	13–30	0.107	0.050	0.071	0.032	0.260	4.76	5.02	5
Bw	30–60	0.033	0.025	0.014	0.025	0.097	1.89	1.99	5
C	60–(130)	0.049	0.015	0.010	0.011	0.085	1.03	1.11	8

Profile 3 – Haplic **Umbrisol** (Arenic, Transportic) over Eutric Brunic Sideralic **Arenosol**
Localization: Pleistocene terrace, flat terrain with slopes < 1°, grass vegetation, 44 m a.s.l.,
N 53°01'45", **E** 19°32'13"



Morphology:

Ah1 – 0–20 cm, humus horizon, fine sand, black (7.5YR 3/1; 10YR 2.5/1), dry, moderate granular fine structure, fine common roots, clear and smooth boundary;

Ah2 – 20–31 cm, humus horizon, fine sand, dark gray (7.5YR 5/1; 10YR 4/1), dry, moderate granular fine structure, fine few roots, abrupt and smooth boundary;

Cu – 31–62 cm, human transported material, fine sand, yellow (10YR 8/4; 10YR 7/6), dry, single grain structure, very few soft ferruginous concretions, abrupt and smooth boundary;

Ab – 62–64 cm, buried humus horizon, fine sand, brown (7.5YR 5/2; 7.5YR 4/3), slightly moist, weak granular fine structure, clear and wavy boundary;

Bwb – 64–90 cm, pedogenetic *in situ* concentration of sesquioxides, fine sand, strong brown (7.5YR 7/8; 7.5YR 5/8), slightly moist, weak granular very fine/single grain structure, very few stones, diffuse and wavy boundary;

C – 90–(150) cm, parent material, fine sand, very pale brown (10YR 8/4; 10YR 7/4), slightly moist, single grain structure, few decayed roots.

Table 7. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
Ah1	0–20	1	3	30	48	14	3	1	1	1	0	FS
Ah2	20–31	1	4	27	51	14	2	1	1	0	0	FS
Cu	31–62	1	4	23	48	17	3	2	2	1	0	FS
Ab	62–64	0	1	15	54	22	4	3	0	1	0	FS
Bwb	64–90	3	5	19	50	17	4	2	1	1	1	FS
C	90–(150)	1	4	16	52	20	3	3	1	0	1	FS

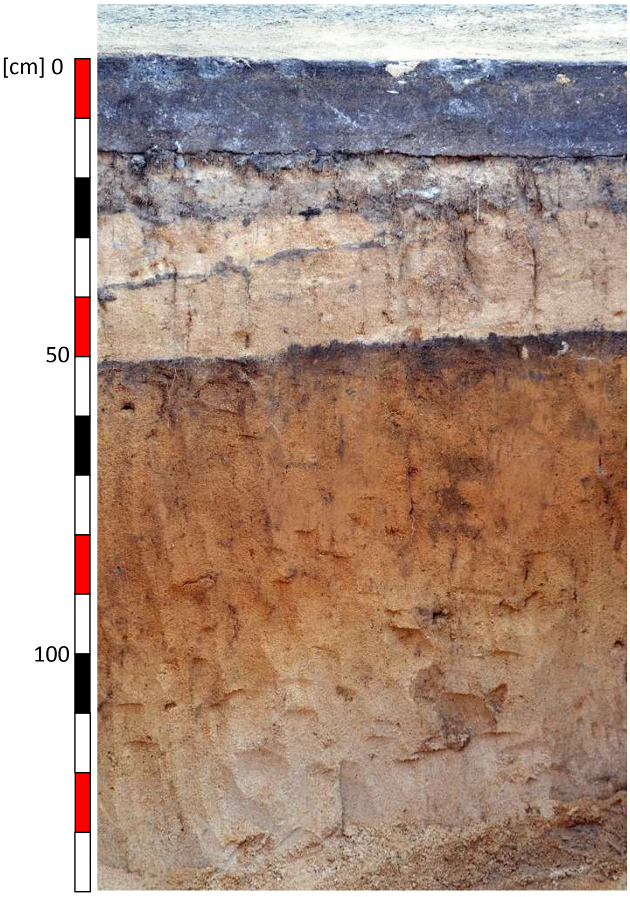
Table 8. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	C/N	pH		$CaCO_3$ [g·kg^{-1}]
					H_2O	KCl	
Ah1	0–20	22.9	1.69	14	6.3	6.2	0.0
Ah2	20–31	11.2	0.76	15	6.5	6.3	0.0
Cu	31–62	-	-	-	7.0	6.2	2.0
Ab	62–64	6.20	0.37	17	6.9	6.0	1.0
Bwb	64–90	-	-	-	6.6	5.9	0.0
C	90–(150)	-	-	-	6.5	5.9	0.0

Table 9. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	BS [%]
		[cmol(+)·kg^{-1}]							
Ah1	0–20	1.12	0.352	0.189	0.167	1.83	2.40	4.23	43
Ah2	20–31	0.952	0.280	0.255	0.146	1.63	0.94	2.57	63
Cu	31–62	0.620	0.130	0.137	0.120	1.01	0.052	1.06	95
Ab	62–64	0.912	0.143	0.153	0.053	1.26	0.165	1.42	88
Bwb	64–90	0.176	0.091	0.123	0.025	0.415	0.084	0.499	83
C	90–(150)	0.048	0.024	0.020	0.011	0.103	0.023	0.126	82

Profile 4 – Ekranic **Technosol** (Eutric, Arenic, Transportic) over Eutric Brunic Sideralic **Arenosol**
Localization: Pleistocene terrace, flat terrain with slopes < 1°, airstrip, 44 m a.s.l.,
N 53°01’45”, **E** 19°32’14”



Morphology:

THM – 0–15 cm, technic hard material - concrete slab;

A/C – 15–25 cm, human transported material mixed with humus layers, fine sand, grayish brown (10YR 6/2; 10YR 5/2), dry, weak granular very fine structure, fine common roots, common soft ferruginous concretions, very few artefacts, abrupt and smooth boundary;

Cu – 25–52/48 cm, human transported material, fine sand, yellow (10YR 8/4; 10YR 7/6), dry, single grain structure, common soft ferruginous concretions, abrupt and smooth boundary;

Ab – 52/48–55/53 cm, buried humus horizon, fine sand, brown (7.5YR 5/2; 7.5YR 4/3), slightly moist, weak granular fine structure, clear and wavy boundary;

Bwb – 55/53–95 pedogenetic *in situ* concentration of sesquioxides, fine sand, strong brown (7.5YR 7/8; 7.5YR 5/8), slightly moist, weak granular very fine/single grain structure, very few stones, few decayed roots, diffuse and wavy boundary;

C – 95–(140) cm, fine sand, very pale brown (10YR 8/4; 10YR 7/4), slightly moist, single grain structure, few decayed roots.

Table 10. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
A/C	15–25	1	3	25	56	14	1	1	0	0	0	FS
Cu	25–52/48	0	2	14	48	29	2	1	1	1	2	FS
Ab	52/48–55/53	1	0	10	51	28	3	4	2	1	1	FS
Bwb	55/53–95	1	3	16	52	22	4	1	2	0	0	FS
C	95–(140)	2	2	13	48	27	6	3	1	0	0	FS

Table 11. Chemical and physicochemical properties

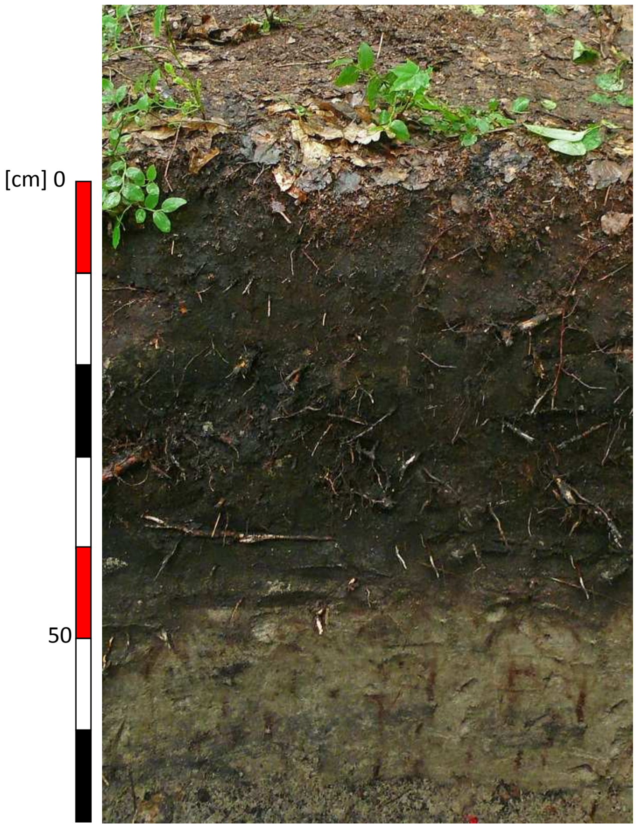
Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	C/N	pH		$CaCO_3$ [g·kg^{-1}]
					H_2O	KCl	
A/C	15–25	3.44	0.18	19	8.7	8.5	trace
Cu	25–52/48	1.12	0.06	19	7.5	7.1	trace
Ab	52/48–55/53	4.10	0.18	23	7.0	6.4	trace
Bwb	55/53–95	-	-	-	6.3	5.6	-
C	95–(140)	-	-	-	6.2	5.7	-

Table 12. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	BS [%]
		[cmol(+)·kg^{-1}]							
A/C	15–25	1.35	0.448	0.115	0.084	2.00	0.94	2.94	68
Cu	25–52/48	0.548	0.253	0.094	0.093	0.988	0.092	1.08	91
Ab	52/48–55/53	0.846	0.305	0.104	0.076	1.33	0.26	1.59	84
Bwb	55/53–95	0.420	0.104	0.095	0.032	0.651	0.093	0.744	88
C	95–(140)	0.155	0.076	0.052	0.020	0.303	0.014	0.317	96

Profile 5 – Dystric Murshic **Histosol**

Localization: Pleistocene terrace, lower part of vast and shallow depression with slopes < 2°, mixed forest, 39 m a.s.l., **N** 53°2'24", **E** 18°30'38"



Morphology:

Ha1 – 0–20 cm, *histic* horizon, highly decomposed organic material, dark olive brown (2.5Y 4/1; 2.5Y 3/3), slightly moist, moderate granular medium structure, fine and medium common roots, common oximorphic mottles, clear and smooth boundary;

Ha2 – 20–45 cm, *histic* horizon, highly decomposed organic material, black (2.5Y 3/1; 2.5Y 2.5/1), moist, moderate granular medium structure, fine and medium common roots, few oximorphic mottles, clear and smooth boundary;

Br1 – 45–60 cm, fine sand, light grayish olive (5Y 6/2; 10Y 6/2), moist, single grain structure, fine and very few roots, many ferruginous soft concretions, strong reduction, clear and smooth boundary;

Br2 – 60–70 cm, fine sand, greenish gray (GLEY1 5GY 6/1; GLEY1 5GY 5/1), moist, single grain structure, fine and very few roots, strong reduction, many ferruginous soft concretions.

Table 10. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
Br1	45–60	3	17	32	38	10	2	1	0	0	0	FS
Br2	60–(70)	2	20	27	42	8	1	2	0	0	0	FS

Table 11. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	C/N	pH	
					H_2O	KCl
Ha1	0–20	194	7.32	27	5.3	4.8
Ha2	20–45	273	9.20	30	5.5	4.9
Br1	45–60	-	-	-	5.8	5.1
Br2	60–(70)	-	-	-	6.1	5.4

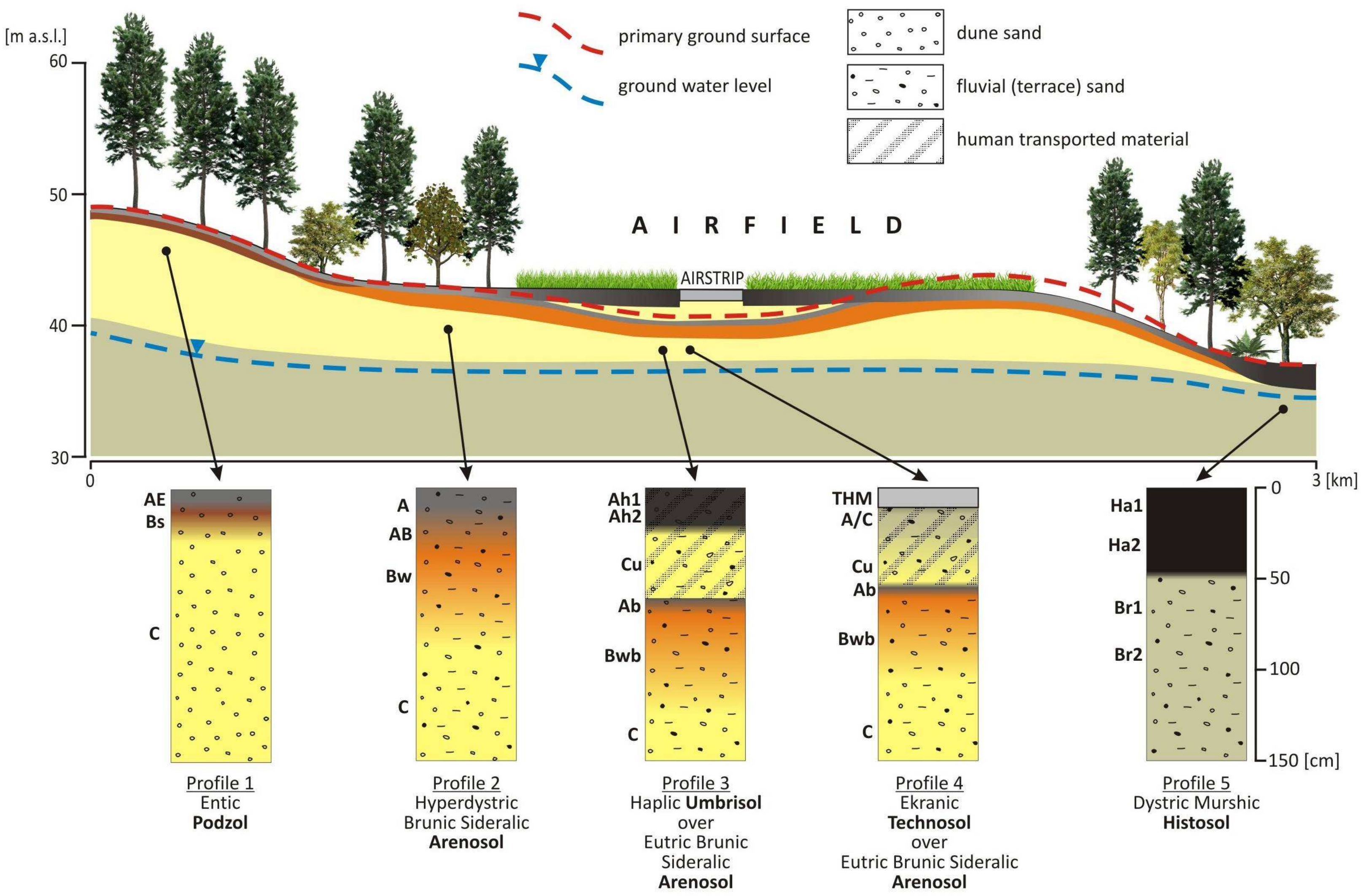


Fig. 2. Technosequence of soils within Toruń Airfield and its surroundings

Climate

The region is located in the cool temperate moist climate zone (IPCC, 2006). According to Köppen–Geiger Climate Classification, the region is located in the warm temperate, fully humid zone with warm summer (Kottek et al., 2006). The average annual air temperature for the period of 1951–2000 is 7.9°C. The warmest month is July (18.1°C). The mean air temperature during January (the coldest winter month) is -2.2°C. The average annual precipitation slightly exceeds 520 mm. July is the wettest month with average precipitation around 90 mm (Wójcik and Marciniak, 2006).

Soil genesis and systematic position

Field studies were conducted in the north-western part of the city, within the Toruń airfield and in its vicinity. The airfield area is situated on terrace IV of the Vistula River (Niewiarowski and Weckwerth, 2006). The contemporary airfield infrastructure (two airstrips in the shape of the letter "T") was built during World War II (Słowiński, 1983). At present, the Pomeranian Flying Club (in Polish: Aeroklub Pomorski) operates in the airfield.

All of the studied pedons in the described area belong to "extremely" sandy soils. Despite very similar properties and high homogeneity of mineral substrate, individual soil pits represent different soil units expressing different stages of development and direction of soil-forming processes. The first profile was located on the top of a small dune covered with a pine monoculture. Combination of the humid climate (endopercolative water regime), acidic reaction of the aeolian sands and the influence of the pine wood led to the podzolization process. As a result of this process the illuvial *spodic* horizon develops, which allows to classify the soil as **Podzol** (IUSS Working Group WRB, 2014). The frequent occurrence of this type of soils was reported in many studies conducted in the Toruń Basin (e.g. Jankowski and Bednarek, 2000; Bednarek and Jankowski, 2006; Jankowski, 2014) The age of the discussed soil is young. The beginning of its development is probably associated with the last planting of tree seedlings, (ca. 80–100 years ago). Lack of the clearly visible eluvial horizon (***Entic*** principal qualifier) confirms the immature stage of soil evolution. Solum of the primeval pedon was probably truncated during the clear cutting.

The second soil profile is also a forest soil and has a morphology similar to the previous one. Nevertheless, there were no manifestations of podzolization. The humus horizon overlaid directly the B horizon and was not depleted of iron compounds. Clearly visible, by its brownish discoloration, horizon Bw has a residual (in situ) concentration of sesquioxides (Jankowski, 2003). In the absence of any diagnostic horizons, this soil with a sandy texture has been defined as **Arenosol**. Accumulation of sesquioxides in the central section is expressed on the second level of systematic position by using the qualifier ***Brunic***. Relatively low CEC combined with high chroma indicates high saturation of the sorption complex with iron and aluminium cations in the Bw horizon (***Sideralic*** principal qualifier). This reflects low fertility of the soil as well as the qualifier ***Hyperdystric*** which emphasized its high acidity (base saturation < 20%).

Profile 3 was located in the immediate vicinity of the air strip in the middle part of the airfield. It consists of two pedons: buried **Arenosol** covered by younger **Umbrisol**. Properties and what is connected with this systematic position of the buried soil are very close to Profile 2. The main difference consists in almost complete lack of the humus horizon, which probably was destroyed during levelling of airfield surface. Originally, this place was a shallow depression filled with sandy sediments (***Arenic***) taken with the aid of machinery from a source area outside the immediate vicinity (***Transportic***). The beginning of the surface soil development can be dated to the period of airfield construction − the first decade of the 20th century. A dense grass cover led to the evolution of a deep, humus-rich surface horizon with a favourable structure, which due to its low base saturation has been classified as *umbric*.

The next soil pit (Profile 4) shows the soil sealed by a concrete slab (technic hard material) which is part of the air strip. According to WRB, a pedon isolated from the external environment by concrete slabs or other continuous materials resulting from industrial processes must be defined as ***Ekranic*** **Technosol.** The air strip lies directly on the human transported (***Transportic***) sandy (***Arenic***) material which was slightly transformed by pedogenesis. Natural **Arenosol** that existed here before the construction of the air field starts at a depth of ca. 50 cm. The main part of this buried soil contains material with brown colour which is the result of residual concentration of sesquioxides (***Brunic***). Low cation exchange capacity of this part of soil is recorded in the ***Sideralic*** principal qualifier.

The last soil pit was located in a depression with a strong influence of ground water. The upper part of the profile (up to 45 cm depth) consists of *organic* material accumulated in the past as groundwater peat. The presence of more than 40 cm thick *histic* horizon is one of the criteria for distinguishing **Histosol.** The present-day ground water level is lower than in past. This resulted in the acceleration of humification and mineralization of *organic* material. As a result of drainage, the material is highly decomposed and has a granular structure which allows the use of ***Murshic*** principal qualifier. The *organic* material directly overlaying the fluvial sand contains many ferruginous concretions and mottling caused by ascending ground water.

Soil sequence

All described pedons significantly differ in terms of pedo- or lithogenesis. Profiles 1, 2, and 5 represent semi-natural soils with different evolution ways indirectly related to relief. However, the topography in the described area reflects changes in lithology and hydrological conditions. Convex, positive forms (dunes) are composed of aeolian sand poor in nutrients and therefore are covered with pine monocultures. Combination of these environmental components led to the development of **Podzols**. Flat terraces built of Pleistocene fluvial sands are slightly more fertile habitats of mixed forests. In such conditions, **Arenosols** with residual accumulation of sesquioxides dominate. **Histosols** evolved within depressions with shallow ground water. The above mentioned Reference Soil Groups form **lithohydrotoposequence**. The situation is further complicated by the influence of human activities. Pedons located within borders of the airfield exhibit significant alterations associated with: (i) previous levelling treatments, (ii) sealing by concrete slabs of the air strip and (iii) changing of vegetation. Translocated sandy material (used to fill former depressions) fulfils the function of parent material of "man made" surface soils – **Umbrisols** covering the buried ***Brunic Sideralic*** **Arenosols**. Significant accumulation of organic matter in the surface of relocated mineral material results from planting the grass vegetation. Originally dune forms and flat terrace plains covered with mixed forest occurred in this area. Unnatural configuration of horizons, sharp and irregular boundaries between them and widespread occurrence of buried Brunic **Arensols** as a result of levelling woks within the Toruń airfield were also described by Charzyński et al. (2013b). Pedons situated near and under the air strip have much higher pH values compared to semi-natural forest soils. Alkaline reaction of upper horizons can be caused by leaching of carbonates from a concrete slab or salt used for snow removal (Charzyński et al. 2013b). Small content of calcium cations combined with high values of pH in layers directly beneath the *technic hard* material may be related to low buffer capacity of road construction materials (Greinert, 2003). It should be noted that soils sealed by the air strip have been classified as **Technosols** because of the *technic hard* material on their surface, but compared with other technogenic soils of Toruń are poor in $CaCO_3$ and *artefacts*. This is related to the airfield location − close to the city borders – in the area with no previous building development (Charzyński et al. 2013b). Nevertheless, the spatial arrangement of the above-described soils represents an interesting example of a **technosequence**.

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Soils developed from red clays of the Lower Triassic in the north-western part of the Świętokrzyskie Mountains

Zbigniew Zagórski, Monika Kisiel

The Świętokrzyskie Mountains (also known as Holy Cross Mountains) are located in the south of Poland in the central part of the Kielce Upland (Fig. 1). Due to the specific geological structure, this is one of the few places where you can observe rock outcrops of older origin on the surface. A large variety of rocks significantly affects the heterogeneity of soil cover in the Świętokrzyskie Mountains. Due to the direct vicinity of older rocks such as e.g. massive Triassic rocks and loose Quaternary deposits, soils specific to mountains can be found next to soils characteristic of lowland areas.

Fig. 1. Location

Lithology and topography

The Świętokrzyskie Mountains are low mountains. The elevation of the main range − Łysogóry − is 500 to 612 m a.s.l. Other ranges are much lower. In this case, the term "mountains" is associated with the geological structure rather than with the landscape. This stems primarily from the fact that both the relative and absolute altitudes do not correspond to the notion of mountains. Only Łysogóry can be described as a low mountain range (Kondracki, 1998). The lowest lying areas are associated with the valleys of rivers and streams. The lowest point in the north-eastern part of the Świętokrzyskie Mountains, is the area of the tributary of the Kamienna River located northwest of Suchedniow (240.6 m a.s.l.). Lower Triassic *(Buntsandstein)* sediments occupy an area of about 500 km^2. They occur as red clay and sandstones, uniform rock formations on the surface, or local outcrops in the vicinity of rocks of different genesis (Barczuk, 1979). There is a clear association of their occurrence with geomorphological forms – the peaks of hills, ridges, slopes or denudation surfaces.

Land use

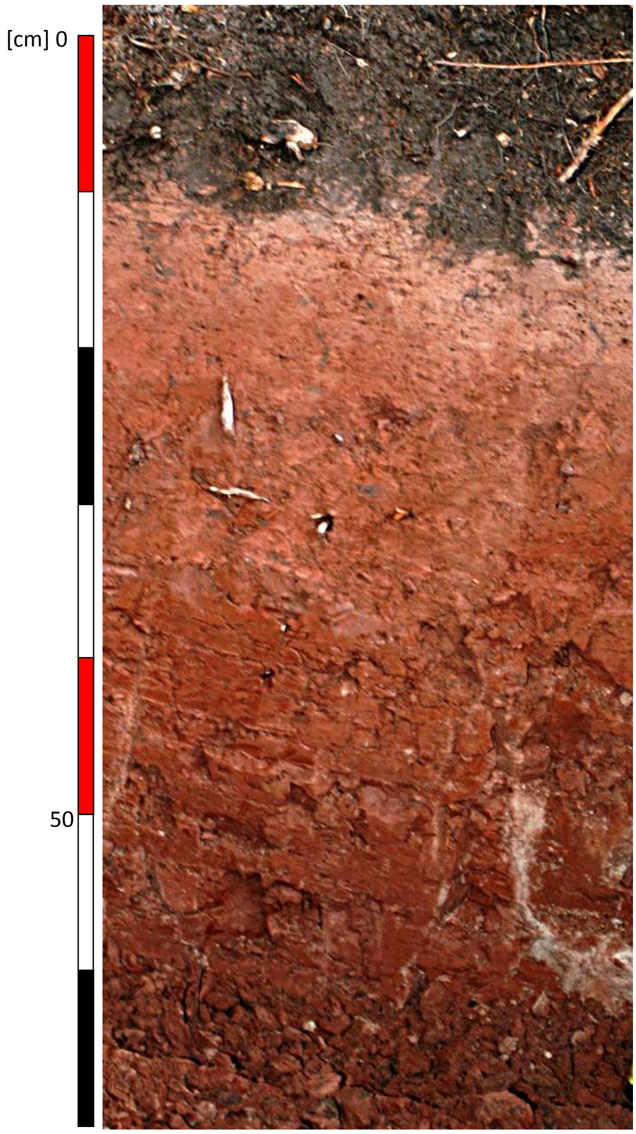
The north-western part of the Świętokrzyskie Mountains is located within the precincts of Suchedniowsko-Oblęgorski Landscape Park. Forests which were once part of the former Jodłowa Forest dominate in the area. The predominant type of plant communities occurring on the lower Triassic sediments are fir forests (*Abietetum polonicum*) and fir-beech forests (*Fagetum carpaticum*).

Climate

The area of the Świętokrzyskie Mountains is located within the middle climate zone of Poland. It is characterised by a transitional climate between Central Europe and subcontinental climates. It has climatic features characteristic of the macroregion of low mountains. The average annual air temperature ranges between 6°C and 7°C, and precipitation ranges from 650 to 800 mm (Lewartowska, 1985).

Profile 1 – Chromic, Leptic **Alisol** (Clayic)

Localization: flat summit of hill, Lower Triassic sediments (clays or claystones with siltstone), beech-fir forest with an admixture of birch, 407 m a.s.l., **N** 51°01'20"; **E** 20°44'02''



Morphology:

A – 0–10 cm, humus horizon, loamy sand, very dark reddish brown (10R 2/2), slightly moist, moderate aggregate crumb medium structure, numerous coarse and medium roots of trees, clear and wavy boundary;

EB – 10–20/25 cm, transitional horizon, sandy loam, dull reddish orange (10R 6/3; 10R 6/4), slightly moist, moderate aggregate subangular medium structure, few coarse roots of trees, gradual and smooth boundary;

Bt – 20/25–42 cm, *argic* horizon, sandy loam, red (10R 5/6), slightly moist, strong aggregate angular coarse structure, common faint clay coatings, gradual and smooth boundary;

C – 42–60 cm, parent material, clay, dark red (10R 3/6), slightly moist, strong aggregate prismatic medium structure, in some places encountered gaps filled with sand light reddish gray (10R 7/1);

R – 60–(70) cm, *continuous rock.*

Table 1. Texture

Horizon	Depth [cm]	Percentage of fraction [mm]									Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.002	< 0.002	
A	0–10	13	2	4	19	37	11	9	12	6	LS
EB	10–20/25	4	4	5	16	32	13	7	13	10	SL
Bt	20/25–42	2	1	4	14	29	14	4	18	16	SL
C	42–60	0	0	0	1	1	2	5	32	59	C

Table 2. Chemical and physicochemical properties

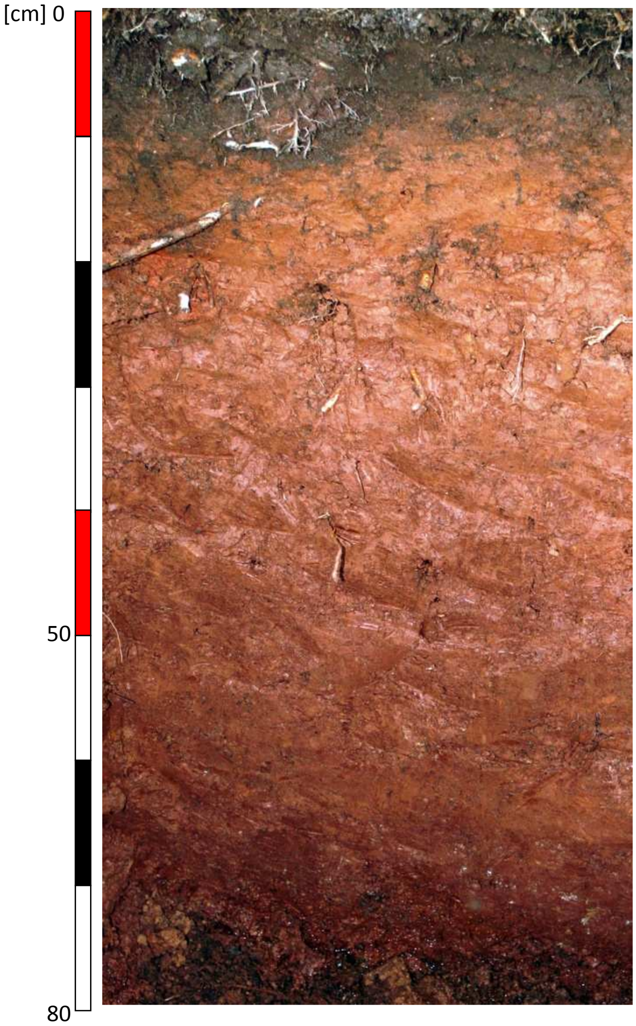
Horizon	Depth [cm]	OC [g·kg^{-1}]	pH	
			H_2O	KCl
A	0–10	18.7	3.9	3.0
EB	10–20/25	2.5	4.3	3.2
Bt	20/25–42	2.9	4.3	3.2
C	42–60	-	4.1	3.0

Table 3. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	CEC_{clay}	BS [%]
		[cmol(+)·kg^{-1}]								
A	0–10	0.345	0.103	0.027	0.005	0.481	6.99	7.47	15.4	6
EB	10–20/25	0.126	0.038	0.021	0.008	0.193	4.10	4.29	34.2	4
Bt	20/25–42	0.174	0.048	0.025	0.005	0.253	6.71	6.96	37.2	4
C	42–60	0.483	0.265	0.064	0.016	0.828	7.54	8.36	14.2	10

Profile 2 – Dystric Chromic Leptic **Cambisol** (Clayic, Colluvic)

Localization: lower slope (foot slope) 2°, Lower Triassic colluvial sediments (clay or mudstone), beech-fir forest with an admixture of alder and buckthorn, 385 m a.s.l.
N 51°01'46"; **E** 20°44'03''



Morphology:

A – 0–10 cm, colluvic material, humus horizon, sandy clay loam, dark reddish gray (10R 3/1), slightly moist, moderate aggregate crumb medium structure, individual stones in the lower section, clear and wavy boundary;

Bw1 – 10–20 cm, colluvic material, *cambic* horizon, silty clay loam, reddish orange (10R 6/6), slightly moist, strong aggregate angular medium structure, individual medium common roots, clear and smooth boundary;

Bw2 – 20–50 cm, colluvic material, *cambic* horizon, silty clay, reddish orange (10R 6/6; 10R 6/8), slightly moist, strong aggregate angular coarse structure, gradual and smooth boundary;

C – 50–80 cm, clay, red (10R 4/6), slightly moist, strong prismatic coarse structure;

R – 80–(90) cm, *continuous rock*.

Table 4. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]									Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.002	< 0.002	
A	0–10	1	2	4	19	26	5	6	16	22	SCL
Bw1	10–20	0	1	1	6	4	10	8	34	36	SiCL
Bw2	20–50	0	0	1	2	1	6	10	37	43	SiC
C	50–80	0	0	1	2	1	13	6	31	46	C

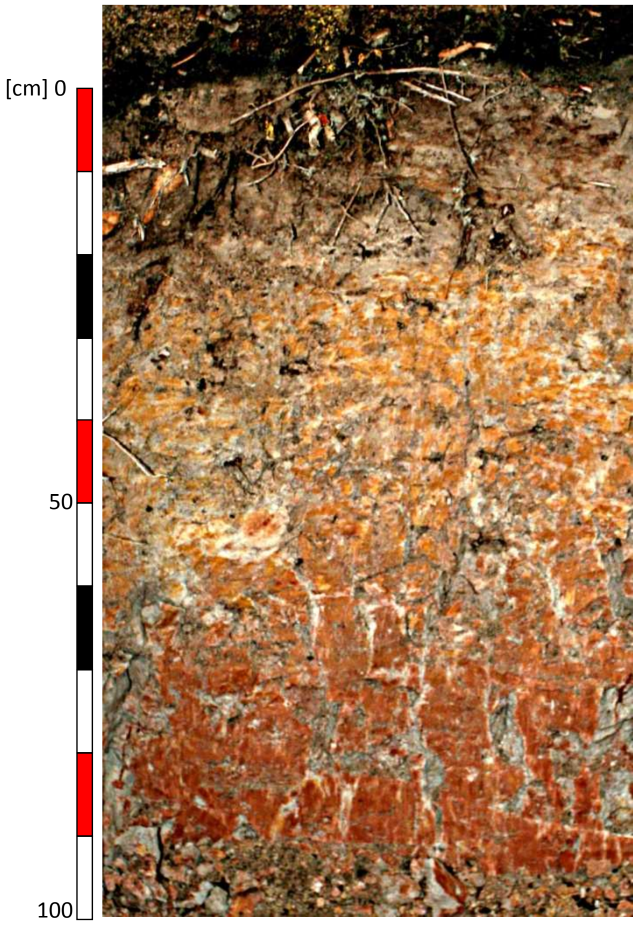
Table 5. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	pH	
			H_2O	KCl
A	0–10	40.2	4.0	3.3
Bw1	10–20	3.7	4.2	3.1
Bw2	20–50	-	4.4	3.1
C	50–80	-	4.5	3.2

Table 6. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	CEC_{clay}	BS [%]
		[cmol(+)·kg^{-1}]								
A	0–10	0.331	0.266	0.043	0.005	0.646	13.7	14.4	1.50	4
Bw1	10–20	0.431	0.564	0.049	0.005	1.050	7.45	8.50	20.0	12
Bw2	20–50	0.937	1.345	0.061	0.008	2.351	11.25	13.6	31.6	17
C	50–80	1.990	1.727	0.059	0.005	3.781	8.84	12.6	27.4	30

Profile 3 – Dystric Vertic **Stagnosol** (Epiloamic, Endoclayic, Chromic)
Localization: flat summit of hill – planation surface, Lower Triassic sediments (clays), fir forest, 330 m a.s.l., **N** 50°59'47"; **E** 20°35'09''



Morphology:

Ah – 0–10 cm, humus horizon, sandy loam, light brownish gray (5YR 7/1), slightly moist, weak aggregate crumb medium structure, medium and fine common tree roots, very few stones in lower section, gradual and smooth boundary;

AEg – 10–20 cm, humus horizon with features of eluviation, sandy loam, mottling: brown (7.5YR 4/6) and brownish gray (5YR 6/1) humus damp patch - stagnic properties, slightly moist, moderate aggregate subangular medium structure, few coarse pebbles in lower section (residual pavement?), boundary clear and wavy;

Btg – 20–45 cm, *argic* horizon, loam, orange (2.5YR 6/8, 2.5YR 7/8), in the cracks and gaps light bluish gray (5BG 7/1) stagnic properties, slightly moist, moderate subangular coarse structure, common faint clay coatings, gradual and smooth boundary;

Btgi – 45–70 cm, *argic* and *vertic* horizon, clay, reddish orange (10R 6/6), in the lower parts reddish brown (10R 4/4), in the cracks bluish gray (5 BG 6/1) stagnic properties, slightly moist, strong aggregate angular medium structure, slickensides and *shrink-swell cracks*, clear and irregular boundary;

Bgi – 70–(100) cm, clay, red (10R4/8), in the cracks bluish gray (5BG 6/1) - stagnic properties, slightly moist, strong aggregate prismatic coarse structure, slickensides and *shrink-swell cracks*.

Table 7. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]									Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.002	< 0.002	
Ah	0–10	3	0	5	12	29	7	10	18	19	SL
AEg	10–20	12	0	3	13	29	8	9	20	18	SL
Btg	20–45	0	1	2	10	22	6	10	23	26	L
Btgi	45–70	0	0	2	10	16	8	6	17	41	C
Bgi	70–(100)	0	0	1	3	0	10	8	24	54	C

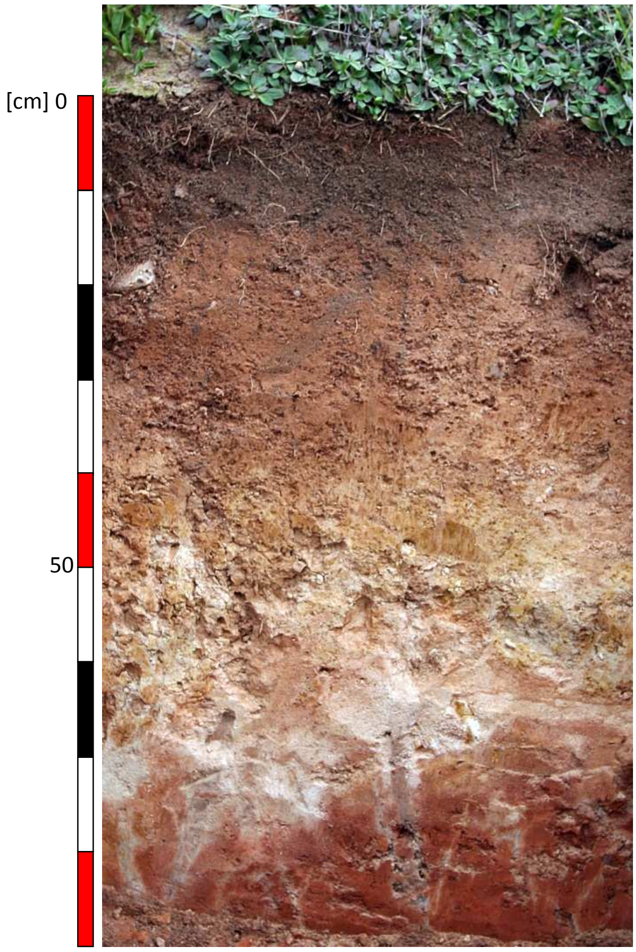
Table 8. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	pH	
			H_2O	KCl
Ah	0–10	79.8	3.2	2.6
AEg	10–20	17.9	3.3	2.7
Btg	20–45	8.0	3.4	2.9
Btgi	45–70	4.8	3.6	2.9
Bgi	70–(100)	1.9	3.8	3.0

Table 9. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	CEC_{clay}	BS [%]
		[cmol(+)·kg^{-1}]								
Ah	0–10	0.781	0.315	0.083	0.006	1.185	17.4	18.5	0	6
AEg	10–20	0.059	0.058	0.015	0.007	0.139	14.0	14.1	43.5	1
Btg	20–45	0.127	0.060	0.029	0.005	0.221	11.5	11.2	32.3	2
Btgi	45–70	0.059	0.119	0.034	0.007	0.218	11.3	11.5	24.0	2
Bgi	70–(100)	0.169	0.413	0.066	0.005	0.654	9.7	10.3	17.8	6

Profile 4 – Dystric Chromic Stagnic Endogleyic **Cambisol** (Epiloamic, Endoclayic, Ruptic)
Localization: the edge of erosive depression, Lower Triassic sediments (loams and clays), mixed forest, mine of clay, 310 m a.s.l., **N** 51°01'02"; **E** 20°37'19''



Morphology:

Ah – 0–12 cm, humus horizon, sandy clay loam, reddish gray (10R 5/1), dry, weak aggregate crumb-granular medium structure, fine common roots, gradual and wavy boundary;

Bw – 12–40 cm, *cambic* horizon, sandy loam, red (10R 4/4), slightly moist, moderate aggregate subangular medium structure, gradual and smooth boundary;

2Eg – 40–70 cm, eluvial horizon, loamy fine sand, upper section – bright reddish brown (5YR 5/8), lower section – light reddish grey (10R 7/1) – a few reductomorphic features (mottles, fine ferruginous concretions) medium wet, moderate aggregate subangular medium structure, clear and wavy boundary;

3BCl – 70–(90) cm, heavy clay, dark red (10R 3/6) in the cracks bluish gray (5BG 7/1), medium wet, gleyic properties, strong aggregate prismatic structure.

Table 10. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]									Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.002	< 0.002	
Ah	0–12	1	3	7	9	23	19	12	8	19	SCL
Bw	12–40	1	6	4	11	28	17	11	7	16	SL
2Eg	40–70	12	5	9	16	39	11	4	8	8	LFS
3BCl	70–(90)	0	1	0	1	1	2	4	28	63	HC

Table 11. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	pH	
			H_2O	KCl
Ah	0–12	19.1	4.2	3.9
Bw	12–40	2.7	3.7	3.2
2Eg	40–70	-	4.3	3.7
3BCl	70–(90)	-	4.6	3.5

Table 12. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	TEB	HA	CEC	CEC_{clay}	BS [%]
		[cmol(+)·kg^{-1}]								
Ah	0–12	1.763	0.679	0.029	0.015	2.486	9.05	11.5	25.3	22
Bw	12–40	0.514	0.207	0.013	0.004	0.738	6.17	6.91	37.3	11
2Eg	40–70	0.641	0.589	0.066	0.011	1.306	5.88	7.19	89.9	18
3BCl	70–(90)	0.810	2.977	0.104	0.011	3.901	10.2	14.1	22.4	28

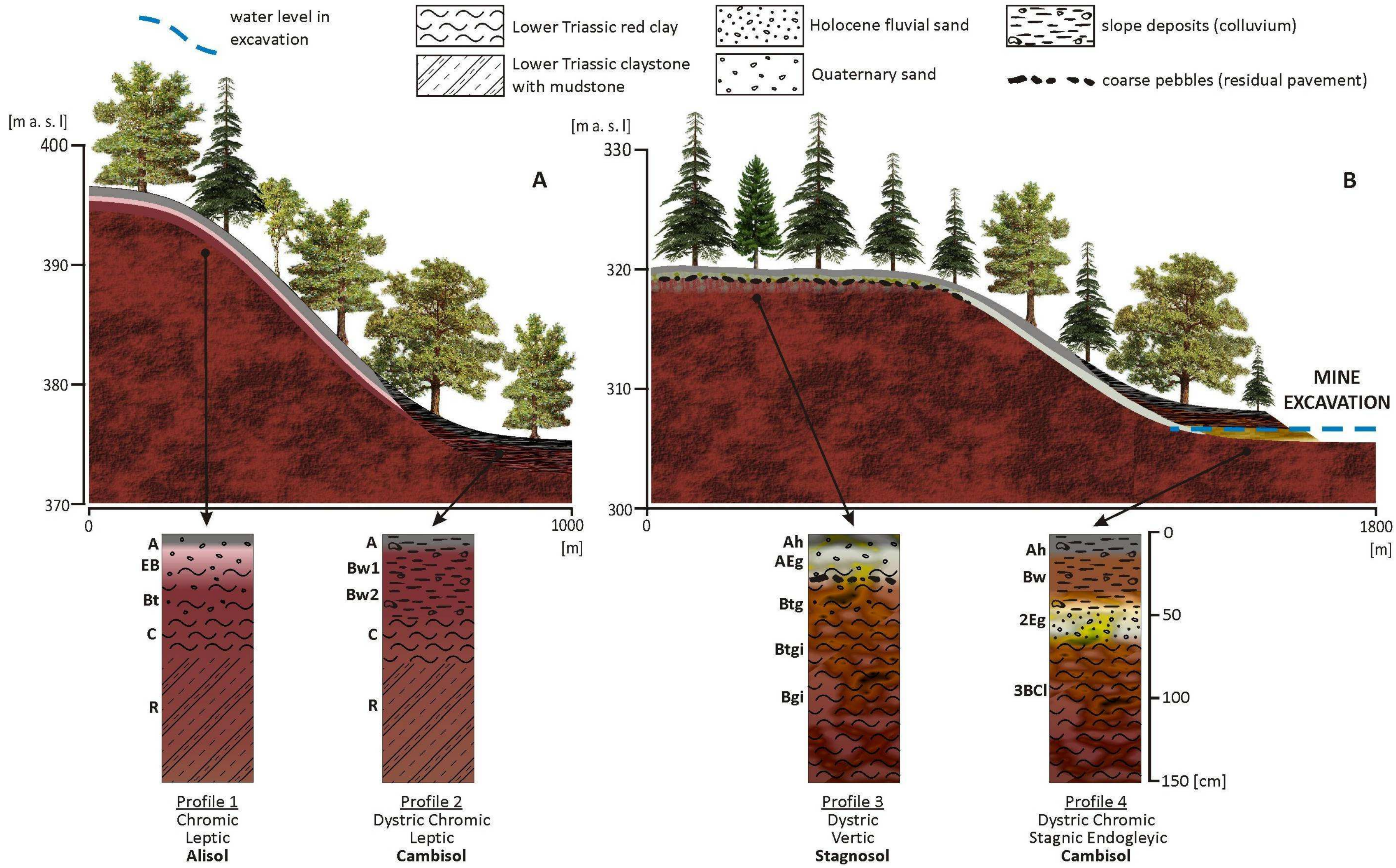


Fig. 2. Litho-toposequence (A) and hydro-litho-toposequence (B) of soils within north-western part of Świętokrzyskie Mountains

Soil genesis and systematic position

One of the major problems of soil science is to determine the relationship between the geogenic factors which include geomorphological processes, parent material, soil processes and properties. As a consequence of a large variety of rock types occurring on the surface, typologically distinct soil units developed next to each other, while the activity of geomorphological processes (past and present) largely obscures the borderline between the units or cause mutual interpenetration. Consequently, complex and complicated soil sequences occur. Following their variability is important in the determination of the WRB soil units (IUSS Working Group WRB, 2014).

Soils developed on red sediments originating from the lower Triassic are characteristic of the Świętokrzyskie Mountains. Some of lower Triassic sediments are formed as clays and mudstones *(Buntsandstein formation)*. They represent typical parent materials for developing soils due to the presence of hematite, which gives the red colour to a soil substrate (Zagórski and Kaczorek, 2002). Therefore, one of the most distinctive features of such soils is their characteristic red colour, which allows the use of the ***Chromic*** qualifier in classification according to WRB. The presented soils are also characterized by specific physicochemical properties (low pH and high exchangeable acidity), allowing the use of the ***Dystric*** qualifier. This is due to the unique properties of the Triassic rocks containing extremely small amounts of calcium and magnesium. Low content of base cations and generally low capacity of the adsorption complex − despite their heavy texture − is a property which distinguishes these soils from the others developed, for example, on Quaternary sediments. This is strictly determined by mineralogical composition of the clay fraction, in which kaolinite usually dominates (Zagórski and Brzychcy, 2009). In some profiles, stagnation of rainwater is very intense, leading to the development of *stagnic* properties and for this reason the qualifier ***Stagnic*** should be applied in many soils.

Soils formed from Lower Triassic clays in the Świętokrzyskie Mountains are always located in specific physiographic conditions and are therefore strongly modified by erosion processes. This often leads to significant shortening of soil profiles on hilltops, slopes and erosion terraces. As a consequence of truncation, the *continuous rock* starts at a depth below 100 cm from the soil surface (Profile 1 and 2 with ***Leptic*** qualifier). Colluvial accumulation of soil substrates took place in the lower parts of the slopes (soils with ***Colluvic*** qualifier).

The specific mineral-petrographic composition of the parent material, e.g., strong cementation of the clay fraction by iron compounds significantly slows down the soil-forming processes such as weathering, leaching or vertical movement of colloids. Therefore, such horizons as *cambic* or *argic* are rather poorly developed. The main feature indicating the presence of the *cambic* horizon (Bw) is the colour change as evidence of hematite weathering and pedogenic formation of subangular structure. In the case of *argic* horizons (Bt), aggregates have only a few clay coatings. Therefore, field qualification for Reference Soil Groups, such as e.g. **Cambisols** or **Alisols,** can be ambiguous. The parent material basically undergoes just the physical destruction e.g. through the freezing or drying cycles. Characteristic cracks or gaps are formed, allowing the use of ***Vertic*** the qualifier. In general, those cracks are filled with the coarser allogenic material originating from the surface. In the surface horizons of soils occurring on flat hilltops or erosion terraces generally a thin layer of residual sandy sediments occurs, often with numerous stones. It is usually a residuum after eroded Quaternary glaciofluvial sediments and glacial tills. In many cases, such soils requires the use of qualifiers ***Ruptic*** or even ***Abruptic***. Macroscopic features of these horizons (colour, texture) indicate sometimes eluviation or leaching processes, based on which they are classified as E horizons. Features of the parent material are also strongly reflected in the physical properties of soils, including mainly very low permeability of these soils. This promotes stagnation of rainwater in the upper part of soils. Water usually stagnates in cracks or spaces between large aggregates giving them reductomorphic features. The ***Stagnic*** qualifier should be used for such soils (Profile 3). Long lasting humidity can lead to mineralogical transformations of iron − the transition of hematite into lepidocrocite, and soil colour changes from red to orange (Zagórski and Kisiel, 2010). For soils located in the marginal zones of river valleys or erosion depressions, sometimes the qualifier ***Gleyic*** applies. Inserts of sand-gravel deposits can be found in the profiles of these soils with groundwater present seasonally. This results in the formation of characteristic reductomorphic features such as gleyic mottling and iron-manganese concretions (Profile 4).

Soil sequence

Described pedons show an example of soils sequences formed on lower Triassic red clay sediments in the western part of the Świętokrzyskie Mountains. The soils are arranged in a characteristic toposequence in areas with an hilly terrain. This relief is the result of local variation in the lithology of rocks (e.g. varying contribution of mudstone in silty sediments) and the past or contemporary geomorphological processes. In the area of flat-topped hills usually **Alisols** or **Luvisols** occur. They are poor shallow clayey reddish coloured soils with certain features of clay translocation (*lessivage* process). The xample of such soils is Profile 1 classified as ***Chromic Leptic*** **Alisol** ***(Clayic).*** On long slopes, at the foot of the hills, soils formed on colluvial sediments occur, which accumulated as a result of slopewash processes. They are mostly red clayey silts or silty loams with an admixture of sand, coming from the destroyed rocks in the upper part of slopes. The example of such soils is ***Dystric Chromic Leptic*** **Cambisol** ***(Clayic, Colluvic)*** – Profile 2. **Stagnosols** dominate on flat erosional planations. They are usually formed in local depressions without outflow and result from the shallow occurrence of Triassic argillaceous rocks and the lack of rainwater drainage. A characteristic feature is the presence of sand and stones on the surface of the layer being the remnant of eroded Quaternary sediments. The upper part of argillaceous rocks is exposed to intensive mechanical destruction (cracks and crevasses). In the crevices, distinct reductomorphic features occur. The example of such soils is Profile 3 − ***Dystric Vertic*** **Stagnosol** ***(Epiloamic, Endoclayic, Chromic).*** In the lower lying areas, adjacent to valleys and erosional hollows, **Cambisols** can be found with strong gleying features. Gleyic features are the result of a high level of ground water, which occurs in sandy-gravelly alluvial sediments. Inserts of these deposits often occur between red argillaceous sediments. The example of such soils is Profile − ***Dystric Chromic Stagnic Endogleyic*** **Cambisol** ***(Epiloamic, Endoclayic, Ruptic)***. Frequent changes in the soil moisture above the argillaceous parent material resulted in the formation of iron concretions and permanent reductomorphic features The presented soil sequence is a typical example of interactions between geomorphological processes and geological structure in the formation of unique soil features. In the Świętokrzyskie Mountains, similar phenomena can be observed in the case of other rock formations occurring on the surface, e.g. limestone, sandstone or shale.

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Soils in the mountain area with high activity of geomorphic processes (the Stołowe Mountains, Poland)

Jarosław Waroszewski, Cezary Kabała, Paweł Jezierski

The Stołowe Mountains are located in south-western Poland (Fig. 1) at the northern border of a large sedimentary unit – the Bohemian Massif. This mountain range has a unique morphology due to the presence of flat sandstone beds, separated from each other by steep escarpments which resulted in a table-shaped morphological formation (Migoń et al., 2011). The Stołowe Mountains are built of three series of alternating sandstones and mudstones of the Upper Cretaceous age, tectonically cut and uplifted (Wojewoda et al., 2011). Although neither the continental or mountain glaciers did not reach this area during the Pleistocene, the Stołowe Mountains were influenced by periglacial conditions, which were responsible for the development of block covers, debris flows and formation of fine-grained solifluction covers (Migoń et al., 2011; Kabała et al. 2011).

Fig. 1. Location

Lithology and topography

The altitude in the Stołowe Mountains varies from 400 m a.s.l. to 919 m a.s.l. More than 50% of the area is dominated by flat table-like highlands and slopes with inclination lower than 10°. Other 26% of the slopes have inclinations between 10° and 20°, while only 22% are steep slopes (Migoń at al., 2011). The soil catena was located in the central part of the Stołowe Mountains below the Białe Ściany rock group (cliffs). The summits and the upper part of slopes are composed of the Coniacian coarse-grained sandstones, while the slope basement is built of the mudstone/claystone complex (the Turonian/Cenomanian age).

Land use

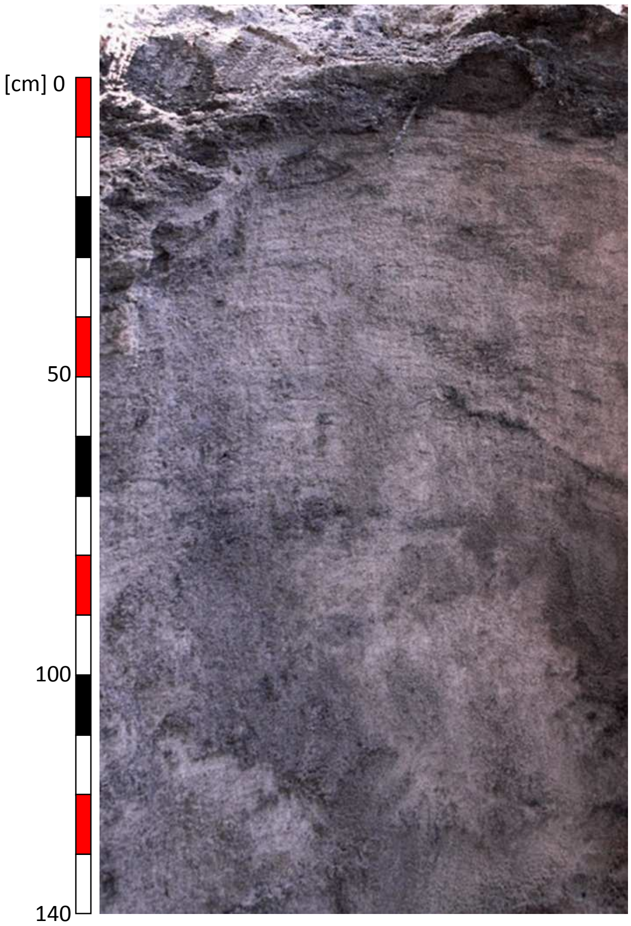
The slopes with a soil catena, like other large areas in the Stołowe Mountains are covered with the monoculture plantations of the Norway spruce (*Picea abies*) established in the 18th and 19th century (Miścicki and Jedryszczak, 2011) in place of native beech (*Fagus sylvaticus*) and fir (*Abies alba*) forests. The forest floor is dominated by bilberry (*Vaccinum myrtillus* L.) and a few species of mosses (*Pleurozium schroeberi*, *Leucobryum glaucum*, *Polytrichum commune* and *Hylocomium splendis*), in varying combinations and density/cover.

Climate

The mean annual air temperature is between 4°C and 6.5°C, in the central (higher) and in the eastern (lower) part of the massif, respectively. The coldest month is January (-3°C) and the warmest one – July (15°C). The mean annual precipitation ranges from 750 mm to 920 mm depending on the altitude (Pawlak, 2008). Snow cover persists for almost 95 days per year (depending on the altitude), between November and May.

Profile 1 – Eutric **Arenosol** (Colluvic)

Localization: accumulation cone below sandstone cliffs, steep slope (inclination 40°), open spruce forest, 780 m a.s.l., **N** 50°27’38,5”, **E** 16°21’26,4”



Morphology:

A – 0–12 cm, humus horizon, sand, dark gray (5Y 4/1), dry, single grain structure, no coarse rock fragments, clear and wavy boundary;

C1 – 12–70 cm, parent material, light gray (2.5Y 7/1), dry, single grain structure, gradual boundary, common very thin (1–2 mm) darker (humus) layers, very few sandstone fragments;

C2 – 70–(140) cm, parent material, white (2.5Y 8/1), dry, single grain structure, few thin (2–3 mm) humus pans, very few sandstone fragments.

Table 1. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
A	0–12	2	0	34	52	10	2	0	1	0	1	S
C1	12–70	0	0	33	54	8	3	0	0	0	1	S
C2	70–(140)	1	0	15	73	9	1	0	1	0	0	S

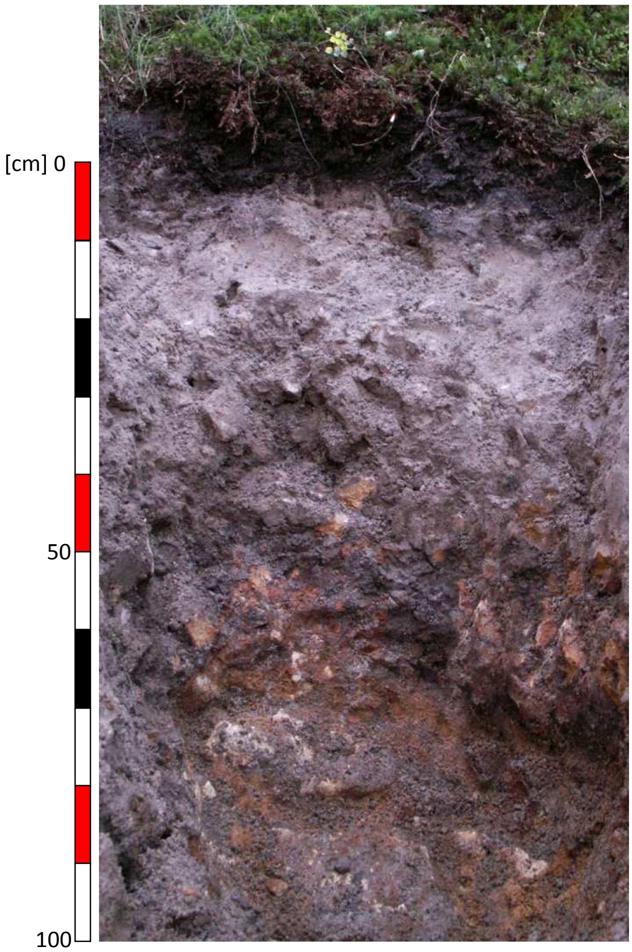
Table 2. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	pH	
			H_2O	KCl
A	0–12	1.90	3.7	3.1
C1	12–70	0.40	4.2	3.5
C2	70–(140)	0.40	4.6	4.0

Table 3. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	BS [%]
		[cmol(+)·kg^{-1}]							
A	0–12	1.31	0.31	0.02	0.09	1.7	0.54	2.3	76
C1	12–70	0.40	0.13	0.61	0.03	1.2	0.21	1.4	85
C2	70–(140)	0.30	0.10	0.65	0.01	1.1	0.06	1.1	95

Profile 2 – Skeletic Stagnic Folic Albic **Podzol** (Arenic, Densic, Ruptic)
Localization: upper part of convex slope (inclination 20°), spruce forest, 760 m a.s.l.,
N 50°27’38.7”, **E** 16°21’32.2”



Morphology:

Oe – 15–0 cm, moderately decomposed organic material, wet, sharp and clear boundary;

AEg – 0–6 cm, humus horizon, sand, gray (2.5Y 5/1), moist, very weak subangular fine structure, weak reductimorphic mottles, many (15–40% vol.) sandstone fragments, gradual and wavy boundary;

Eg – 6–25 cm, eluvial horizon with *albic* material, sand, light gray (2.5Y 7/1), moist, single-grain structure, weak reductimorphic mottles, many sandstone fragments, clear and wavy boundary;

EBg – 25–40 cm, light olive brown (2.5YR 5/3), moist, moderate subangular fine structure, moderate reductimorphic mottles, abundant (40–80% vol.) sandstone fragments, clear boundary;

Bhsd – 40–50 cm, *spodic* horizon, sandy loam, strong brown (7.5YR 4/6), moist, strong platy fine structure, abundant sandstone fragments, diffuse boundary;

Bs – 50–(100) cm, *spodic* horizon, sand, reddish yellow (7.5YR 6/8), dry, strong platy/angular fine structure, abundant sandstone fragments.

Table 4 Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
Eg	6–25	30	3	17	30	30	7	3	4	3	3	S
EBg	25–40	40	4	19	30	29	9	0	2	2	6	S
Bhsd	40–50	70	3	17	27	30	5	0	7	5	5	SL
Bs	50–(100)	80	3	19	31	30	6	1	2	4	4	S

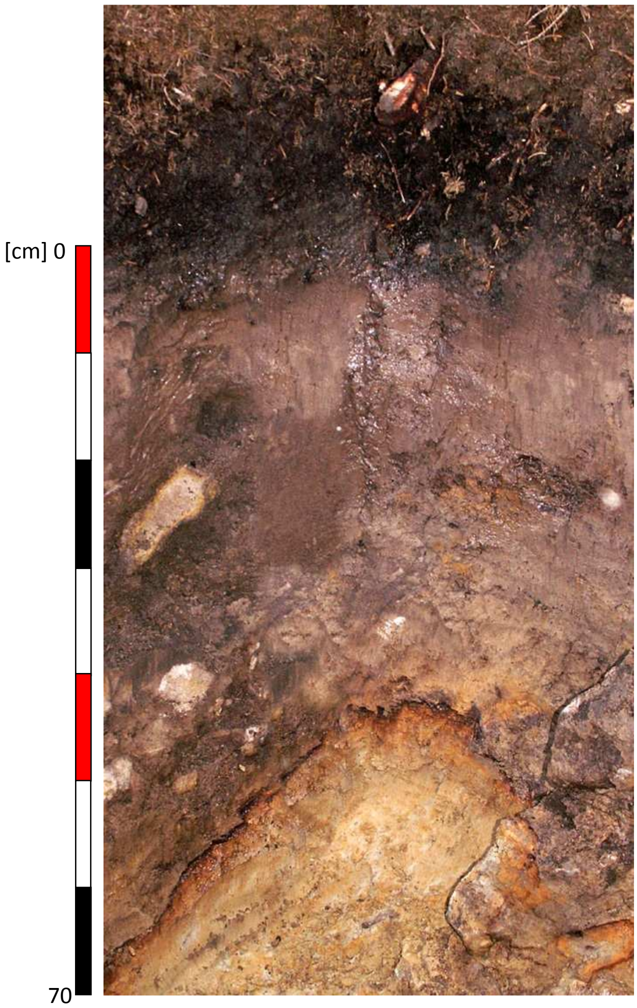
Table 5. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	pH	
			H_2O	KCl
Oe	15–0	494	3.2	2.4
AEg	0–6	3.20	3.7	3.4
Eg	6–25	1.30	3.8	3.5
EBg	25–40	0.90	3.6	3.3
Bhsd	40–50	14.8	3.7	3.3
Bs	50–(100)	4.50	4.2	4.0

Table 6. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	TEB	HA	CEC	BS [%]
		[cmol(+)·kg^{-1}]							
Oe	15–0	5.38	1.02	0.53	0.12	7.0	7.72	14.8	48
AEg	0–6	0.37	0.11	0.01	0.03	0.5	0.30	0.8	64
Eg	6–25	0.25	0.08	0.01	0.02	0.4	0.22	0.6	63
EBg	25–40	0.35	0.12	0.02	0.03	0.5	0.92	1.4	36
Bhsd	40–50	0.36	0.13	0.06	0.04	0.6	3.16	3.7	16
Bs	50–(100)	0.38	0.13	0.04	0.04	0.6	1.35	1.9	30

Profile 3 – Dystric Albic Histic **Stagnosol** (Loamic, Placic)
Localization: mid slope section (20°), spruce forest, 740 m a.s.l., **N** 50°27'41,0", **E** 16°21'33,1"



Morphology:

Oa – 22–0 cm, strongly decomposed organic material, wet, sharp boundary;

AEg – 0–4 cm, humus horizon, sandy loam, dark grayish brown (2.5Y 4/2), moist, moderate platy fine structure, reductimorphic mottles, common (5–15% vol.) sandstone fragments, clear boundary;

Eg – 4–21 cm, eluvial horizon with *albic* material, sandy loam, light brownish gray (2.5Y 6/2), wet, moderate platy fine structure, very common reductimorphic mottles, water flow at the contact of Eg and EBg horizons, common sandstone fragments, gradual boundary;

EBg – 21–42 cm, transitional horizon, sandy loam, light yellowish brown (2.5Y 6/3), wet, strong platy fine structure, very common reductimorphic mottles, many (15–40% vol.) sandstone fragments, clear boundary;

Bsm – 42–45 cm, *placic* layer, dark reddish brown (5YR 3/4), moist, sharp upper boundary;

2Cg – 42–(100) cm, parent material, sandy loam, brownish yellow (10YR 6/8), dry, strong platy/angular fine structure, common reductimorphic mottles (10YR 6/8, 5GY 7/1), common sandstone fragments.

Table 7. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
AEg	0–4	10	1	8	12	30	25	6	6	4	8	SL
Eg	4–21	10	0	1	2	31	30	7	8	6	15	SL
EBg	21–42	30	0	2	5	40	28	4	5	5	11	SL
2Cg	45–(100)	15	0	0	1	30	31	9	6	5	18	SL

Table 8. Chemical and physicochemical properties

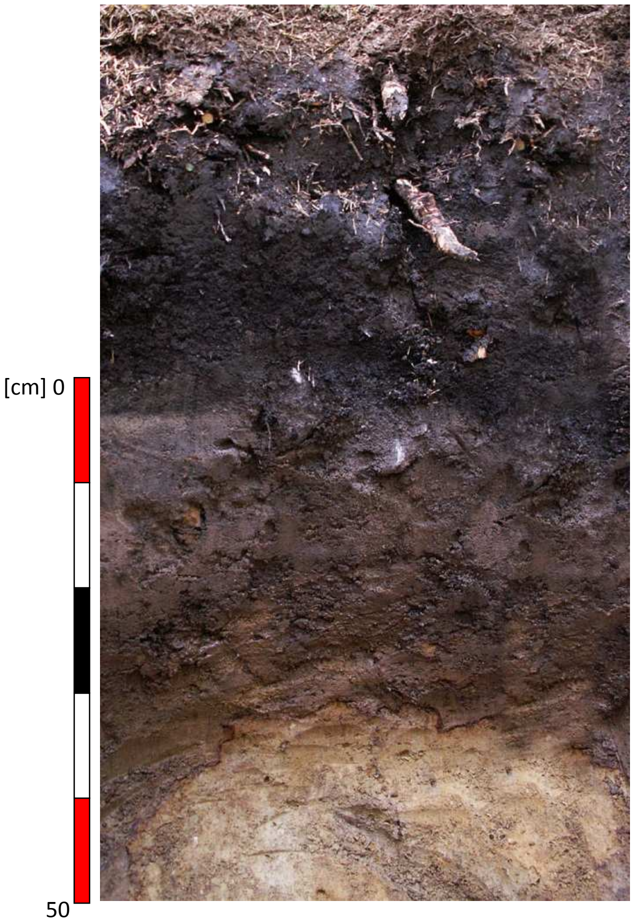
Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	pH	
			H_2O	KCl
Oa	22–0	478	3.2	2.5
AEg	0–4	11.7	3.4	2.9
Eg	4–21	3.20	3.5	3.1
EBg	21–42	2.30	3.7	3.5
2Cg	45–(100)	0.60	4.1	3.8

Table 9. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	BS [%]
		[$cmol(+) \cdot kg^{-1}$]							
Oa	22–0	0.95	0.60	0.64	0.14	2.3	8.14	10.5	22
AEg	0–4	0.40	0.15	0.05	0.04	0.6	2.57	3.2	20
Eg	4–21	1.72	0.17	0.10	0.10	2.1	2.66	4.8	44
EBg	21–42	0.41	0.14	0.06	0.04	0.6	2.71	3.4	19
2Cg	45–(100)	0.42	0.15	0.11	0.04	0.7	3.03	3.7	19

Profile 4 – Dystric Albic Histic **Planosol** (Placic, Ruptic)

Localization: foot slope (inclination 6°), spruce forest, 727 m a.s.l., **N** 50°27’44,4”, **E** 16°21’33,9”



Morphology:

Oa – 26–0 cm, strongly decomposed organic material, wet, clear boundary;

Eg – 0–16 cm, eluvial horizon with *albic* material, loamy sand, gray (2.5Y 5/1), wet, moderate angular fine structure, very common reductimorphic mottles, many (15–40% vol.) sandstone fragments, clear boundary;

2Bdg – 16–38 cm, sandy loam, olive brown (2.5Y 4/4), wet, moderate platy structure, common reductimorphic mottles, many sandstone and mudstone fragments, clear boundary;

2Bm – 38–38.4 cm, *placic* layer, dark reddish brown (5YR 3/3), moist, sharp upper boundary;

2Cd – 38.4–(100) cm, parent material, sandy loam, olive yellow/yellow (2.5Y 6–7/8), dry, moderate platy medium structure, many sandstone and mudstone fragments.

Table 10. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
Eg	0–16	10	3	16	24	29	12	6	6	0	4	LS
2Bdg	16–38	20	2	12	20	23	9	8	11	2	13	SL
2Cd	38.4–(100)	20	1	9	15	21	9	13	19	6	7	SL

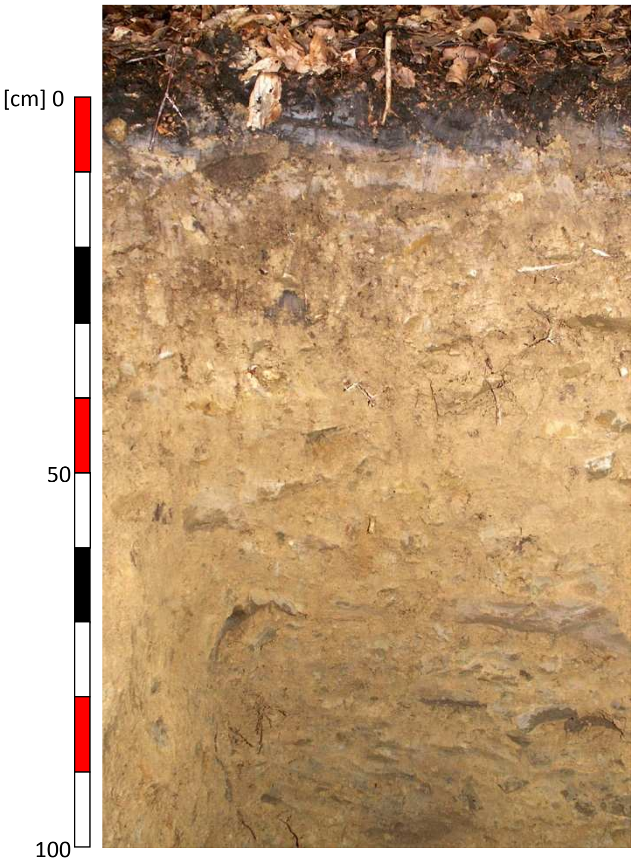
Table 11. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	pH	
			H_2O	KCl
Oa	26–0	83.5	3.4	2.7
Eg	0–16	2.80	3.9	3.5
2Bdg	16–38	8.70	3.9	3.5
2Cd	38.4–(100)	0.40	4.3	4.0

Table 12. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	BS [%]
		[cmol(+)·kg^{-1}]							
Oa	26–0	1.54	0.51	0.16	0.13	2.34	4.52	6.86	34
Eg	0–16	0.31	0.09	0.02	0.03	0.45	0.51	0.96	46
2Bdg	16–38	0.40	0.12	0.04	0.03	0.59	1.12	1.71	35
2Cd	38.4–(100)	0.50	0.17	0.04	0.05	0.76	0.81	1.57	48

Profile 5 – Dystric Endoskeletic **Cambisol** (Loamic)
Localization: plateau below slope (inclination 2°), beech forest, 715 m a.s.l.,
N 50°27’44,4”, **E** 16°21’33,9”



Morphology:

Oe – 8–0 cm, moderately decomposed organic material (forest litter), gradual boundary;

A – 0–12 cm, humus horizon, loam, dark grayish brown (10YR 4/2), strong subangular medium structure, very few mudstone fragments, gradual boundary;

Bw – 12–52 cm, *cambic* horizon, loam, dark yellowish brown (10YR 4/6), strong subangular medium structure, few mudstone fragments, gradual boundary;

C – 52–(100) cm, parent material, loam, brownish yellow (10YR 6/6), angular medium structure, common/abundant mudstone fragments.

Table 13. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]									Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.002	< 0.002	
A	0–12	2	5	8	3	26	7	11	23	17	L
Bw	12–52	5	5	6	11	19	7	9	28	15	L
C	52–(100)	15	10	8	7	27	4	13	15	16	L

Table 14. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	pH	
			H_2O	KCl
Oe	8–0	235	4.1	3.6
A	0–12	26.2	4.0	3.5
Bw	12–52	4.20	4.4	3.8
C	52–(100)	2.40	4.8	4.3

Table 15. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	CEC_{clay}	BS [%]
		[cmol(+)·kg^{-1}]								
A	0–12	1.76	0.65	0.21	0.19	2.81	3.26	6.07	35.7	46
Bw	12–52	1.90	0.73	0.28	0.19	3.10	3.06	6.16	38.5	50
C	52–(100)	6.40	1.64	0.34	0.25	8.67	2.23	10.90	72.7	80

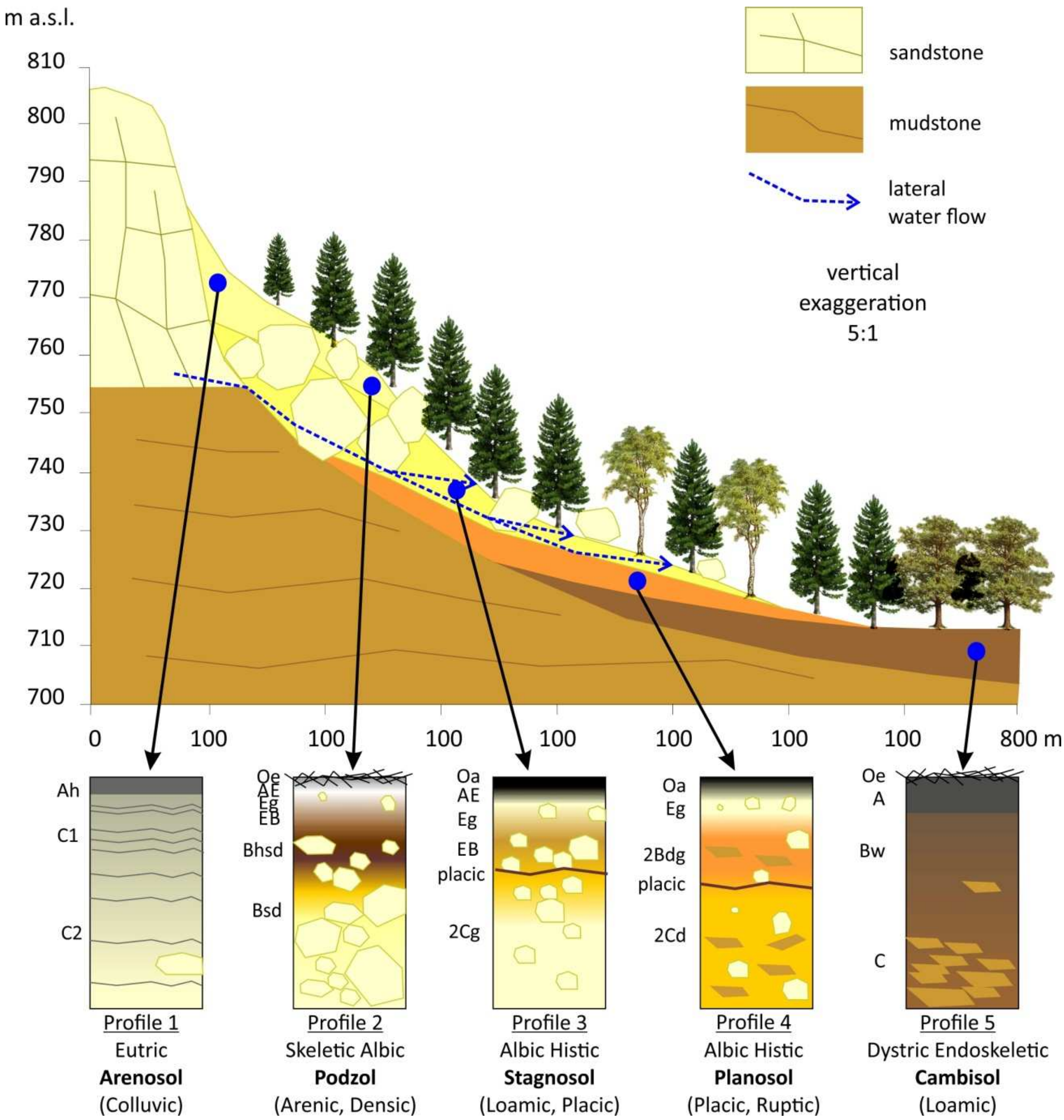


Fig. 2. Litho-toposequence of soils within the Stołowe Mountains

Soil genesis and systematic position

Soil morphology and classification in the analyzed slope catena is controlled by different types of parent material, often stratified, developed below the sandstone escarpments/cliffs. The soil in Profile 1 was formed in a steep accumulation cone and is built of loose, coarse-grained sand, free of rock fragments (Table 1 and Table 2). In the profile morphology, a gray humus layer A overlies the loose sand (parent material of the soil profile) with very thin strata of more humic material that testifies its origin from erosion and accumulation processes. Based on the sand texture and lack of coarse rock fragments throughout the profile, the soil was classified as **Arenosol** with an indication of colluvial origin of the parent material (IUSS, 2014). Arenosols are poorly developed soils (often the first stage of the soil development), poor in nutrients, and seasonally excessively drained, thus they represent poor habitats where only heath vegetation or pioneer coniferous forest may develop. The analysis revealed a unique discrepancy between chemical properties (Table 2): soil has acidic reaction whereas base saturation is above 50%. This is because the base saturation was calculated using the sum of exchangeable bases and exchangeable acidity which is exceptionally low. To indicate the high base saturation, we used the ***Eutric*** principal qualifier.

Transport of sand regolith to the mid-slope position has produced soils with dual morphology (Profile 2). Grayish, loose, upper horizons (*albic* material) are underlain by dark brown, massive soil with features of organic matter and iron accumulation that meet the criteria of the ***Spodic*** horizon. Due to the presence of ***Spodic***, the soil in Profile 2 was classified as **Podzol**, with the typical ***Albic*** qualifier (IUSS, 2014). An abrupt change in the volume of coarse fragments within the profile was defined as a *lithic discontinuity* and indicated by the ***Ruptic*** supplementary qualifier.

The soil forming processes in the next two profiles (3 and 4) are controlled by erosion and short-range water transport on the slope, and gradual accumulation of sorted materials as evidenced by a progressive increase in medium, fine and very fine sand fractions, and silt and clay. The fine-grained soil texture and the transformation of bottom layers by solifluction (recognizable in macro-stratification and massiveness of the material), are the main causes of water stagnation within the soil profile expressed by a *stagnic colour pattern*. The prolonged saturation with water rich in iron over the impermeable layer led to formation of the *placic* layer (Lapen and Wang, 1999), which additionally increases the water stagnation. Profile 3, due to the presence of *reducing conditions* and *stagnic* properties prevailing within 50 cm from the mineral soil surface, belongs to **Stagnosols**, while the soil in Profile 4, having similar diagnostic properties and *abrupt textural difference*, is classified as **Planosol**. Both soils do not have any features of *albeluvic glossae* or *retic* properties. The other important difference between Profile 3 and 4 consists in coarse rock fragments: there are only sandstone fragments throughout Profile 3 (higher location), whereas Profile 4 (lower position) contains sandstone fragments in the upper horizon, and mixed mudstone and sandstone fragments in the subsoil. This indicates the occurrence of the mudstone regolith at this position of the slope.

The soil located in the foot-slope position (Profile 5) is developed from the pure mudstone regolith, without any recognizable admixture of sandstone fragments. Fine, loamy texture (***Loamic***) and well developed pedogenic structure permit the identification of the *cambic* horizon. **Cambisols** are well drained, thus no redoximorphic features or peat accumulation occur in/on these soils. In spite of acid reaction, the soils create relatively good habitats for demanding deciduous species, including the beech forest.

Soil sequence in the catena

The soil catena is a kind of **litho-toposequence** and presents the transition from the soils developed from sandstone to soils developed from pure mudstone regolith, where the bedrock impact is revealed indirectly due to geomorphic (slope) processes which move the sandstone regolith down the slope and mask other parent materials. Steep, upper parts of the slope are covered by deep **Arenosols** developed from the washed sandstone regolith, recently accumulated in colluvial cones. More stable, stratified sandstone regoliths in the mid-slope section are parent material for Podzols, often with *stagnic* properties. The lower slope section is covered by **Stagnosols** and **Planosols**, both saturated with water due to impermeable subsoil, and often having the *placic* horizons. Upper **Stagnosols** are developed from the pure sandstone regolith, while the lower **Planosols** are formed from the sandstone/mudstone mixed regolith. The foot-slope is covered by well drained **Cambisols** developed from the pure mudstone regolith.

Altitudinal zonation of soils in the mountain areas is well documented, mainly in terms of climatic zonation (Bockheim et al. 2000; Alexander and Dushey 2011; Badia et al. 2013), but mostly on a scale of the entire mountain range (Birkeland et al. 2003; Kabała et al. 2011). This catena has shown that a clear vertical soil zonation, significantly enhancing the environmental variability, may also occur on short distances, on a scale of a single slope, where weathering and geomorphological processes have diversified the sandstone- and mudstone-derived materials.

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Forested hilly landscape of Bükkalja Foothill (Hungary)

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Fig. 1. Location

The Bükkalja Foothill area is a transitional hilly area between the tectonically uplifted Bükk Mountains and the subsiding Great Plain. Due to its transitional position and moderate tectonic uplift, younger geological strata are not denudated as it was in the central core of the Bükk mountains, which is a 20 km-by-7 km wide Mesozoic limestone plateau (called Giants' Table) with a rim of white cliffs dominating the surrounding lower mountains and the maximum elevation at Mount Istállóskő (959 m). Because of the moderate uplift, the denudation of Bükkalja was not so intense as in the Bükk montains, therefore Mesozoic limestones are covered by younger sedimentary and volcanic strata. Various Eocene to Oligocene marine sediments, and Miocene rhyolite tuffs dominate at the surface, causing significant geodiversity and affecting the geomorphological conditions.

Lithology and topography

Egri-Bükkalja is a lithologically diverse area, since Miocene rhyolite tuffs prevail within the region, but the soil profiles of the catena at the Síkfőkút Forestry and Ecological Research Station are situated on the Upper Oligocene "Kiscelli clay", and so called „Egri formation" which are also lithologically diverse formations of marine sediments, consisting of aleurit, clay, clayey marl, and locally also coarse sand and gravel rich in manganese lodes (Gyalog, 2005). Locally also redeposited volcanic tuffs (rhyolite tuff) occur, eroded from the surrounding areas. The average height of the surface is 320–340 m a.s.l. Higher plateaus are almost plain, dissected by NW-SE parallel valleys shaped by creeks coming from the higher regions of the Bükk mountains (Dobos, 2012).

Land use

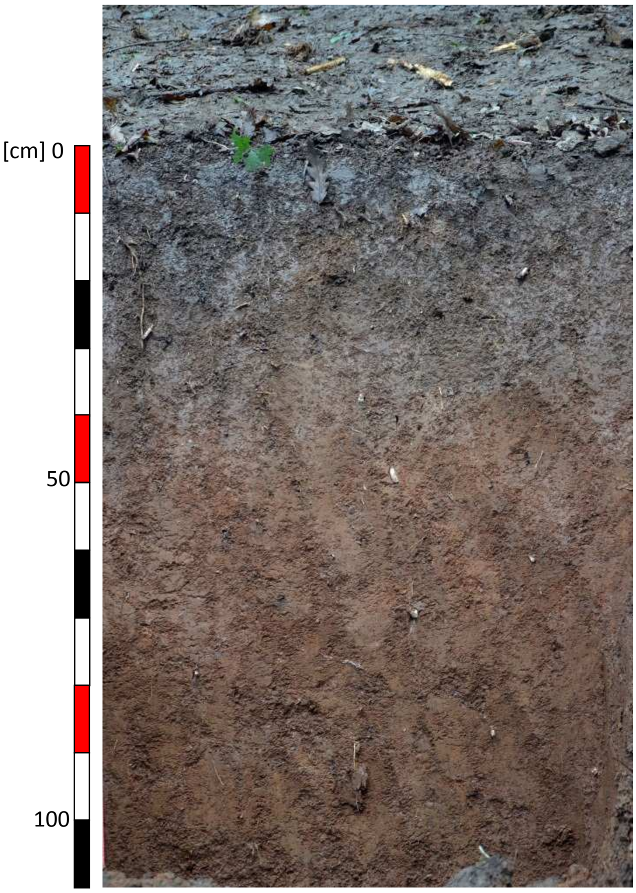
The vegetation is deciduous forest, typical *Quercetum petraeae-cerris*. The dominant hardwood species are sessile oak and turkey oak (Oláh et al., 2012; Tóth et al., 2013). The typical land use of the landscape is forest management on higher plateaus, vineyards and orchards on southern slopes. Arable lands, meadows and grasslands occur only to a lesser extent in the vicinity of villages. Apart from native forests, also plantations occur, dominated by locust tree (*Robinia pseudo-acacia*). The investigated sequence is situated within the Síkfőkút Forestry and Ecological Research Station, which is declared as a nature conservation area, therefore it has not been used or managed since 1973, only monitoring activities are conducted (Varga et al., 2008).

Climate

According to Köppen–Geiger Climate Classification, the region is located in the warm temperate zone, fully humid with warm summer (Kottek et al., 2006). The average annual air temperature is 10.1°C. The warmest month is July (22°C). The mean air temperature during January (the coldest winter month) is about -1°C. The average annual precipitation is 554 mm (Antal and Justyák, 1995). June is the wettest month with average precipitation of around 65–75 mm.

Profile 1 – Chromic Protovertic **Luvisol** (Clayic, Cutanic)

Localization: Bükkalja Foothill, plateau, 2°, deciduous woodland, 320 m a.s.l., **N** 47°55’38.5”, **E** 20°26’38.6”



Morphology:

Oi – 1–0 cm, slightly decomposed organic material

A – 0–12 cm, humus horizon, loam, dark brown (7.5YR 5/3; 7.5YR 3/2), slightly moist, moderate granular medium structure, very fine or fine few roots, gradual and wavy boundary;

AB – 12–35 cm, transitional horizon, clay loam, dark brown (7.5YR 5/4; 7.5YR 3/4), slightly moist, moderate granular coarse structure, very fine or fine few roots, gradual and wavy boundary;

Bti – 35–88 cm, *argic* and *protovertic* horizon, clay, dark reddish brown (5YR 4/8; 5YR 3/4), slightly moist, strong angular coarse structure, medium few roots, slickensides, diffuse and smooth boundary;

BC – 88–(110) cm, transitional horizon, clay, strong brown (7.5YR 3/6; 7.5YR 4/6), slightly moist, massive/strong angular coarse structure.

Table 1. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
A	0–12	0	0	0	0	14	28	17	13	11	17	L
AB	12–35	0	0	0	0	12	17	17	12	12	30	CL
Bti	35–88	0	0	0	0	13	10	11	6	12	48	C
BC	88–(110)	0	0	0	0	15	13	10	8	9	45	C

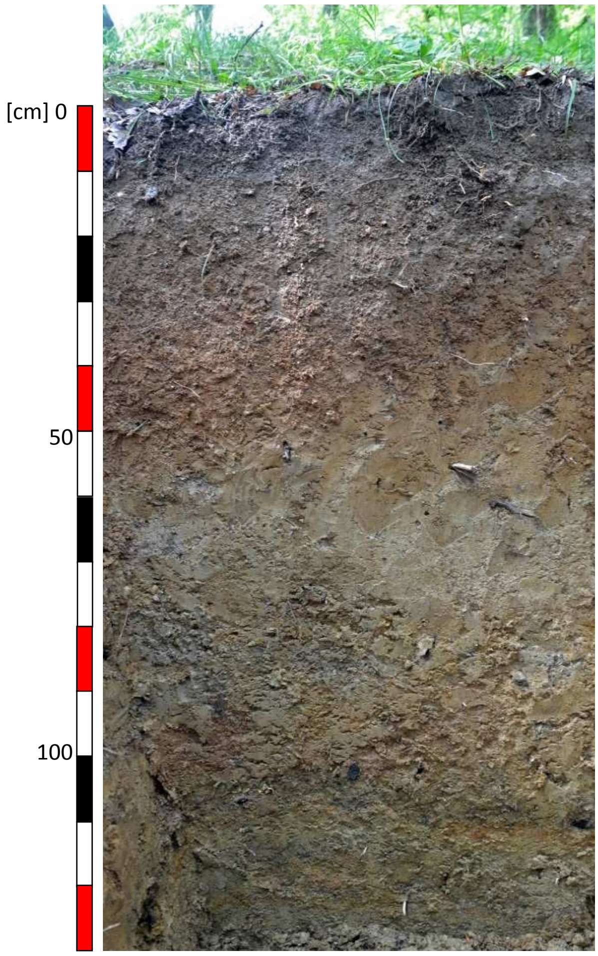
Table 2. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	C/N	pH	
					H_2O	KCl
Oi	1–0	301	8.7	35	-	-
A	0–12	36.8	3.8	10	6.1	4.7
AB	12–35	19.8	2.1	9	5.5	4.0
Bti	35–88	6.0	0.7	9	5.6	4.2
BC	88–(110)	5.7	0.6	10	5.8	4.5

Table 3. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	CEC_{clay}	BS
		[cmol(+)·kg^{-1}]								[%]
Oi	1–0	66.2	6.64	2.03	0.167	75.0	-	-	-	-
A	0–12	19.3	4.12	0.545	0.050	24.0	11.2	35.2	131.3	68
AB	12–35	15.3	4.66	0.361	0.054	20.4	17.1	37.5	101.9	54
Bti	35–88	19.6	6.59	0.503	0.092	26.8	9.86	36.7	72.1	73
BC	88–(110)	26.0	6.46	0.457	0.271	33.2	7.53	40.7	86.0	81

Profile 2 – Protovertic Endostagnic Abruptic **Luvisol** (Clayic, Cutanic)
Localization: Bükkalja Foothill, upper slope, 8°, deciduous forest, 311 m a.s.l.
N 47°55,565’, **E** 20°26,819’



Morphology:

Oi – 1–0 cm, slightly decomposed organic material;

A – 0–15 cm, humus horizon, sandy loam, dark brown (10YR 4/2; 10YR 3/3), slightly moist, moderate granular medium structure, fine common roots, common burrows, gradual and smooth boundary;

AB – 15–30 cm, transitional horizon, clay loam, dark yellowish brown (10YR 4/3; 10YR 3/4), slightly moist, moderate granular coarse structure, very fine or fine few roots, few burrows, gradual and smooth boundary;

Bt – 30–50 cm, *argic* horizon, clay, dark yellowish brown (10YR 5/4; 10YR 4/6), slightly moist, moderate subangular medium structure, common faint clay coatings, fine and medium few roots, few burrows, few fine mottles, gradual and smooth boundary;

Btig – 50–100 cm, *argic* and *protovertic* horizon, clay, brownish yellow (10YR 7/4; 10YR 6/6), slightly moist, strong angular coarse structure, common faint clay coatings, fine and medium few roots, few burrows, slickensides, common reductimorphic mottles, clear and wavy boundary;

Btcg – 100–110 cm, *argic* horizon, clay loam, yellowish brown (10YR 6/4; 10YR 5/6), slightly moist, common manganous nodules and iron concretions, clear and wavy transition,

Btig2 – 110–(130) cm, *argic* and *protovertic* horizon, clay, yellow (10YR 8/4; 10YR 7/8), slightly moist, strong angular coarse structure, slickensides, common reductimorphic mottles;

Table 4. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
A	0–15	0	0	1	3	32	18	12	9	9	16	SL
AB	15–30	0	0	2	2	25	10	9	7	8	37	CL
Bt	30–50	0	0	1	1	23	9	8	7	7	44	C
Btig	50–100	0	0	1	2	29	9	7	5	5	42	C
Bcg	100–110	8	0	5	2	23	8	9	7	9	37	CL
Btig2	110–(130)	0	0	0	1	10	9	9	11	14	46	C

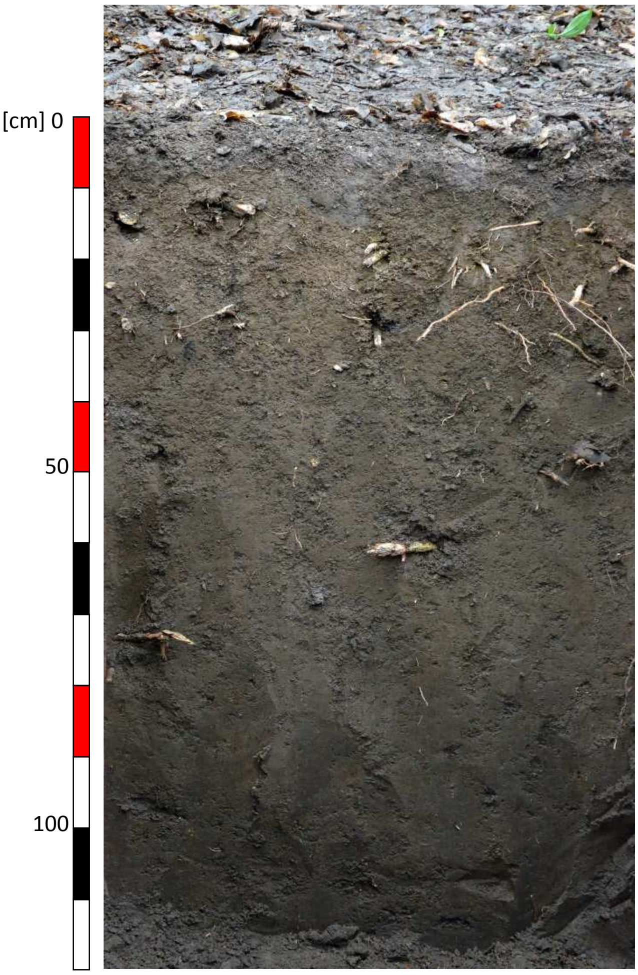
Table 5. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	C/N	pH	
					H_2O	KCl
Oi	1–0	301.4	1.05	29	-	-
A	0–15	35.2	0.27	13	5.6	4.2
AB	15–30	11.4	0.11	10	5.4	3.8
Bt	30–50	5.4	0.05	11	5.4	3.9
Btig	50–100	3.3	0.03	10	5.4	3.8
Bcg	100–110	3.2	0.04	9	5.2	3.9
Btig2	110–(130)	3.2	0.04	9	5.4	3.9

Table 6. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	CEC_{clay}	BS [%]
		[cmol(+)·kg^{-1}]								
Oi	1–0	52.5	8.41	3.120	0.197	64.2	-	-	-	-
A	0–15	15.0	4.31	0.280	0.064	19.7	17.7	37.4	156.8	53
AB	15–30	10.0	4.55	0.744	0.072	15.4	17.1	32.5	77.1	47
Bt	30–50	14.3	6.55	0.450	0.100	21.4	11.7	33.1	70.9	65
Btig	50–100	17.6	6.52	0.434	0.150	24.7	10.1	34.8	80.1	71
Bcg	100–110	30.0	9.48	0.630	0.358	40.5	12.5	53.0	140.2	76
Btig2	110–(130)	29.8	9.07	0.832	0.502	40.2	8.31	48.5	103.0	83

Profile 3 – Mollic **Umbrisol** (Loamic, Colluvic);
Localization: Bükkalja Foothill, lower slope, 5°, deciduous forest, 280 m a.s.l.
N 47° 56,623’, **E** 20° 26,972’



Morphology:

Ah1 – 0–7 cm, colluvic material, *mollic* horizon, loam, dark brown (10YR 5/2; 10YR 3/3), slightly moist, moderate granular medium and fine structure, fine and medium common roots, gradual and smooth boundary;

Ah2 – 7–20 cm, colluvic material, *mollic* horizon, loam, dark yellowish brown (10YR 5/3; 10YR 3/4), slightly moist, moderate granular medium and fine structure, medium common roots, gradual and smooth boundary;

Ah3 – 20–70 cm, colluvic material, humus horizon, clay loam, very dark grayish brown (10YR 6/2; 10YR 3/2), slightly moist, moderate subangular medium structure, medium and coarse few roots, gradual and smooth boundary;

Ah4 – 70–(120); colluvic material, humus horizon, clay loam, very dark gray (10YR 5/1; 10YR 3/1), slightly moist, moderate subangular medium structure, fine and very few roots, few pieces of bricks, charcoals;

Table 7. Texture

Horizon	Depth [cm]	Percentage of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
Ah1	0–7	0	0	0	3	19	28	20	13	8	9	L
Ah2	7–20	0	0	0	0	16	22	19	13	11	19	L
Ah3	20–70	0	0	0	0	16	20	15	11	11	27	CL
Ah4	70–(120)	0	0	0	0	19	17	13	10	11	30	CL

Table 8. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	C/N	pH	
					H_2O	KCl
Oi	3–0	360.3	1.61	22	-	-
Ah1	0–7	29.8	0.41	7	5.2	4.4
Ah2	7–20	23.4	0.19	12	5.2	3.9
Ah3	20–70	13.4	0.13	10	5.6	4.4
Ah4	70–(120)	15.2	0.12	13	5.3	4.6

Table 9. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	CEC_{clay}	BS [%]
		[cmol(+)·kg^{-1}]								
Oi	3–0	70.7	14.40	4.930	0.240	90.3	-	-	-	-
Ah1	0–7	20.4	4.03	0.293	0.070	24.8	19.0	43.8	370.8	57
Ah2	7–20	11.8	2.96	0.327	0.083	15.2	17.8	33.0	130.6	46
Ah3	20–70	13.8	3.80	0.309	0.097	18.0	9.93	27.9	86.0	64
Ah4	70–(120)	15.5	3.95	0.352	0.105	19.9	9.20	29.1	79.3	68

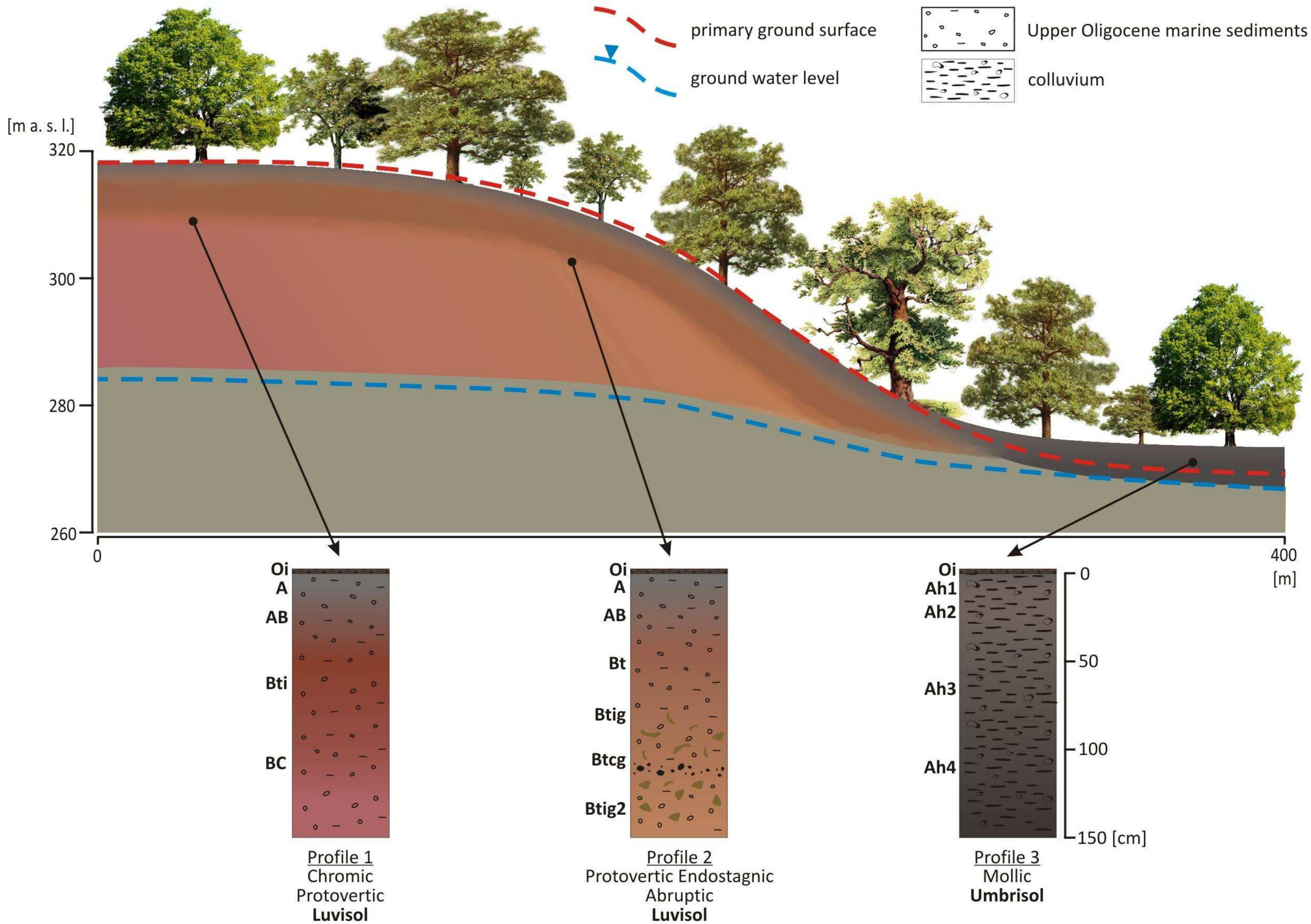


Fig. 2. Litho-toposequence of soils within Bükk Mountains foothills

Soil genesis and systematic position

Profile 1 and 2 are characterized by a high content of clay fraction, which is a typical lithological feature of the Upper Oligocene marine deposits. According to WRB (IUSS Working Group WRB, 2014), this textural feature was expressed by the ***Clayic*** supplementary qualifier. In both cases, the *lessivage* process had a significant impact on soil properties and morphology. Climatic conditions (warm temperate and fully humid zone) in this region favour the movement of the clay fraction from the upper to lower section of the soil profile (Quénard et al., 2011). The acidic reaction of the described soils is another important factor conducive to clay translocation. The *lessivage* process led to vertical textural differentiation and formation of the *argic* horizons. In the second profile, a textural change was very sharp, which is expressed by the ***Abruptic*** qualifier. The significant amount of illuvial clay coatings (supplementary qualifier ***Cutanic***) on the surface of soil aggregates in Bt horizons was easily visible already at the stage of field work. Low pH values in Profile 1 and 2 should indicate a small proportion of cations in the sorption complex. Nevertheless, the base saturation in Bt horizons is more than 50% and the clay fraction is characterized by high activity – CEC in clay values are higher than 30 $cmol_c \cdot kg^{-1}$. For this reason, pedons with *argic* horizons were classified as **Luvisols** (IUSS Working Group WRB, 2014). The relatively high base saturation combined with low pH values are not typical and is probably associated with specific nature of the examined marine sediments. Not only the effects of *lessivage* were observed in the described soils. Changes in the soil moisture and a high content of alternate swelling and shrinking clay resulted in the formation of *slickensides* in the Bt horizons. The occurrence of these pressure faces produced by shrink-swell forced in the soil material with a thickness of more than 15 cm and with more than 30% of clay is indicated by the ***Protovertic*** principal qualifier.

The parent material on the plateau (Profile 1) shows a high degree of mineral transformations because of long exposition to weathering processes. These processes started before the cold climate period of the last glacial maximum. Well-weathered marine sediments were not significantly affected by later erosion and sedimentation processes. Therefore, their properties are associated with the previous geological periods. Because these deposits were transformed under warmer climatic conditions, the substrate of pedogenesis still have reddish colour. The intense reddish colour of the Bti horizon (the hue in moist material is redder than 7.5 YR) was the reason why the ***Chromic*** qualifier was added in the case of Profile 1. This feature should be partially treated as relict (Stefanovits, 1985).

The soil located on the middle slope position (Profile 2) had some *stagnic* properties caused by stagnation of rainwater on the poorly permeable *argic* horizon. The surface of aggregates had reductimorphic colours, while oximorphic colours dominated inside the aggregates. Because the layer with *stagnic* properties was thick and started at a depth of 50 cm, the qualifier ***Endostagnic*** was used. At a depth of 100–110 cm, common manganese nodules and iron concretions occurred. Theses mineral concentrations can be associated with the past or actual soil water conditions, and were formed by the precipitation of mineral compounds from soil solutions.

The lower slope position (Profile 3) is covered by the soil, the properties of which derive from the *colluvic* material. This feature was expressed by adding the ***Colluvic*** supplementary qualifier. The investigated colluvium (slope deposits) differs considerably from the previously described marine sediments. It contains some amounts of charcoals, pieces of bricks and ceramics. The mineral material contains significant amounts (more than 10 $g \cdot kg^{-1}$) of organic carbon up to a depth of more than 120 cm. The humus nature affects the greyish colour of all horizons. Lack of stratification may result from bioturbations. Low C/N ratios and a large number of roots confirm intensive biological activity in all horizons. The two upper humus layers are on the border between the *umbric* and the *mollic* diagnostic horizons. The deeper horizon (Ah3) cannot be treated as part of *mollic* or *umbric* because its colour is not dark enough. The base saturation calculated based on the weighted average up to a depth of 20 cm

(Ah1 and Ah2) is exactly 50% and hardly meets the criteria of *mollic*. Soils with the *mollic* horizon and with lack of *calcic* are classified as **Phaeozems**. In this RSG, the base saturation must be higher than 50% up to a depth of 100 cm. The base saturation in Profile 3, between the depth of 7 cm and 20 cm, is slightly lower – 46%. Therefore, the soil was defined as ***Mollic* Umbrisol**.

Soil sequence

Luvisols developed from marine deposits covering the flat plateau and upper parts of the slope, while Umbrisols derived from the *colluvial* material occurring in the lower slope position. The main factors affecting the spatial variability of the soil cover are topography and associated lithology. For this reason, the spatial arrangement of the described soils forms **litho-toposequence**.

Both **Luvisols** (Profile 1 and 2) belong to the mature soils with a well-developed sequence of genetic horizons. The *argic* horizons begin at a relatively shallow depth of 30–35 cm and are directly covered by surface humus horizons. The "eluviation zone", which is depleted of the clay fraction due to the *lessivage* process, has a small thickness. The described soils differ from natural, undisturbed Luvisols in other regions in the lack of bleached E horizons between A and Bt horizons (Jankauskas and Fullen, 2002; Kühn, 2003; Phillips, 2007). Many authors interpret it as an indicator of soil erosion (Olson et al., 1994; Phillips et al., 1999; Kobierski, 2013; Podlasiński, 2013). According to Świtoniak (2014), Luvisols with A horizons overlay directly the Bt horizons, and with a textural change at a depth of 20–30 cm should be treated as moderately eroded. The calculated thickness of truncation in these soils located within young morainic landscapes is about 40–50 cm. Nevertheless, the soil erosion had probably little influence on the discussed pedons (Profile 1 and 2). The erosion is usually triggered off by agricultural activities (Olson et al., 1994; Smolska, 2002; Dotterweich, 2008; Świtoniak, 2014), while the soil cover within the Síkfőkút Forestry and Ecological Research Station had no signs of previous agricultural use. The shallow occurrence of the *argic* horizon may result from the heavy texture of marine deposits. In view of the study conducted by Kjaergaard et al. (2004), the colloid leaching from the initially wet and moderately wet soils decreased with the increasing clay content. Therefore, the low permeability of marine clay and clay loam could prevent the development of clearly visible eluvial horizons. Despite the fact that Luvisols located on the plateau and the upper slope position were not significantly transformed by the slope processes, the erosion had certain impact on the soil cover in the Bükkalja region. The last pedon (**Umbrisol**) contains *colluvial* material with a thickness of more than 120 cm. The rate of colluvium accumulation was probably slow. This is evidenced by lack of stratification in Profile 3 and the occurrence of well-developed soils at higher elevations which are potentially exposed to the erosion. The lack of eroded soils in the vicinity of Profile 3 proves that soil forming processes are "faster" than soil truncation. With a very slow rate of soil formation (Morgan, 2005), any soil loss within the investigated area had to be less than 1 t $ha^{-1}{\cdot}yr^{-1}$.

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Alluvial plain with wind-blown sand dunes in South-Nyírség, Eastern Hungary

Tibor József Novák, Gábor Négyesi, Bence Andrási, Botond Buró

Nyírség is a large sand alluvial fan in NE Hungary, which is a result of alluvial sedimentation processes during the Pleistocene by rivers coming from the NE Carpathians, like Tisza, Bodrog and Szamos (Borsy, 1961, 1978). Because of the tectonic subsidence of surroundings, and the uplift of Nyírség, these rivers shifted to the north and east, and the area of Nyírség was abandoned by river channels (Borsy et al 1985, Kiss & Bódis 2000). As a consequence, the sandy surfaces dried in the late Pleistocene and the early Holocene aeolian processes reshaped the surface of the former alluvium (Borsy, 1991; Kiss 2000, Lóki et al. 2012). Strong NE winds blew away fine dust fractions, which were deposited west of Nyírség, and accumulated in small wet depressions within the landscape. At the same time, well sorted, blowout fine sand formed the dunes. The first significant sand movement was in the Upper Pleniglacial and the Late Glacial (Borsy, 1991). In more humid interstadial periods and in the Holocene, vegetation protected the surface and the soil became to develop until the beginning of the next dry period (Ujházy et al., 2003). The aeolian transformations did not end completely in the Pleistocene. In the Holocene small areas of sands were moved by aeolian processes, which were mainly triggered by anthropogenic impact (Buró et. al., 2012, Lóki et. al., 2012). Dél-Nyírség is a wind-blown sand area with afforested sand dunes, blown-sand covered plains with grasslands and arable lands, and small depressions located between dunes with wet meadows and bogs.

Fig. 1. Location

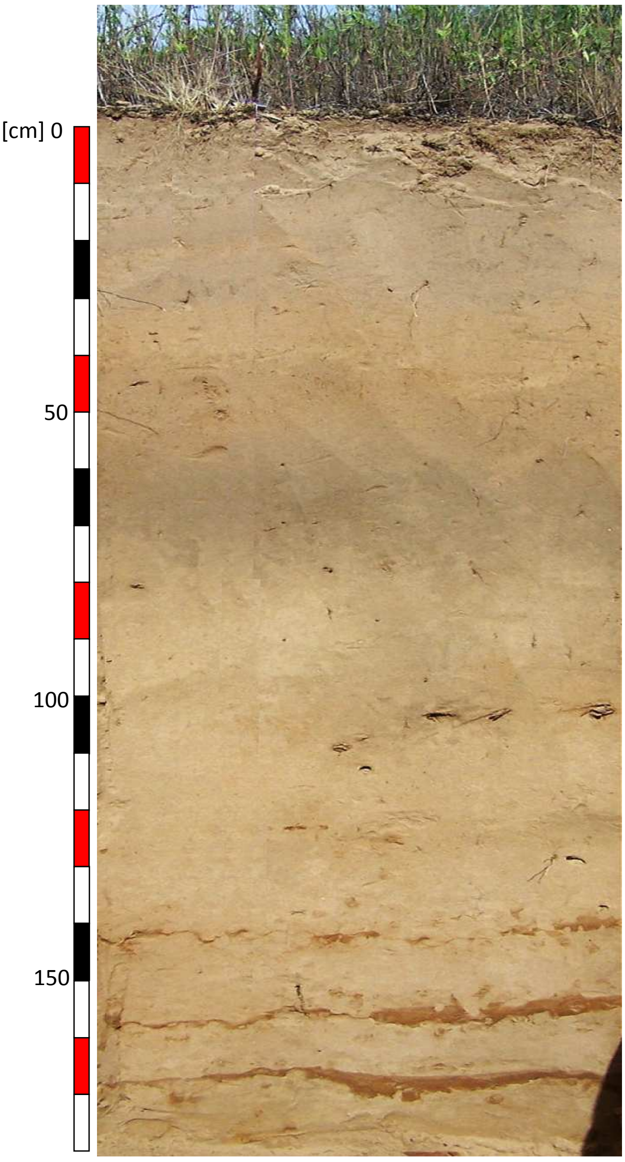
Lithology and topography

The presented soil profiles are located in South-Nyírség. The surface is divided by dunes and deflation hollows. The blown sand is deposited on the fluvial sediment. The sand layers redeposited by aeolian processes are several meters thick. The fine sandy material at the surface layers of wet depressions is mixed with wind-blown dust (silt). The dunes are highly sandy and contain small amounts of silt fraction. More silty layers contain also higher amount of primary calcium carbonates than sand. The windward sites of the dunes are less inclined 7–12°, than the leeward sites 12–20° (Kiss, 2000). The average of elevation differences are 10–20 m. The average height of the surface is 138.2 m.

Land use

Nyírség is situated within the forest steppe zone where natural vegetation could be oak forest steppes. The land use is dominated by forestry and grasslands; arable lands are also present but to a lesser extent. At present, afforestation consists mainly in planting of non-native species (*Robinia pseudoacacia*, *Populus x hybr.*, *Quercus rubra*, etc.) (Borhidi and Sánta, 1999).

Profile 1 – Calcaric Bathylamellic **Arenosol** (Aeolic)
Localization: top of wind-blown sand dunes, flat terrain <1°, dry short grassland and shrubs, 159 m a.s.l., **N** 47°41'53", **E** 22°6'48"



Morphology:

Oi – 0,5–0 cm, slightly decomposed organic material;

A – 0–30 cm, fine sand, yellowish brown (10YR 4/3; 10YR 5/4), dry, single grain structure, fine common roots, gradual and smooth boundary;

C – 30–55 cm, fine sand, light yellowish brown (10YR 6/4; 10YR 5/4), dry, single grain structure, fine few roots, gradual and smooth boundary;

Ab – 55–65 cm, buried humus horizon, fine sand, yellowish brown (10YR 4/3; 10YR 5/4), dry, single grain structure, fine few roots, gradual and smooth boundary;

E – 65–142 cm, eluvial horizon, fine sand, yellowish brown (10YR 4/3; 10YR 5/4), dry, single grain structure, fine and medium few roots, abrupt and wavy boundary

Bts – 142–143 cm, fine sand, lamellic accumulation of iron-hydroxides, dark yellowish brown (10YR 3/6; 10YR 4/4), slightly moist, weakly cemented, massive structure, abrupt and wavy boundary

E2 – 143–158 cm, interlamella

Bts2 – 158–160 cm, lamella

E3 – 160–171 cm, interlamella

Bts3 – 171–173 cm, lamella

E4 – 173–(180) cm, interlamella

Table 1. Texture

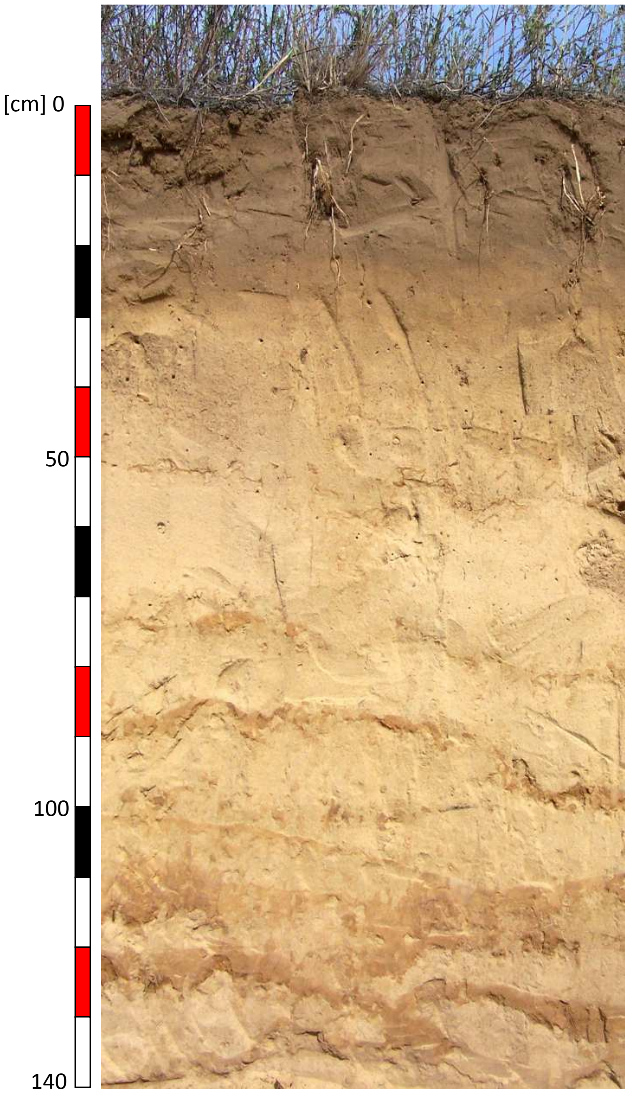
Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
A	0–30	0	0	0	19	72	4	2	2	1	1	FS
C	30–55	0	0	0	18	70	6	2	1	1	3	FS
Ab	55–65	0	0	0	20	71	3	1	1	1	3	FS
E	65–142	0	0	0	19	68	8	1	1	1	2	FS
Bts	142–143	0	0	0	12	68	13	3	1	0	2	FS
E2	143–158	0	0	0	20	67	4	1	2	1	6	FS
Bts2	158–160	0	0	0	19	69	2	1	2	1	7	FS
E3	160–171	0	0	0	19	72	5	1	1	1	2	FS
Bts3	171–173	0	0	0	15	73	1	1	1	1	7	FS
E4	173–(180)	0	0	0	18	75	4	1	1	0	2	FS

Table 2. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	pH		$CaCO_3$ [g·kg^{-1}]
			H_2O	KCl	
A	0–30	1.9	5.4	4.6	25
C	30–55	0.8	6.8	5.6	23
Ab	55–65	3.4	5.9	4.9	20
E	65–142	1.2	6.7	5.1	36
Bts	142–143	0.7	6.7	5.3	28
E2	143–158	0.3	6.5	4.9	22
Bts2	158–160	0.3	6.5	5.2	26
E3	160–171	0.4	6.3	5.2	24
Bts3	171–173	1.2	6.3	5.0	20
E4	173–(180)	0.8	6.3	5.0	25

Profile 2 – Calcaric Lamellic Brunic **Arenosol** (Aeolic, Ochric)

Localization: wind-blown sand dune top position, slightly undulating surface, <2°, short grass with few *Robinia* shrubs, 156 m a.s.l., **N** 47°41’55”, **E** 22°6’47”



Morphology:

Oi – 1–0 cm, slightly decomposed organic material;

Ah – 0–18 cm, humus horizon, fine sand, dark brown, dark yellowish brown (10YR 3/3; 10YR 3/4), dry, weak granular structure, fine and common roots, gradual smooth boundary;

Bw – 18–34 cm, fine sand, dark yellowish brown (10YR 3/4; 10YR 4/4), dry, single grain structure, very fine few roots, gradual wavy boundary;

E – 34–51 cm, eluvial horizon, fine sand, yellowish brown (10YR 4/3; 10YR 5/4), dry, single grain structure, abrupt and wavy boundary;

Bts – 51–52 cm, lamellic accumulation of iron-hydroxides, fine sand, dark yellowish brown (10YR 3/6; 10YR 4/4), dry, weakly cemented, massive structure, abrupt and wavy boundary;

E2 – 52–72 cm, interlamella, eluvial horizon, fine sand, light yellowish brown (10YR 6/4; 10YR 4/4), dry, single grain structure, abrupt and wavy- irregular boundary;

Bts2 – 72–74 cm, lamella, dark brown (7,5YR 3/4; 7,5YR 4/4), dry, moderately cemented, massive structure, abrupt and wavy boundary;

E3 – 74–82 cm, interlamella

Bts3 – 82–85 cm, lamella

E4 – 85–98 cm, interlamella

Bts4 – 98–102 cm, lamella

E5 – 102–107 cm, interlamella

Bts5 – 107–115 cm, lamella

E6 – 115–121 cm, interlamella

Bts6 – 121–126 cm, lamella

E7 – 126–138 cm, interlamella

Bts7 – 138–(140) cm, lamella

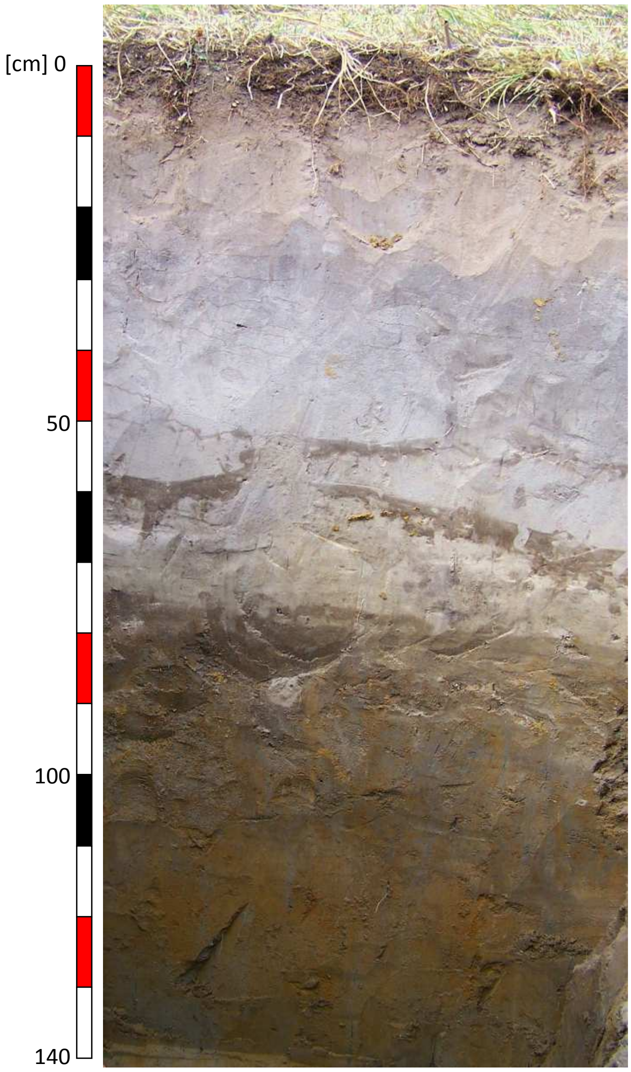
Table 3. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
Ah	0–18	0	0	0	19	71	4	2	2	1	2	FS
Bw	18–34	0	0	0	20	68	6	2	1	1	3	FS
E	34–51	0	0	0	22	69	3	1	1	1	3	FS
Bts	51–52	0	0	0	14	68	8	1	1	1	7	FS
E2	52–72	0	0	0	11	69	16	1	1	0	2	FS
Bts2	72–74	0	0	0	20	67	1	1	2	1	9	LFS
E3	74–82	0	0	0	19	72	5	1	1	0	3	FS
Bts3	82–85	0	0	0	21	67	2	1	2	1	7	FS
E4	85–98	0	0	0	18	75	4	1	1	0	2	FS
Bts4	98–102	0	0	0	15	73	1	1	1	1	7	FS
E5	102–107	0	0	0	29	65	1	0	1	0	3	FS
Bts5	107–115	0	0	0	31	62	1	0	2	1	5	FS
E6	115–121	0	0	0	23	71	2	0	1	0	2	FS
Bts6	121–126	0	0	0	34	59	2	1	0	0	4	FS
E7	126–138	0	0	0	13	81	3	0	1	0	2	FS
Bts7	138–(140)	0	0	0	20	67	1	0	2	1	9	LFS

Table 4. Chemical, physicochemical and sorption properties

Horizon	Depth [cm]	OC [$g\cdot kg^{-1}$]	pH		$CaCO_3$ [$g\cdot kg^{-1}$]	Fe	Mn	Mg	Al	TEB	HA	CEC	CEC_{clay}	BS [%]
			H_2O	KCl		[$mg\cdot kg^{-1}$]				[$cmol(+)\cdot kg^{-1}$]				
Ah	0–18	5.0	5.2	4.1	25	6	9	2	6	7.4	4.5	11.9	0.0	62
Bw	18–34	3.3	4.4	4.1	23	8	10	2	8	6.9	3.1	10.0	0.0	69
E	34–51	3.4	4.7	4.2	20	8	11	2	8	7.9	1.2	9.1	0.0	87
Bts	51–52	1.2	6.7	5.1	36	17	18	2	17	9.1	2.6	11.7	107	78
E2	52–72	0.7	6.7	5.3	28	9	12	1	9	9.1	2.8	11.9	472	77
Bts2	72–74	0.3	6.5	4.9	22	19	21	2	19	8.5	1.4	9.9	98.3	86
E3	74–82	0.3	6.3	5.0	26	8	11	1	8	5.3	2.7	8.0	232	66
Bts3	82–85	0.4	6.8	5.2	24	16	18	2	16	6.3	1.3	7.6	88.6	83
E4	85–98	1.2	6.3	5.0	20	8	12	1	8	6.4	1.3	7.7	175	83
Bts4	98–102	0.9	6.3	5.0	25	14	17	2	14	6.6	2.4	9.0	83.6	73
E5	102–107	1.0	6.3	5.1	23	8	11	1	8	5.5	2.7	8.2	157	67
Bts5	107–115	0.5	6.4	5.2	17	10	12	1	10	6.1	1.6	7.7	119	79
E6	115–121	0.8	6.8	5.4	41	9	13	2	9	7.7	1.7	9.4	330	82
Bts6	121–126	0.5	6.8	5.4	40	9	12	1	9	7.2	1.3	8.5	169	85
E7	126–138	0.5	6.8	5.4	25	8	11	1	8	7.1	1.8	8.9	357	80
Bts7	138–(140)	0.7	6.9	5.2	18	12	14	2	12	7.0	1.2	8.2	63.9	85

Profile 3 – Calcaric Albic Endogleyic **Arenosol** (Aeolic, Ochric)
Localization: wind-blown sand dunes, lower slope, flat < 1°, short grassland and shrub, 150 m a.s.l.
N 47°42'5", **E** 22°6'52"



Morphology:

Oi – 1–0.5 cm, slightly decomposed organic material;

Oe – 0.5–0 cm, moderately decomposed organic material;

Ah – 0–17 cm, humus horizon, fine sand, light brownish gray/ grayish brown (10YR 6/2; 10YR 5/2), dry, weak granular medium structure, fine dense roots, gradual and smooth boundary;

E – 17–62 cm, eluvial horizon with *albic* material, fine sand, light brownish gray,/grayish brown (2.5Y 6/2; 2.5Y 5/2), dry, weak subangular very fine structure, fine and few roots, gradual and irregular boundary;

Bts – 62–68 cm, lamellic accumulation of iron-hydroxides and organic matter, fine sandy loam, grayish brown, dark grayish brown (2.5Y 5/2; 2.5Y 4/2), slightly moist, single grain structure, clear and irregular and broken boundary;

E2 – 68–75 eluvial horizon, fine sand, light brownish gray/grayish brown (2.5Y 6/2; 2.5Y 5/2), slightly moist, single grain structure, gradual and smooth boundary;

BClo – 75–(140) cm, loamy fine sand, gleyic color pattern, dark greenish gray, dark grayish brown (10Y 4/1, 10YR 4/2), moist, single grain structure.

Table 5. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
Ah	0–17	0	0	0	11	53	25	6	3	1	1	FS
E	17–62	0	0	0	9	54	25	5	4	1	2	FS
Bts	62–68	0	0	0	10	34	27	5	4	3	18	FSL
E2	68–75	0	0	0	9	54	23	5	4	1	4	FS
BClo	75–(140)	0	0	0	12	55	18	3	3	2	7	LFS

Table 6. Chemical and physicochemical properties

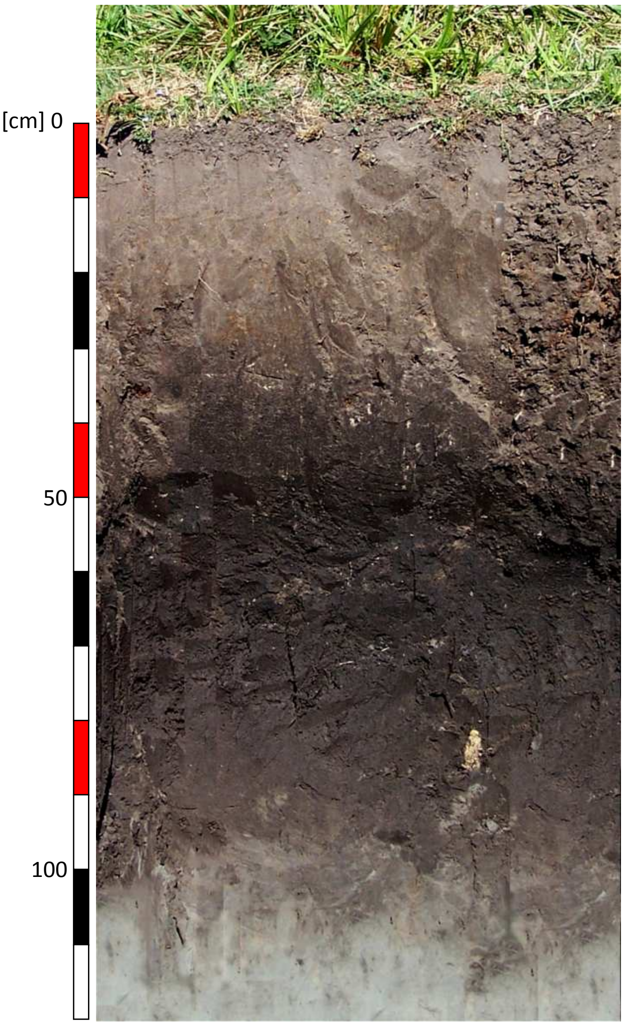
Horizon	Depth [cm]	OC [g·kg^{-1}]	pH		$EC_{1:2.5}$ [dS·m^{-1}]	$CaCO_3$ [g·kg^{-1}]
			H_2O	KCl		
Ah	0–17	4.4	6.3	5.7	0.08	0
E	17–62	1.4	7.3	6.6	0.04	18
Bts	62–68	4.6	7.6	6.2	0.08	30
E2	68–75	1.7	7.1	6.1	0.06	24
BClo	75–(140)	0.9	7.2	6.0	0.24	21

Table 7. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	CEC_{clay}	BS [%]
		[cmol(+)·kg^{-1}]								
Ah	0–17	6.3	2.3	2.1	0.1	10.8	5.7	16.5	110	65
E	17–62	4.9	1.1	0.4	0	6.4	3.2	9.6	235	67
Bts	62–68	5.8	1.4	0.6	0.2	8	1.1	9.1	0.0	88
E2	68–75	4.1	0.7	0.2	0.1	5.1	1.4	6.5	13.8	78
BClo	75–(140)	4.8	1.9	0.6	0.3	7.6	1.6	9.2	86.4	83

Profile 4 – Calcaric Endogleyic **Phaeozem** (Loamic)

Localization: alluvial plain at the feet of wind-blown sand dunes, flat terrain with slopes < 1° lower part, level land, short grassland, extensive grazed, 150 m a.s.l., **N** 47°42’17”, **E** 22°6’46”



Morphology:

Oi – 3–1 cm, slightly decomposed organic material;

Oe – 1–0 cm, moderately decomposed organic material;

Aho – 0–35 cm, *mollic* horizon, fine sandy loam, very dark grayish brown, very dark brown (10YR 3/2; 10YR 2/2), dry, moderate granular medium structure, common fine reddish-brown crack and pore infillings, fine common roots, gradual smooth boundary;

Ahok – 35–82 cm, *mollic* horizon, fine sandy loam, very dark grayish brown, very dark brown (10YR 2/2; 10YR 2/1), slightly moist, moderate granular–subangular medium structure, few fine reddish-brown crack and pore infillings, common fine-medium soft carbonate concentrations, gradual wavy boundary;

AClk – 82–105 cm, transitional horizon, loamy fine sand, dark grayish brown, very dark grayish brown (10YR 4/2; 10YR 3/2), gleyic color pattern, moist, single grain structure, gradual and broken boundary;

2Cr – 105–(120) cm, sand, olive gray, greenish gray (5Y 4/2; 10Y 5/1), wet, single grain structure, reducing conditions.

Table 8. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
Aho	0–35	0	0	0	8	34	17	15	15	5	6	FSL
Ahok	35–82	0	0	0	9	51	7	6	10	5	12	FSL
AClk	82–105	0	0	0	7	56	14	8	6	4	5	LFS
2Cr	105–(120)	0	0	0	47	47	4	0	0	0	2	S

Table 9. Chemical and physicochemical properties

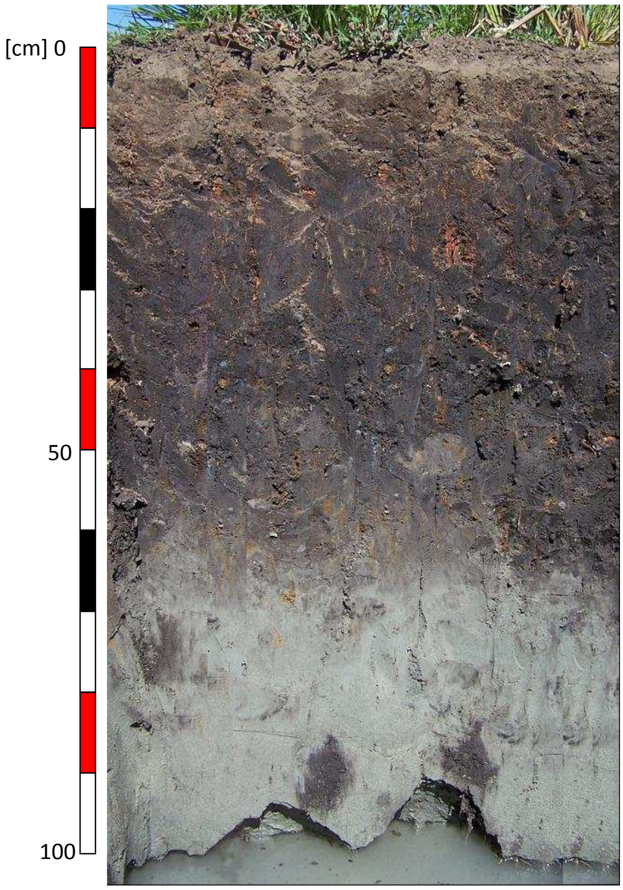
Horizon	Depth [cm]	OC [g·kg^{-1}]	pH		$EC_{1:2.5}$ [dS·m^{-1}]	$CaCO_3$ [g·kg^{-1}]
			H_2O	KCl		
Aho	0–35	64.1	6.3	5.6	0.618	-
Ahok	35–82	18.4	6.9	6.1	0.919	114
AClk	82–105	5.2	7.8	7.1	0.217	75
2Cr	105–(120)	0.9	7.2	5.9	0.118	17

Table 10. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	TEB	HA	CEC	CEC_{clay}	BS [%]
		[cmol(+)·kg^{-1}]								
Aho	0–35	6.7	15.2	8.2	0.1	30.2	15.1	45.3	0.0	67
Ahok	35–82	12.4	7.9	0.4	0.3	21.0	9.2	30.2	0.0	70
AClk	82–105	10.5	7.3	0.5	0.4	18.7	3.1	21.8	72.0	86
2Cr	105–(120)	6.4	3.8	0.6	0.3	11.2	0.0	11.2	402	100

Profile 5 – Calcaric Mollic **Gleysol** (Epiloamic, Endoarenic)

Localization: alluvial plain with wind-blown sand dunes, flat terrain bottom, with slopes < 1°, groundwater fed wet meadow with sedges and few willow shrubs, 148 m a.s.l.
N 47°42'16", **E** 22°6'49"



Morphology:

Oe – 6–5 cm, moderately decomposed organic material;

Oa – 5–0 cm, strongly decomposed organic material;

Aho – 0–45 cm, *mollic* horizon, fine sandy loam, dark grayish brown (10YR 2/2; 10YR 3/2), slightly moist, moderate granular medium structure, many fine reddish-brown crack and pore infillings, fine common roots, gradual smooth boundary;

AClo – 45–65 cm, transitional horizon, loamy fine sand, very dark gray (10YR 2/1; 10YR 3/1) dark grayish brown (10YR 3/2; 10YR 4/2), to light olive brown(2,5Y 4/3, 2,5 Y 5/3) gleyic color pattern, moist, weak granular structure, very few roots, common fine reddish-brown crack and pore infillings, very few very fine soft vivianite concentrations, gradual and broken boundary;

2Cr – 65–(105) cm, fine sand, greenish gray (5G 5/1; 10Y 6/1), very wet, single grain structure, reducing conditions;

105 cm, groundwater level.

Table 11. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
Aho	0–40	0	0	0	10	52	5	6	10	5	12	FSL
AClo	40–65	0	0	0	7	56	14	8	6	3	6	LFS
2Cr	65–(105)	0	0	0	47	47	4	0	0	0	2	S

Table 12. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g\cdot kg^{-1}$]	pH		$EC_{1:2.5}$ [$dS\cdot m^{-1}$]	$CaCO_3$ [$g\cdot kg^{-1}$]
			H_2O	KCl		
Aho	0–40	51.2	6.1	5.4	0.798	0
AClo	40–65	4.9	7.1	5.8	0.219	57
2Cr	65–(105)	0.4	7.1	5.9	0.117	14

Table 13. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	CEC_{clay}	BS [%]
		[$cmol(+)\cdot kg^{-1}$]								
Aho	0–40	9.5	3.1	0.6	0.1	13.3	9.3	22.6	0.0	59
AClo	40–65	7.7	2.6	0.7	0.1	11.1	7.3	18.4	20.8	60
2Cr	65–(105)	3.9	1.1	0.5	0.1	5.6	1.6	7.2	290	78

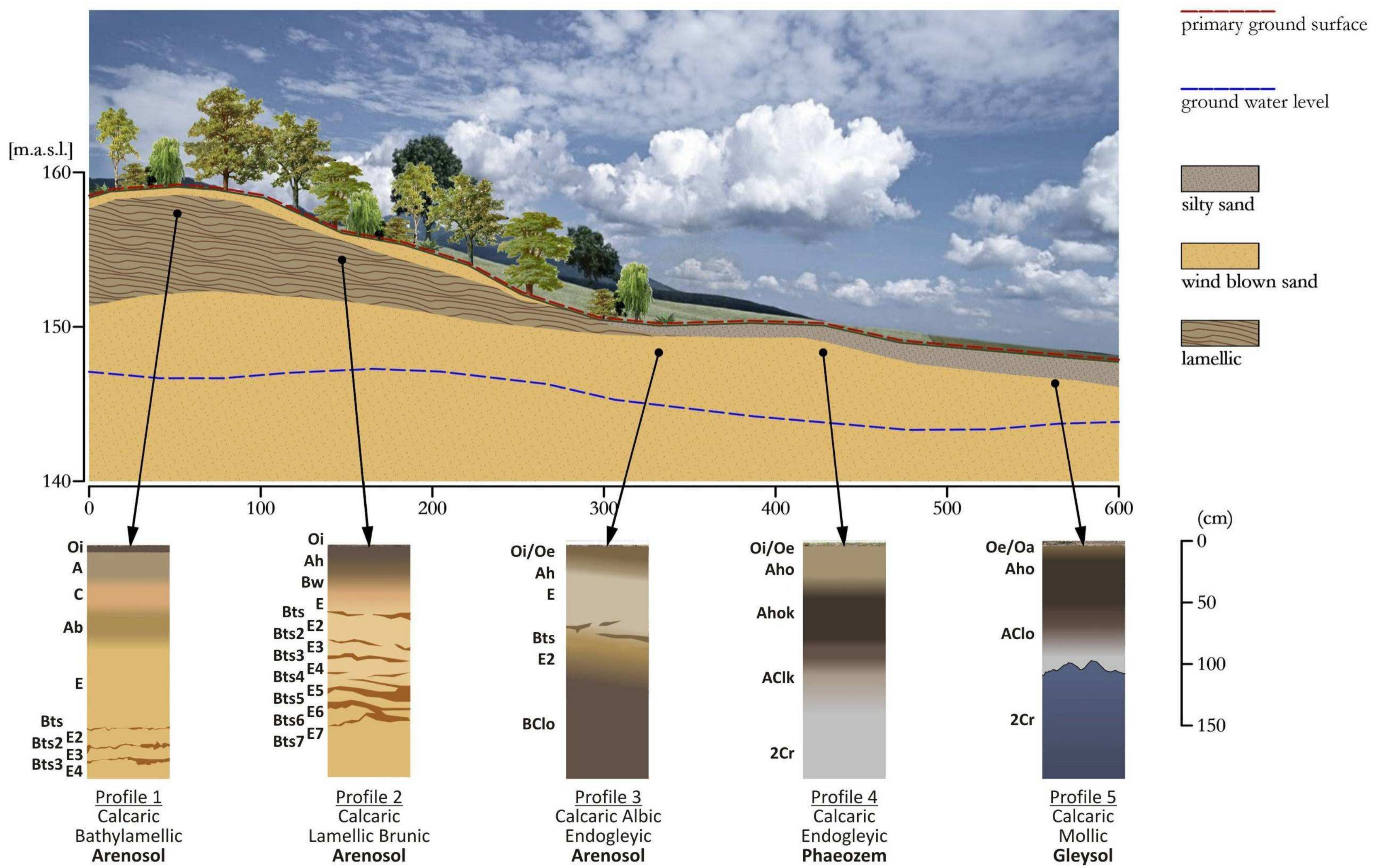


Fig. 2. Litho-hydrosequence of soils in Alluvial plain with wind-blown sand dunes

Climate

According to Köppen-Geiger Climate Classification, the region is located in the warm temperate zone, fully humid with warm summer (Kottek et al., 2006). The average annual air temperature is 9.6–9.8°C. The warmest month is July (20.4°C). The mean air temperature during January (the coldest winter month) is about -2°C. The average annual precipitation is 550–580 mm. June is the wettest month with average precipitation around 65–75 mm. The prevailing wind directions are N, NE and SW (Borsy, 1961).

Soil genesis and systematic position

A characteristic feature of soil profiles on the investigated dunes are ***lamellic*** appearance of Bts soil horizons occurring at a varying depth and thickness within sand dunes. They were also described in the earliest pedological studies from Nyírség (Kléh – Szűcs, 1954; Stefanovits, 1954, 1959; Kádár, 1957), but their genetics was highly controversial (Kádár, 1957; Borsy, 1978). Since the material of the dunes is wind-blown fine sand showing no evidence of stratification, a lithogenic origin of these lamellae could be excluded. They could be interpreted as colloidal iron oxide and hydroxide accumulation strata (Bockheim & Hartemink, 2013) in distinct layers initiated by drying-up of wetting fronts according to the suggestions of Rawling (2000) and Torrent et al. (1980). The amount of colloidal illuvial coats on the single sand grains or indurated and cemented lamellas, the thickness of which varying from few mm to several decimeters generally increasing with the depth. The lamellae appear also in depth shallower than the recent wetting fronts, therefore their development could be supposed to start in the late Pleistocene. Humid climate phases during the Holocene and the late Pleistocene favour the genesis of lamellae due to deeper and frequent wetting, while during dry climate phases, they could be interpreted as relic soil features. The dune (Profiles 1, 2) soils were classified as **Arenosols** (IUSS Working Group WRB, 2014). In addition to the presence of the Bts horizon, this RSG was distinguished based on (1) the fine sand texture in the whole 100 cm soil layer, and (2) the lack of other diagnostic features. In some cases, the texture of distinct lamellae (Profile 3) is finer than for Arenosols requiring loamy sand (fine sandy loam: Profile 3), but accumulated thickness of such layers does not exceed 15 cm within 100 cm starting from the surface, therefore Profile 3, which is situated on the plain terrain at the base of dunes, have been classified as **Arenosol**. In dry periods or as a consequence of former land use changes, sand movement and redeposition of sand by Aeolian processes could reoccur even in historic and recent time (Sipos et al., 2006), therefore former soils could be covered by recent sand layers. In Profile 1, the buried soil is covered by later aeolian sand deposition, which is expressed by ***Areninovic***. Profiles having more than 10 cm thick sandy material at the surface, redeposited apparently by wind, holds the ***Aeolic*** supplementary qualifier as well.

In Profile 2, accumulated thickness of lamellae exceeds 15 cm within 200 cm starting from the soil surface, therefore this feature was expressed by using ***Lamellic;*** while in the case of Profile 1 and Profile 3, cumulative thickness of lamellae is less than 15 cm within 200 cm, thus the lamellic is not used in spite of the visible presence of lamellae.

Below the surface zone and in the interlamellic space, there are light coloured layers with single grain structure, characterized by dynamic iron depletion and eluviation processes, which is most strongly expressed in the case of Profile 3, where a well-developed thick soil horizon consisting of the *albic* material developed.

An additional characteristic of Profile 2 is a slight enrichment of organic content, and the evidence of changes in the structure and coloration below the topsoil compared to the underlying soil horizons. Nonetheless, the organic content is too low, and the structure not sufficiently developed to describe this A horizon as a diagnostic one. The evidence of changes in Profiles 2–3 is expressed in topsoil layers, but they do not meet criteria for the *cambic* horizon. Their texture is fine sand, thus the ***Brunic*** qualifier was used instead of *cambic*.

The parent material of dunes contains calcium carbonate varying between 1.5 and 3.6%. In Profiles 1 and 2, the calcium-carbonate content of soil layers between 20–50 cm exceeds 2%, therefore ***Calcaric*** was used. In one case (Profile 4), *secondary carbonates* occur in the form of soft concretions, therefore the profile meets the criteria of ***Calcic***. Secondary carbonates are probably not only a result of precipitation of carbonates leached from topsoil, but the capillary rising groundwater and the evaporating water balance.

In the lower position, at the base of the dunes, the rising capillary groundwater affects the pedogenetic processes, which occur in Profile 3 only in the subsoil as the *gleyic colour pattern*, in changing oxidized and reduced iron forms, which in this case is described by the ***Endogleyic*** qualifier. In the deeper position, the groundwater impact is more expressed, while some iron concentrations occur closer to the surface, along root channels and pores. The *Gleyic colour pattern* prevails in the pedon and the reducing *conditions* occur in the lower part of Profiles 4 and 5; the pattern starts within 50 cm below the surface, while these pedons were classified as **Gleysols**. Profile 5 was saturated with groundwater below the depth of 105 cm, even in the driest period of the year when profile was dug.

Additionally, the two profiles (4 and 5) were very rich in organic carbon content, having deep humus layers, with granular structure and base saturation higher than 50%, which meets the criteria of the *mollic* horizon, therefore the ***Mollic*** principal qualifier was used in both cases.

Profiles 1–3 are developed on fine sand as parent material. Sand dominates also in deeper horizons of Profile 4 and 5, however with a higher proportion of medium- and fine-grained sand. The presence of *lithological discontinuity* was identified in Profiles 4–5 by an abrupt change in the grain size distribution, changing top-down from mostly fine sandy loam into sand. Within the sand fraction in the uppermost layers, the fine sand dominates, which changes in the lower layers into half medium and half fine sand. The dust (0.02–0.05 mm) content of surface layers is also higher compared to other profiles. This could be caused not only by weathering processes of topsoil, which are not particularly intensive in these sandy soils, but rather by the sorting effect of wind accumulation processes during the accumulation of dunes, which consist of fine, well-sorted sand; in wet conditions of depressions, the sand is covered by sandy loam. The material at the bottom was not well-sorted by wind; additionally the blown dust could be trapped and fine sandy loam strata cover the less sorted sand material. This *lithic discontinuity* is restricted to Profiles 4–5 and occurs within 100 cm, but the ***Ruptic*** qualifier was not used because it is not included on the list assigned to **Gleyslos**.

Soil sequence

The described soil sequence is characterized by quite similar lithogenesis. The soil profiles are developed from wind-blown fine sand and dust. Differences in the grain size distribution are, however, characteristic of depressions between dunes and lower plain areas. Dunes are mainly composed of fine sand and, to a lesser extent, medium sand, well sorted by aeolian accumulation processes. In the lower wet areas, the sand is not so well sorted, and consists of fine and medium sand in almost equal proportions, mixed with Aeolian silt at the surface, which was trapped by temporary surface waters. The main differences that cause different directions of the soil-forming processes are associated with the topography and the influence of groundwater. The spatial arrangement of pedons represents a typical **litho-hydrosequence**. The surface of dunes and slopes is covered by **Arenosols**, developed with no influence of the rising groundwater level. The soils found at the bottom of depressions − **Gleysols** − are strongly influenced by ground water.

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Urban soils on the drift sand areas in Hungary

Gábor Sándor, György Szabó

Debrecen is the seat of Hajdú-Bihar county, situated in the eastern part of Hungary, at a distance of 230 km from the capital and 35 km from the Romanian border – 21° 38′ E and 47° 31′ N. (Fig. 1.) With an area of 461.65 km^2 and a population of around 200.000, **Debrecen** is the second largest and most populated city of the country. Debrecen is located on the border of Hajdúság and Nyírség landscape units. Hajdúság is a loess plain, which was affected by the sand movement in the würm. The most characteristic drift sand areas in Hungary can be found in Nyírség. The central and the eastern part of the city belongs to this landscape unit (Martonné, 2008).

Fig. 1. Location

Lithology and topography

The presented soils are located in the northern part of Debrecen within South-Nyírség. The city is situated in a gentle depression at a height of about 110–120 m above sea level. The area rises westwards and eastwards (Marosi, Somogyi 1990). The drift sand areas were formed on sandy alluvial cones which were accumulated by rivers (Borsy 1987). In the geological history, there were two big periods of sand movement. The first one was in the second half of Würm, in the upper pleniglacial (27000–20000). The other sand movement period took place in the late Pleistocene, in the late-glacial (13000–10000). Asymmetric blow-out dunes are the most spectacular forms of drift sand (Martonné 2008).

Land use

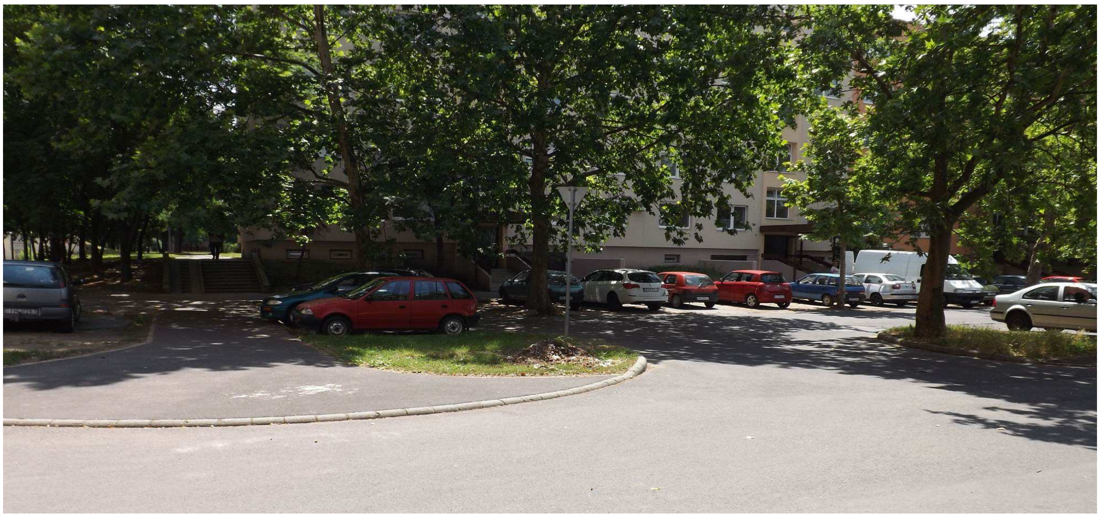
Debrecen is located in Eupannonicum within the Nyírség flora district (Szegedi 1999). The native forests (*Querco-Ulmetum, Convallario Quercetum tibiscense*) are almost absent, replaced by locust trees (*Robinia pseudoacacia*) and planted pines. The investigated profiles are located in the northern part of Debrecen. The surroundings of the studied profiles were different: residential district with 4–14 storey apartment houses with small parks and playgrounds, recreational areas and a cemetery (Sándor et al. 2013).

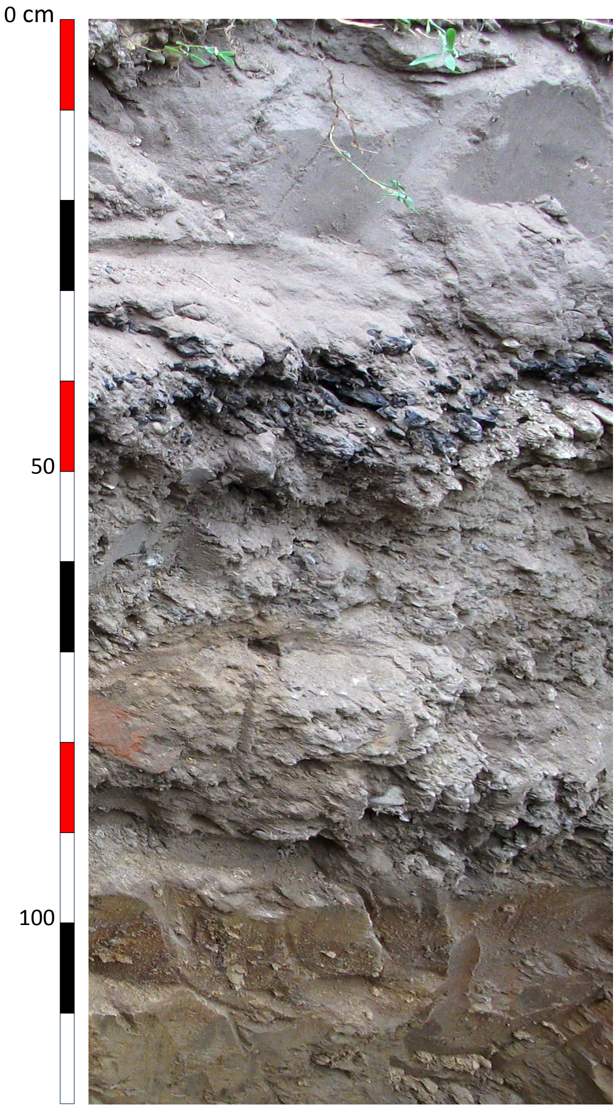
Climate

The climate is temperate warm and temperate dry (Marosi, and Somogyi, 1990). According to the Köppen–Geiger Climate Classification, the region is located in the warm temperate, fully humid with warm summer zone (Kottek et al., 2006). The average annual precipitation is 588 mm. The number of sunshine hours is about 2000, the maximum value is in July and the minimum in December. The potential evaporation is 760 mm/year. The average annual air temperature is between 9.6 and 9.9°C. The warmest month is July (21.2°C). The mean air temperature during January (the coldest winter month) is -2.5°C (Szegedi, 1999).

Profile 1 – Urbic **Technoso**l (Eutric, Arenic, Calcaric, Ochric, Transportic)

Localization: The profile is located in the northern part of Debrecen. Residential district with 4–14 floors apartment houses with small parks and playgrounds, 121 m a.s.l.
N 47°32'49", **E** 21°36'12"





Morphology:

Au – 0-32 cm, humus horizon, sand, light gray (10YR 7/2; 10YR 4/2), single grain structure, very dry, abrupt boundary, numerous artefacts;

THM – 32–47 cm, *technic hard* material – asphalt mixture, weakly permeable;

Cu – 47–90 cm, loamy sand, light brownish gray (10YR 6/2; 10YR 4/2), single grain structure, very dry, abrupt boundary, many artefacts;

C – 90–(115) cm, loam, yellowish brown (10YR 7/6; 10YR 5/6), weak structure, slightly moist, no artefacts.

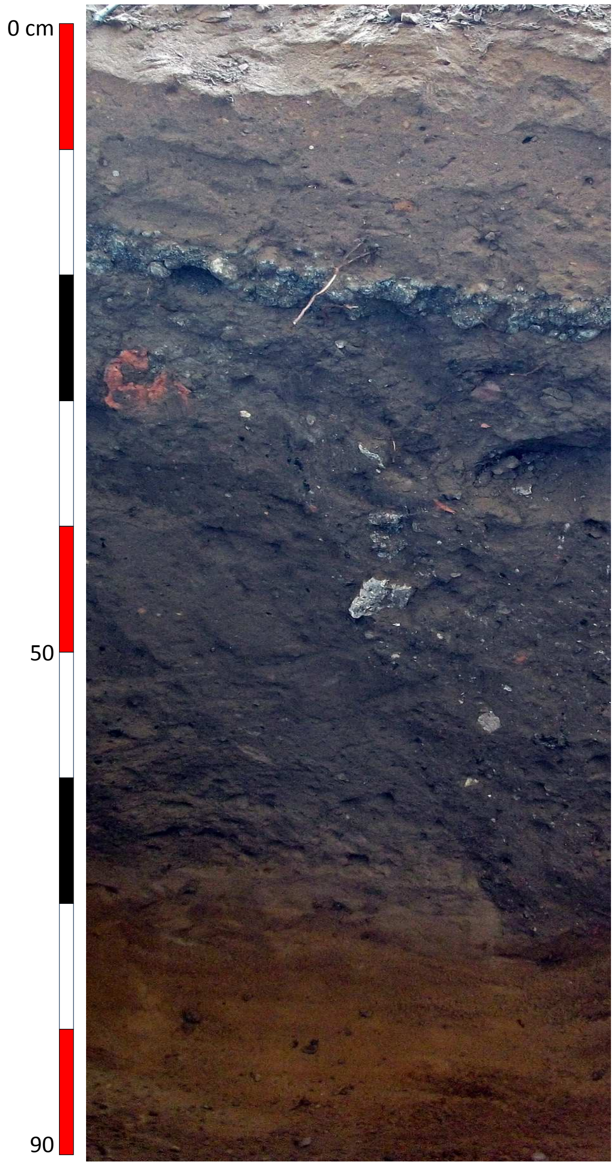
Table 1. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.2	0.2–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
Au	0–32	16	0	2	16	62	9	3	4	1	3	S
Cu	47–90	16	0	3	13	56	11	4	5	3	5	LS
C	90–(115)	0	0	0	1	25	16	26	14	4	14	L

Table 2. Chemical and physicochemical properties

Horizon	Depth [cm]	Organic matter [%]	OC [g·kg^{-1}]	pH		$CaCO_3$ [g·kg^{-1}]
				H_2O	KCl	
Au	0–32	0.61	3.5	7.6	7.2	22.0
Cu	47–90	0.15	0.9	8.3	7.9	34.0
C	90–(115)	0.3	1.7	7.5	6.2	27.0

Profile 2 – Urbic **Technosol** (Eutric, Arenic, Calcaric, Ochric, Transportic)
Localization: The profile is situated in the northern part of the city, 124 m a.s.l.
N 47°33’8”, **E** 21°37’49”



Morphology:

A – 0–17/21 cm, HTM – human transported material (humus layer), sand, dry, weak structure, light brownish gray (10YR 6/2; 10YR 4/2), few artefacts, clear boundary;

THM – 17/21–21/25 cm, *technic hard* material – weakly permeable;

Aub – 21/25–68 cm, humus horizon, sand, dry, weak structure, grayish brown (10YR 5/2; 10YR 3/2), common artefacts, gradual boundary;

C – 68–(88) cm, sand, single grain, dry, brownish yellow (10YR 6/6 ; 10YR 4/2), very few artefacts.

Table 3. Texture

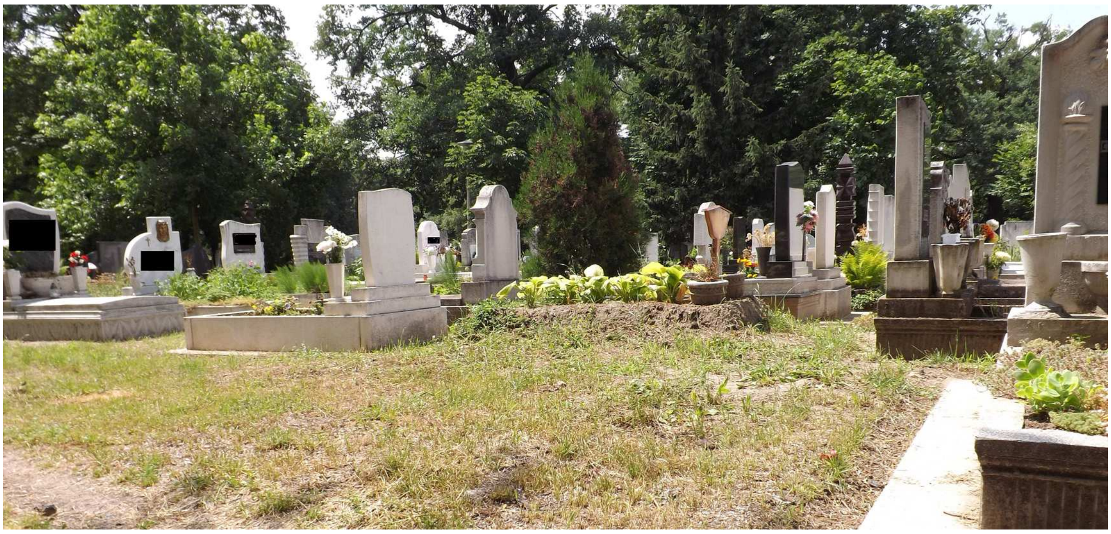
Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.2	0.2–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
A	0–17/21	4	0	1	11	52	27	2	3	1	3	S
Aub	21/25–68	14	1	1	13	57	17	4	4	2	1	S
C	68–(88)	1	0	1	16	66	11	2	2	1	1	S

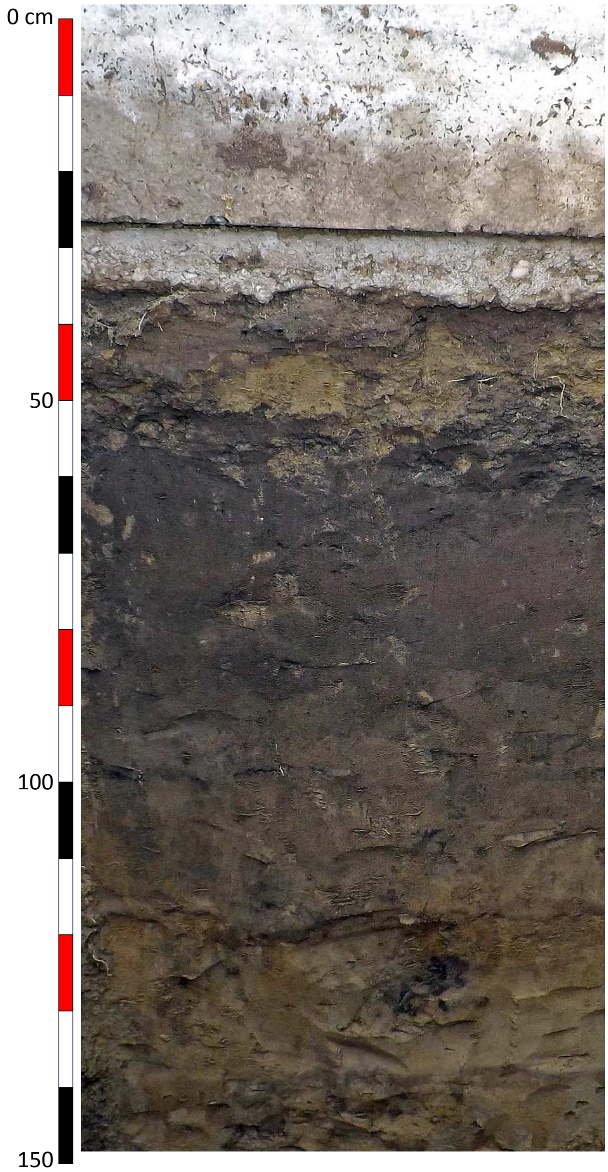
Table 4. Chemical and physicochemical properties

Horizon	Depth [cm]	Organic matter [%]	OC [$g \cdot kg^{-1}$]	pH		$CaCO_3$ [$g \cdot kg^{-1}$]
				H_2O	KCl	
A	0–17/21	0.67	3.9	7.7	6.9	28.6
Aub	21/25–68	1.26	7.3	7.6	7.2	29.1
C	68–(88)	0.21	1.2	7.3	6.8	20.3

Profile 3 – Ekranic **Technosol** (Eutric, Calcaric, Thaptomollic)

Localization: The profile is situated in the area of the public cemetery in the northern part of the city, 124 m a.s.l., **N** 47°33’30”, **E** 21°39’00”





Morphology:

THM – 0–35 cm, *technic hard* material, concrete slab;

A/C – 35–54 cm, mixed horizon, sandy loam, light yellowish brown (10YR 6/4; 10YR 6/8) and dark grayish brown (10YR 4/2; 10YR 3/2), abundant mottles, weak structure, very dry, abrupt boundary, no artefacts;

Ab1 – 54–85 cm, humus horizon, loamy sand, dark grayish brown (10YR 4/2; 10YR 3/2), weak structure, dry, clear boundary, no artefacts;

Ab2 – 85–104 cm, humus horizon, sand, grayish brown (10YR 5/2; 10YR 4/2), single grain, dry, clear boundary, no artefacts;

C1 – 104–130 cm, loamy sand, brown (10YR 6/3; 10YR 5/3), single grain, slightly moist, gradual boundary, no artefacts;

C2 – 130–(155) cm, sandy loam, brownish yellow (10YR 6/4; 10YR 6/8), single grain, slightly moist, no artefacts.

Table 5. Texture

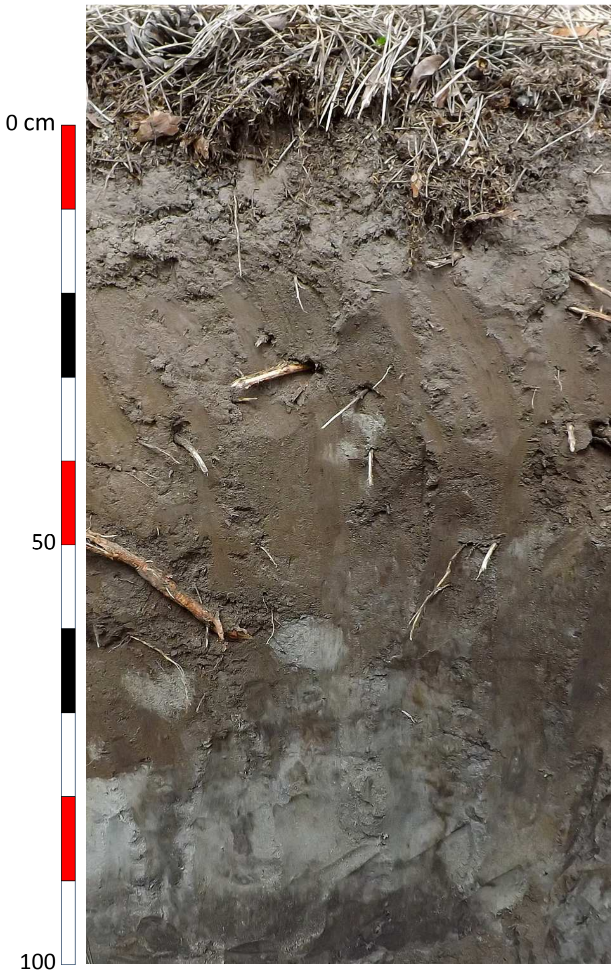
Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.2	0.2–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
A/C	35–54	0	0	1	6	41	25	10	6	3	8	SL
Ab1	54–85	0	0	1	12	50	15	6	7	3	6	LS
Ab2	85–104	0	0	1	10	58	16	5	4	2	4	S
C1	104–130	0	0	1	10	57	17	5	4	1	5	LS
C2	130–(155)	0	0	1	6	37	23	11	6	3	13	SL

Table 6. Chemical and physicochemical properties

Horizon	Depth [cm]	Organic matter [%]	OC [g·kg^{-1}]	pH		$CaCO_3$ [g·kg^{-1}]
				H_2O	KCl	
A/C	35–54	0.86	5.00	7.6	7.5	39.0
Ab1	54–85	1.47	8.50	7.7	7.4	25.0
Ab2	85–104	0.57	3.30	7.7	7.2	23.0
C1	104–130	0.26	1.50	7.7	7.0	32.0
C2	130–(155)	0.43	2.50	7.7	6.8	28.0

Profile 4 – Calcaric **Arenosol** (Aeolic, Ochric)

Localization: The profile is situated on the drift sand area in the surroundings of the city, **N** 47°34’57”, **E** 21°42’26”



Morphology:

Oi – 7–0 cm, slightly decomposed organic material;

A – 0–18 cm, humus horizon, sand, very dry, weak granular structure, grayish brown (10YR 5/2; 10YR 3/3), very fine and few roots, clear boundary;

Ab – 18–62 cm, buried humus horizon, sand, dry, weak granular structure, yellowish brown (10YR 5/4; 10YR 3/3), coarse and many roots, common mottles, diffuse boundary;

C1 – 62–79 cm, sand, dry, weak structure, light gray (10YR 6/1; 10YR 5/2), abundant mottles, diffuse boundary;

C2 – 79–(100) cm, sand, weak subangular very thin structure, very dark grayish brown (10YR 5/1; 10YR 3/2), moist, few mottles.

Table 7. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–1.0	1.0–0.5	0.5–0.2	0.2–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	
A	0–18	0	0	1	15	53	20	4	4	2	1	S
Ab	18–62	0	0	1	14	54	17	4	5	2	3	S
C1	62–79	0	0	1	16	63	10	3	3	1	3	S
C2	79–(100)	0	0	1	16	56	14	3	3	1	6	S

Table 8. Chemical and physicochemical properties

Horizon	Depth [cm]	Organic matter [%]	OC [g·kg^{-1}]	pH		$CaCO_3$ [g·kg^{-1}]
				H_2O	KCl	
A	0–18	0.9	5.2	4.8	3.9	46.9
Ab	18–62	1.04	6.0	5.0	3.9	57.6
C1	62–79	0.2	1.2	6.3	5.3	54.6
C2	79–(100)	0.34	2.0	6.3	5.1	50.7

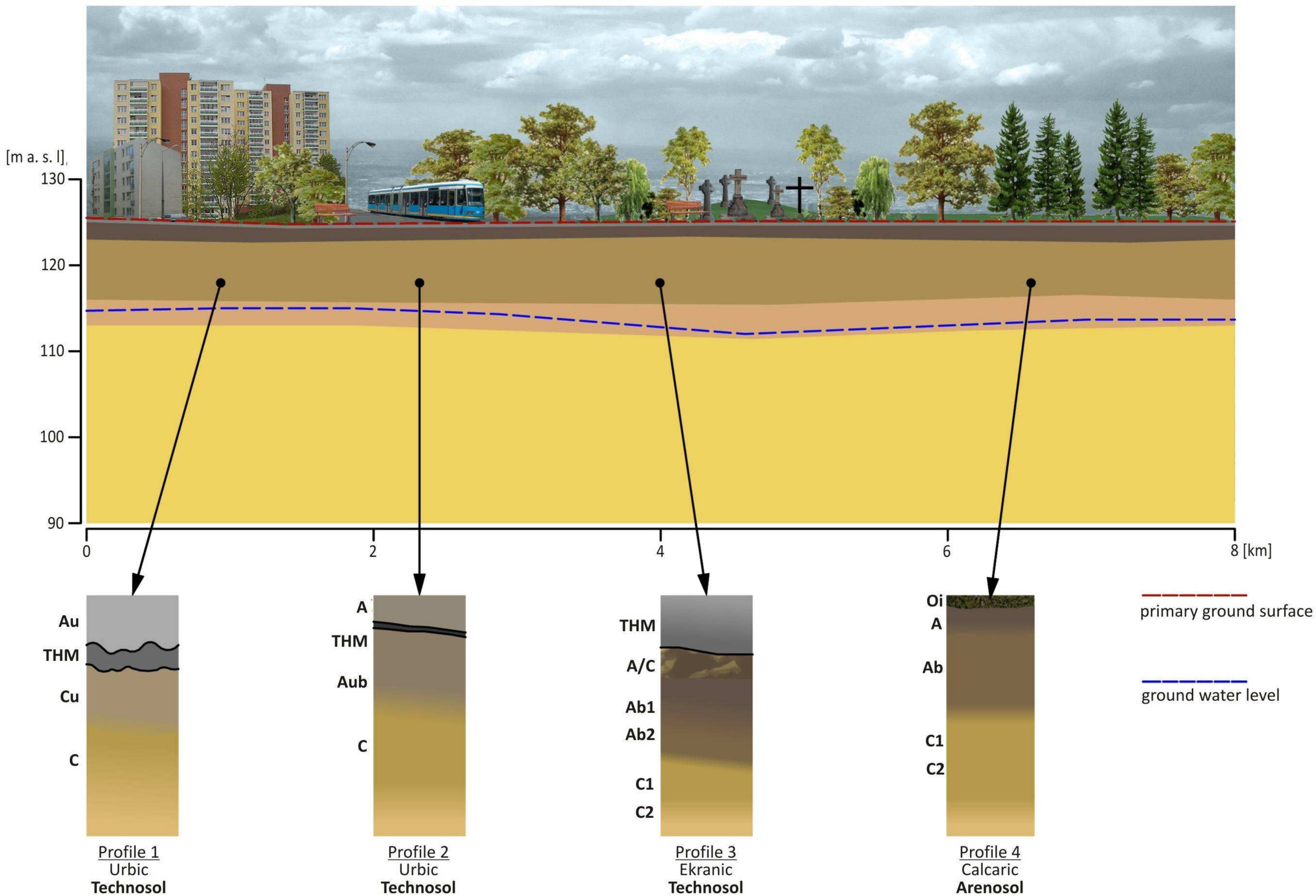


Fig. 2. Technosequence on the drift sand areas of Hungary

Soil genesis and systematic position

The investigated area was originally covered by Arenosols, which consist of weakly developed A and C horizons with a low humus content. In each of the pedons located within the city, the original genetic soil horizons can be identified and the sand fraction was the dominant in every soils (Table 1, 3, 5, 7). The soils within the city with the artefacts content, the *technical hard* material and the surface sealing were ranked among the **Technosol** Reference Group (IUSS Working Group WRB, 2014). Changes in the soils greatly depend on the location of the soil profile within the city. Profile 1 and 2 are extremely disrupted, therefore the ***Urbic*** qualifier was used in both cases. This is clearly visible from the content of artefacts (construction and demolition rubble). In addition, the *technical hard* material (THM) layer and *lithic discontinuity* of technogenic origin occur in both pedons, therefore the ***Transportic*** qualifier was used. The further common feature of the soils is the presence of calcium carbonates, the content of that exceeded 2%. This has been emphasized by the qualifier ***Calcaric*** used in the soil names. The uppermost 1 m thick layer contains a material with a thickness of 30 cm and with a texture of loamy sand or coarser, thus the supplementary qualifier ***Arenic*** was used (Profile 1 and 2) (IUSS Working Group WRB, 2014).

The physical and chemical properties of the cemetery soils greatly depend on the age and the use of a given cemetery (Charzyński et al., 2011). Profile 3 is located in the area of an old public cemetery of Debrecen. In the upper, more than 30 cm thick layer of the presented cemetery profile, a *technical hard* material (concrete slab) can be found (***Ekranic***), which is followed by the anthropogenically mixed (A/C) layer consisting of natural lower soil horizons. The determination of the artefact content is of great importance in the case of cemetery soils. Other researches showed that metallic parts of the coffins (nails, handles, latches and other ornaments) may be important for the heavy metal contamination of the cemetery soils (Olivier and Jonker, 2012), and pointed out that pathogenic substances can increase the organic carbon content in the soils (Charzyński et al., 2011). The studied profile did not contain any artefacts. At a depth of 54 cm, the Ab1 horizon starts, which can be considered as natural, thus the ***Thaptomollic*** supplementary qualifier was used. The deeper part of the humus horizon was described as Ab2 due to different physical properties and colour. It contains a smaller amount of humus and has a sandy texture. Significant differences can be observed in the texture of the parent material (C1 and C2).

The last profile of the described sequence is located on the drift sand area outside the city and represent seminatural soil. Sand is the dominant texture (more than 90%) in every horizons of Profile 4, with the prevailing fraction of 0.1–0.2 mm (Table 7). This texture is characteristic of the typical Hungarian drift sands (Lóki et al., 2008). Based on the texture class, the soil profile was classified as **Arenosol** (IUSS Working Group WRB, 2014). Buried soils are very common on the drift sand areas due to the sand movement. Buried humus horizons are usually found at a depth of 0.5–1.5 m (Lóki et al., 2008). In Profile 4 (A), young aeolian deposits have a thickness of 18 cm. This feature can be highlighted by using the ***Aeolic*** qualifier. Some remains of the older surface A horizons are also visible in the bottom part of the profile as dark grey lens of the humus material in the parent material (C1, C2). Previous researches explain the development of the buried soils with the anthropogenic surface processes during the 18th–19th century, including the deforestation and the expansion of agricultural areas (Lóki et al., 2008). Some enrichment with iron compounds (yellowish brown colour) is visible in the Ab horizon. However, the ***Brunic*** qualifier cannot be applied for the humus horizon. The lower section of the parent material has a significant clay increase of 3%. It should be noted that this feature resulted from lithogenesis – natural textural differentiation of drift sands.

Soil sequence

The described soils represent a different degree of changes in the basic soil properties due to the technogenic influence exerted on the soil cover of Debrecen and its vicinity (**technosequence**). The most important human-induced changes in the soils of urban areas are as follows: the increased artefact content, higher pH, the increased amount of substances available for plants, soil sealing and compaction, and the accumulation of contaminants (Géczy, 2007, Puskás et al., 2006, 2008; Puskás, 2008).

As evidenced by the presented study of spatial variability in the technogenic changes, Profile 1 and Profile 2 are most significantly transformed. In these cases, the types of human activities were similar, since the construction of panel buildings constructed from pre-fabricated concrete blocks and other infrastructure were the dominant feature of this part of Debrecen. As mentioned above, despite significant transformations of the soils, the original genetic soil horizons can be still recognized. The description of the profiles indicates also the secondary, human-induced properties of the soil material (Profile 1 Au-Cu; Profile 2 Aub). The coexistence of natural and anthropogenic/technogenic features is clearly visible in Profile 3. The upper part of the soil is strongly disturbed by human activities (*technic hard* material and strongly mixed A/C horizon), while a well-developed humus horizon of the buried soil is located below the depth of 54 cm. The last profile of the sequence is located on the drift sand area of South-Nyírség, outside the city. The profile is a great example of the semi-natural **Arenosol** within the drift sand area. It should be noted that periods of intensive aeolian processes in this region can be connected with human activities (for example deforestation). The surface horizon represents a recent humus horizon, which is overlying the buried A horizon followed by the parent rock (A-Ab-C1-C2).

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