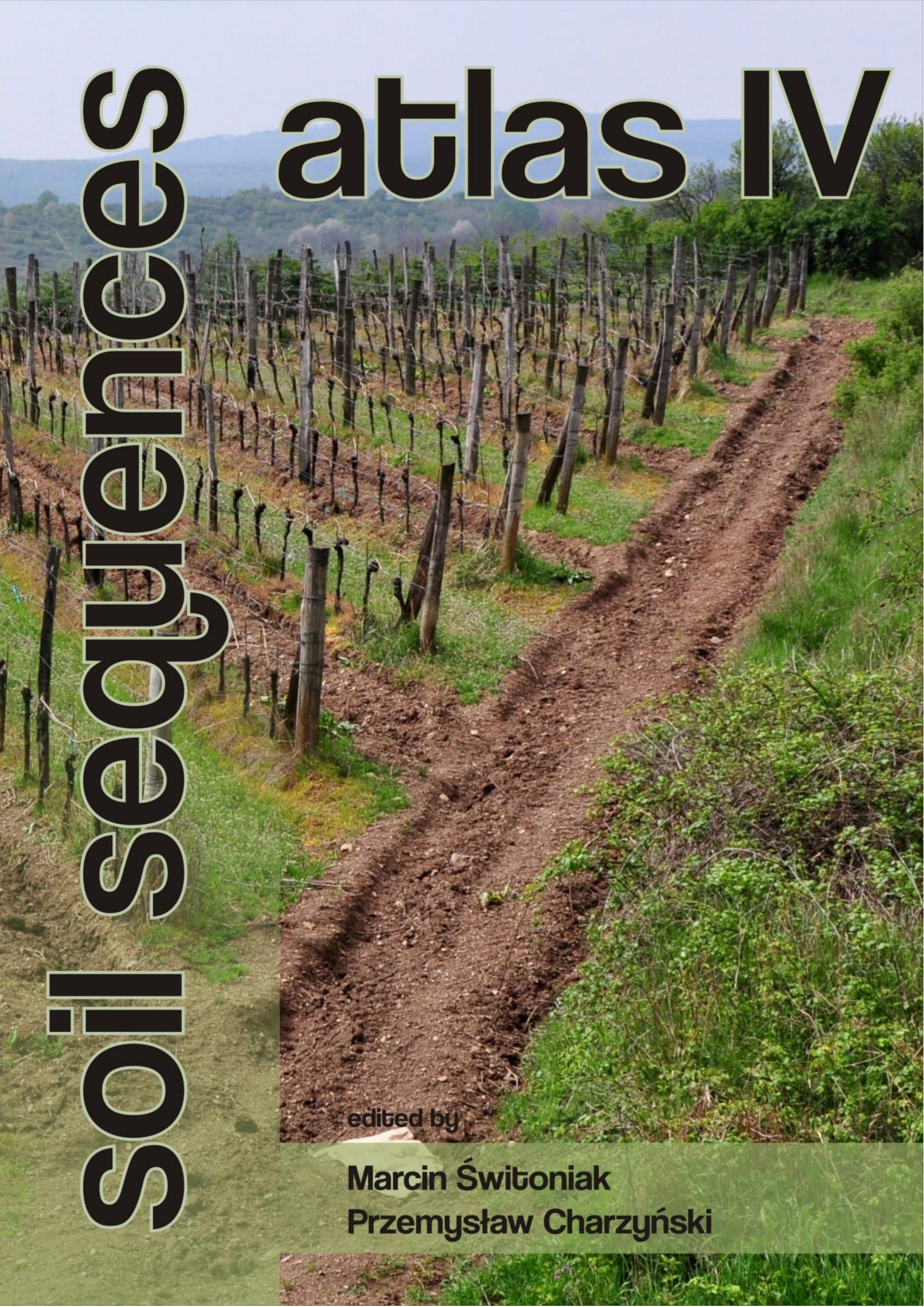


soil sequences atlas IV

edited by

Marcin Świtoniak
Przemysław Charzyński

Soil Sequences Atlas IV

Soil Sequences Atlas IV

Edited by
Marcin Świtoniak
Przemysław Charzyński

Toruń 2018

Editors
Marcin Świtoniak, Nicolaus Copernicus University, Toruń, Poland
Przemysław Charzyński, Nicolaus Copernicus University, Toruń, Poland

Reviewers
prof. *Masayuki Kawahigashi,* Tokyo Metropolitan University, Japan
prof. *Andrzej Greinert,* University of Zielona Góra, Poland

Language editing
Tim Brombley, Ewa Kaźmierczak

Cover design
Marcin Świtoniak

Photographs on the cover
Przemysław Charzyński and Marcin Świtoniak

PUBLISHER:
Machina Druku
ul. Szosa Bydgoska 50
87-100 Toruń
tel. 56 651 97 80

COMMISSIONED:
Nicolaus Copernicus University in Toruń
ul. Gagarina 11
87-100 Toruń
POLAND
www.umk.pl

PRINT:
Machina Druku
www.machinadruku.pl

ISBN 978-83-951878-2-7

Co-funded by

Erasmus+

The views expressed in this work are those of the contributors and do not necessarily reflect those of the European Commission.

Soil Sequences Atlas IV
M. Świtoniak, P. Charzyński (Editors)
First Edition

CONTENTS

FOREWORD

The significant spatial variability of soil cover results from the diverse impacts of different soil-forming factors. This book presents pedovariability in the form of a collection of soil sequences typical of particular landscape types. The fourth part of the Soil Sequences Atlas contains description of 75 pedons (with soil profile photo, description of morphology and laboratory data) grouped into 15 chapters each representing a different environmental setting specific to Central or East Europe and Caucasia. The Atlas begins by presenting a pedo-landscape dominated by alluvial and gleying processes (the Vistula River delta in Poland). Next comes a group of chapters devoted to mountainous regions that comprises different soil-forming processes, e.g. podzolisation (Karkonosze Mts., Poland) or humus accumulation (Trialeti Range, Georgia). The second part of the book focuses on issues related to slope processes in different landscapes, from karst sinkholes in the Pre-Ural forest–steppe (Russia), through loess plateaus (Hungary, Belarus) and glacial morainic plateaus (Latvia, Lithuania, Poland) to areas that feature glacial curvilineations or are covered by outwash plains (Poland).

The collected data is intended as a useful educational tool in teaching soil science, and in supporting an understanding of the reasons behind the variability of soil cover, and also as a WRB classification guideline. It is intended to be useful not only to students but also to practitioners in agriculture, forestry, environmental protection and landscape planning.

The Atlas was developed as part of the EU Erasmus+ FACES project (Freely Accessible Central European Soil).

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 2015[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, 2015. World Reference Base for soil resources 2014, update 2015 International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Report No. 106. FAO, Rome.

2 FAO, 2006. Guidelines for Soil Description, Fourth edition. FAO, Rome.

3 Bouyoucos, G.M., 1951. Particle analysis by hydrometer method. Agronomy Journal 43, 434–438.

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 – Vistula River delta, Poland
2 – Čabranka River valley, Slovenia
3 – Karkonosze Mountains, Poland
4 – Carpathians, Wdźar Mountain, Poland
5 – Trialeti Range, Sakartvelo (Georgia)
6 – Karst sinkhole, Pre-Ural forest-steppe, Russia
7 – Loess plateau in North Mezőföld, Central Hungary
8 – Loess plateau, Trnava Hilly Land, Slovakia
9 – Tribeč mountain range and Nitra valley slope, Slovakia
10 – Morainic Hills, Latvia
11 – Hummocky moraine landscapes, Lithuania
12 – Horatskaya Plain, Belarus
13 – Glacial curvilineations, Dobrzyń Lakeland, Poland
14 – Undulating glacial moraine, Poznań Lakeland, Poland
15 – Kettle-holes within outwash plain, Brodnica Lake District, Poland

A human-influenced soil sequence in the Vistula River delta (Gdańsk, Poland)

Piotr Hulisz, Magdalena Lazarus, Marcin Świtoniak, Przemysław Charzyński

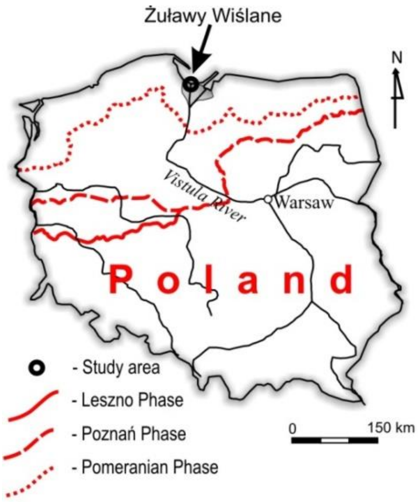


Fig. 1. Location

The research area includes right embankments of the Dead Vistula (Sobieszewska Pastwa, Sobieszewska Island) which is the right natural mouth of the Vistula River to the Baltic Sea. It was cut off from the mainstream by the construction of the artificial channel called the Vistula Cut in Świbno (1889–1895) and the lock in Przegalina (1914–1917) (Makowski, 1995). According to Kondracki (2014) it is a part of the Żuławy Wiślane – a mesoregion that was formed as a result of both alluvial processes and human activity (mostly drainage). The nearest city is Gdańsk (Sobieszewo district).

Lithology and topography

The Vistula River delta constitutes a vast delta plain. The whole area is geologically young and started forming around 6,000 years ago in connection with water level rises in the Baltic Sea during successive transgressions (Augustowski, 1972; Starkel, 1988). The area is flat and only slightly elevated above sea level. It is cut by river beds, drainage channels and ditches. A certain variety is added to the landscape by embankments built along larger watercourses (Mojski, 1990). The delta is built from different sediments, namely: riverine (sands and silts) and lake-swamp (clays, gyttja, peats). The largest area is occupied by alluvial soils (Witek, 1965). The construction of the Vistula Cut and the regulation works at the river mouth significantly contributed to the enlargement of the land area and transformation of the soil cover (Hulisz et al., 2015).

Land use

Due to the large hydrographical anthropogenic transformations, the Vistula River delta is an area of great agricultural importance. Meadow communities, especially prevalent on the river embankments, have a small share. Also, in swampy places or along the riverbeds, rushes develop. As a result of the separation from the main river course and thus greater inflow of brackish Baltic waters, an increase in water salinity is observed (Cyberski and Mikulski, 1976). This favours the local development of halophilous vegetation such as *Juncus gerardii*, *Aster tripolium*, *Glaux maritima* and *Plantago winteri* (Markowski, Stasiak, 1984; Lazarus and Wszałek-Rożek, 2016).

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 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 this region. The average annual wind speed in the coastal zone may exceed 5 $m \cdot s^{-1}$, while in the interior zone only 2 $m \cdot s^{-1}$ (Kwiecień and Taranowska, 1974). Strong winds (above 10 $m \cdot s^{-1}$) occur for ca. 70 days a year (Kwiecień, 1990).

Profile 1 – Eutric Fluvic **Gleysol** (Arenic, Nechic, Protosalic)
Localization: Sobieszewska Pastwa, flat terrain, flood zone, 2 m a.s.l., reed rush (*Phragmitetum australis*)
N 54°19'9.42" **E** 18°51'48.61"

Morphology:

Az – 0–5 cm, humus horizon, sand, brownish black (10YR 2/2, moist), slightly moist, fine weak granular/single grain structure, fine and few roots, earthworm channels, moderately salty, irregular and diffuse boundary;

Az2 – 5–15 cm, humus horizon, sand, brownish brown (10YR 4/1, moist), slightly moist, weak granular/single grain structure, fine and very few roots, strongly salty, irregular and diffuse boundary;

Clz – 15–45 cm, sand, yellowish brown (2.5Y 6/3, moist), moist, single grain structure, medium and single roots, strongly salty, single weak iron concretions, smooth and diffuse boundary;

Clz2 – 45–(60) cm, sand, yellowish brown (2.5Y 5/3, moist), wet, single grain structure, strongly salty, iron concretions, fine and very few roots.

Table 1. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	
Az	0–5	0	1	21	48	16	10	2	1	0	1	S
Az2	5–15	0	1	22	51	17	6	1	1	0	1	S
Clz	15–45	0	1	19	54	17	3	1	1	0	4	S
Clz2	45–(60)	0	1	29	55	13	2	0	0	0	0	S

Table 2. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	St [$g \cdot kg^{-1}$]	pH		C/N	C/S	$CaCO_3$ [$g \cdot kg^{-1}$]	EC_e [$g \cdot kg^{-1}$]
					H_2O	30% H_2O_2				
Az	0–5	19.2	1.88	2.82	6.3	4.1	10	7	1.00	3.89
Az2	5–15	6.70	0.70	1.60	6.2	4.5	10	4	0.00	4.12
Clz	15–45	1.00	-	1.96	6.4	4.5	-	1	1.00	4.05
Clz2	45–(60)	0.20	-	1.72	6.5	4.2	-	<1	0.00	5.12

Profile 2 – Eutric Fluvic **Gleysol** (Siltic, Protosalic)
Localization: Sobieszewska Pastwa, flat terrain, flood zone, 2.5 m a.s.l., unused meadows (*Molinio-Arrhenatheretea* class) transforming into herbaceous/rush communities,
N 54°19'11.60" **E** 18°51'49.08"

Morphology:

Az – 0–12 cm, humus horizon, very fine sandy loam, brownish black (10YR 2/2, moist), moist, fine weak granular structure, fine/medium and few roots, earthworm channels, strongly salty, sharp and clear boundary;

Clz – 12–30 cm, very fine sandy loam, yellowish brown (2.5Y 5/1, moist), moist, medium moderate subangular structure, strongly salty, weak iron concretions, smooth and diffuse boundary;

Clz2 – 30–(60) cm, silt loam, yellowish brown (2.5Y 4/1, moist), wet, medium weak subangular structure, strongly salty, iron concretions.

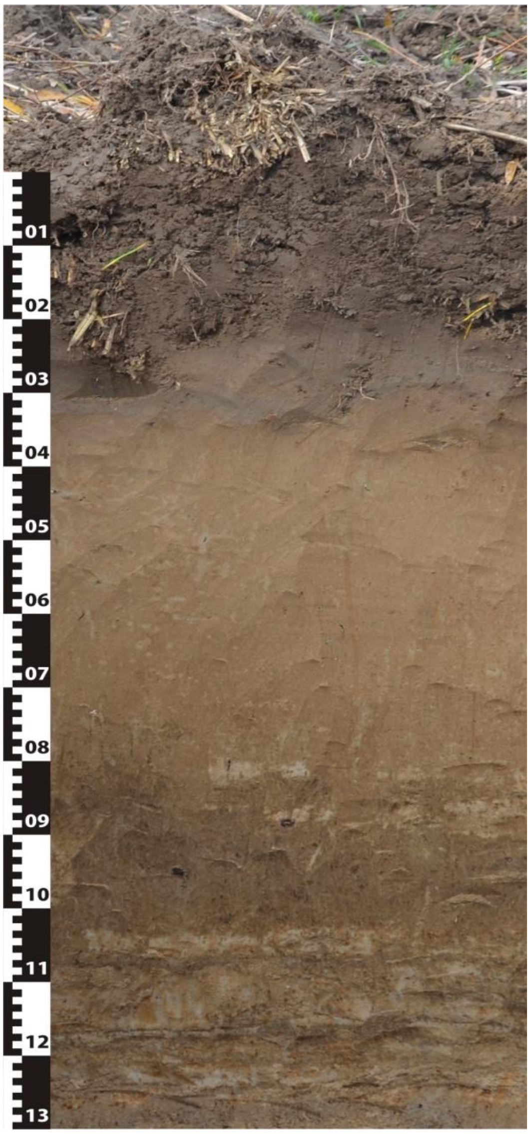
Table 3. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	
Az	0–12	0	0	5	8	18	41	13	7	2	6	VFSL
Clz	12–30	0	0	1	2	13	37	18	11	5	13	VFSL
Clz2	30–(60)	0	0	1	1	1	9	37	23	9	19	SiL

Table 4. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	St [$g \cdot kg^{-1}$]	pH		C/N	C/S	$CaCO_3$ [$g \cdot kg^{-1}$]	EC_e [$g \cdot kg^{-1}$]
					H_2O	30% H_2O_2				
Az	0–12	71.3	6.74	2.08	6.8	4.8	11	34	1.00	4.30
Clz	12–30	8.60	-	2.16	8.0	4.2	-	4	4.00	5.24
Clz2	30–(60)	8.40	-	1.78	8.2	7.4	-	5	16.0	8.08

Profile 3 – Eutric Endofluvic Endostagnic **Cambisol** (Aric, Loamic, Bathygleyic)
Localization: Sobieszewska Pastwa, flat terrain, inter-embankment zone, 3.5 m a.s.l., arable field
N 54°19'13.42" **E** 18°51'52.69"



Morphology:

Ap – 0–20 cm, plough humus horizon, sandy loam, brownish black (10YR 3/2), moist, medium weak granular structure, very fine and common roots, earthworm channels, abrupt and smooth boundary;

Ap2 – 20–30 cm, plough humus horizon, sandy loam, brownish gray (10YR 5/1), slightly moist, medium weak subangular structure, very fine and few roots, abrupt and wavy boundary;

Bw – 30–80 cm, sandy loam, yellowish brown (10YR 5/6), slightly moist, medium weak subangular structure (platy in the upper part), very fine and few roots, common mottles, very few small manganese and iron concretions, diffuse and smooth boundary;

C – 80–90 cm, layered loamy fine sand, light gray (10YR 8/1, 60%) and brown (10YR 4/4, 40%), slightly moist, medium weak subangular structure, few small manganese and iron concretions, clear and smooth boundary;

(Ab)C – 90–105 cm, sandy loam, brown (10YR 4/4, moist), slightly moist, fine weak subangular structure, few small manganese and iron concretions, clear and smooth boundary;

C(l) – 105–(130) cm, layered sandy loam, light gray (10YR 8/1), slightly moist, single grain structure, layered, many orange (7.5YR 6/8) and yellowish brown mottles (10YR 5/6), iron concretions.

Table 5. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	0	0	1	3	33	25	18	7	4	9	SL
Ap2	20–30	0	0	1	3	31	31	14	7	5	8	SL
Bw	30–80	0	0	0	2	40	25	18	5	2	8	SL
C	80–90	0	0	0	1	46	34	11	2	1	5	LFS
(Ab)C	90–105	0	0	0	3	43	24	12	6	3	9	SL
C(l)	105–(130)	0	0	0	1	44	28	19	3	1	4	SL

Table 6. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	St [$g \cdot kg^{-1}$]	pH		C/N	C/S	$CaCO_3$ [$g \cdot kg^{-1}$]	EC_e [$g \cdot kg^{-1}$]
					H_2O	30% H_2O_2				
Ap	0–20	11.3	0.92	1.64	5.9	3.1	12	7	1.00	0.25
Ap2	20–30	9.80	0.89	1.82	6.0	3.1	11	5	1.00	0.56
Bw	30–80	3.90	-	1.68	6.3	4.3	-	2	0.00	0.42
C	80–90	1.50	-	1.82	6.9	5.2	-	1	1.00	0.68
(Ab)C	90–105	2.90	-	1.98	7.3	5.8	-	2	1.00	0.92
C(l)	105–(130)	1.60	-	2.04	7.7	6.8	-	1	1.00	0.35

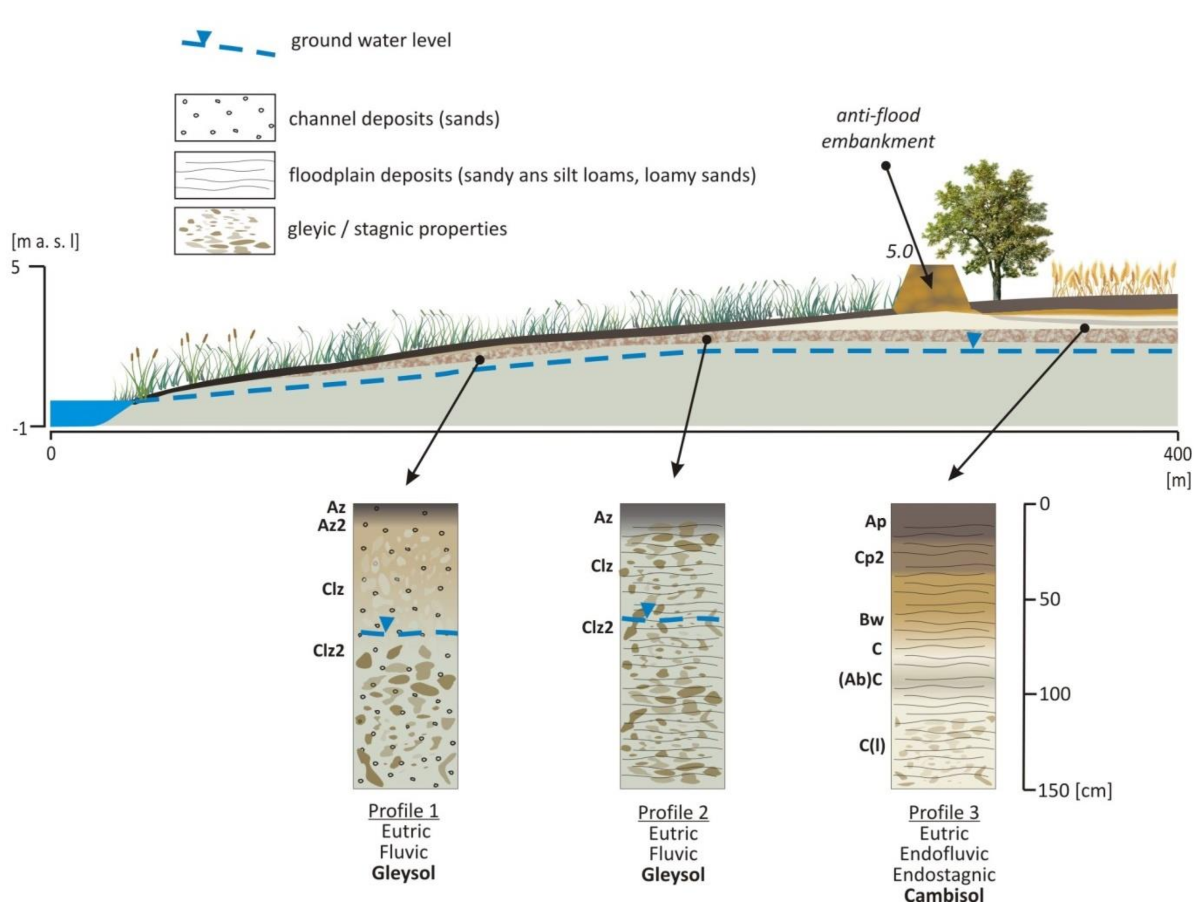


Fig. 2. A human-influenced soil sequence in the Vistula River delta (Gdańsk, Poland)

Soil genesis and systematic position

The river mouth areas are the most vulnerable sites for dynamic interaction of the fluvial and marine processes, which makes the environment very unstable (Wright, 1985; Jegliński, 2013; Hulisz, 2013). In such conditions, pedogenesis can usually be interrupted by geogenetic processes, which lead to the destruction or overbuilding of soil profiles. Another significant factor modifying the properties of soils is human impact, which is mainly seen in the fragmenting of river courses by dams and channel diversions (Maselli and Trincardi, 2013; Hulisz et al., 2015).

The parent materials of the studied soils were alluvial sediments: sands (***Arenic*** qualifier; profile 1), silt loams (***Siltic*** qualifier – profile 2) and sandy loams (***Loamic*** qualifier – profile 3). The accumulation of soil organic matter in those soils could have primarily occurred in different environments: either autochthonous or allochthonous. The stratification evidenced by decreased content of soil organic carbon (profile 1) or morphologically visible layers (profiles 2 and 3) met the criteria for a *fluvic* material. Moreover, uncoated mineral grains within the top 5 cm of the mineral soil surface (***Nechic*** qualifier) was observed in profile 1.

Due to the impact of shallow groundwater, profiles 1 and 2 were characterised by *gleyic* properties. Relatively high drops in pH after reaction of samples with 30% H_2O_2, and low C:S ratio values, may suggest the accumulation of sulphides (IUSS Working Group WRB, 2015; Hulisz et al., 2017), which was favoured by *reducing conditions*. However, a wider range of laboratory analyses is needed to ultimately verify the presence of *sulfidic* material.

Along with the distance from the riverbed, a greater alteration by pedogenic processes was visible, but it was mainly influenced by human activity (cut off from freshwater flooding, amelioration and agricultural soil use). This resulted in the disappearance of the original stratification, the development of the pedogenic structure (***Endofluvic*** and ***Cambic*** qualifiers) and the ploughing horizon (***Aric*** qualifier), and a significant lowering of the groundwater table (***Bathygleyic*** qualifier) in the soil behind the flood bank (profile 3).

Due to hydrotechnical transformation (sluice construction) the studied area is fed mainly by seawater during storms, and for this reason the waters of the Dead Vistula are brackish (Cyberski and Mikulski, 1976; Żakowski et al., 2014). Nevertheless, the salinisation that affected the soils represented by profiles 1 and 2 can also be considered a human-induced process. It seems to be relatively stable, which was confirmed by the occurrence of halophytes such as *Aster tripolium* in the immediate surroundings (Piernik, 2003; Lazarus and Wszałek-Rożek, 2016; Hulisz et al., 2016). These soils had EC_e values lower than 15 $dS \cdot m^{-1}$, which did not fulfil the criteria for a *salic horizon*. However, the presence of salinity features was expressed by the use of the ***Protosalic*** qualifier. The last soil (profile 3) was non-saline, which was caused by the land amelioration.

In addition, the ***Eutric*** qualifier was used to emphasise the pH values above 5.5 in H_2O in all soils, which can serve as an equivalent of the criterion of effective base saturation as suggested by Kabała and Łabaz (2018, in press).

According to the WRB system (IUSS Working Group WRB, 2015), the studied soils were classified as follows: profile 1 – ***Eutric Fluvic*** **Gleysol (Arenic,** ***Nechic, Protosalic*****)**, profile 2 – ***Eutric Fluvic*** **Gleysol (*****Siltic, Protosalic*****)** and profile 3 – ***Eutric Endofluvic Endostagnic*** **Cambisol (*****Aric, Loamic, Bathygleyic*****)**.

Soil sequence

The studied soils were characterised by the low diversity of their morphology and other properties, which was conditioned by very local geomorphological and hydrological conditions, as well as human impact. That is why it is difficult to identify the soil cover patterns by referring to typical hydro-toposequences or chronosequences (Fig. 2).

The lithological variability along the transect is typical of lowland floodplains (Kordowski, 2001). The closest to the water line are Eutric Fluvic Gleysols formed on channel sands (profile 1), which are affected by shallow saline groundwater. Those soils may be flooded during the backflow of Baltic seawater during storm surges. Then, about 200–250 m further from the riverbed, the parent materials of these soils are silt loams (profile 2). Behind the flood embankment, Eutric Endofluvic Endostagnic Cambisol occurs, which is also developed from fine-grained floodplain sediments (profiles 3). The last soil profile shows some properties related to anthropogenic transformations, especially the construction of flood embankments and agricultural use (profiles 3), resulting in dehydration, desalinisation, changes in morphology (the presence of ploughing and *cambic* horizons). This sequence is an example of both direct and indirect human influence on coastal plain soils, which is often multidirectional (Witek, 1965; Phillips et al., 1999; Hulisz et al., 2015).

References

Augustowski, B., 1972. *Coastal lowlands (Pobrzeże Bałtyckie)*. In: Galon, R. (Ed.), Geomorphology of Poland, 2. PWN, Warsaw: 111–128 (in Polish).

Cyberski, J., Mikulski, Z., 1976. *Hydrological relations.* In: Augustowski, B. (Ed.), Żuławy Wiślane. GTN, Gdańsk: 239–288 (in Polish).

Filipiak, J., Miętus, M., Owczarek, M., 2004. Meteorological conditions. In: W., Krzymiński, E., Łysiak-Pastuszak, M., Miętus, (Eds.), Environmental conditions of Polish zone of the southern Baltic Sea in 2001. Materiały Oddziału Morskiego IMGW, Gdynia, 9–32 (in Polish).

Hulisz, P., 2013. *Genesis, properties and systematics position of the brackish marsh soils in the Baltic coastal zone*. Rozprawy habilitacyjne. Wyd. UMK: 137 pp. (in Polish with English summary).

Hulisz, P., Michalski, A., Dąbrowski, M., Kusza, G., Łęczyński, L. 2015. *Human-induced changes in the soil cover at the mouth of the Vistula River Cross-Cut (northern Poland).* Soil Sci. Ann. 66, 2: 67–74.

Hulisz, P., Piernik, A., Mantilla-Contreras, J., Elvisto, T. 2016. *Main driving factors for seacoast vegetation in the Southern and Eastern Baltic.* Wetlands 36: 909–919.

IUSS Working Group WRB, 2015. *World Reference Base for soil resources 2014, update 2015. International soil classification system for naming soils and creating legends for soil maps*. World Soil Resources Report No. 106. FAO, Rome.

Jegliński, W., 2013. *Development of the Gulf of Gdańsk coast in the area of the Dead Vistula mouth.* Przegl. Geol. 61, 10: 587–595.

Kabała, C., Łabaz, B. 2018. *Relationships between soil pH and base saturation – conclusions for Polish and international soil classifications.* Soil Sci. Ann. 69(4) (in print), DOI: 10.2478/ssa-2018-0021

Kondracki, J., 2014. *Regional geography of Poland*. PWN, Warsaw (in Polish).

Kordowski, J., 2001. *Lithology and genesis of the lower Vistula River overbank floodplain deposits between Górsk and Chełmno*. Przegl. Geogr. 73, 3: 351–369.

Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F. 2006. *World Map of Köppen-Geiger Climate Classification updated.* Meteorol. Z., 15, 259–263.

Kwiecień, K., 1990. Climate. In: A., Majewski, (Ed.). Gdańsk Gulf. Wyd. Geologiczne, Warszawa, 66–119 (in Polish).

Kwiecień, K., Taranowska, S., 1974. *Climatic conditions.* In: Moniak, J. (Ed.), Geographic, natural and economic study of the Gdańsk voivodship. GTN, Gdańsk: 91–143 (in Polish).

Lazarus, M., Wszałek-Rożek, K., 2016. *Two rare halophyte species: Aster tripolium L. and Plantago maritima L. on the Baltic coast in Poland - their resources, distribution and implications for conservation management.* Biodiv. Res. Conserv. 41, 1: 51–60.

Łomniewski, K., 1974. *Hydrological relations.* In: Moniak, J. (Ed.), Geographic, natural and economic study of the Gdańsk voivodship. GTN, Gdańsk: 145–191(in Polish).

Makowski, J., 1995. The hundredth anniversary of the creating the Vistula Cross-Cut 1895-1995. IBW PAN, Gdańsk (in Polish).

Markowski, R., Stasiak, J., 1984. *Anthropogenic changes in the flora of the estuary area of the Vistula Cross-cut in the last century.* – Zesz. Nauk. Wydz. BiNoZ UG, Biologia 5: 27–59 (in Polish with English abstract).

Marks, L., 2012. *Timing of the Late Vistulian (Weichselian) glacial phases in Poland*. Quat. Sci. Rev. 44, 81–88.

Maselli, V., Trincardi, F., 2013. *Man-made deltas.* Sci. Rep. 3, 1926: 1–7. DOI:10.1038/srep01926

Mojski, J.E. 1990. *The Vistula river delta.* In: Starkel, L. (Ed.), Evolution of the Vistula River valley during the last 15 000 years, part III. Geographical Studies, Special Issue 5, IGiPZ PAN: 126–141.

Phillips, J.D., Golden, H., Cappiella, K., Andrews, B., Middleton, T., Downer, D., Kelli, D., Padrick, L., 1999. *Soil redistribution and pedological transformations on coastal plain croplands*. Earth Surf. Proc. Land. 24: 23– 39.

Piernik, A. 2003. *Inland halophilous vegetation as indicator of soil salinity*. Basic Appl. Ecol. 4: 525–536.

Starkel, L. 1988. *History of the river valleys in the Holocene.* In: Starkel, L. (Ed.), Changes in the geographical environment of Poland. Ossolineum, Wrocław: 87–107 (in Polish).

Witek, J., 1965. *Soils of the Żuławy Wiślane*. Pamiętnik Puławski, Prace IUNG 18: 157–266 (in Polish).

Wright, L.D., 1985. *River deltas.* In: Davis Jr., R.A (Ed.), Coastal sedimentary environments. Springer New York: 1–76.

Żakowski, K., Narożny, M., Szociński, M., Darowicki, K., 2014. *Influence of water salinity on corrosion risk - the case of the southern Baltic Sea coast*. Environ. Monit. Assess. 186, 8: 4871–4879.

Soils of the northern slopes of the Čabranka River valley (S Slovenia, municipality Loški potok)

Blaž Repe

The study area is located in the southern part of Slovenia, in the southernmost part of the Loški potok municipality, on the northern slopes (above left banks) of the Čabranka River valley, on the border with Croatia (Fig 1). The area is part of the Dinaric Mountains, which start in Slovenia and extend further over the Balkan Peninsula in the south-eastern direction (Gams 2003). In this part, the Dinaric Mountains consist of many units. They are a combination of hilly karstic plateaus, divided by elongated and narrow lowlands or karstic poljes and some very deep gorge-like river valleys. The area is characterised by carbonate rocks (hard limestone and dolomite), middle range elevations and slope inclinations (700 m a.s.l. and 15°), mountain climate, high afforestation rate (above 75%) and very low population density (less than 15 inh./km^2) (Perko and Orožen Adamič, 1998). The municipality of Loški potok represents all aforementioned features, except for its southernmost part, the Čabranka River valley (Fig. 1).

Fig. 1. Location

The study area lies on the left bank slopes of the Čabranka River. The area is 1 km wide and follows the course of the Čabranka River in the length of 4.5 km, from its source near the village of Podplanina to the village of Pungert (Fig. 2) where the river exits the study area.

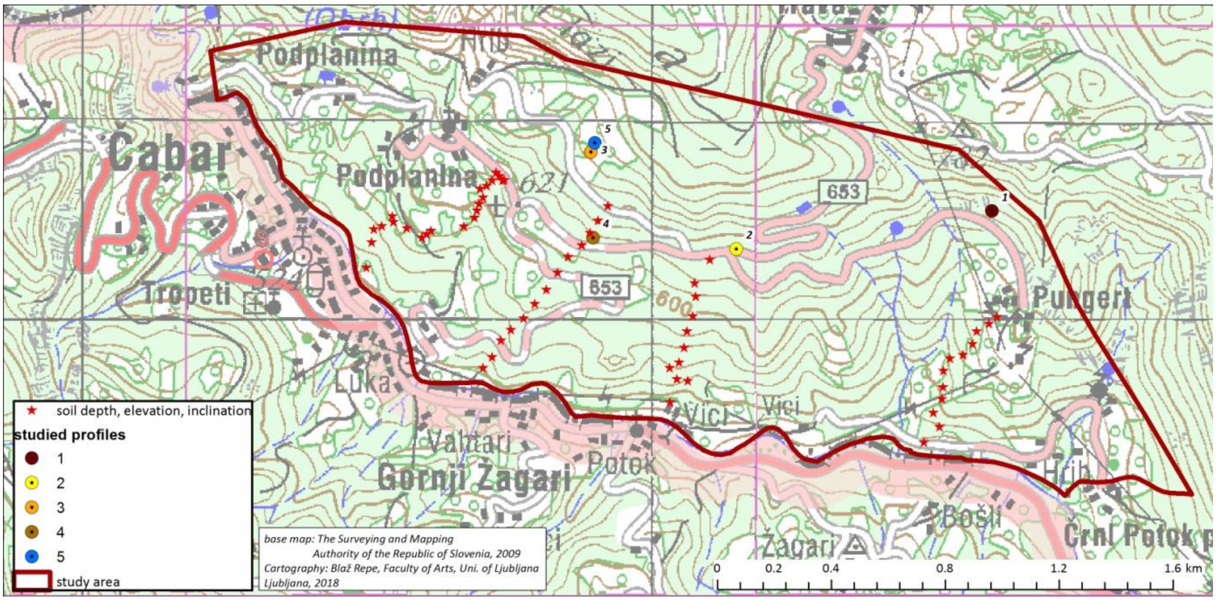


Fig. 2. Study area

Lithology and topography

The study area is very atypical for the surrounding Dinaric Mountains, since it is almost entirely composed of consolidated silicate sedimentary parent material, with acid products of weathering. According to a 1 : 100.000 scale geological map (Savić and Dozet, 1985), the slopes on the left side of the Čabranka River are predominantly made of the Permian sand and clay stones, the latter being mostly slaty. In some isolated spots, patches of silicate, sandstone gravel, compacted into conglomerate can also be found. These rocks represent 91% of the study area and they extend further to the south, over the Čabranka River to Croatia. The rest (9%) can be found as a narrow belt of carbonate rocks in the northern part of the study area. They represent a transition to the very typical lithological structure of the Dinaric Mountains, Triassic and Jurassic limestones and dolomites, the latter being the case here. The dolomite is very hard, resistant to chemical weathering, but on the other hand very brittle. On the footslopes and some scarce flat parts, colluvial material, predominantly silicate is accumulating.

Fig. 3. A view over the research area (Blaž Repe)

The elevations range from 440 m a.s.l. in the south-eastern part (where the Čabranka exits the study area) to 879 m a.s.l. in the central northern part on dolomite (where the main road enters the area). The average elevation is 608 m a.s.l. The entire area is represented by various types of slopes (concave, convex, straight, irregular, some parts resemble cliffs) and covered with ravines and gullies. At present, erosion is the main surface process (Lipovec, 1998). The maximum inclination is 82°, while the average is 24°. Some flat areas occur on a very narrow alluvial plain (up to 70 m). The prevailing aspect of slopes is south to south-east (Fig. 3).

Climate and hydrology

The climate of the surrounding area is transitional between the lower mountainous and temperate continental climate of western and southern Slovenia (Ogrin, 1996). The climate is typically udic, moderately continental, with higher rates of precipitation (around 1800 mm/year) (ARSO, 2005). Winters are harsh (frost can occur as late as June and as early September), summers are relatively short and warm, the growing season starts two weeks or even later compared to other continental parts of Slovenia. Most of the precipitation falls in late autumn, the snow cover can be very thick and occurs every winter (Puncer, 1980 c.v. Lipovec, 1998). There is no meteorological station that would record temperature in this area. The nearest station with the most similar climate is located in Babno Polje. The average annual temperature is 6.1 C, the hottest month is July (15°C), the coldest one is January (–3.5 C). Lowlands, karstic poljes and valleys experience temperature inversion, which further lowers the minimum temperatures. The microclimate of the study area is also an exception. Steep slopes facing south can receive large amounts of annual solar radiation (4100 MJ/km^2) (Gabrovec, 1996), and very warm and even dry conditions can occur in summer. This is reflected in small areas of thermophilous forest associations (*Ostryo carpinifoliae-Fagetum* and *Querco pubescenti-Ostryetum carpinifoliae*) in the exposed and steepest parts of the slopes.

The hydrology of the surrounding area is clearly karstic with no lentic or lotic water. However, impermeable rocks of the study area facilitate normal surface hydrology. Due to the steep and short slopes and karstic hinterland, the streams depend exclusively on precipitation. The amounts of water in streams are generally low, but can become torrential and cause severe soil erosion during summer thunderstorms.

Land use

The vegetation and land use is typical for the consolidated silicate sedimentary parent material and acid soils. The forest cover is very dense and the dominant tree species is beech (*Fagus sylvatica*). The dominant forest associations are acidophilus beech forests with sweet chestnut (*Castaneo sativae-Fagetum*) and degraded Scots pine forest with common bilberry (*Vaccinio vitis-idaeae-Pinetum silvestris*) (Marinček, 1987). Due to steep slopes and heavy erosion processes, these forests frequently have a protective function (Ogrin et al., 2017). As a result of harsh climate conditions, steep slope inclinations, shallow and acid soils, as well as remoteness from urban agglomerations, these areas have never been used for agricultural purposes. The forests cover more than 83% of the total area and some farms live on forestry.

Soils were described according to the Guidelines for Soil Description and Classification, Central and Eastern European Students' Version (Świtoniak et al., 2018).

Profile 1 – Eutric Dolomitic Rendzic Skeletic **Leptosol** (Humic, Loamic)

Localization: Just below the shoulder of the slope; hard Jurassic dolomite, inclination 21°, 639 m a.s.l., light pioneer forest: Scots pine, beech, spring heath and other species,
N 45°35'50.08" **E** 14°40'38.01

Morphology:

O – 3–0 cm, partly or poorly decomposed and dried beech leaves and pine needles;

Ah – 0–7 cm, mollic horizon, sandy loam, common and angular coarse fragments, very dark brown (7.5YR 2.5/2), granular structure, moist, friable, common roots, clear smooth boundary;

AC – 7–15 cm, mollic horizon, sandy loam, common and angular coarse fragments, dark brown (7.5YR 3/2), granular structure, moist, friable, common roots, clear and smooth boundary;

C1 – 15–23 cm, many angular coarse fragments of dolomites, clear boundary;

C2 – 23–31 cm, abundant and angular coarse fragments, gradual boundary;

CR – 31–(50) cm, continuous rock.

Table 1. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm					Textural class
		2-0,2	0,2-0,05	0,05-0,02	0,02-0,002	<0,002	
O	3–0	-	-	-	-	-	-
Ah	0–7	60.1	8.7	19.7	10.6	0.9	SL
AC	7–15	62.3	9.2	19.5	8.3	0.7	SL
C1	15–23	-	-	-	-	-	-
C2	23–31	-	-	-	-	-	-
CR	31–(50)	-	-	-	-	-	-

Table 2. Chemical and physicochemical properties

Horizon	Depth [cm]	$CaCO_3$ [$g\cdot kg^{-1}$]	pH [KCl]	OC [$g\cdot kg^{-1}$]
O	3–0	-	-	-
Ah	0–7	146	6.5	43.7
AC	7–15	171	6.7	23.9
C1	15–23	-	-	-
C2	23–31	-	-	-
CR	31–(50)	-	-	-

Table 3. Sorption properties

Horizon	Depth [cm]	TEB	CEC	BS [%]
		[$cmol(+)\cdot kg^{-1}$]		
O	3–0	-	-	-
Ah	0–7	42.3	45.9	92.2
AC	7–15	33.8	34.2	98.8
C1	15–23	-	-	-
C2	23–31	-	-	-
CR	31–(50)	-	-	-

Profile 2 – Dystric Skeletic **Leptosol** (Humic, Loamic)

Localization: Very steep upper slope, visible signs of erosion processes, inclination 35°, 671 m a.s.l., acid Permian sandstone, acidophyllus pioneer forest: silver birch, Scots pine, eagle fern, heather etc.
N 45°35'45.66" **E** 14°39'56.61"

Morphology:

A – 0–17 cm, humus horizon, sandy clay loam, common and angular coarse fragments, dark brown (7.5YR 3/3), granular structure, moist, friable, common roots clear boundary;

CBw – 17–39 cm, loam; abundant and angular coarse fragments, dark yellowish brown (10YR 4/4), subangular blocky structure, moist, firm, common roots, gradual boundary;

R – 39–(50) cm, continuous rock.

Table 4. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm					Textural class
		2-0,2	0,2-0,05	0,05-0,02	0,02-0,002	<0,002	
A	0–17	30.6	24.4	5.8	16.0	23.2	SCL
CBw	17–39	27.1	17.9	8.3	22.8	23.9	L
R	39–(50)	-	-	-	-	-	-

Table 5. Chemical and physicochemical properties

Horizon	Depth [cm]	$CaCO_3$ [$g \cdot kg^{-1}$]	pH [KCl]	OC [$g \cdot kg^{-1}$]
A	0–17	8.7	3.8	50.4
CBw	17–39	6.9	3.9	18.5
R	39–(50)	-	-	-

Table 6. Sorption properties

Horizon	Depth [cm]	TEB	CEC	BS [%]
		[$cmol(+) \cdot kg^{-1}$]		
A	0–17	9.1	35.9	25
CBw	17–39	8.6	39.7	22
R	39–(50)	-	-	-

Profile 3 – Dystric Skeletic Leptic **Cambisol** (Humic, Loamic)
Localization: gentle middle slope, inclination 45°, 742 m a.s.l., acid sedimentary Permian sandstone, acidophyllus secondary forest: Norway spruce, only a few eagle ferns, **N** 45°35'56.58" **E** 14°39'33.02"

Morphology:

O – 7–0 cm, partly or poorly decomposed and dried spruce needles and some beech leaves (blown);

A – 0–10 cm, humus horizon, loam, few angular coarse fragments, dark brown (7.5YR 3/3), granular structure, moist, friable, common roots, clear boundary;

ABw – 10–18 cm, *cambic* horizon, loam, few angular coarse fragments, brown (7.5YR 4/4), granular structure, moist, friable, common roots, clear boundary;

Bw – 18–29 cm, *cambic* horizon, sandy loam, common and angular coarse fragments, yellowish brown (10YR 5/4), subangular blocky structure, slightly moist, firm, few roots, clear boundary;

BwC – 29–40 cm, transitional horizon, sandy loam, many angular coarse fragments, light yellowish brown (10YR 6/4), subangular blocky structure, slightly moist, firm, few roots, clear boundary;

R – 40–(60) cm, continuous rock.

Table 7. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm					Textural class
		2-0,2	0,2-0,05	0,05-0,02	0,02-0,002	<0,002	
O	7–0	-	-	-	-	-	-
A	0–10	19.7	21.6	7.7	26.8	24.2	L
ABw	10–18	20.6	23.5	2.5	29.6	23.8	L
Bw	18–29	24.9	42.4	8.5	24	0.2	SL
BwC	29–40	27.6	43.5	6.8	21.1	1.0	SL
R	40–(60)	-	-	-	-	-	-

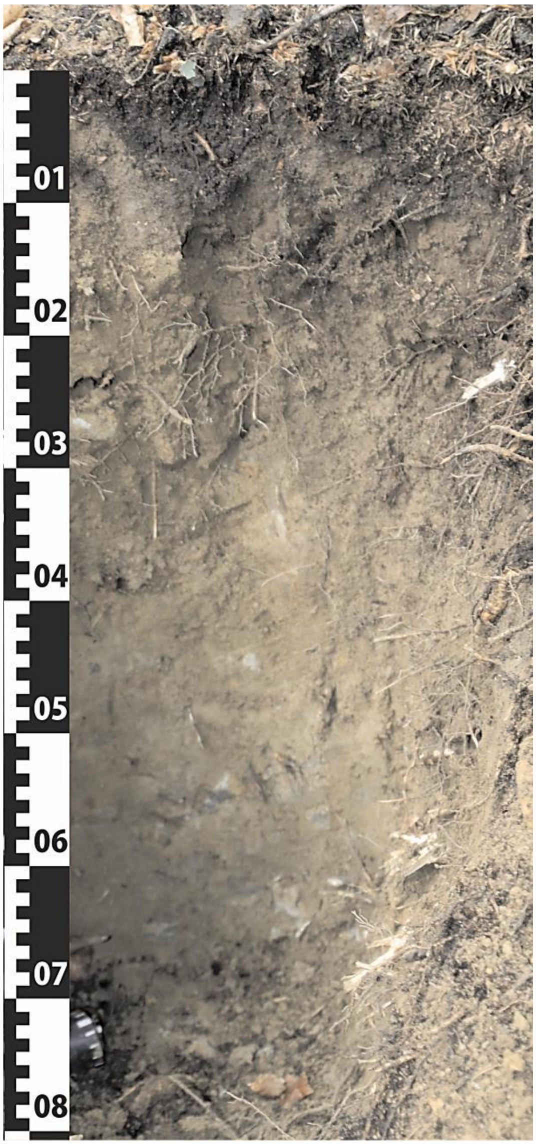
Table 8. Chemical and physicochemical properties

Horizon	Depth [cm]	$CaCO_3$ [$g \cdot kg^{-1}$]	pH [KCl]	OC [$g \cdot kg^{-1}$]
O	7–0	-	-	-
A	0–10	7.3	3.3	81.0
ABw	10–18	6.9	3.4	63.5
Bw	18–29	7.8	3.6	10.5
BwC	29–40	8.2	4.0	9.5
R	40–(60)	-	-	-

Table 9. Sorption properties

Horizon	Depth [cm]	TEB	CEC	BS [%]
		[$cmol(+) \cdot kg^{-1}$]		
O	7–0	-	-	-
A	0–10	23.7	68.5	35
ABw	10–18	24.8	69.0	36
Bw	18–29	23.5	54.6	43
BwC	29–40	22.2	52.8	42
R	40–(60)	-	-	-

Profile 4 – Endoskeletic Leptic **Alisol** (Cutanic, Humic, Loamic)
Localization: gentle middle slope, inclination 10°, 646 m a.s.l., acid sedimentary Permian sandstone, typical acidophilic forest: beech, sweet chestnut, bilberry, eagle fern, heather, hairy wood-rush, **N** 45°35'48.40" **E** 14°39'42.84"



Morphology:

O – 7–0 cm, partly or poorly decomposed and dried beech leaves, eagle fern and bilberry parts

Ah – 0–5 cm, humus horizon, loam, few angular coarse fragments, very dark brown (7.5YR 2.5/3), granular structure, moist, friable, common roots, clear boundary;

AB – 5–15 cm, transitional horizon, loam; few angular coarse fragments, dark yellowish brown (10YR 3/4), subangular blocky structure, moist, friable-firm, common roots, clear boundary;

Bt – 15–43 cm, *argic* horizon, clay loam, many angular coarse fragments, yellowish brown (10YR 5/4), subangular blocky structure, common cutans, slightly moist, firm, few roots, gradual boundary;

BC – 43–72 cm, transitional horizon, loam, many angular coarse fragments, olive yellow (2.5YR 6/6), subangular blocky structure, slightly moist, firm, few roots, gradual boundary;

R – 72–(80) cm, continuous rock.

Table 10. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm					Textural class
		2-0,2	0,2-0,05	0,05-0,02	0,02-0,002	<0,002	
O	7–0	-	-	-	-	-	-
Ah	0–5	23.7	20.1	10	35.5	10.7	L
AB	5–15	19.5	17.5	10.7	30	22.3	L
Bt	15–43	20.9	14.3	10.6	27.2	27	CL
BC	43–72	21.2	25.7	7.8	26.9	18.4	L
C	72–(80)	-	-	-	-	-	-

Table 11. Chemical and physicochemical properties

Horizon	Depth [cm]	$CaCO_3$ [$g \cdot kg^{-1}$]	pH [KCl]	OC [$g \cdot kg^{-1}$]
O	7–0	-	-	-
Ah	0–5	8.6	3.1	94.5
AB	5–15	8.4	3.4	62.5
Bt	15–43	9.4	3.4	16.0
BC	43–72	10.9	3.5	4.0
C	72–(80)	-	-	-

Table 12. Sorption properties

Horizon	Depth [cm]	TEB	CEC	BS [%]
		[$cmol(+) \cdot kg^{-1}$]		
O	7–0	-	-	-
Ah	0–5	18.0	54.3	33
AB	5–15	23.4	62.8	37
Bt	15–43	27.0	66.1	41
BC	43–72	24.6	57.8	43
C	72–(80)	-	-	-

Profile 5 – Eutric Histic **Gleysol** (Loamic, Skeletic)

Localization: flat part of the middle slope, below a small spring, inclination 0°, 747 m a.s.l., acid sedimentary Permian sand- and claystone, hydro- and hygrophyllus herbaceous vegetation (marsh-marigold, eagle fern, horsetail, peat moss),
N 45°35'57.65" **E** 14°39'33.63"

Morphology:

Ha – 0–10 cm, *histic* horizon, strongly decomposed organic material, very dark brown (10YR 2/2), massive, wet; loose, few roots, gradual boundary;

Bl – 10–22 cm, sandy loam; very few angular coarse fragments, brown (7.5YR 4/4) and strong brown (7.5YR 5/8), gleyic properties, massive /subangular weak structure, wet, very friable, few roots, gradual boundary;

Cr – 22–(40) cm, parent material with reducing conditions, loam, abundant and angular coarse fragments, massive structure, free water, loose.

Table 13. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm					Textural class
		2-0,2	0,2-0,05	0,05-0,02	0,02-0,002	<0,002	
Ha	0–10	-	-	-	-	-	-
Bg	10–22	29.3	27.8	8.2	30.5	4.2	SL
Cr	22–(40)	30.1	19.5	7.4	24.9	18.1	L

Table 14. Chemical and physicochemical properties

Horizon	Depth [cm]	$CaCO_3$ [$g \cdot kg^{-1}$]	pH [KCl]	OC [$g \cdot kg^{-1}$]
Ha	0–10	6.7	5.3	253
Bg	10–22	5.1	5.1	119
Cr	22–(40)	-	-	-

Table 15. Sorption properties

Horizon	Depth [cm]	TEB	CEC	BS [%]
		[$cmol(+) \cdot kg^{-1}$]		
Ha	0–10	53.1	71.8	74.0
Bg	10–22	47.4	67.2	70.5
Cr	22–(40)	-	-	-

Soils over consolidated silicate sedimentary parent material

Slovenia's moderate and humid climate causes relatively slow soil formation processes. This is particularly evident in mechanical and chemical weathering of parent material and its minerals. Minerals therefore enter the pedosphere in the size class of silt, sand and even skeletal parts. They are chemically only partially changed or even completely unchanged. The parent material directly and strongly affects the soil properties (Repe, 2017). The parent material is considered to be the most important factor in the soil formation in Slovenia. It is also the crucial factor that is most commonly used to differentiate between soil types. A total of 93% of Slovenia's territory is composed of sedimentary rocks, mainly limestone and dolomite, and only 4% belongs to the metamorphic group, while 3% is of magmatic origin (Plenčar et al. 2009). Since carbonate rocks dominate, the most commonly soil types in Slovenia are ***Eutric* Leptosols, *Chromic* Cambisols** and ***Eutric* Cambisols**. Together they cover more than 56% of the territory. Silicate sedimentary rocks in Slovenia show relatively little resistance to mechanical weathering. Although the topography is hilly and very diverse, ***Dystric* Cambisols** almost entirely dominate on silicate rocks (20.7% of the territory), while the cover of ***Dystric* Leptosols** is almost negligible (2.1%) (Repe, 2017). The study area of the Čabranka River entirely belongs to the region of the Dinaric Mountains, but based on the parent material, the developed soils and vegetation it could be placed in the Pre-Alpine region, where silicate sedimentary parent material occurs. All soils in this region are relatively well developed, mainly acid, with low base saturation. The dominant soil units are ***Dystric* Cambisols**, ***Dystric* Planosols** on consolidated and unconsolidated silicate clastic sedimentary parent material, and ***Eutric* Gleysols, *Eutric* Fluvisols** on alluvial sediments. Other significant soil units are ***Dystric* Leptosols; *Eutric* Cambisols, Planosols, Gleysols, Fluvisols; Stagnosols, Gleyic, *Haplic* Luvisols** (Vrščaj, Repe and Simončič, 2017). Water retention of these rocks is relatively high and small streams or even springs often appear on slopes. Streams are formed in narrow basins and gorges, so the hydrographic net in this pedosequence is relatively well developed (Stritar, 1991).

The region is characterised by middle-range hills, with gentle slopes, and azonal forest associations of *Vaccinio-Pinetum sylvestris*. This is a pioneer association occurring mostly at infertile sites. Acidophilic beech forests of *Blechno-Fagetum* associations and *Castaneo sativae-Fagetum* associations are much more common in this area. They grow on ***Dystric* Cambisol** and various non-calcareous geological formations. In many cases, forests of *Castaneo sativae-Fagetum* have been transformed either to spruce (*Picea abies*) monoculture forests or to coppice forests with a mix of sweet chestnut (*Castanea sativa*), Scots pine (*Pinus sylvestris*), and sessile oak (*Quercus petraea*). In this region, thermophilous beech forests (*Ostryo carpinifoliae-Fagetum*) cover large areas with southern exposure, from lowlands to an altitude of around 1000 m a.s.l., with a relatively large amount of precipitation (Vrščaj, Repe and Simončič, 2017).

In the case of soils, not many studies have been carried out in the regions of Slovenia with consolidated silicate sedimentary parent material. In the case of the Čabranka River valley, no studies are available.

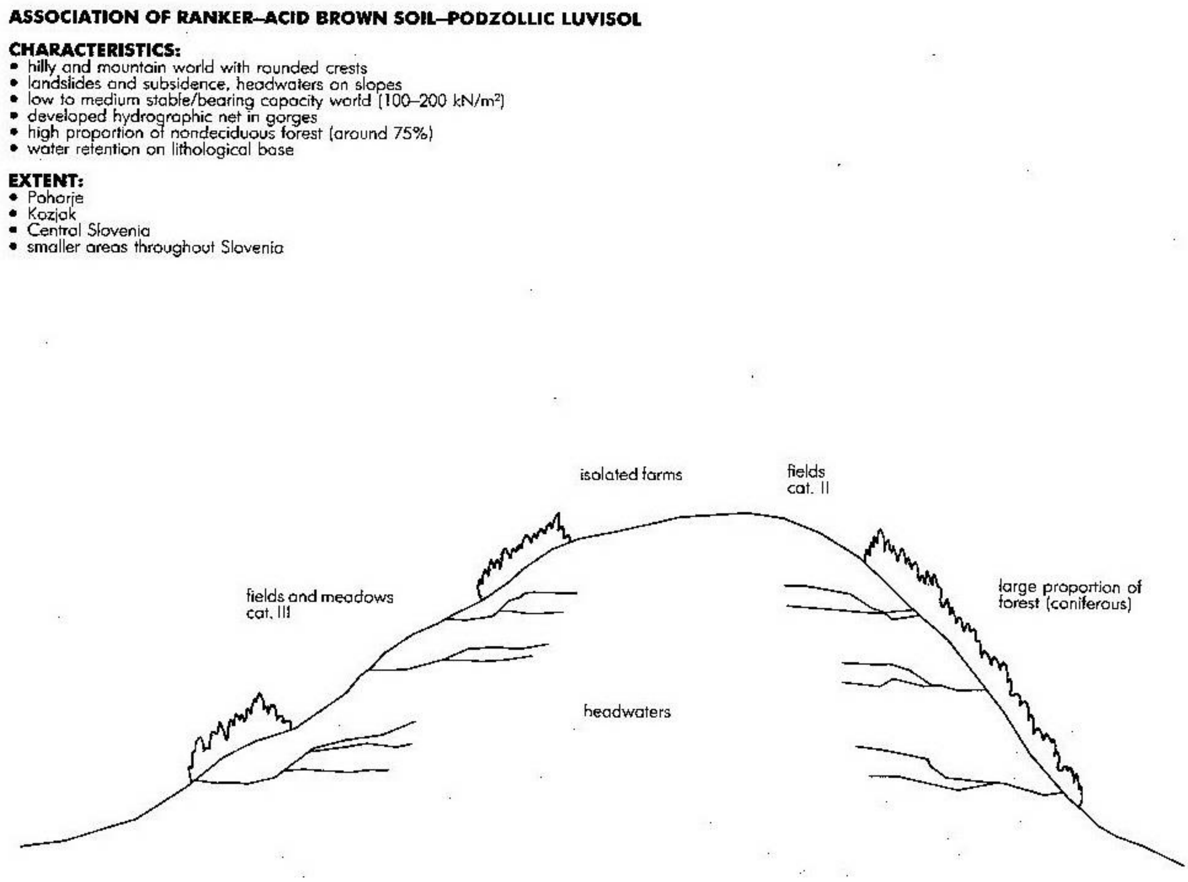


Fig. 4. Landscape on noncarbonatic rocks (association: ranker – acid brown soils – podzollic luvisols) (Stritar, 1991)

An example of soil sequences with hard, sedimentary, silicate parent material in the Čabranka River valley (an example of soil litho- and toposequence)

In his book, Stritar (1991) uses the term *noncarbonate rocks* to describe most of the parent material in the study area. This term refers to those earth crusts that contain less than 5% of calcium carbonate or do not contain any carbonates at all. Noncarbonate rocks are systems with a pedosequence associated with brown (dystric) soils, divided into subsystems according to the geolithological character of the parent material. Magmatic and metamorphic rocks, which occur in Slovenia to any significant extent only in the Pohorje Mountains, form larger mountain massifs, while noncarbonate Tertiary rocks (silica grits, silica sands, noncarbonate conglomerates, etc.) form an undulating relief. Stritar recognized the following soil (topo)sequences (based mainly on topographic position of the soil type): ranker (***Dystric* Leptosol**) – brown acid soils (***Dystric* Cambisol**) – podzolic brown soils (***Albic* Luvisol**) – podzols (***Haplic* Podzol**) (Fig. 4). All equivalents of the soil taxa according to WRB (IUSS Working Group WRB, 2015) are very general.

Rankers show many similarities (topography, morphology, mechanical properties) with rendzinas. A dark brown A horizon lies directly on the parent material (lithic or regolithic). In Slovenia, most of them show dystric chemical properties. They are only found on steeper relief covered with forest and show signs of erosion. Since parent material weathers relatively fast (compared to much harder magmatic or metamorphic rocks or even limestone or dolomite), a ranker is not a very common soil type in Slovenia. Soils occupy more developed stages like **Umbrisols, Cambisols** or even **Luvisols**. Brown acid soils represent a more developed stage of soil on noncarbonate rocks. They show similarities with eutric brown soils. Soil is deeper, with the development of structure (subangular blocky) and colours (YR hues) related to *in situ* development of silt and clay particles (Bw horizons). This is expressed mainly by siltic and not so often clayic qualifiers. The pH values are usually 5.5 or lower (but rarely extremely low). Base saturation is below 50%. Some of these soils can be classified as **Umbrisols** or **Luvisols**. Podzolic brown soils could be an equivalent of **Luvisols**. If heavy leaching occurs, an Albic classifier can be added. Not many researches on this type of soil have been carried out. Most of the **Luvisols** have been described on carbonate parent material. They were formerly described as **Haplic Luvisols** or even **Acrisols**, but newer researches would classify them as **Luvisols** or **Alisols** (Turniški, 2016; Turniški and Grčman, 2018). **Podzols** are a very rare soil type/group in Slovenia. Extreme leaching, combined with very acid products of silicate rock weathering, cold mountain climate with large amounts of precipitation and coniferous forest (*Picea abies*, *Abies alba* and *Pinus sylvestris*) that contributes to the formation of acid organic matter, can be found in some isolated places of the Alpine region (Pokljuka, Mežakla) and the Pohorje Mountains (Repe, 2017). Some are classified as **Podzols** and some as **Retisols**. Since the parent material is impermeable to water, a normal (surface) river network is well developed. Therefore, other soil types like **Planosols, Gleysols** and soils with fluvic properties can be found within the aforementioned association. They can also be found on slopes.

The soil sequence on the slopes of the Čabranka River valley only partially follows the above-mentioned pattern, described by Stritar (1991). The studied sequence is partially litho- partially topofunction and could be simplified to: ***Eutric* Leptosol** – ***Dystric* Leptosol** – ***Dystric* Cambisol** – ***Skeletic* Luvisol** – ***Skeletic / Fluvic* Gleysol** (Fig. 4).

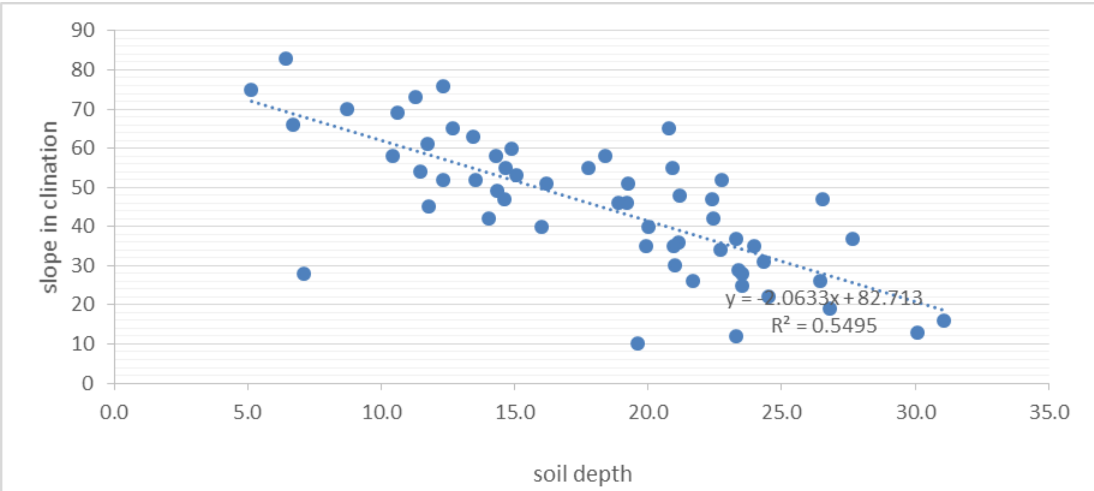


Fig. 5. Relationship between soil depth and slope inclination

In the studies of the soil sequence on the Polhograjsko hills (Repe, 2006; Świtoniak and Charzyński, 2018) and in the karstic area near the town of Postojna (Bergant, 2011), the relationship between soil depth and inclination has been established. Due to the mosaic soil patterns on carbonate parent material, the soil sequence on hard and compact carbonate parent material is very difficult to determine, model or predict. A simple study was also conducted in the Čabranka River valley. Four approximately straight transects were selected. They follow the path from the upper to lower parts of the slopes. The soil depth was measured every 30-50 m by augering, slope inclination was estimated by a simple clinometer, the elevation and point location were determined using a GNSS device

(Fig. 2). A total of 57 triplets of soil depth, elevation and slope inclination were recorded. The assumption from previous studies remains that the thickness of soil increases with decreasing inclination and elevation. The relationship between both relief elements and soil depth was calculated using the Pearson correlation coefficient and multiple regression analysis. A clear relationship was established between soil depth and slope inclination (*soil depth = -2.0633 x slope inclination + 82.713;* $R^2 = 0.5495$). The relationship is quite strong (Fig. 5) and shows high correlation between soil depth (and soil type) and some topographic features.

On the other hand, no significant relationship was established between soil depth and elevation. We could attribute this fact to the very low relative elevation differences and the correlation between soil depth and microtopography rather than general topography. Similar results were obtained by Repe (2006) in the study of digital soil mapping in the Polhograjsko hills where 68.3% of the variability was explained by silicate parent material. Higher slope inclinations have proportionally shallower soils, larger and coarser fragments, with lesser clay content and less developed soil.

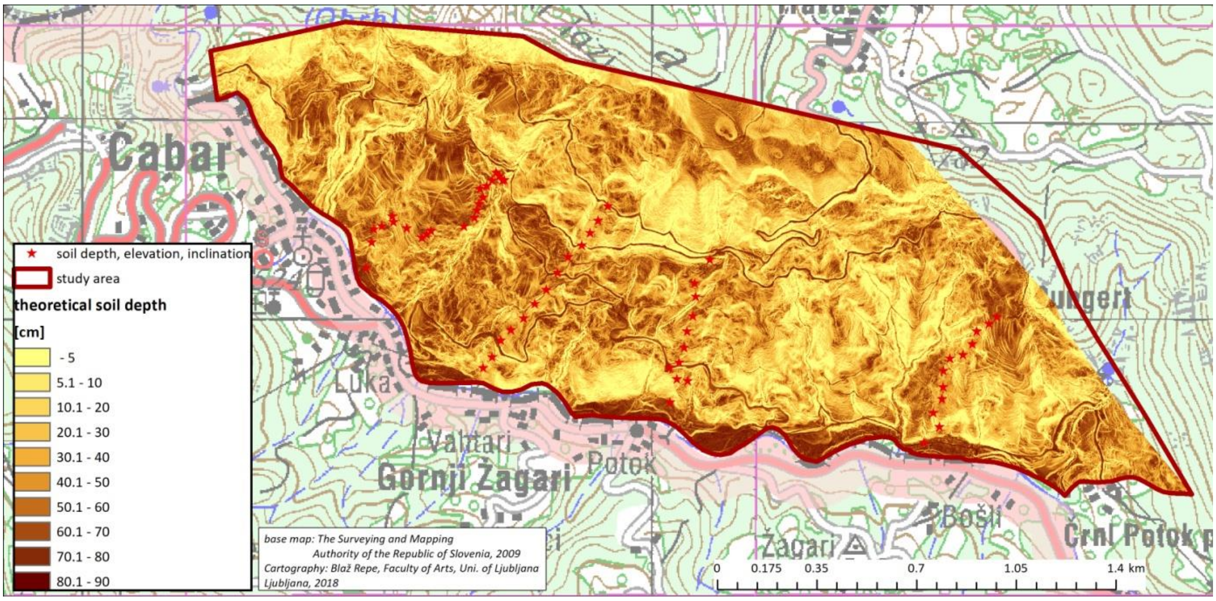


Fig. 6. Theoretical distribution of soil depth according to the slope inclination topofunction

The studied soil sequences of the slopes of the Čabranka valley could be summarised in several final conclusions:

- We can determine quite equal macro- and mesoclimatic conditions for all profiles. The slopes where pits were dug faced nearly the same general south-eastern direction.
- The transition between the first two soil types could be described as a lithofunction. Both soils (both Leptosols) show many similarities. They occur on a similar upper slope position and elevation of the study area. They are both influenced by heavy slope processes, especially erosion, removal of developed soil material and its accumulation into the lower positions. They are both very young, shallow and skeletal, with hummus accumulation as one of the main soil forming factors. Parent material weathers mainly mechanically. The only real difference is parent material, carbonate for the first and silicate for the second profile. Due to this fact, differences in chemical properties can be observed, mainly in pH values and base saturation.

– Profiles 2–5 express mainly topofunction. Since the climatic conditions could be described as constant, the rate and direction of the weathering process are very similar for all four locations. This results in the similarity of some chemical properties. All soils express some dystric features (the content of calcium carbonate and coarse fragments, pH values, base saturation etc.). The parent material is the same for all profiles, i.e. consolidated silicate sedimentary parent material with acid products of weathering. The parent material is impermeable to water, which prevents the loss of water into the rock. All water finds its way to the bottom of the Čabranka River valley, either through soil or as a surface runoff. The main difference are topographical features (slope inclination, slope type), which directly influence the water runoff. Distinct automorphic features and related processes develop in the upper and steeper parts of the slopes, while hydromorphic ones in the lower and flatter parts (Repe, 2007). This consequently leads to the intensity of slope processes: transport of small particles into lower positions of the slope and accumulation of soil material in the flatter (not necessarily lower) parts of the slope. This results in differences in soil development stages, properties and processes:

Upper and steeper parts of slopes
- Shallow soils,
- More coarse fragments,
- Smaller clay content,
- Surface water runoff,
- Removal of soil particles,
- Less developed soil types,
- Smaller number of horizons,
- Thinner horizons,
- Main process is accumulation of humus,
- Formation of different Leptosols or Umbrisols form,
- Pine forest.

Lower and flatter parts of slopes
- Thicker soils,
- Less coarse fragments,
- Larger clay content
- Vertical movement of water through the profile,
- Accumulation of soil particles,
- More developed soil types,
- Larger number of horizons,
- Thicker horizons,
- Main process is development of cambic features,
- Formation of different Cambisols or Luvisols,
- Beech forest.

The slope position and small-scale relative vertical distance is much more important. If the topography is concave, hydromorphic features develop regardless of the slope position or elevation, due to impermeable parent material (Stagnic or Gleyic) (Profile 5).

– As the field research revealed, the elevation does not play an important role in such small study areas. However, all soils are still relatively shallow (very young topography with high relief energy; Fig. 6).

– The entire surveyed area is covered with forest. It occurs in different types or associations. Steeper slopes and shallow soils with lithic contact are covered by pioneer, partially degraded forest of Scots pine, silver birch and some beech trees. Low inclinations with thicker and more developed soils are covered with a mature stage of forest: beech forest with sweet chestnut (Marinček 1987).

A similar situation was reported by Stritar (1991; Fig. 7).

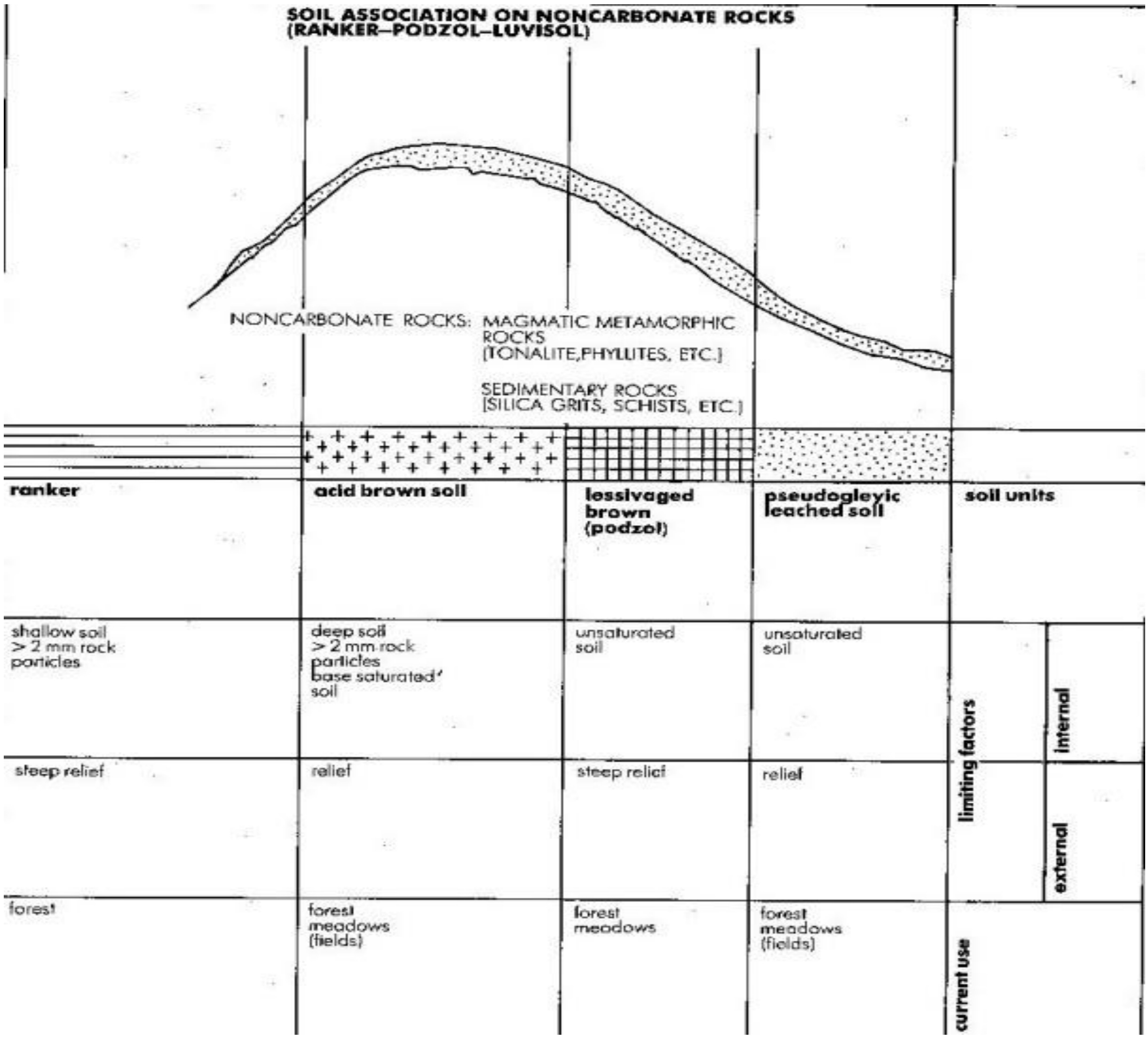
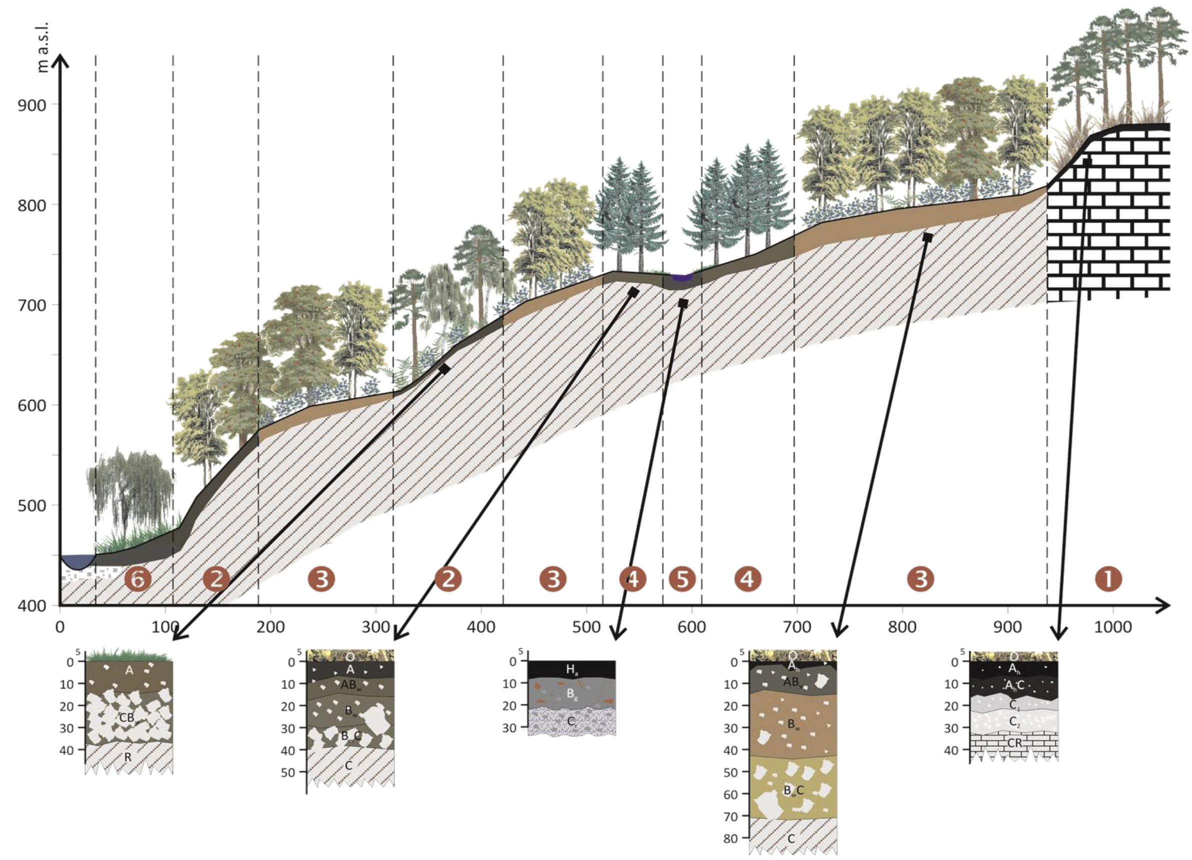


Fig. 7. Pedosequence on noncarbonate rocks (association: ranker – podzol – luvisol) (association: ranker – acid brown soils – podzollic luvisols) (Stritar, 1991)

In the past, the soil sequence on silicate rocks was, according to the regionalisation of agricultural production, strictly adapted to animal husbandry and timber exploitation. Some plateaus were exploited as meadows, pastures and occasionally fields, but they were of lesser importance to crop cultivation. The limited internal factors are soil depth, the presence of > 2 mm rock particles and low base saturation. Relief is an external limiting factor. Nonsaturated dystric soils provide better conditions for forest stands, mostly coniferous ones, and for agriculture. Spatial analysis has shown that only 20% of this pedosequence is allocated to agriculture, while the rest is covered with forest. Some places have potential for soft fruit (blueberries), while the southern slopes of Pohorje – for vineyards. Rural tourism is an additional activity that has recently (1991) been developed on this land, especially on mountain farms. The local community is involved in the mentioned activities that provide an additional source of income (Stritar, 1991).



	parent material	topography	hydrology	land use / vegetation type	soil group (part of the soil sequence)
1	dolomite	undulating, very steep	freely drained, dry	light, pioneer forest on calcareous MP of *Pinus sylvestris* with *Erica carne*	Rendzic and Lithic Leptosols
2	sedimentary siliceous rocks	very steep	freely drained, dry-moist	light, pioneer, degraded, acidophilic forest of *Pinus sylvestris* and *Betula pendula* with *Pteridium aquillinum, Vaccinum myrtillus, Calluna vulgaris, Luzula pilosa*	Dystric and Lithic Leptosols
3	sedimentary siliceous rocks	gentle slopes	freely drained, moist	acidophilic forest of *Fagus sylvatica* and *Castanea sativa* with *Vaccinum myrtillus, Calluna vulgaris, Luzula pilosa*	Dystric Cambisols and Haplic Luvisols, Umbrisols
4	sedimentary siliceous rocks	nearly flat	freely drained, moist	secondary acidophilic forest of *Picea abies* with *Pteridium aquillinum*	Haplic Luvisols and Dystric Cambisols, Umbrisols
5	non compacted accumulation (colluvial), siliceous	flat (in the middle of the slope)	stagnating, saturated	herbaceous and hydrophyllus plants *Pteridium aquillinum, Athyrium filix-femina, Oxalis acetosella, Equisetum sp., Lamium orvala, Petasites sp., Caltha palustris, Sphagnum sp.*	Gleysols, Planosols, Regosols
6	non compacted accumulation (alluvial), mixed	flat (bottom of the valley)		Salix alba Fraxinus excelsior Alnus incana Carex sp.	Gleysols, Fluvisols, Regosols

Fig. 8. Soil sequences in the slopes of the Čabranka Valley

At present, the study area only partially follows the past and general trends in land use. The percentage of forest in these parts of Slovenia (the Dinaric Mountains, Loški potok municipality) is still very high, up to 75% or even more and still increasing. Apart from the hilly and diverse karstic features (topography and lack of surface water) and shallow soils, the mountain climate does not allow other types of land use. Nevertheless, the central, lower and flatter part of the municipality (villages of Retje, Hrib-Loški Potok and Travnik), with carbonate parent material, alluvial/colluvial deposits and deeper soils in particular (Eutric Cambisols), creates conditions for some self-sufficient agricultural production (potato) and gardens (Fig. 9). After Slovenia gained independence and during the period of transition to the market economy, the predominantly forested area of the Loški Potok municipality was strongly affected by the decline of most industrial plants in the region. Due to its remoteness, the area does not offer many job opportunities (Frelih et al., 2002). In the southern part of the municipality (villages of Podpreska, Draga, Srednja vas pri Dragi and Trava), the remoteness is even more expressed. More fields are abandoned and in addition houses are deserted and falling apart. Shops, inns, factories and local small craft production has been absent from this parts for decades (Fig. 10).

Fig. 9. Available flat land in the central part of the municipality Loški potok (top left). Tiny strips of arable land next to the village of Retje (bottom left). Deeper and more productive Eutric Cambisols of the flat areas (right). (Blaž Repe)

The present state of the study area is even worse. Steep slopes, initial soil forms and acidic shallow soils do not offer good growing conditions for cultivated plants. The soils very often do not even provide a good substrate for tree varieties and forests on this soil sequence are of inferior quality. Some sporadic forestry is the only economy in the study area.

Fig. 10. Soil research in the Loški potok municipality, with abandoned fields transformed into grassland (top left). Still active gardens, with decaying buildings in the village Podpreska (bottom left). Remains of the former timber factory in Podpreska, now completely abandoned (right). (Blaž Repe)

References

ARSO, 2005: Climatology of Slovenia, average precipitation, period: 1961–1990. Slovenian Environment Agency, Ljubljana, Slovenia.

Bergant, J., 2011: Relief as pedeogenetic factor on karst areas. Diploma thesis. Department of geography, Faculty of arts, Ljubljana University. Ljubljana Slovenia.

Frelih, S., Lebar, D., Pipan, P., Pisanec, J., 2002: Development possibilities of Loški Potok municipality. Works (Dela) 17. Department of geography, Faculty of arts, Ljubljana University. Ljubljana Slovenia.

Gabrovec, M., 1996: Solar radiation and the diverse relief of Slovenia. Geogr Zb 47–68

Gams, I., 2003: Karst in Slovenia in space and time. Založba ZRC, ZRC SAZU, Ljubljana.

IUSS Working Group WRB, 2015: World Reference Base for Soil Resources 2014, update 2015 International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome.

Lipovec, B., 1998: Geography of the Dragarska Valley. Diploma thesis. Department of geography, Faculty of arts, Ljubljana University. Ljubljana Slovenia.

Marinček, L., 1987: Beech forests of Slovenia. Delavska enotnost, Ljubljana. 153 p.

Ogrin, D., 1996: The climate types in Slovenia. Geogr Bull. Bulletin of the Association of the Geographical Societes of Slovenia 68, Ljubljana. p. 39–56.

Ogrin, D., Cigale, D., Repe, B., Stepišnik, U., Trobec, T., Natek, K., Prašnikar, D., Vysoudil, M., Špes, M., Plut, D., 2017: Kamniška Bistrica. a geographic perspective of a mountain valley. GeograFF, Department of geography, Faculty of arts, Ljubljana University. Ljubljana Slovenia.

Perko, D., Orožen Adamič, M. (ed.), 1998: Slovenija: Landscapes and people. Mladinska knjiga. Ljubljana.

Plenčar. M., Vrabec. M., Novak. M., 2009: Geology of Slovenia. Geological Survey of Slovenia, Ljubljana

Puncer, I., 1980: Dinaric silver fir and beech forest of Kočevje region. Slovenska akademija znanosti in umetnosti, Ljubljana.

Repe, B., 2006: Geographical soil map and its use within geography. Doctoral thesis, Geography Department, Faculty of Arts, University of Ljubljana, Ljubljana, Slovenia.

Repe, B., 2007: Soil water content and its distribution according to relief. Works (Dela) 28. Department of geography, Faculty of arts, Ljubljana University. Ljubljana Slovenia.

Repe, B., 2017: Pohorje - Slovenia's pedological exception. Geografija podravja, Maribor.

Savić, D., Dozet, S., 1984: Basic geological map, page Delnice (Basic geological map of Yugoslavi). Geološki zavod, OOUR za geologiju i paleontologiju Zagreb and Geološki zavod, Ljubljana.

Stritar, A., 1990: Landscape and landscape systems. Partizanska knjiga, Ljubljana, Slovenia. 176 p.

Świtoniak, M., Charzyński, P., (ed.) 2018: Soil Sequence Atlas II. Nicolaus Copernicus University in Toruń. Poland.

Świtoniak, M., Kabała, C., Karklins, A., Charzyński, P., Hulisz, P., Mendyk, L., Michalski, A., Novak, T.J., Penizek, V., Reintnam, E., Repe, B., Saksa, M., Vaisvalavicius, R., Waroszewski, J., 2018: Guidelines for Soil Description and Classification Central and Eastern European Students' Version. Nicolaus Copernicus University in Toruń. Poland.

Turniški, R., 2016: Pedological, mineralogical and geochemical characteristic of leached soils in Slovenia. Diploma Thesis. Department of Agronomy, BiotechnicalFaculty, University of Ljubljana, Ljubljana, Slovenia.

Turniški, R., Grčman, H., 2018: Leached soils in Slovenia: Pedological properties, spatial distribution and classification. Acta agriculturae Slovenica, vol. 111, No. 1, 2018. Ljubljana.

Vrščaj, B., Repe, B., Simončič, P., 2017: Soils Of Slovenia. World soils book series, ISSN 2211-1255. Dordrecht, Springer. 216 p.

Soils developed within mid-mountain range slope deposits (eastern Karkonosze Mts.)

Michał Dudek, Jarosław Waroszewski, Cezary Kabała

The Karkonosze Mts. form the highest and largest mountain range in the Sudetes and lie in south-western Poland along the border with Czech Republic. The Polish part of the Karkonosze Mts. is built mainly from granite of the Carboniferous age, surrounded by a series of metamorphic rocks. The highest peak, Śnieżka (1,602 m a.s.l.), is composed of hornfels (extremely resistant to weathering). The Karkonosze Mts. are known for their specific harsh climate, high moors, subalpine meadows and mountain pine shrubs. During the Pleistocene cold periods, several morphological landforms were developed e.g. cirques, solifluction lobes, patterned grounds, etc. Traces of Pleistocene glaciers are also recorded in the landscape in the form of glacial moraines (Traczyk, 2009; Kabała, 2015).

Fig. 1. Location

Lithology and topography

The Kowarski Grzbiet, where the catena was located, is a 4-km-long ridge in the easternmost part of the Karkonosze Mountains, with two culminations – the Skalny Stół (1,281 m a.s.l.) and Czoło (1,266 m a.s.l.) peaks. The north-western and south-western slopes of the Kowarski Grzbiet are steep, with inclinations of 28° to 44°. The eastern slopes of the ridge are less steep, having an inclination 10°–18° (Kasprzak and Traczyk, 2013). The initial regoliths transported, segregated and accumulated along the slopes created slope cover beds that are the proper parent material for the mountain soils.

Land use

The Kowarski Grzbiet is covered predominantly with spruce (*Picea abies*) forests with billberry (*Vaccinium myrtillus*) and a few species of grasses (*Poa nemoralis*, *Agrostis capillaries*, *Agrostis canina*, *Poa trivialis and Festuca pratensis*) in the forest floor. The lower part of the slope is covered with coniferous forest with some admixture of silver birch (*Betula pendula*) and mountain ash (*Sorbus domestica*). Most of the area is deforested due to atmospheric pollution during the 1980s (Waroszewski et al., 2009) and regular hurricane winds (Pawlik, 2012).

Climate

Mean annual precipitation varies between 900 mm at the footslope to 1300 mm in the summit. The mean annual air temperature is between 7 °C at 600 m a.s.l. and 1–2 °C at 1600 m a.s.l. The coldest month in the Karkonosze Mountains is January (-6.1 °C) and the warmest is July (9.4 °C) (Sobik et al. 2013).

Profile 1 – Katoskeletic Folic Albic **Podzol** (Loamic, Densic, Raptic)
Localization: Upper part of convex slope, spruce forest, 1269 m a.s.l, **N** 50°45’11.9”, **E** 15°47’38.7”

Morphology:

Oi – 14–6 cm, slightly decomposed organic material, clear and wavy boundary;

Oe – 6–0 cm moderately decomposed organic material, clear and wavy boundary;

E – 0–22 cm eluvial horizon with an *albic* material, sandy loam, light gray (10YR 6/1), mica schist fragments, clear boundary at stone line;

2Bh – 22–55 cm, loamy sand, light gray (10YR 4/3), amphibole schist fragments, clear boundary;

2Bhs – 55–61 cm, *spodic* horizon, loamy sand, dark reddish brown (5YR 3/3), amphibole schist fragments, gradual boundary;

3BC – 61–80 cm transitional horizon, sandy loam, light olive brown (2.5Y 5/4), amphibole schist fragments, gradual boundary;

3C – 80–(105) cm parent material, light olive brown (2.5Y 5/5); amphibole schist fragments.

Table 1. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm									Textural class
		>2	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	
E	0–22	40	1	3	7	31	23	17	12	6	SL
2Bh	22–55	80	2	9	14	34	21	10	6	4	LS
2Bhs	55–61	90	7	14	17	26	14	12	6	4	LS
3BC	61–80	90	3	8	10	25	17	19	12	6	SL

Table 2. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	pH KCl	BC [cmol(+)·kg^{-1}]	Fe_o	Al_o [%]	Al_o+1/2Fe_o
E	0–22	29.8	2.36	1.01	0.071	0.050	0.09
2Bh	22–55	36.7	3.01	1.00	1.768	0.512	1.36
2Bhs	55–61	31.8	3.65	0.74	1.520	0.752	1.46
3BC	61–80	6.1	3.98	0.61	0.325	0.462	0.58

Profile 2 – Skeletic Folic Albic **Podzol** (Loamic, Raptic)
Localization: Upper part of straight slope, spruce forest, 1241 m a.s.l, **N** 50°45'14.3", **E** 15°47'38.5"

Morphology:

Oi – 13–7 cm, slightly decomposed organic material, gradual and wavy boundary;

Oe – 7–0 cm strongly decomposed organic material, clear and wavy boundary;

E – 0–12 cm eluvial horizon with *albic* material, sandy loam, grayish brown (10YR 5/2), mica schist clasts, clear boundary;

2Bhs – 12–47 cm, *spodic* horizon, sandy loam, yellowish red (5YR 4/4), amphibole schist fragments, gradual boundary;

2Bs – 47–63 cm, illuvial horizon, sandy loam, yellowish brown (10YR 5/6), amphibole schist fragments, gradual boundary;

2BC – 63–78 cm transitional horizon, sandy loam, yellowish brown (10YR 6/6), amphibole schist clasts, gradual boundary;

3C – 78–(89) cm parent material, sandy loam, brownish yellow (10YR 6/8), amphibole schist fragments.

Table 3. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm									Textural class
		>2	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	
E	0–12	60	3	7	8	24	18	20	14	6	SL
2Bhs	12–47	70	4	8	14	32	18	12	8	4	SL
2Bs	47–63	80	8	9	11	26	17	15	10	4	SL
3C	78–(89)	90	7	10	12	27	17	13	10	4	SL

Table 4. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	pH KCl	BC [cmol(+)·kg^{-1}]	Fe_o	Al_o [%]	Al_o+1/2Fe_o
E	0–12	50.1	2.42	1.26	0.141	0.075	0.15
2Bhs	12–47	34.6	3.31	0.92	3.100	0.803	2.35
2Bs	47–63	13.1	4.05	0.63	0.608	0.573	0.88
3C	78–(89)	09.3	4.00	0.66	0.288	0.563	0.71

Profile 3 – Skeletic Folic Albic **Podzol** (Loamic, Raptic)
Localization: Middle slope (straight), spruce forest, 1198 m a.s.l,
N 50°45′17.3″, **E** 15°47′40.8″

Morphology:

Oi – 11–6 cm, slightly decomposed organic material, clear and wavy boundary;

Oa – 6–0 cm highly decomposed organic material, clear and wavy boundary;

E – 0–15 cm eluvial horizon with *albic* material, sandy loam, grayish brown (10YR 5/2), mica schist fragments, clear and wavy boundary;

2Bh – 15–25 cm, *spodic* horizon weakly cemented with iron, loamy sand, very dark gray (5YR 3/2-3), amphibole schist clasts, clear and wavy boundary;

2Bhs – 25–41 cm, *spodic* horizon, sandy loam, strong brown (7.5YR 4/6), amphibole schist clasts, gradual boundary;

3BC – 41–(53) cm transitional horizon, sandy loam, yellowish brown (10YR 5/6), amphibole schist fragments.

Table 5. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm									Textural class
		>2	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	
E	0–15	40	2	4	7	27	16	16	22	6	SL
2Bh	15–25	60	2	9	22	31	17	9	6	4	LS
2Bhs	25–41	80	3	7	11	27	18	16	12	6	SL
3BC	41–(53)	90	8	12	12	21	16	15	12	4	SL

Table 6. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	pH KCl	BC [cmol(+)·kg^{-1}]	Fe_o	Al_o [%]	Al_o+1/2Fe_o
E	0–15	49.9	2.73	0.88	0.395	0.113	0.31
2Bh	15–25	58.8	3.10	0.93	5.350	0.689	3.36
2Bhs	25–41	18.3	3.66	0.77	1.848	0.530	1.45
3BC	41–(53)	10.8	4.03	0.60	0.503	0.475	0.73

Profile 4 – Dystric Endoskeletic Histic Stagnic **Cambisol** (Loamic, Colluvic)
Localization: lower part of concave slope, spruce forest, 1178 m a.s.l,
N 50°45'19.4", **E** 15°47'45.2"

Morphology:

Oe – 10–0 cm, moderately decomposed organic material;

EBg – 0–15 cm, horizon having sandy loam texture, very dark brown (7.5YR 4/2), common redoximorphic mottles, clear and wavy boundary;

2Bw1 – 15–30 cm, *cambic* horizon, sandy loam, dark brown (7.5YR 3/4), gradual boundary;

2Bw2 – 30–42 cm, *cambic* horizon, sandy loam,dark yellowish brown (10YR 4/4), gradual boundary;

3BC – 42–63 cm transitional horizon, sandy loam, olive brown (2.5Y 4/4), gradual boundary;

3C – 63-83 cm, parent material, olive brown (2.5Y 4/5).

Table 7. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm									Textural class
		>2	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	
EBg	0–15	30	5	8	14	23	16	14	14	6	SL
2Bw1	15–30	40	5	7	18	30	16	10	8	6	SL
2Bw2	30–42	60	8	11	15	23	13	10	12	8	SL
3BC	42–63	70	8	11	17	24	12	10	12	6	SL

Table 8. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	pH KCl	BC [cmol(+)·kg^{-1}]	Fe_o	Al_o [%]	Al_o+1/2Fe_o
EBg	0–15	47.1	3.69	0.63	1.718	0.321	1.18
2Bw1	15–30	20.9	3.83	0.68	1.739	0.481	1.35
2Bw2	30–42	07.4	4.09	0.47	0.591	0.279	0.57
3BC	42–63	05.7	4.30	0.44	0.279	0.296	0.44

Profile 5 – Dystric Histic **Stagnosol** (Episiltic, Skeletic, Colluvic)
Localization: lower part of concave slope, spruce forest, 1145 m a.s.l,
N 50°45’21.6”, **E** 15°47’51.9”

Morphology:

Oi – 14–8 cm, slightly decomposed organic material;

Oa – 8-0 cm, highly decomposed organic material, clear and wavy boundary;

Eg – 0–20 cm, eluvial horizon with *albic* material, silt loam, dark grayish brown (10YR 5/2), friable consistency, *stagnic* properties (common reductimorphic and oximorphic colors), gradual boundary;

EBg – 20–38 cm, transitional horizon, silt loam, dark brown (7.5YR 4-5/4), friable consistency, *stagnic* properties (common reductimorphic and oximorphic colors), gradual boundary;

2Bwg – 38–50 cm, *cambic* horizon, loam, dark brown (10YR 5/6), firm consistency, *stagnic* properties (common reductimorphic and oximorphic colors), gradual boundary;

3BC – 50–75 cm *cambic*/transitional horizon, loam, strong brown (10YR 5/8), very firm consistency, gradual boundary;

3C – 75–(95) cm, parent material, strong brown (10YR 5/6-8), very firm consistency.

Table 9. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm									Textural class
		>2	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	
Eg	0–20	30	2	2	5	16	13	25	31	6	SiL
EBg	20–38	50	1	3	5	15	14	23	29	10	SiL
2Bwg	38–50	40	2	4	6	18	14	21	25	10	L
3BC	50–75	80	2	3	5	17	17	25	25	6	L

Table 10. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	pH KCl	BC [cmol(+)·kg^{-1}]	Fe_o	Al_o [%]	Al_o+1/2Fe_o
Eg	0–20	53.7	3.06	0.90	1.058	0.260	0.79
EBg	20–38	36.9	3.33	0.69	1.280	0.278	0.92
2Bwg	38–50	20.8	3.60	0.82	1.203	0.400	1.00
3BC	50–75	20.7	3.77	0.70	1.325	0.568	1.23

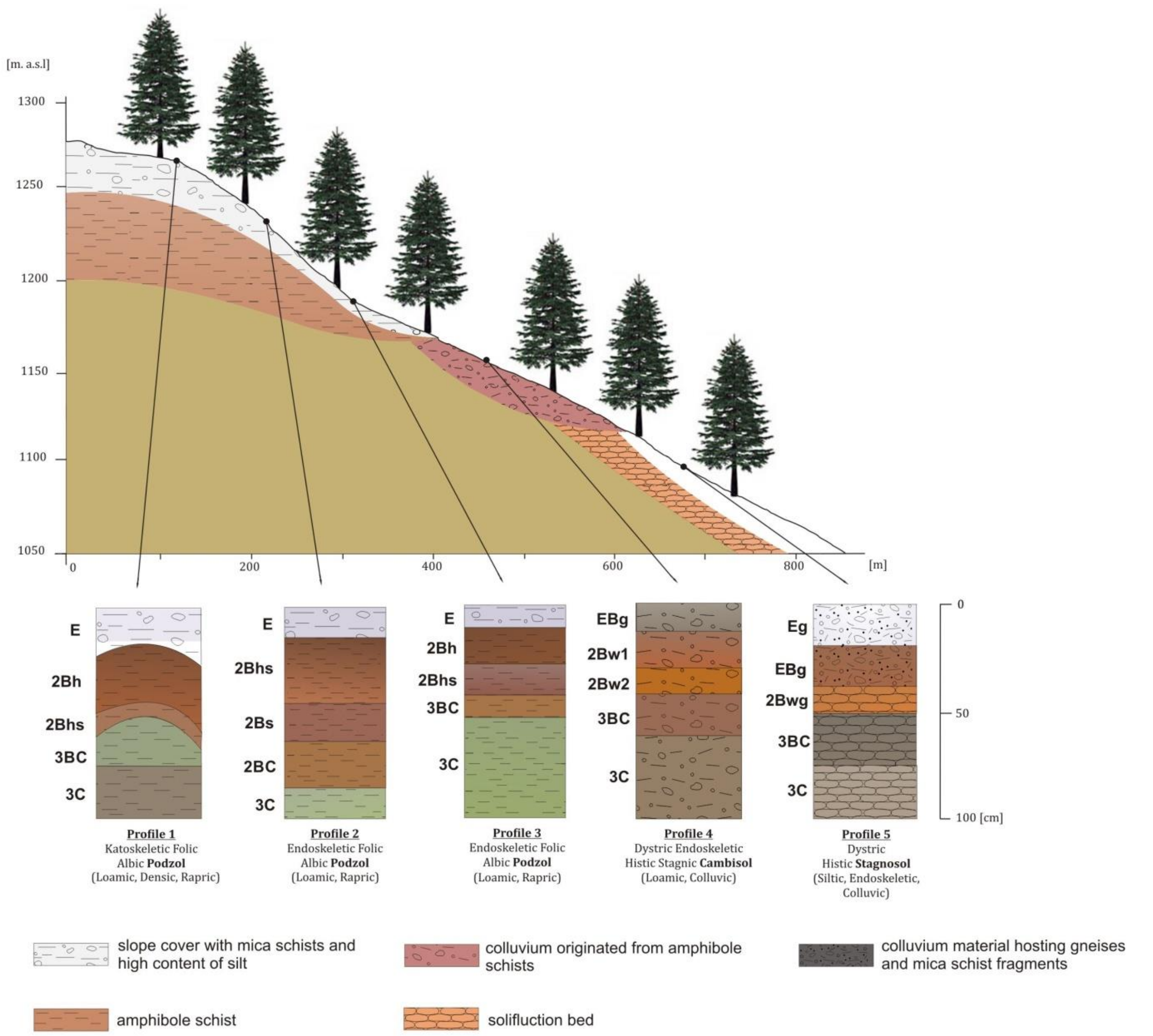


Fig. 2. Soil topolithosequence along slope having different types of slope deposits on Kowarski Grzbiet

Soil genesis and systematic position

The wide variety of soils is very typical of mountain areas. It is the effect of variable inclination and exposure of slopes, weather conditions, and the zonal system of the vegetation, which is connected with the position above sea level. Natural geomorphic processes in the mountains influence the soil development by controlling soil forming processes, stimulating or hampering them.

In the analysed catena, the domination of **Podzols** is connected with the properties of the parent material, the presence of coniferous forests and the relatively high precipitation. Profiles 1, 2 and 3 were classified as **Podzols** according to the WRB classification (IUSS Working Group WRB, 2015). In the Kowarski Grzbiet, the typical materials identified on slopes are deposits hosting products of the weathering of gneiss, mica schists and amphibolite schists. Soils that developed under spruce forests have low fertility, acid reaction and low content of base cations (Table 2, 4, 6, 8, 10). The main soil forming process here is podzolisation, i.e. translocation of organic matter, iron and aluminium (Tables 2, 4, 6) that results in the development of grey eluvial horizon (*albic* material) and dark illuvial horizon (*spodic*). The first three profiles in the soil catena feature a lack of A horizon and the presence of thick forest litter (*folic*). Profiles 1 and 3 have texture of sandy loam in the surface mineral horizons and loamy sand in the subsoil. The only exceptions are Profile 2 with sandy loam texture throughout the profile, and Profile 1 with silt loam texture in the topsoil (probable aeolian silt addition). All podzolised soils contain high amounts of rock fragments, although the type of rock varies between topsoil horizons (E) and subsoil (Bh, Bhs, Bs, BC, C). The coarse material present in the topsoil horizons of all studied **Podzols** consists of mica schists, while the coarse material in the subsoil is represented by amphibole schists; therefore, at the contact of E and Bh/Bhs horizons a lithological boundary was detected and highlighted with the ***Raptic*** qualifier. Soil located in the middle of a concave slope (Profile 4) was formed from relocated material (Waroszewski et al., 2018) with significant share of coarse fragments (mostly gneisses and mica schists). The topsoil organic layer hosts a moderately decomposed peat substrate, so the ***Histic*** qualifier was added. At the depth 15–42 cm a *cambic* horizon was recognised; therefore, soil was classified as **Cambisol**. Acid parent material caused low trophic status (***Dystric***). The soil from the lowest part of the slope was classified as **Stagnosol** (Profile 5) due to the characteristic stagnic colour pattern in Eg, EBg and 2Bwg horizons. Reductimorphic and oximorphic colours were visible >25% of the total area in these horizons (***Stagnic***). Below Eg horizon, a greyish, well-structured horizon with stagnic properties was identified that fulfilled the criteria for *cambic*. A thick and highly/moderately decomposed (Oi, Oa) *histic* organic horizon was found above the mineral surface of the soil. The presence of **Stagnosols** is associated with the topography. They are usually formed in local depressions or flattened slope sections saturated with water for a long period of time. Profile 5 has a different texture compared to the other soils in the catena. The texture in the mineral topsoil layer is silt loam and the subsoil has loam texture. Therefore, the silty topsoil, which is free of stones, was recognised as colluvium (presumably also having aeolian silt input – Waroszewski et al., 2018).

Soil sequence in the catena

Soil profiles in the catena are developed from stratified materials formed in the course of different slope processes (mass wasting, solifluction, creeping, aeolian silt contribution). A clear stratification can be detected in **Podzols** – Profiles 1, 2 and 3. These profiles also have a significantly higher amount of silt in topsoil horizons comparing with the subsoil. Soils formed in the top and middle part of the soil catena are developed from two types of materials: 1) amphibolite schists derived strata with cryoturbation features, and 2) mica schist materials (e.g. Profile 1), while in the lower-slope section, the soils were formed on slope deposits having mica schist/gneiss signatures. The last two pedons (Profile 4 and 5) contain materials related with slope washing processes and have different source areas (Waroszewski et al., 2018). Profile 4, which fully developed within colluvial materials, was classified as **Cambisols**. In the last profile, the stagnic properties within colluvium over solifluction deposits classify this soil as **Stagnosols**. Both soil profiles host ***Histic*** horizons.

References

IUSS Working Group WRB, 2015. World Reference Base for soil resources 2014, update 2015 International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Report No. 106. FAO, Rome.

Kabała, C., Bogacz, A., Łabaz, B., Szopka, K., & Waroszewski, J. 2013. *Diversity, dynamics and threats of soils*. Nature of the Karkonosze National Park. Jelenia Góra, 91-126.

Kabała, C., 2015. *Soils of Lower Silesia origins, diversity, and protection*. Polish Soil Science Society.

Kasprzak, M, Traczyk, A. 2013. *Relief and landforms. In Nature of the Karkonosze National Park*, Knapik R, Raj A (eds). Jelenia Góra;47–90 (in Polish).

Pawlik, Ł., 2012. *Zniszczenia w lasach sudeckich pod wpływem orkanu Cyryl – implikacje historyczne i regionalne.* Przegląd Geograficzny, 84(1): 53-75.

Sobik, M., Błaś, M., Migała, K., Godek, M., Nasiółkowski, T., 2013. *Climate. In Nature of Karkonosze Mts. National Park*, Knapik R, Raj A (eds). Karkonoski Park Narodowy: Jelenia Góra; 147–187 (in Polish).

Traczyk, A., 2009. *Glaciation of the Sniezne Kotly in the Western Karkonosze Mts. in the light of morphometric analysis and GIS*. Opera Corcontica, (46), 41.

Waroszewski, J., Kabala, C., Szopka, K.. 2009. *Trace elements in soils of upper zone of spruce forest on Szrenica Mount and the Kowarski Grzbiet Range in the Karkonosze Mountains*. Journal of Elementology 14(4): 805–814.

Waroszewski, J., Egli, M., Brandová, D., Christl, M., Kabala, C., Malkiewicz, M., Kierczak J., Glina B., Jezierski P. 2018. *Identifying slope processes over time and their imprint in soils of medium-high mountains of Central Europe (the Karkonosze Mountains, Poland)*. Earth Surface Processes and Landforms. *43*(6), 1195-1212.

Diversity of soils derived from andesite in the Polish Carpathians based on the case of soil cover of Wdżar Mount

Tomasz Zaleski, Bartłomiej Kajdas, Ryszard Mazurek

Tertiary andesite (13.5–10.8 Ma; Birkenmajer & Pecskay, 2000; Trua et al., 2006) occurs only in a few places in the Polish part of the Carpathians. The largest andesitic body is observed at Mt Wdżar (766 m a.s.l.), SE from the village of Kluszkowce (Fig. 1). Since Wdżar is an elevation protruding over sandstones and shales of the Magura Nappe of the Outer Flysch Carpathians, it provides an opportunity to investigate the properties of soils originating directly from andesite.

Fig. 1. Location

Lithology and topography

Volcanic rocks, represented mainly by andesites (volcanic intermediate rocks), are quite widespread along the Carpathians arc. Andesites can be find in Transcarpathian Ukraine in the east, in the Moravian Carpathians in the west, and in NW Romania (Birkenmajer et al. 2004). In the Polish Carpathians, the volcanics are present in the regions of the Pieniny, while flysch rocks –in the Outer Carpathians. The so-called Pieniny Andesite Line (PAL) is a zone of about 5 km width and 20 km length, which cuts through the rocks of the Pieniny Klippen Belt (PKB) and flysch of the Magura Nappe in the Outer Flysch Carpathians. Andesites are relatively abundant, but present in low volume, forming clusters of small- to moderate sized hypabyssal bodies, dykes and sills (Birkenmajer 2004).

Two phases of the Miocene volcanic activity in the Pieniny region were recognised. The first phase intrusions are more widespread, mainly parallel/subparallel to the northern longitudinal distribution of PKB. Intrusions are represented by basic through normal to acidic rocks (plagioclase andesites, amphibole-augite andesites, magnetite andesites). The dykes of andesite of the first phase are dissected by transverse faults. The second phase intrusions are present mainly in the westernmost part of PAL (Mt Wdżar and its vicinity) and consists of fresh, usually coarse-porphyritic amphibole-augite andesite; they are undeformed and perpendicular to the PKB (Birkenmajer 2004, Krobicki & Golonka 2008).

Land use

Historically, Mt Wdżar was intensively used for agriculture. Arable lands were established in the lower parts of the mountain, on the slopes below 15°, while steeper slopes were used as pastures. From the mid 19th century to the beginning of the 1970s, an active quarry of andesite was located at the slope of the mountain. In the 1970s, after the quarry was closed, steep southern and western slopes of the mountain were afforested, mainly with Scots pine (*Pinus Silvestris* L.) and European larch (*Larix decidua* Mill.). Slopes with the northern and eastern exposures are still used as meadows or pastures. The only known in Poland habitat of *Woodsia ilvensis* is located at Mt Wdżar, between andesite boulders.

Profile 1 – Skeletic Cambic **Phaeozem** (Colluvic, Humic, Loamic, Amphisiltic)
Localization: Foothill of Wdżar Mountain, inclination 25-30°, 687 m a.s.l.,
N 49°27′13.63″ **E** 20°19′7.74″

Morphology:

Of – 4–0 cm, poorly decomposed *organic* material containing mainly moss and conifer needles;

Ah – 0–34 cm, *mollic* horizon, sandy loam, brownish black (7.5YR 2/2), slightly moist, medium strong granular structure, many angular andesite coarse fragments, common roots, clear and wavy boundary;

ABw1 – 34–60 cm, *cambic* horizon, silt loam, very dark brown (7.5YR 2/3), fine strong blocky subangular structure, moist, abundant angular andesite coarse fragments, few roots, diffuse boundary;

ABw2 – 60–91 cm, *cambic* horizon, silt loam, very dark brown (7.5YR 2/3), fine strong blocky subangular structure, moist, abundant angular andesite coarse fragments, very few roots, gradual boundary;

BwC1 – 91–150 cm, dark brown (7.5YR 3/4) loam, fine strong blocky subangular structure, moist, abundant angular andesite and shale coarse fragments, very few roots;

BwC2 – 150–(200) cm, dark brown (7.5YR 3/4) loam, fine strong blocky subangular structure, moist, abundant angular andesite and shale coarse fragments, very few roots.

Table 1. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	0–34	40	3	5	6	10	21	19	26	4	6	SL
ABw1	34–60	50	2	5	8	12	12	14	31	6	10	SiL
ABw2	60–91	60	1	6	9	13	10	18	28	5	10	SiL
BwC1	91–150	60	2	7	10	13	12	13	27	7	8	L
BwC2	150–(200)	70	3	9	10	13	11	14	27	3	11	L

Table 2. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	C/N	pH			$CaCO_3$ [$g \cdot kg^{-1}$]
					H_2O	KCl	NaF	
Ah	0–34	50.8	4.0	12.7	5.5	4.3	10.6	-
ABw1	34–60	11.3	0.6	18.8	6.5	4.7	10.4	-
ABw2	60–91	9.6	0.3	32.0	6.8	4.9	10.6	-
BwC1	91–150	6.9	0.4	17.3	6.8	5.0	10.5	-
BwC2	150–(200)	7.0	0.7	10.0	6.9	5.1	10.4	-

Table 3. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	BS [%]
		[$cmol(+) \cdot kg^{-1}$]							
Ah	0–34	303	46.2	5.12	2.91	357	106	463	77.2
ABw1	34–60	327	64.5	1.95	4.39	397	39.7	437	90.9
ABw2	60–91	328	86.3	2.04	4.56	421	30.6	451	93.2
BwC1	91–150	295	90.1	1.55	4.54	391	26.8	418	93.6
BwC2	150–(200)	322	90.0	2.33	4.51	419	25.4	445	94.3

Profile 2 – Mollic Lithic **Leptosol** (Colluvic, Humic, Loamic)

Localization: lower slope - inclination 20° of andesitic hill Wdżar Mt., along ski slope; 692 m a.s.l., coniferous trees (pine, larch), grasses, moss
N 49°27′22.2″ **E** 20°19′11.7″

Morphology:

Of – 6–0 cm, poorly decomposed moss felt;

AhC – 0–20 cm, brownish black (7.5YR 3/2), sandy loam, moist, medium strong granular structure, many angular andesite coarse fragments, common roots, abrupt boundary with slightly weathered andesite;

R – 20–(70) cm, *continuous rock* – andesite.

Table 4. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	
AhC	0–20	30	7	12	11	13	15	10	16	5	11	SL

Table 5. 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	NaF	
AhC	0–20	25.6	1.70	15.0	6.0	4.9	9.9	-

Table 6. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	CEC_{clay}	BS [%]
		[cmol(+)·kg^{-1}]								
AhC	0–20	387	80.9	13.1	0.64	482	45.4	527	-	91.4

Profile 3 – Mollic Lithic **Leptosol** (Humic, Loamic)

Localization: upper slope - inclination 30° of andesitic hill Wdżar Mt., coniferous trees (pine, larch), 698 m a.s.l., **N** 49°27′15.65″ **E** 20°19′4.6″

Morphology:

Ah – 0–15 cm, brownish black (7.5YR 2/2), sandy loam, moist, medium strong granular structure, common angular andesite coarse fragments, common roots, abrupt boundary with fresh andesite;

R – 0–(40) cm, *continuous rock* - andesite.

Table 7. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	0–15		1	3	4	9	39	18	20	3	3	SL

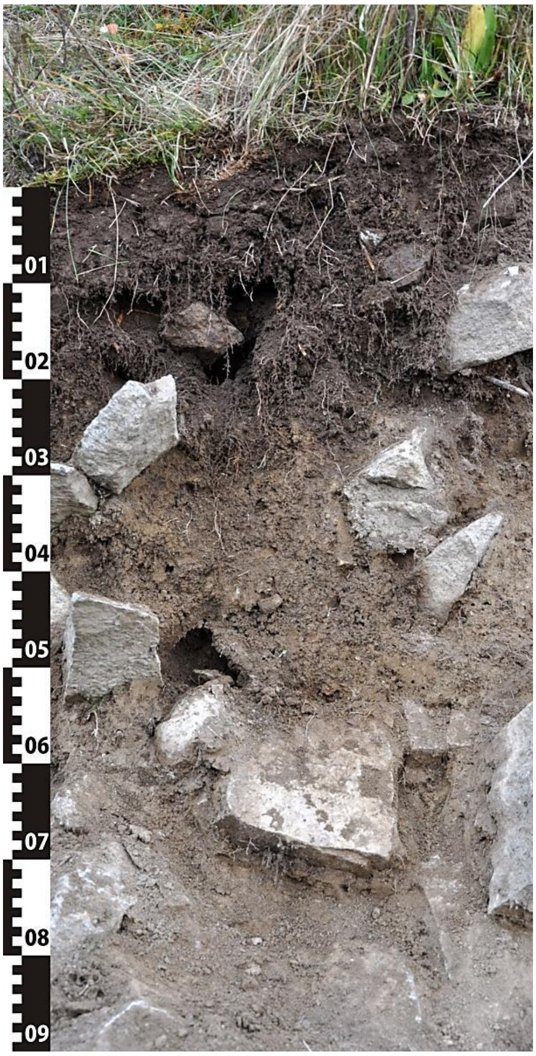
Table 8. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	Nt [g·kg^{-1}]	C/N	pH			$CaCO_3$ [g·kg^{-1}]
					H_2O	KCl	NaF	
Ah	0–15	41.6	3.1	13.4	5.6	4.2	10.5	-

Table 9. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	CEC_{clay}	BS [%]
		[cmol(+)·kg^{-1}]								
Ah	0–15	319	57.1	3.75	1.99	382	94.7	477	-	80.1

Profile 4 – Skeletic Cambic **Phaeozem** (Colluvic, Humic, Endoloamic, Anosiltic)
Localization: Near the top of andesitic hill Wdżar Mt., 747 m a.s.l.,
N 49°27′19.82″ **E** 20°19′8.66″E



Morphology:

Ah – 0–30 cm, dark brown (7.5YR 3/3), silt loam, moist, medium strong granular structure, many angular andesite coarse fragments, common roots, clear smooth boundary;

BwC – 30–60 cm, brown (10YR 4/4), silt loam, moist, medium strong granular structure, many angular andesite coarse fragments, common roots, clear and wavy boundary;

C – 60–80 cm, dull yellowish brown (10YR 5/4), loam, medium moderate granular structure, abundant angular andesite coarse fragments, few roots, abrupt boundary with slightly weathered firm andesite

R – 80–(90) cm, *continuous rock* - andesite.

Table 10. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	0–30	40	4	13	11	13	5	21	25	4	4	SiL
BwC	30–60	40	1	5	6	12	13	21	26	4	11	SiL
C	60–80	60	4	9	8	11	12	18	23	5	9	L

Table 11. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	C/N	pH			$CaCO_3$ [$g \cdot kg^{-1}$]
					H_2O	KCl	NaF	
Ah	0–30	34.0	3.0	11.3	5.6	4.5	10.4	-
BwC	30–60	7.5	0.8	9.4	6.5	4.8	10.3	-
C	60–80	4.8	0.4	12.0	6.6	4.9	10.3	-

Table 12. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	TEB	HA	CEC	CEC_{clay}	BS [%]
		[$cmol(+) \cdot kg^{-1}$]								
Ah	0–30	200	26.1	2.06	1.72	229	698.9	298	-	76.9
BwC	30–60	186	21.1	0.42	2.56	210	28.7	239	-	88.0
C	60–80	176	22.5	0.63	2.98	202	23.9	226	-	89.4

At present, Mt Wdżar has mainly a recreational value. Since the end of the 1990s, Mt Wdżar has been used mainly as a ski resort in winter. In warmer seasons, the slopes of Mt Wdżar are used for mountain biking.

Climate

Wdżar Mt is located on the geographical border between Pieniny Mountains and Gorce Mountains. In this area mountain climat with vertical climat zones is presents. Below 600 m a.s.l it is moderate warm climat, between 600 and 1100 m a.s.l moderate cool and above 1100 m a.s.l. cool. Annual precipitation varies with height – at the foothills it is from 800 to 900 mm with mean annual air temperature ranging from +4 to +6°C, and at the highest region from 1200 to 1240 mm with mean annual air temperature ranging from +2 to +4°C (Hess 1965; Obrębska-Starklowa et al., 1995). During early spring and autumn warm and dry halny foehn wind is frequent in this area. Masses of humid air generated near man-made reservoir on the Dunajec River, so called Lake Czorsztyn, have also significant influence on the themperature and humidity of the area. The amount of days with fog and higher humidity over last 20 years is increasing in comparison to earlier decades (Miczyński et al. 2010).

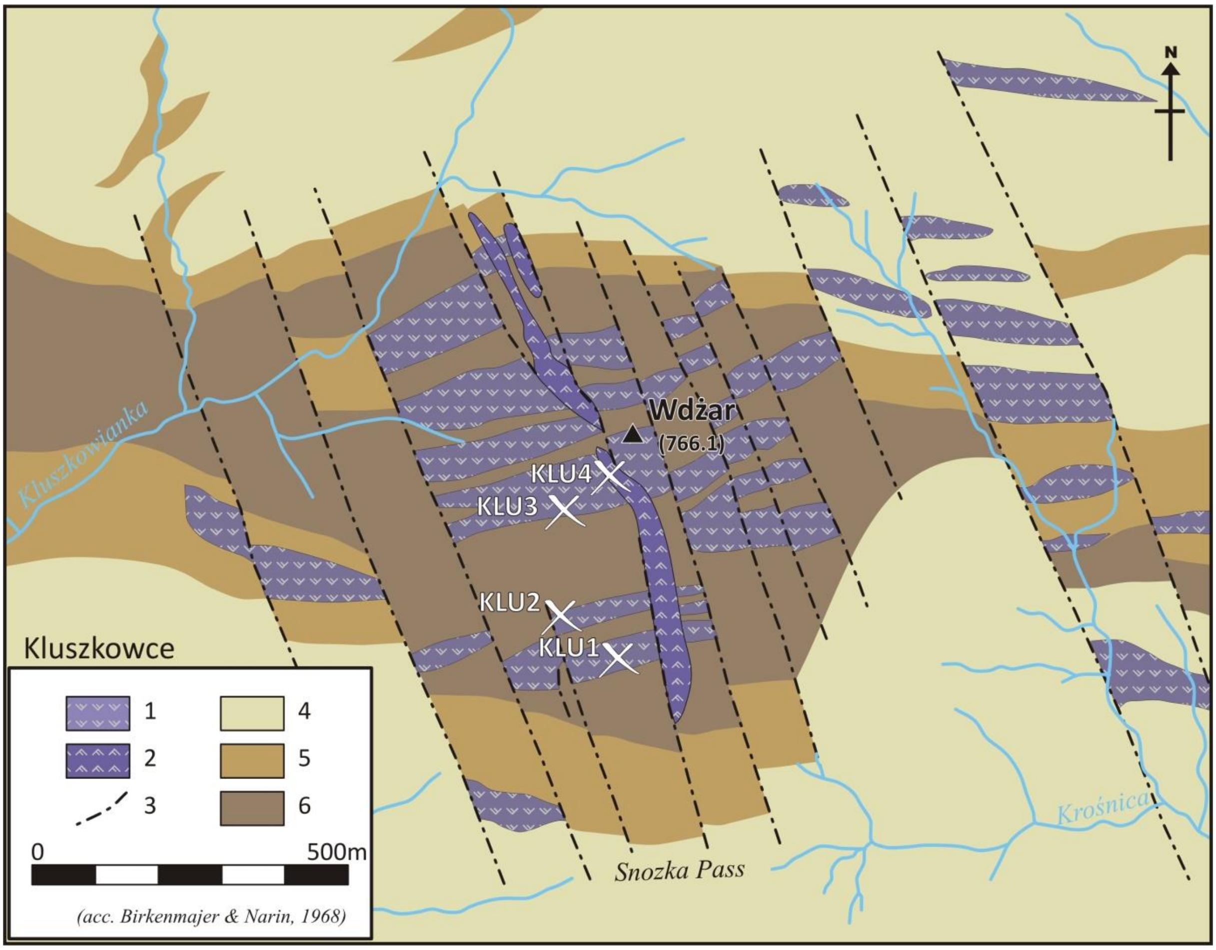


Fig. 2. Simplified geological map of Mt Wdżar near Kluszkowce (after Birkenmajer & Nairn, 1968, modified) with location of soil profiles.
1 - amphibole andesite (first phase intrusions); 2 - amphibole-pyroxene andesite (second phase intrusions); 3 - faults; 4 - Magura sandstones (middle Eocene); 5 - sub-Magura beds (lower Eocen); 6 - Kluszkowce beds (lower Eocene - Paleocene)

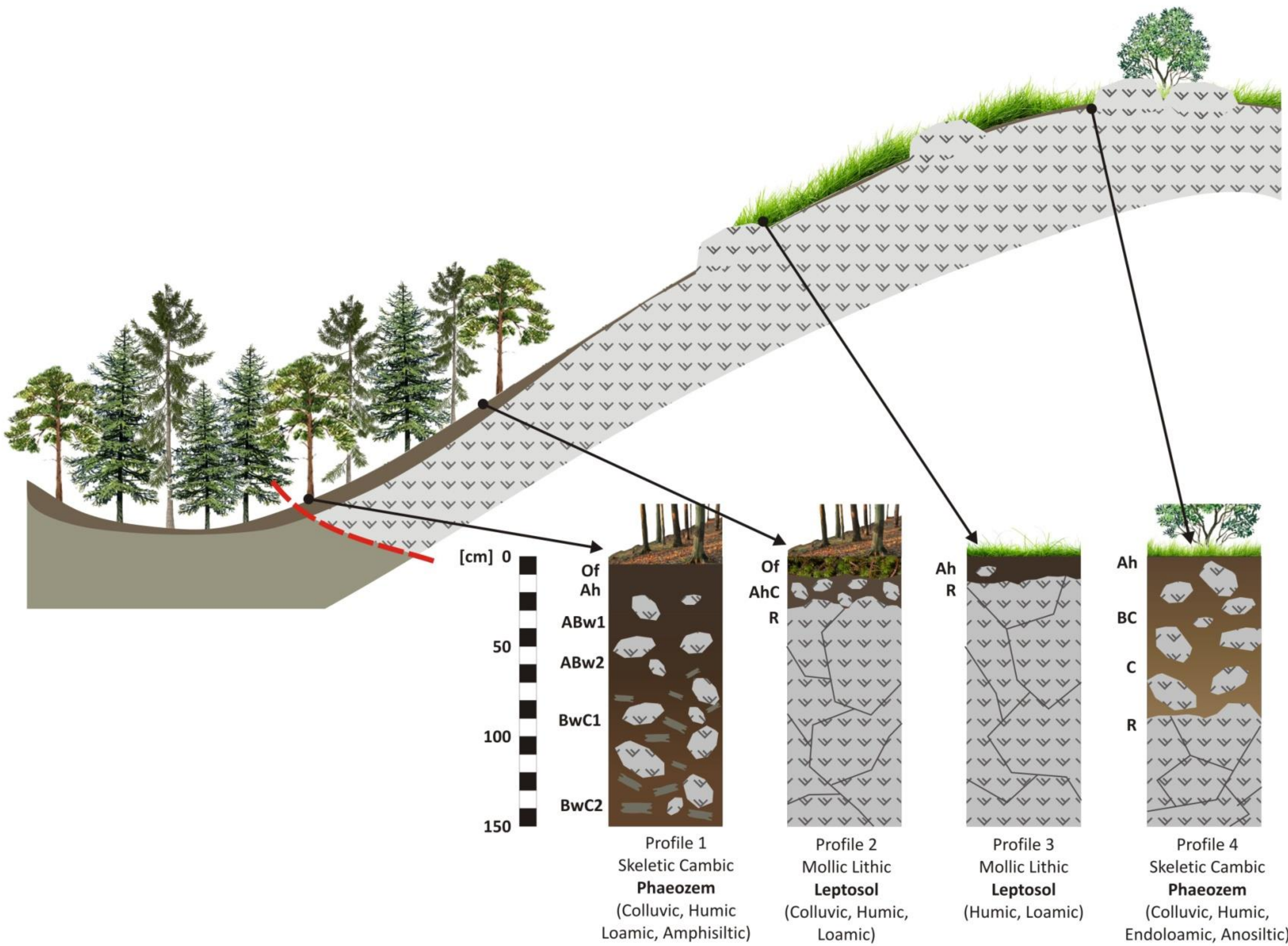


Fig. 3. Lithotoposequence of soils derived from andesite in Wdżar Mountain

Soil genesis and systematic position

Profile 1, classified as ***Skeletic Cambic*** **Phaeozem** ***(Colluvic, Humic, Loamic, Amphisiltic)***, is situated in the lower part of the steep slope, not impacted by anthropopressure. The soil has developed from colluvium containing large quantities of stones and boulders (Table 1). It shows a slight variation in morphology, colour and the limits of horizons. Dark brown colour of weathered mineral horizons and humic horizons is similar despite large differences in the carbon content (Table 2) in these horizons. The humic horizon shows more acidic reaction compared to lower mineral horizons.

Profile 2 and profile 3 represent ***Mollic Lithic*** **Leptosols**, which occur in the middle part of the slope of Mt Wdżar on steeper places or places where parent andesite is present under the shallow surface of soil cover. In this type of areas, shallow (not thicker than several centimetres) soil cover is present due to the presence of erosion and denudation activity.

Deeper ***Skeletic Cambic*** **Phaeozem** ***(Colluvic, Humic, Endoloamic, Anosiltic)*** (profile 4) was also described from places where weathered material was accumulated in cracks and crevices of bedrock on flattened areas near the summit of Mt Wdżar. The thickness of mineral horizons of these soils ranges from 20 to 50 cm.

In the lowest part of Mt Wdżar, around the abandoned quarry, anthropogenic soils, e.g. **Technosols,** are present on mine heaps. Anthropogenic soils were not examined during this study.

Soil cover on Mt Wdżar represents different stages of soil development. Shallow, ca. 15 cm deep, ***Mollic Lithic*** **Leptosols** and deeper, 60 cm and over 200 cm deep, ***Skeletic Cambic*** **Phaeozems** were distinguished. Soils developed from andesite show many simillarities in chemical and physical properties of genetic horizons. The studied soils have sandy loam, loam and silt loam texture. Regardless of the depth of the profile, the surface humic horizons show acid reaction, while cambic and parent material horizons show neutral reaction. More acidic reaction may result from the afforestation carried out in the 1970s. The cation exchange capacity (CEC) ranges between 526.9 and 298.2 mmol(+)·kg^{-1} in humus horizons and between 451.4 and 225.8 mmol(+)·kg^{-1} in cambic and parent material horizons. The amount of exchangeable Ca^{2+} ranges between 175.8 and 386.8 mmol(+)·kg^{-1} and is about 6 times higher than the sum of Mg^{2+}, Na^{+} and K^{+} in the soil horizon. Despite the large amount of Ca^{2+}, no active carbonates were detected in the analysed soil, and the high content of Ca^{2+} is a result of chemical composition of primary andesite, containing Ca-bearing plagioclases, amphiboles and pyroxenes. Andesite from Mt Wdżar shows a minor degree of hydrothermal alteration, visible mainly as the presence of secondary clay minerals, which were formed at the expense of primary plagioclases. The soils formed from andesite usually contain a large amount of clay minerals and a very small amount of primary quartz. Two generations of clay minerals can be distinguished in the soils studied. Coarse clays (< 2.0 μm), which were formed during the hydrothermal alteration of andesite, consist mainly of vermiculite. In fine clays (< 0.2 μm), derived from rock weathering and soil development, smectite is the main component. Quartz present in the investigated soil seems to be of eolian origin. **Luvisols** and **Retisols** derived from loess are common in the close vicinity of Mt Wdżar, in the vast Orava-Nowy Targ Intramontane Basin.

Soils derived from andesites found in the Carpathians (e.g. Slovakia, Hungary) are usually classified as **Andosols**. However, the weathering mantles present in the Polish part of the Carpathians on andesitic hills (Mt Wdżar, Mt Bryjarka, Mt Jarmuta) do not show any characteristics of volcanic ashes, therefore they do not meet the diagnostic criteria for ***andic*** horizons. Only pH values measured in NaF (Tables 2, 5, 8, 11) meet the ***andic*** horizon criteria.

Soil sequence

The soil cover on Mt Wdżar creates a peculiar mosaic of shallower and deeper soils. The diversity of soil profiles and their systematic affiliation are mainly the effect of relief and depth of solid bedrock. Shallow ***Mollic Lithic*** **Leptosols** are present mainly in the upper part of the mountain and on steep, over 25°, slopes. Thicker ***Skeletic Cambic*** **Phaeozems** are more common in the lower and flatter, below 10°, parts of the slope. There are only slight differences in chemical and morphological properties between the analysed soils. Weathered andesite provides very fertile parent material for newly formed soils. High values of CEC and high overall proportion of Ca^{2+} in the Total Exchangeable Bases result from the large amount of calcium in primary andesite and its subsequent hydrothermal and weathering alterations.

Acknowledgments

This Research was financed by the Ministry of Science and Higher Education of the Republic of Poland (DS-3167/IGiA/18).

References

Birkenmajer, K., 2003. Post-collisional Late Middle Miocene (Sarmatian) Pieniny Volcanic Arc, Western Carpathian. Bull. Pol. Acad. Sc., Earth Sc., 51: 79-89.

Birkenmajer, K., Delitala, M.C., Nicoletti, M., Petrucciani, C., 1987. K-Ar dating of andesite intrusions (Miocene), Pieniny Mts., Carpathians. Bull. Pol. Acad. Sc., Earth Sc., 35: 11-19.

Birkenmajer, K., Nairn, A.E.M., 1968. Paleomagnetic Studies of Polish Rocks. III. Neogene Igneous Rocks of the Pieniny Mountains, Carpathians (in Polish). Annales De La Societe Geologique De Pologne, XXXVIII (4): 475-489.

Birkenmajer, K., Pećskay, Z., 1999. K-Ar dating of the Miocene andesite intrusions, Pieniny Mts, West Carpathians. Bull. Pol. Acad. Sc., Earth Sc., 47: 155-169.

Hess, M., 1965. Piętra klimatyczne w polskich Karpatach Zachodnich. — Zeszyty Naukowe UJ, Prace Geograficzne, 11: 1–255.

Jurewicz, E., Hercman, H., Nejbert, K., 2007. Flowstone-like calcite in the andesite of Jarmuta Mt. – dating the Holocene tectonic activity in the vicinity of Szczawnica (Magura Nappe, Outer Carpathians, Poland). Acta Geologica Polonica, Vol. 57 (2007), No. 2, pp. 187-204.

Lexa, J., Konećny, V., 1998. Geodynamic aspect of the Neogene to Quaternary volcanism, in Rakús M ed., Geodynamic development of the Western Carpathians: Geological Survey of Slovak Republic, Bratislava, pp. 219-240.

Michalik, M., Ladenberger, A., Skublicki, Ł., Warzecha, M., Zych, B., 2004. Petrological characteristics of the Pieniny andesite. Mineralogia Polonica – Special Papers, 24: 283-286.

Miczyński, J., Zuska, Z., Jabłońska-Korta, U., Jurkiewicz, T., 2010. An attempt to estimate changes in local climate due to the creation of reservoirs on the example of fog distribution in Czorsztyn (in Polish), Pieniny–Zapora – Zmiany – Monografie Pienińskie, 2: pp.123–129.

Nejbert, K., Jurewicz, E., Macdonald, R., 2012. Potassium-rich magmatism in the Western Outer Carpathians: Magmagenesis in the transitional zone between the European Plate and Carpathian–Pannonian region. Lithos, 146–147: 34–47.

Obrębska-Starklowa, B., 1995. Differentiation of topoclimatic conditions in a Carpathian foreland valley based on multiannual observations, Zesz. Nauk. UJ, Prace Geogr., 101, pp. 1-110.

Szymański, W., Szkaradek, M., 2018. Andesite weathering and soil formation in a moderately humid climate: A case study from the Western Carpathians (southern Poland). Carpathian Journal of Earth and Environmental Sciences 13(1): 93-105.

Trua, T., Serri, G., Birkenmajer, K. & Pécskay, Z., 2006. Geochemical and Sr–Nd–Pb isotopic compositions of Mts Pieniny dykes and sills (West Carpathians): Evidence for melting in the lithospheric mantle. Lithos, 90: 57–76.

Soil Sequences of the Trialeti Range, Sakartvelo (Georgia)

Ilia Kunchulia, Tengiz Urushadze, Tamar Kvrivishvili, Giuli Tsereteli, Rusudan Kakhadze

The Trialeti Range is a south-western range in the Lesser Caucasus Mountains in central Georgia (Fig. 1). North-east of the Javakheti volcanic plateau, the range is located on the right shore of river Mtkvari (Kura) starting west of the city Akhaltsikhe and ending in the capital Tbilisi to the east. The range is about 150 km long and has a maximum width of 30 km. The total area of the range is around 4,393 km^2, with a 408-km perimeter.

Fig. 1. Location

Lithology and topography

The main parent materials of the range are carbonate rocks (limestones, marls) with volcanogenic rocks (tuffs, tufobreccias, etc.), volcanites (andesites, andesite–basalts) and sedimentary rocks (sandstones, clay shales, etc.), loess, loess loams, clay shales, etc., and young lavas (andesites, basalts, dolerites) (Urushadze et al., 1999). The ages of the parent materials are upper Cretaceous, Palaeocene, Eocene, Oligocene, Miocene, Pliocene and post-Pliocene (Machavariani, 2004).

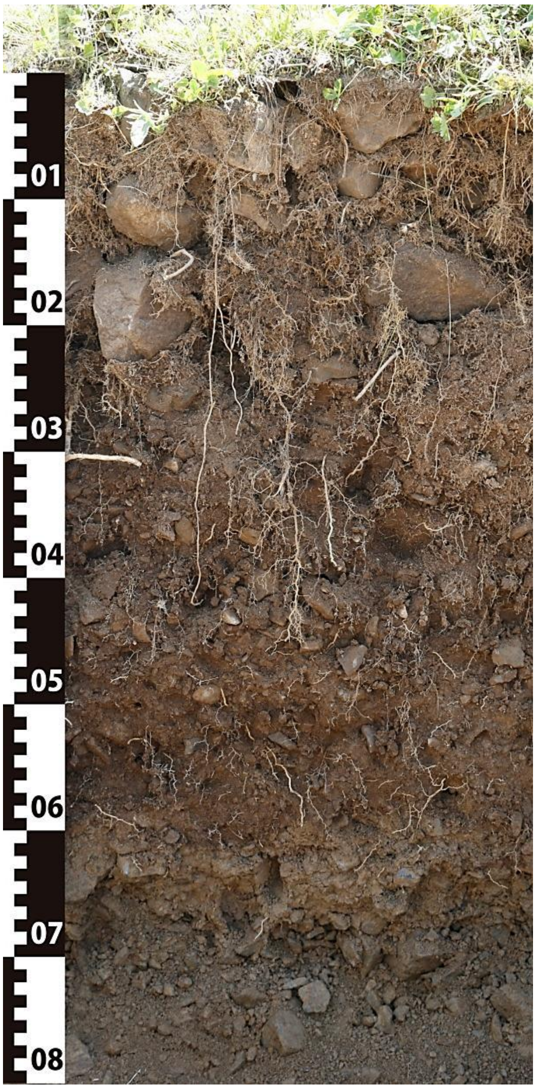
Peaks in the range reach 2,300–2,800 metres above sea level (a.s.l.) and the lowest edge is at the shores of Mtkvari, south-east of Tbilisi. The edges of some slopes reaching 40–45°. Also, along its whole north–south length to the west, the capital of the country, Tbilisi, is located on ridges (Satskepela, Armazi, Mskhaldidi, Lisi, Mtatsminda, Kojori, Tabori and Teleti) of the range (Lachashvili et al., 2017).

Land use and vegetation

This territory is an important natural geographic region of East Georgia, as are most of its mountains after the Great Caucasus range, because there are several protected areas (Algeti National Park, Nedzvi, Ktsia-Tabatskuri and Tetrobi managed reserves) and many tourism resorts (Bakuriani, Tsagveri, Manglisi, Kodjori, etc.).

Including the protected areas, because of its high altitudes and mountain landscape, the Trialeti range is mainly covered with forests and grassland. It constitutes an important summer pasture zone and meadows for nomadic herders and local communities, being one of the main sources of income. Vegetation cover of the range has been modified by human activities. The foothills are used for agriculture and the lower mountains are covered with secondary vegetation and xerophytic species (*Carpinus orientalis*, *Paliurus*, etc.), while the lower belt of mountains is covered with oaks and the upper part with beech and hornbeam, and the top with sub-alpine forest. There is significant occurrence of coniferous forests, especially in the west of the range and, azonally, pine forests (Kunchulia et al., 2018).

Profile 1 – Dystric Hyperskeletic **Leptosol** (Humic, Loamic)
Localization: Tskratskharo Pass, top of the slope, inclination >35°, unused and unmanaged land, 2435 m a.s.l., **N** 41°41.240′ **E** 043°31.164′



Morphology:

Ah – 0–10 cm, humus horizon, sandy loam, skeletal, black (7.5YR 2/1) granular structure, sandy friable, common roots, gradual and smooth boundary;

AB – 10–30 cm, transitional horizon, sandy clay loam, coarse gravel and stones, dark reddish brown (5YR 3/3.5), granular fine blocky structure, roots, diffuse boundary;

Bw – 30–50 cm, sandy clay loam, fine and medium gravels, dark reddish brown (5YR 3/4), blocky structure, slightly compacted, very few roots, clear and smooth boundary;

CR – 50–(80) cm, regolith, sandy loam, abundant rock fragments, reddish brown (5YR 4/4), weak subangular structure.

Table 1. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm							Textural class
		>1.0	1.0-0.25	0.25-0.1	0.1-0.05	0.05-0.005	0.005-0.001	< 0.001	
A	0–10	-	1	23	40	5	16	15	SL
AB	10–30	-	1	19	32	11	17	21	SCL
BC	30–50	-	1	13	37	3	23	22	SCL
CD	50–(80)	-	2	26	34	9	15	14	SL

Table 2. Chemical and physicochemical properties

Horizon	Depth [cm]	pH [H_2O]	OC [$g \cdot kg^{-1}$]	CEC [$cmol \cdot kg^{-1}$]	Percentage (%) of CEC				
					Ca	Mg	K	Na	H
A	0–10	5.1	47.5	28.1	54.8	24.0	3.51	0.36	17.3
AB	10–30	5.2	46.3	24.4	51.2	31.5	1.27	0.26	15.8
BC	30–50	5.6	38.6	18.5	48.6	30.2	2.36	0.35	18.5
CD	50–(80)	5.9	32.3	25.8	52.4	27.2	2.64	0.34	17.5

Profile 2 – Mollic **Leptosol** (Humic, Loamic)

Localization: Tskratskharo pass, middle slope, inclination of the slope is >45°, altitude 2,324 m a.s.l., Parent material andesite-basalt; **N** 41°41.189′ **E** 043°30.662′

Morphology:

Ah – 0–10 cm, *mollic* horizon, sandy loam, dark brown (7.5YR 3/2), fine crumby structure, slightly compacted, common roots, a few gravels, clear and smooth boundary;

AB – 10–24 cm, *mollic* horizon, sandy clay loam, dark brown (10YR 3/2.5), blocky structure, loamy, stones, common roots, slightly compacted, clear and smooth boundary;

R – 24–(60) cm, *continuous rock.*

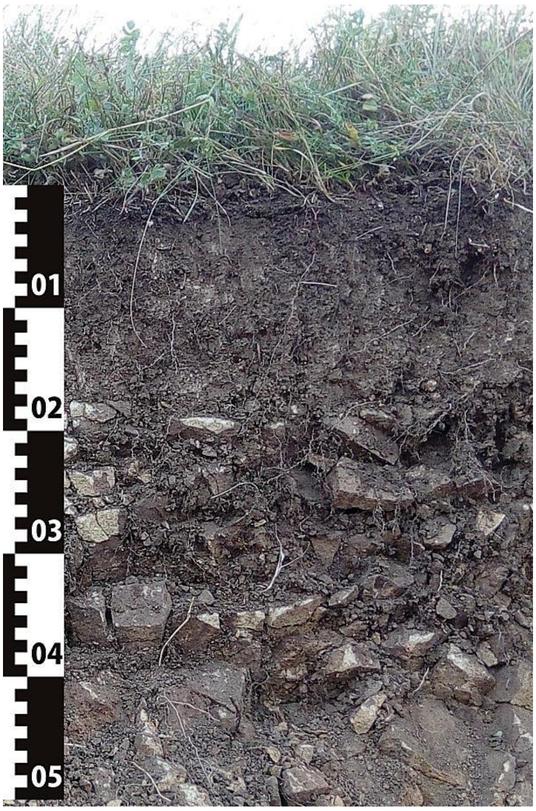
Table 3. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm							Textural class
		> 1.0	1.0-0.25	0.25-0.1	0.1-0.05	0.05-0.005	0.005-0.001	< 0.001	
A	0–10	-	1	23	40	7	16	15	SL
AB	10–24	-	1	19	32	11	17	21	SCL

Table 4. Chemical and physicochemical properties

Horizon	Depth [cm]	pH [H_2O]	OC [$g \cdot kg^{-1}$]	CEC [$cmol \cdot kg^{-1}$]	Percentage (%) of CEC				
					Ca	Mg	K	Na	H
A	0–10	5.8	49.1	17.2	62.2	34.5	1.11	0.22	1.97
AB	10–24	5.8	37.2	17.2	58.4	38.6	0.56	0.42	1.98

Profile 3 – Skeletic Leptic **Phaeozem** (Humic, Loamic)
Localization: Central part of the range, next to Algeti National Park and the start point of the river Vere, upper slope (shoulder), inclination 4–6° altitude 1,620 m a.s.l.;
N 41°43.05312’ **E** 044°26.96994’



Morphology:

Ah – 0–20 cm, *mollic* horizon, sandy loam, very dark grey (5YR 3/1), gradient to dark brown (7.5YR 3/2), crumby structure, many roots, compacted, common biological activity (ants, bugs, etc.), abrupt and smooth boundary;

AR – 20–40 cm, transitional horizon, sandy loam, brown (7.5YR 4/3.5), friable, common roots, abundant rock fragments, clear and smooth boundary;

R – 40–(70) cm, *continuous rock,* strongly weathered sandstone.

Table 5. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm							Textural class
		> 1.0	1.0-0.25	0.25-0.1	0.1-0.05	0.05-0.005	0.005-0.001	< 0.001	
Ah	0–20	-	4	39	19	6	15	17	SL
AR	20–40	-	2	43	18	6	11	19	SL

Table 6. Chemical and physicochemical properties

Horizon	Depth [cm]	pH [H_2O]	OC [$g \cdot kg^{-1}$]	CEC [$cmol \cdot kg^{-1}$]	Percentage (%) of CEC				
					Ca	Mg	K	Na	H
Ah	0–20	5.6	47.9	36.2	68.7	27.1	3.04	0.18	0.97
AR	20–40	5.7	41.9	32.3	79.2	18.8	0.73	0.30	0.99

Profile 4 – Eutric Hyperskeletic **Leptosol** (Loamic)
Localization: East part of the Trialeti range, Kojori ridge, upper slope, inclination 5°, altitude 1,303 m a.s.l.;
N 41°40.04850’ **E** 044°40.56462’

Morphology:

Ah – 0–11 cm, humus horizon, sandy clay loam, dark brown (10YR 3/3), common roots, crumby structure, friable, clear and smooth boundary;

BC – 11–30 cm, transitional horizon, sandy loam, dark brown (10YR 3/3), crumby structure, weathered calcareous rocks – abundant rock fragments, clear and smooth boundary;

R – 30–(40) cm, strongly weathered sandstone.

Table 7. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm							Textural class
		> 1.0	1.0-0.25	0.25-0.1	0.1-0.05	0.05-0.005	0.005-0.001	< 0.001	
Ah	0–11	-	1	34	19	7	16	22	SCL
BC	11–30	-	4	45	19	4	13	15	SL

Table 8. Chemical and physicochemical properties

Horizon	Depth [cm]	pH [H_2O]	$CaCO_3$ [$g \cdot kg^{-1}$]	OC [$g \cdot kg^{-1}$]	CEC [$cmol \cdot kg^{-1}$]	Percentage (%) of CEC				
						Ca	Mg	K	Na	H
Ah	0–11	7.7	7.9	41.4	35.3	73.33	25.77	0.61	0.29	-
BC	11–30	7.1	2.6	36.1	36.1	73.70	25.89	0.31	0.09	-

Profile 5 – Eutric Hyperskeletic Endoleptic **Regosol** (Loamic)

Localization: Kojori ridge, nearby territory to the Profile 4, middle slope, south exposition, inclination 5–7°, altitude 1298 m a.s.l.;
N 41°40.04538′ **E** 044°40.61256′

Morphology:

Ah – 0–8 cm, humus horizon, sandy clay loam, dark brown (10YR 3/3), fine granular-crumby structure, common roots, slightly compacted, clear and smooth boundary;

AB – 8–20 cm, transitional horizon, brown (10YR 4/3), rock structure, dominated by rock fragments, common roots, clear and smooth boundary;

C – 20–(40) cm, parent material, stones and gravels.

Table 9. Texture

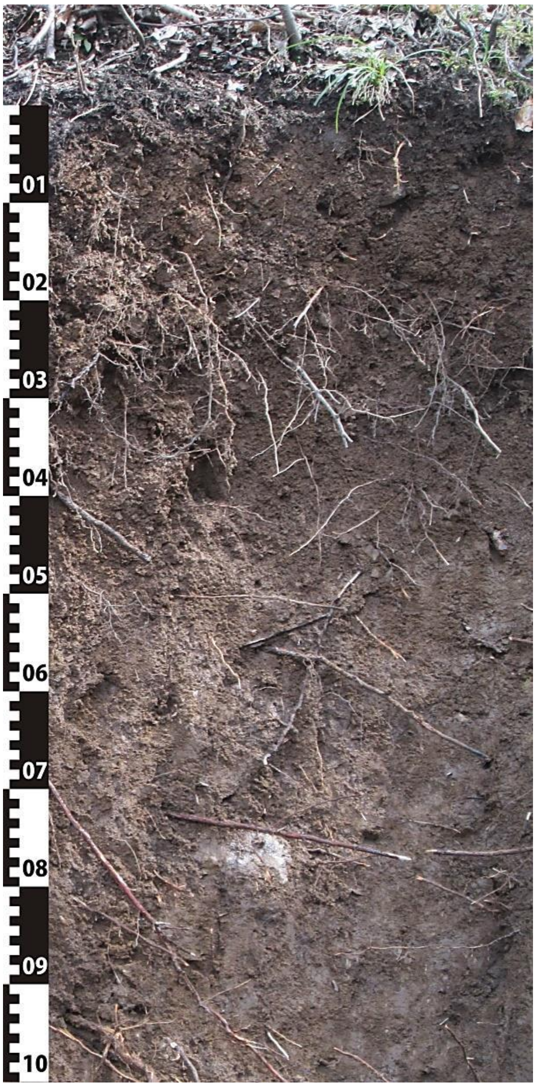
Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm							Textural class
		> 1.0	1.0-0.25	0.25-0.1	0.1-0.05	0.05-0.005	0.005-0.001	< 0.001	
Ah	0–8	-	1	34	19	7	16	22	SCL
AB	8–20	-	4	45	19	4	13	15	SL

Table 10. Chemical and physicochemical properties

Horizon	Depth [cm]	pH [H_2O]	$CaCO_3$ [$g \cdot kg^{-1}$]	OC [$g \cdot kg^{-1}$]	CEC [$cmol \cdot kg^{-1}$]	Percentage (%) of CEC				
						Ca	Mg	K	Na	H
Ah	0–8	7.3	0.26	-	37.5	74.06	24.69	1.21	0.04	-
AB	8–20	6.7	0.00	-	35.3	74.32	24.77	0.55	0.36	-

Profile 6 – Luvic **Phaeozem** (Loamic, Humic)

Localization: Road of Tskneti- Kiketi, Trialeti ridge, altitude 1300 m a.s.l; northern exposition, inclination 12-14°. Parent rock: sandstone **N** 41°40'48.8" **E** 44°41'12.4"



Morphology:

Ah – 0–15 cm, *mollic* horizon, sandy loam, very dark grayish brown (10YR 3/2), granular structure, friable, few roots, clear and smooth boundary;

AB – 15–35 cm, *mollic* horizon with some features of *argic* horizon (few cutans), silt loam, common coarse fragments, dark brown (7.5YR 3/2), crumby, compact, no roots, gradual boundary;

Bt – 35–70 cm, *argic* horizon, clay loam, few coarse fragments, brown (7.5YR 3.5/3), crumby, compact, cutans, few roots, gradual boundary;

C – 70–(100) cm, parent material, clay loam, brown (7.5YR 4.5/4), crumby.

Table 11. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm						Textural class
		2.0-0.63	0.63-0.2	0.2-0.063	0.063-0.020	0.020-0.002	< 0.002	
Ah	0–15	3	23	28	19	21	6	SL
AB	15–35	4	8	11	25	27	25	SiL
Bt	35–70	4	6	11	22	24	33	CL
C	70–(100)	4	8	13	18	28	29	CL

Table 12. Chemical and physicochemical properties

Horizon	Depth [cm]	pH [H_2O]	pH [KCl]	OC [$g \cdot kg^{-1}$]	CEC [$cmol \cdot kg^{-1}$]	Percentage (%) of CEC				
						Ca	Mg	K	Na	H
Ah	0–15	6.4	5.9	45.8	36.1	82	10	2	0	-
AB	15–35	6.1	4.2	21.2	26.2	71	9	0	0	-
Bt	35–70	6.7	4.8	10.4	29.1	82	10	0	1	-
C	70–(100)	6.8	5.3	6.9	29.6	86	10	0	1	-

Profile 7 – Haplic **Chernozem** (Loamic)
Localization: Lisi lake, Trialeti ridge, altitude 750 m a.s.l., slope sediments (colluvium);
N 41°44'29.9" **E** 44°43'47.2"

Morphology:

Ah_1 – 0–15 cm, *chernic* horizon, loam, very dark gray (10YR 3/1), granular structure, many roots, compact, gradual boundary;

Ah_2 – 15–25 cm, *chernic* horizon, loam, very dark grayish brown (10YR 3/2), granular structure, loamy, compact, common roots, gradual boundary;

AB – 25–40 cm, transitional horizon, loam, brown (10YR 4/3), compact, crumby structure, few roots, gradual boundary;

BC – 40–75 cm, transitional horizon, sandy clay loam, gray (10YR 4.5/1), crumby structure, few soft concretions of carbonates – white (10YR 8/1), gradual boundary;

Ck – 75–(110) cm – parent material with *protocalcic* properties, sandy clay loam, grayish brown (10YR 5/2), crumby structure, common soft concretions and nodules of secondary carbonates.

Table 13. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm						Textural class
		2.0-0.63	0.63-0.2	0.2-0.063	0.063-0.020	0.020-0.002	< 0.002	
Ah_1	0–15	15	13	18	19	10	25	L
Ah_2	15–25	14	12	17	20	15	22	L
AB	25–40	15	18	18	10	19	20	L
BC	40–75	18	20	20	9	11	22	SCL
Ck	75–(110)	20	21	20	8	10	21	SCL

Table 14. Chemical and physicochemical properties

Horizon	Depth [cm]	pH [H_2O]	$CaCO_3$ [$g\cdot kg^{-1}$]	OC [$g\cdot kg^{-1}$]	CEC [$cmol\cdot kg^{-1}$]	Percentage (%) of CEC				
						Ca	Mg	K	Na	H
Ah_1	0–15	7.3	13.3	23.6	33.5	81	19	-	-	-
Ah_2	15–25	7.7	26.7	19.3	34.8	85	15	-	-	-
AB	25–40	7.7	44.4	15.0	34.1	80	20	-	-	-
BC	40–75	8.2	111	9.8	30.4	79	21	-	-	-
Ck	75–(110)	8.3	133	5.5	27.0	80	20	-	-	-

Profile 8 – Skeletic **Chernozem** (Aric, Loamic, Petrocalcic, Raptic)

Localization: Tserovani, Mukhrani valley, altitude 530 m a.s.l., formed on carbonate sedimentary rocks and cobbles; **N** 41°53'33.5" **E** 44°41'05.5"

Morphology:

Ahp – 0–25 cm, *Chernic* horizon, loam, common rock fragments, very dark gray (10YR 2.5/1), crumb-granular structure, many roots, compact, primary carbonates, gradual boundary;

Ah – 25–40 cm, *Chernic* horizon, loam, common rock fragments, very dark grayish brown (10YR 2.5/1.5), skeletic, crumb-granular structure, roots, primary carbonates, clear and smooth boundary;

BC – 40–60 cm, transitional horizon, loam, common rock fragments, very dark grayish brown (10YR 3/2), few roots, few white (10YR 8/1) nodules and soft concretions of secondary carbonates, gradual boundary;

Ck – 60–(100) cm, *petrocalcic* horizon, loam, abundant rock fragments, pale brown (10YR 6/3), massive, compact, common nodules and soft concretions of secondary carbonates.

Table 15. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm						Textural class
		2.0-0.63	0.63-0.2	0.2-0.063	0.063-0.020	0.020-0.002	< 0.002	
Ahp	0–25	15	13	15	21	18	18	L
Ah	25–40	13	11	14	18	22	22	L
BC	40–60	13	10	13	19	21	24	L
Ck	60–(100)	12	8	11	26	21	22	L

Table 16. Chemical and physicochemical properties

Horizon	Depth [cm]	pH [H_2O]	$CaCO_3$ [$g{\cdot}kg^{-1}$]	OC [$g{\cdot}kg^{-1}$]	CEC [$cmol{\cdot}kg^{-1}$]	Percentage (%) from CEC				
						Ca	Mg	K	Na	H
Ahp	0–25	7.3	57.8	27.4	28.3	79	21	-	-	-
Ah	25–40	7.9	44.4	22.7	36.8	76	24	-	-	-
BC	40–60	7.9	62.2	13.3	36.2	78	22	-	-	-
Ck	60–(100)	8.3	53.3	10.5	25.7	79	21	-	-	-

Profile 9 – Cambic **Calcisol** (Hypocalcic, Siltic)

Localization: Karsani, altitude 480 m a.s.l. formed on colluvic material,
N 41°49'56.5" **E** 44°43'02.3"

Morphology:

A – 0–30 cm, humus horizon, silt loam, dark yellowish brown (10YR 4/4), granular-crumby, structure, dry, compact, very few stones, many roots, clear and smooth boundary;

Bk$_1$ – 30–60 cm, *cambic* horizon, silt loam, yellowish brown (10YR 5/6), crumby structure, few stones, dry, compact, few nodules and soft concretions of secondary carbonates, few roots, gradual boundary;

Bk$_2$ – 60–80 cm, *calcic* horizon, silt loam, yellowish brown (10YR 5/6), crumby structure, few stones, dry, compact, many nodules and soft concretions of secondary carbonates, few roots, gradual boundary;

Ck$_1$ – 80–110 cm, *calcic* horizon, silt loam, yellowish brown (10YR 5/8), crumby structure, many nodules and soft concretions of secondary carbonates, gradual boundary;

Ck$_2$ – 110–(140) cm, *calcic* horizon, silt loam, yellowish brown (10YR 5/8), crumby structure, many nodules and soft concretions of secondary carbonates, gradual boundary.

Table 17. Texture

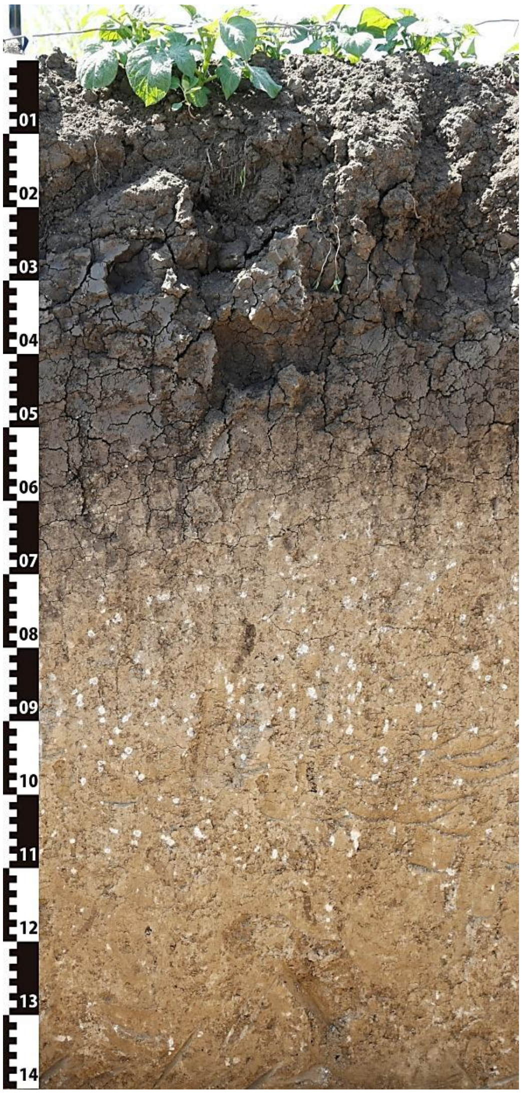
Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm						Textural class
		2.0-0.63	0.63-0.2	0.2-0.063	0.063-0.020	0.020-0.002	< 0.002	
A	0–30	1	2	4	31	37	25	SiL
Bk_1	30–60	2	2	4	30	38	24	SiL
Bk_2	60–80	1	3	4	29	39	24	SiL
Ck_1	80–110	1	2	5	28	40	24	SiL
Ck_2	110–(140)	1	2	4	30	39	24	SiL

Table 18. Chemical and physicochemical properties

Horizon	Depth [cm]	pH [H_2O]	$CaCO_3$ [$g \cdot kg^{-1}$]	OC [$g \cdot kg^{-1}$]	CEC [$cmol \cdot kg^{-1}$]	Percentage (%) from CEC				
						Ca	Mg	K	Na	H
A	0–30	7.9	222	22.7	40.6	84	16	-	-	-
Bk_1	30–60	7.3	218	14.3	57.3	82	18	-	-	-
Bk_2	60–80	7.4	235	13.1	44.7	84	16	-	-	-
Ck_1	80–110	7.5	244	4.6	42.6	85	15	-	-	-
Ck_2	110–(140)	7.5	244	4.6	47.3	83	17	-	-	-

Profile 10 – Calcic **Chernozem** (Clayic)

Localization: Bolnisi district, village Nakhiduri (agricultural land, basically are grown potatoes), altitude 480 m a.s.l.



Morphology:

Ap – 0–20 cm, *chernic* horizon, silty clay, very dark brown (10YR 2/2), granular-blocky structure, compact, very few roots, abrupt boundary;

A – 20–40 cm, *chernic* horizon, silty clay, very dark grayish brown (10 YR3/2), granular-crumby structure, compact, very few roots, loamy, gradual boundary;

AB – 40–65 cm, transitional horizon, silty clay, dark brown (10YR 3/3), crumby structure, no roots, marks of humus coatings on the surface of aggregates, gradual boundary;

BC – 65–80 cm, transitional horizon, silty clay, yellowish brown, (10YR 4.5/4), crumby structure, friable, few humus coatings, few white (2.5YR 8/2) nodules and soft concretions of secondary carbonates, gradual boundary;

Ck1 – 80–100 cm, *calcic* horizon, clay, yellowish brown (10YR 5/6), crumby structure, friable, loamy, many soft concretions and nodules of secondary carbonates, gradual boundary;

Ck_2 – 100–(130) cm, *calcic* horizon, clay, yellowish brown (10YR 5/6), crumby structure, friable, many soft concretions and nodules of secondary carbonates.

Table 19. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm						Textural class
		2.0-0.63	0.63-0.2	0.2-0.063	0.063-0.020	0.020-0.002	< 0.002	
Ap	0–20	0	0	13	15	30	42	SiC
A	20–40	0	0	13	16	29	42	SiC
AB	40–65	0	0	13	16	31	40	SiC
BC	65–80	0	0	12	17	30	41	SiC
C_{k1}	80–100	0	0	11	16	21	52	C
C_{k2}	100–(130)	0	0	10	15	20	55	C

Table 20. Chemical and physicochemical properties

Horizon	Depth [cm]	pH [H_2O]	$CaCO_3$ [$g \cdot kg^{-1}$]	OC [$g \cdot kg^{-1}$]	CEC [$cmol \cdot kg^{-1}$]	Percentage (%) from CEC				
						Ca	Mg	K	Na	H
Ap	0–20	6.0	–	20.7	32.4	71	29	-	-	-
A	20–40	6.7	–	–	32.1	74	26	-	-	-
AB	40–65	7.0	–	15.1	30.3	68	32	-	-	-
BC	65–80	7.6	178	8.2	30.1	68	32	-	-	-
C_{k1}	80–100	8.1	213	8.1	28.0	71	29	-	-	-
C_{k2}	100–(130)	8.1	227	5.3	28.1	72	28	-	-	-

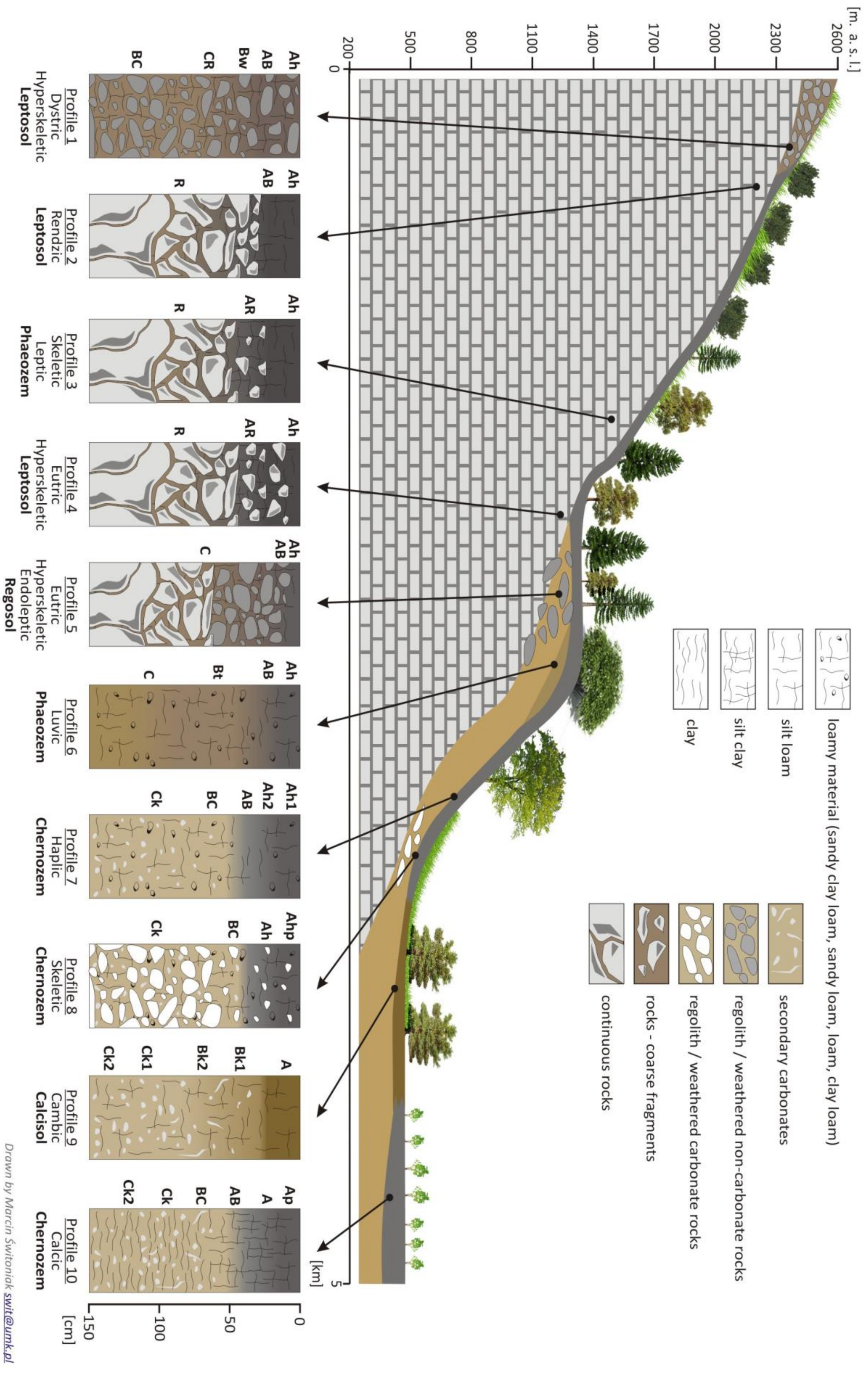


Fig. 2. Topo-climatic soil sequence in of Trialeti Range, Sakartvelo (Georgia)

Climate

The climate conditions of the Trialeti Range are significantly affected by its geographic location, diversity of reliefs, hydrological regime and abundance of forest massifs, especially in its central part. The vegetation period least from 4 to 6 months, starting in May and ending in September–October. East and north slopes of the range have a moderately humid climate up to 750 m a.s.l. with moderately cold winter and a long, warm summer and two peaks of precipitation. The eastern part of the range is in the drought part of the Kvemo Kartli region.

The annual precipitation fluctuates between 550 and 875 mm because of the sizes and area of the range, as well as different reliefs. Average annual temperature and precipitation are 7.2°C and 750 mm, respectively. Most of the precipitation is from the end of spring and the start of summer, while winter months have less precipitation. The range is relatively cool during the summer. Maximum temperatures reach 31–33C° and minimal temperatures in winter are -26C° (Kojori). Relative humidity on Manglisi-Kojori area is about 70–74% throughout the year.

Soil sequences of central and east parts of the range are presented based on two recent studies (Kunchulia et al., 2018; Urushadze et al., 2016).

Soil genesis and systematic position

Profile 1 – there are two zones marked in the pedon. The absence of continuous rock can be observed in <80 cm of the profile. In the upper part of the soil, the coarse fragment content is higher than 80% (***Hyperskeletic*** qualifier), and it was classified as a Leptosol. It also has a horizon rich in *humic* substances, which was expressed by the ***Humic*** qualifier (Tables 1 and 2). The whole profile has a loamy texture (***Loamic***) in fine earth fractions.

Profile 2 – was located at a lower altitude (about 100 m). The main difference between the first soil (Mountain–meadow) and the second (Mountain–forest–meadow) is vegetation. The climate for both types is cold, resulting from the altitude of their occurrence being >2,000 m. The vegetative period is 3–4 months, precipitation is 700–1,500 mm and average annual temperature is 3–4°C. The cold climate conditions and nature of the parent material facilitates intensive physical weathering of rocks, which results in the accumulation of boulders and gravel in the upper part of the soil profile. In the picture the upper part of the 0–24 cm of profile with few rock fragments and abundant roots can be observed. From 24 cm bedrock that fulfils the criteria of *continuous rock* begins (starts ≤25 cm) and is sufficiently consolidated; there are almost no cracks where roots can enter and material is intact (no significant displacement has taken place). For this reason the pedon fulfils the criteria of **Leptosol**. The profile has a Mollic horizon because its base saturation is >50% throughout the entire thickness (Table 4), there are no carbonates, and it has a high percentage of OC, thickness ≥20 cm and a Munsell colour value of ≤3 (moist) in all layers. Because the Mollic directly overlays the continuous rock, the final name of the classified soil is ***Mollic*** **Leptosol** (***Humic***, ***Loamic***) (Table 3).

Profile 3 – the profile is divided into three zones. Layer 1 – Ah (0–20 cm) has fine earth content of 90%, Layer 2 (AR) (20–40 cm) has fine earth content of 10% and Layer 3 (40–75 cm) has fine earth content of 3% (Table 5). The result is 28.1% fine earth fraction averaged over 75 cm depth. Thus, this profile cannot be a **Leptosol** because it cannot meet its criteria. It will end up as a **Phaeozem** because of the *mollic* horizon and having ***Leptic*** and ***Skeletic*** principal qualifiers and ***Loamic*** supplementary qualifiers.

Profiles 4 and 5 represent comparatively young soils developed on different grades of weathered sandstone. We can observe two zones in Profile 4. The upper zone is very shallow soil with rock fragments and the deeper one is bedrock with lots of cracks and roots in it. Because of the abundant cracks and roots, it cannot be classified as *continuous rock*, which prohibits it being recognised as ***Lithic***, despite the fact that rocks start <10 cm. In this case the content of fine earth must be averaged – content of fine earth is 19.2%. ***Eutric*** and ***Hyperskeletic*** principal qualifiers and ***Loamic*** supplementary qualifiers can be used.

In Profile 5 upper part (0–17 cm) with about 70% of fine earth and deeper (17–75 cm) with average fine earth content of 10% (Table 9). The profile has 23.6% of fine earth. *Continuous rock* starts at 75 cm. As the profile cannot fulfil the criteria for a **Leptosol** or any other RSG due to limitation of depth, it will be a **Regosol** with ***Endoleptic***, ***Skeletic*** and ***Eutric Principal*** and ***Loamic*** supplementary qualifiers.

Profile 6 – the profile is characterised by heavy texture and a sharp increase of the clay content with depth, high base saturation, low exchange acidity with reaction from weak acid to neutral, (in water) and from acid to weak acid (in KCl) (Tables 11 and 12).

By Georgian classification the profile belongs to Brown Forest soils with a *mollic* surface horizon, granular structure, high base saturation, and organic carbon content >0.6%. Therefore, the soil belongs to the group of **Phaeozems** because of its *mollic* horizon and bases saturation ≥50%. The main qualifier is ***Luvic***, which indicates the existence of an *argic* horizon, cation exchange capacity higher than 24 cmol/kg, and an increased content of clay with depth through illuviation.

Profile 7 – the profile has a loamy texture and high base saturation. The reaction changes from neutral to alkaline. The calcium carbonate content increases with depth and the organic carbon content gradually decreases (Tables 13 & 14).

By Georgian classification the profile belongs to Cinnamonic Soils. By WRB the profile belongs to the group of **Chernozems** with the core prefix qualifier ***Haplic***, which is typical for Chernozems without *calcic* horizons, because the characteristics are: (a) well expressed *chernic* horizon – deep, dark (almost blackish) coloured, with a surface horizon rich in humus and (b) the existence of common secondary carbonates – *protocalcic* properties starting at a depth of 75 cm.

Profile 8 – the profile is characterised by loamy texture (***Loamic***), high base saturation and, in the middle of the profile, increased clay content, with reaction changing from neutral to alkaline. The whole profile contains carbonates (Tables 15 and 16). By the Georgian classification the soil belongs to Meadow cinnamonic soils, and by WRB to the **Chernozems**, because of the following characteristics: *chernic* horizon – well expressed, deep, black coloured, upper horizon rich in humus. Main qualifier is ***Skeletic***, because of high rock content. Moreover, we can add several additional sub-qualifiers: ***Petrocalcic***, because of a *petrocalcic* horizon through secondary carbonates, with strong reaction by 10% HCl; ***Ruptic*** because of a lithological discontinuity from the surface to the depth of 100 cm; ***Aric*** because of deep cultivation/tillage from the surface till ≥20 cm depth.

Profile 9 – by Georgian classification the profile belongs to the cinnamonic soils with the following diagnostic indicators: silty loam texture (***Siltic***), regular distribution of clay from the surface to the depth, with no evidence of illuviation. The soil is saturated with bases. The reaction is neutral or slightly alkaline. The calcium carbonate content in the entire profile does not exceed 25% (Tables 17 and 18) but amount of secondary carbonates in form of soft concretions and nodules fulfil the criteria of a *calcic* horizon. This profile belongs – according to its clay distribution, base saturation >50%, presence of calcium carbonate neoformations – to the **Calcisols**, according to WRB. The main qualifier is ***Cambic***, which express the Bw horizon. This horizon also contains secondary carbonates but their content is too low for a *calcic* horizon. The additional suffix is ***Hypocalcic***.

Profile 10 – the profile shows a deep humus horizon – *chernic*; leaching of carbonates in the upper part of the profile, probably through frequent and continuous irrigation. The soil profile is characterised by silty clay and clay texture (***Clayic***) and high base saturation. The plough horizon is weakly acidic. The organic carbon content is gradually decreasing. Carbonates with many secondary forms (*calcic* horizon) are observed in the middle part of the profile (Tables 19 and 20). By Georgian classification the profile is a Grey cinnamonic soil, with a well-developed, thick, dark coloured, horizon rich in humus. The profile has a very high base saturation, except the upper part of the horizon, which is rich in humus. This specific profile identified as Grey cinnamonic soil belongs according to these diagnostic characteristics to the group of **Chernozems**. The occurrence of *calcic* horizons allow the principal qualifier **Calcic** to be used and the profile to be defined according to WRB as a ***Calcic*** **Chernozem**.

Soil sequence

Georgia has very diverse soil cover because of the high diversity of climate (macro, micro and meso), relief and other factors that change over relatively short distances. In the high mountain area (>2,000 m a.s.l.) according to the recent research there occur ***Leptic*** **Phaeozems** and **Leptosols** that have either a weakly developed profile with ***Hyperskeletic*** qualifier or a shallow profile with *continuous rock* diagnostic property and ***Mollic*** qualifier (Kunchulia et al., 2018). The profiles have mostly siltic texture and high accumulation of humus. At higher altitudes (>2,000 m a.s.l.) the cold climate conditions and the nature of the parent material facilitate intensive physical weathering of rocks, which results in accumulation of boulders and gravel in the upper part of the soil (Urushadze and Blum, 2014).

At lower altitudes (1,000–2,000 m a.s.l.) **Phaeozems**, **Leptosols** and **Regosols** have been identified on the range, but with different principal qualifiers. For example, in Profile 3 ***Leptic*** and ***Skeletic*** qualifiers can be observed in the case of **Phaeozems** at an altitude of 1,620 m a.s.l., while the ***Luvic*** qualifier was found at an altitude of 1,300 m a.s.l., which shows stronger development of profiles from a northern exposition. There were also **Leptosols** and shallow **Regosols** with ***Skeletic*** and ***Eutric*** qualifier that have less depth and content of organic materials compared to the *mollic* horizon that resulted from more intense decomposition and dryer conditions compared to higher mountain areas.

On lower areas (<1,000 m a.s.l.) well developed profiles were observed in the sampled soils, even on mountainous areas of the range. Profiles 7 and 8 are well developed Chernozems with ***Haplic*** and ***Skeletic*** qualifiers, respectively. The **Chernozems** have loamy texture and high base saturation in the profile. In this part of mountain slopes some **Calcisols** (probably **Chernozems** that eroded in the past) can also be observed. Similar shallowing of Chernozems and changing into Calcisol by human-induced erosion was previously described in other countries (Penížek et al., 2018).

On the south of the range, in the Mashavera river valley, on intensive agricultural irrigated land there occur **Chernozems** with *calcic* horizons because of the accumulation of abundant amounts of secondary calcium carbonates in the lower part of the profile (probably influenced by irrigation). These soils can also have ***Anthrotoxic*** qualifier because of contamination of the Mashavera river with heavy metals from upstream mining idustry (Withanachchi et al., 2018), however, ***Toxic*** qualifier is not listed for **Chernozems**.

According to the national classification system, all soil types that are distributed from 900 (1,000) to 1,900 (2,000) metres above sea level are classified as Brown forest soils; also, soils between 1,800 (2,000) and 3,000 (3,200) m a.s.l. can be Mountain–forest–meadow; or Mountain–meadow soils between 1,800 (2,000) and 3,200 (3,500) m a.s.l. (The main difference between the last two types of soils is vegetation.) Soil types have lower-level units, such as subtype, family, variety, species, etc. and it is partly based on zonal distribution (a landscape-geographic approach [Urushadze and Blum, 2014]). The problem with the current classification system in Georgia is that is not precise and has not been updated for decades.

In Georgia, considering the variation of the climate, as well as other soil-forming factors (parent rock, vegetation, age of soil cover, land use, etc.), we can assume that above 900 (1,000) metres a.s.l. there are many more RSGs according to the WRB, because Brown forest, Mountain–forest–meadow and Mountain–meadow soils cover 50.4% of the territory of Georgia. This kind of zonal distribution of soils leads to problems of correlation of the Georgian system with the WRB, bearing in mind the fact that every new edition of the WRB requires reclassification of the soils according to the new or updated rules and features.

Aknowlegements

Authors want to express their gratitude to Winfried Blum and Giorgi Ghambashidze for their contribution to the researches and Gia Chkhatarashvili for pictures of soil profiles and landscapes. Likewise, thanks to editors of the Soil Sequences Atlases series.

References

Kunchulia, I., Kakhadze, R., Tsereteli, G., Ghambashidze, G., Urushadze, T., 2018. Classification of shallow and skeletal mountain soils with the WRB system on the example of the Trialeti Range, Lesser Caucasus (Georgia), Bulletin of Geography. Physical Geography Series No. 14: 91-98. DOI: https://doi.org/10.2478/bgeo-2018-0004.

Lachashvili, N.J., Khachidze, M.N., Eradze, N.V., Khetsuriani, L.D., 2017. Steppe of Tbilisi environs (East Georgia, South Caucasus), Annals of Agrarian Science, Volume 15, Issue 3, 332-338. DOI: https://doi.org/10.1016/j.aasci.2017.06.003.

Machavariani, M., 2004. Brown forest soils of Trialeti Range, pp. 128, Tbilisi, Georgia (in Georgian).

Penížek, V., Zádorová, T., Němeček, K., 2018. Soils of hilly loess region in Zdanice Forest, South-east Czechia. In: Soil Sequences Atlas II, eds. Świtoniak, M., Charzyński, P., Machina Druku, Toruń: 115 – 126.

Urushadze, T., Iashvili, N., Chankseliani, A., Chkeidze, T., Gugunava, T., Kanchaveli, A., Kirvalidze, R., Lezhava, V., Lortkipanidze, R., Machavariani, J., Mardaleishvili, R., Mgeladze, E., Mindeli, K., Palavandishvili, S., Parulava, S., Petriashvili, R., Tabidze, B., Tarasashvili, N., Tavartkiladze, A., Zarandia, K., 1999. Soil Map of Georgia, editor-in-chief T. Urushadze, editor of cartography – J. Kekelia, Joint-stock company "Cartography", editor E. Shekelashvili, technical editor M. Razmadze, Tbilisi, Georgia. (https://esdac.jrc.ec.europa.eu/content/soil-map-georgia).

Urushadze, T. F., Blum, W.E.H., Kvrivishvili, T. O., 2016. Classification of soils on sediments, sedimentary and andesitic rocks in Georgia by the WRB system, Annals of Agrarian Science, Volume 14, Issue 4, 351-355. DOI: https://doi.org/10.1016/j.aasci.2016.09.015.

Urushadze, T.F., Blum, W.H.E., 2014, Soils of Georgia, New-York, Nova Science Publishers, Incorporated, pp. 242.

Withanachchi, S.S., hambashidze, G., Kunchulia, I., Urushadze, T., PloegerWater, A., 2018, Quality in Surface Water: A Preliminary Assessment of Heavy Metal Contamination of the Mashavera River, Georgia. International journal of environmental research and public health, Vol. 15, Issue 4, p. 621 doi:10.3390/ijerph15040621

Diversity of soils in the karst sinkholes in the Pre-Ural forest-steppe

Maria Smirnova, Maria Gerasimova

Kungur insular forest-steppe is the northern vanguard of forest-steppe landscapes in Europe, and it may be explained by the impact of calcareous rocks and complicated history of regional flora. In the Pleistocene, invasion of Siberian xerophytic pine forests was followed by another invasion in the Mid-Holocene, and these were European feather grass steppes (Buzmakov, Sannikov, 2014). Accordig to De Waale et al. (2009), calcareous rocks are responsible for soil moisture deficit; hence, fir-spruce forests surrounding the Kungur region could not survive there (Kadebskaya, Naumkin, 2012). The area is very famous for its karst phenomena, which most impressive result is the Kungur Cave with its picturesque and bizarre carvings, halls, tunnels, columns. Since 1965, the area was declared as a nature monument. It is under control of State authorities.

Fig. 1. Location

Lithology and topography

The origin and evolution of karst topography within the whole Pre-Ural region is related to the Caspian Sea level – its fluctuations in the Pleistocene and the Holocene, resulting in well-known transgressions and regressions; hence, the age of karst topography is considered to be several thousands years (Gorbunova et al., 1992; Kungur Ice Cave…, 2005). Karstic rocks – Low Permian (Artinskian stage) limestone and dolomite occur directly on the surface: at the depth of 10-15 m they are underlain by gypsum and anhydrite of the Kungurian stage. Thus, parent rocks are represented by stony eluvium of limestone on the main subhorizontal surface and colluvium on the slopes of sinkholes.

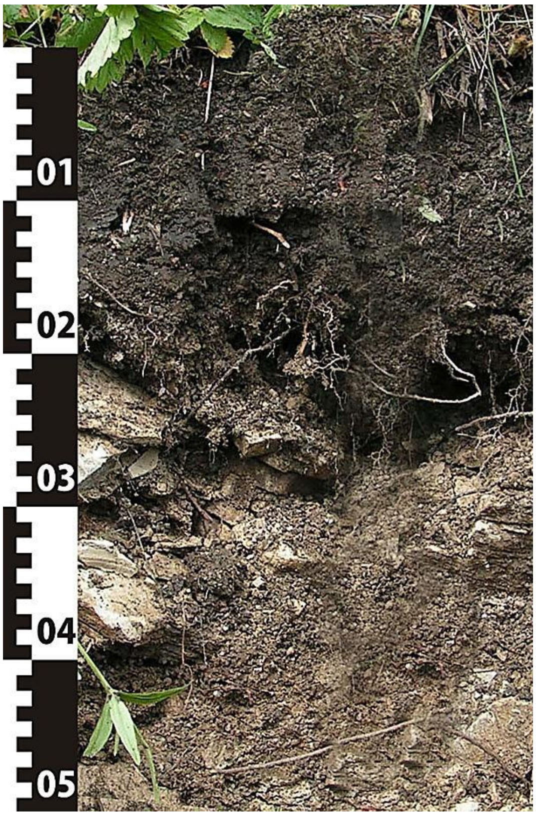
The sinkhole studied has a distinct conical shape, weakly undulating slopes, which are 20 m long and have an average slope gradient of 33º. The depth of the sinkhole is 11 m, diameter – 33 m. There is a ponor in its bottom: it means that the sinkhole is connected with an underground hollow. All these features permit to qualify the sinkhole as a solution doline.

Land use

The sinkhole was located in the territory of protected area «Ice Mount» near the town of Kungur. Natural vegetation is rather modified owing to the proximity of the town; ruderal species are not uncommon. Mesophytic steppe communities alternate with the meadows ones, and the admixture of hygrophytes in sinkholes, sometimes bushes, was recorded.

Profile 1 - Calcaric Rendzic **Leptosol** (Siltic, Humic)

Location: subhorizontal inter-sinkhole main surface (152 m a.s.l.). Steppe with feather grass (*Stipa pennata*), fescue (*Festuca valesiaca*), wormwood species and forbs: *Fragaria vesca, Filipendula vulgaris*, *Trifolium repens, Sanguisorba officinalis*, *Echinops ritro*, etc.
N 57°26'29.2" **E** 57°7'30.9"



Morphology:

Ah – 0–20 cm, *mollic* horizon, silt loam, very dark gray (10YR 3/1), weakly moist, weakly compact, fine angular blocky to crumbly structure, weak effervescence, many fine roots, few fine fragments of calcareous rocks, abrupt boundary;

R – 20–(47) cm, hard weakly weathered limestone (85%), light gray (10YR 7/1) with light yellowish brown (10 YR 6/4) fine earth (15%).

Table 1. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	0–20	13	3	17	17	7	5	16	18	14	3	SiL

Table 2. Chemical and physicochemical properties

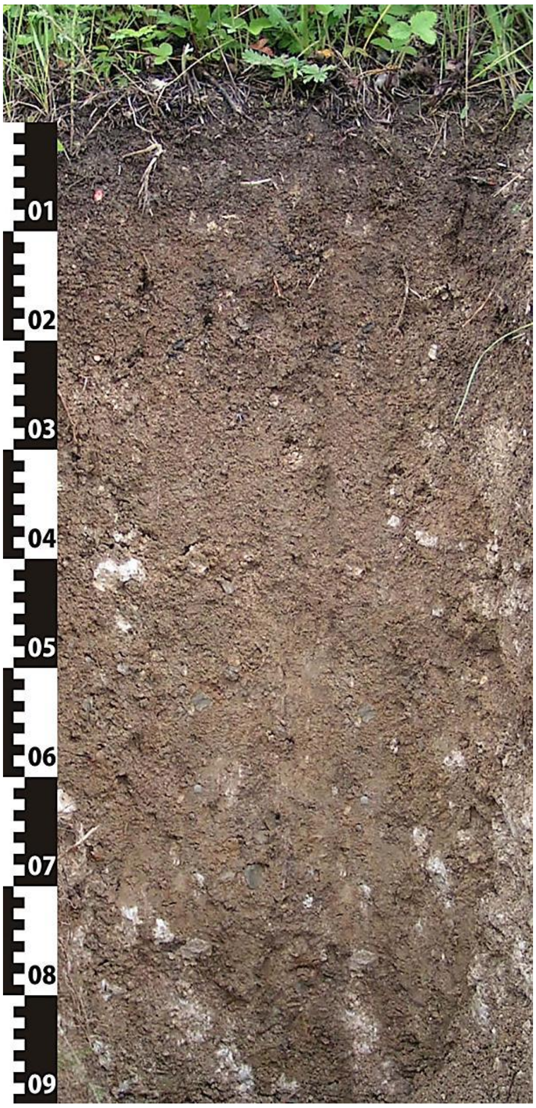
Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	C/N	pH H_2O	$CaCO_3$ [$g \cdot kg^{-1}$]
Ah	0–20	32	4.1	7.9	7.3	11

Table 3. Elemental composition

Horizon	Depth [cm]	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	MnO	TiO_2	K_2O	P_2O_5
		[%]								
Ah	0–20	50.51	10.42	8.21	19.65	8.03	0.18	0.65	1.80	0.27

Profile 2 - Calcaric Cambic **Phaeozem** (Siltic, Colluvic, Protocalcic)

Location: upper part of the sinkhole slope (3 m from the edge and 17 m down to the bottom; 151 m a.s.l.), inclination 33°. Grass-forb community dominated by wild strawberry (*Fragaria vesca*), feather grass (*Stipa pennata*), (*Poa pratensis L.*) and dropwort (*Filipendula vulgaris*).
N 57°26'29.2" **E** 57°7'30.9"



Morphology:

Ah – 0–9 cm, humus horizon, silt loam, dark grayish brown (10YR 3/2), weakly moist, friable, fine crumbly to subangular blocky structure, weak effervescence starting at 6 cm, densely pierced by fine roots, very few fine fragments of calcareous rocks, clear transition and wavy boundary;

Ahk – 9–25 cm, silt loam, grayish brown (10YR 3/3) with darker mottles, some of them vertical (earthworm passage ways), weakly moist, fine subangular blocky, visible effervescence, many fine roots, very few fine fragments of calcareous rocks, clear transition and wavy boundary;

ABwk – 25–42 cm, silt loam, light yellowish brown (10YR 5/4), weakly moist, friable, fine subangular blocky, visible effervescence, few fine soft carbonate concretions and pseudomycelium, very few fine roots, few fragments of calcareous rocks (up to 2x3x5 cm in size), gradual transition by the abundance of fragments, diffuse boundary;

BCk – 42–(90) cm, silt loam, light yellowish brown (10YR 5/4), weakly moist, similar to the above horizon but has more limestone fragments, rather firm, weak subangular blocky structure, visible effervescence, no carbonate pedofeatures.

Table 4. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	0–9	14	4	16	16	7	6	19	19	11	2	SiL
Ahk	9–25	16	3	17	18	8	7	20	16	9	2	SiL
ABwk	25–42	21	5	14	14	5	5	14	19	20	4	SiL
BCk	42–(90)	27	6	15	15	5	5	13	17	19	5	SiL

Table 5. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	C/N	pH H_2O	$CaCO_3$ [$g \cdot kg^{-1}$]
Ah	0–9	34	6.1	5	7.6	23
Ahk	9–25	12	1.5	8	7.7	39
ABwk	25–42	-	-	-	8.0	86
BCk	42–(90)	-	-	-	7.4	46

Table 6. Elemental composition

Horizon	Depth [cm]	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	MnO	TiO_2	K_2O	P_2O_5
		[%]								
Ah	0–9	47.07	11.85	3.84	21.98	12.53	0.17	0.69	1.69	0.18
Ahk	9–25	40.34	12.15	4.54	26.32	13.82	0.12	0.67	1.65	0.17
ABwk	25–42	38.81	11.15	3.82	30.2	13.6	0.13	0.62	1.52	0.15

Profile 3 - Cambic Someric **Phaeozem** (Siltic, Colluvic, Hyposkeletic) over Cambic Someric **Phaeozem** (Siltic, Colluvic, Hyperhumic, Hyposkeletic) over **Cambisol** (Siltic, Colluvic)

Location: medium part of the sinkhole slope (10 m down from the edge, and 10 m to the bottom; 148 m a.s.l.), slope gradient 33^{o}. Plant community with fern (*Gymnocarpium dryopteris*) and herbs: *Aegopodium podagraria*, *Alchemilla vulgaris, Galium aparine, etc.*
N 57°26'29.2" **E** 57°7'30.9"

Morphology:

Ah – 0–13 cm, *mollic* horizon, silt loam, very dark gray (10YR 2/2), moist, friable to slightly firm, fine crumbly and subangular blocky structure, weak effervescence at 10 cm, common fine roots, few fine fragments of calcareous rocks, clear and smooth boundary;

ABwk – 13–40 cm, transitional horizon, silt loam, dark grayish brown (10YR 3/3), moist, rather firm, subangular blocky (fine and medium blocks), visible effervescence, common fine roots, many fragments of calcareous rocks, clear and smooth boundary;

2Ahkb – 40–53 cm, buried *mollic* horizon, silt loam, black (10YR 2/1), moist, firm, fine crumbly and granular structure, visible effervescence, pierced by fine roots with fine aggregates hanging on them, few fine fragments of calcareous rocks of different weathering degree, clear and smooth boundary;

2ABwkb – 53–72 cm, transitional horizon, silt loam, dark brownish gray (10YR 3/2), moist to weakly wet, firm, fine crumbly, visible effervescence, few fine roots, abundant fragments of calcareous rocks of different weathering degree, clear and smooth boundary;

3Akb – 72–79 cm, buried humus horizon, silt loam, very dark grayish brown (10YR 3/2), moist to weakly wet, firm, weak subangular blocky structure, visible effervescence, few fine roots, abundant fragments of calcareous rocks, clear and smooth boundary;

3Bwb – 79–(110) cm, buried *cambic* horizon, loam, brown (10YR 4/3), moist to weakly wet, firm, weak subangular blocky structure, weak effervescence, few fragments of calcareous rocks in upper 10 cm.

Table 7. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	0–13	11	4	14	13	7	7	20	19	14	2	SiL
ABwk	13–40	23	3	18	18	5	6	23	15	10	2	SiL
2Akb	40–53	9	3	12	15	7	6	21	18	15	3	SiL
2ABwkb	53–72	26	6	16	17	8	6	25	14	6	2	SiL
3Akb	72–79	20	6	17	16	8	6	17	17	10	3	SiL
3Bwb	79–(110)	6	7	15	17	8	7	21	17	6	2	SiL

Table 8. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	C/N	pH H_2O	$CaCO_3$ [$g \cdot kg^{-1}$]
Ah	0–13	46	3.7	12	7.4	17
ABwk	13–40	19	2.6	7	8.1	41
2Akb	40–53	37	3.4	11	7.5	38
2ABwkb	53–72	-	-	-	8.1	52
3Akb	72–79	-	-	-	7.5	49
3Bwb	79–(110)	-	-	-	7.9	45

Table 9. Elemental composition

Horizon	Depth [cm]	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	MnO	TiO_2	K_2O	P_2O_5
		[%]								
Ah	0–13	50.51	10.42	6.13	17.65	12.21	0.19	0.65	1.80	0.27
ABw	13–40	48.56	11.31	5.83	17.37	14.27	0.19	0.66	1.47	0.18
2Akb	40–53	53.03	10.81	6.92	15.81	10.01	0.33	0.75	1.85	0.21
2ABwkb	53–72	50.30	11.10	6.20	18.10	11.20	0.21	0.71	1.20	0.17
3Akb	72–79	51.20	10.80	5.90	16.30	10.43	0.26	0.69	1.33	0.23
3Bwb	79–(110)	63.77	9.81	4.40	10.61	6.79	0.12	0.49	1.37	0.20

Profile 4 - Cambic **Phaeozem** (Siltic, Colluvic, Pachic)

Location: lower part of the sinkhole slope (17 m from the edge and 3 m to the bottom of the sinkhole; 144 m a.s.l.), slope gradient 33^{o}. Grass-forb community with leguminous plants and predominance of *Aegopodium podagraria*. **N** 57°26'29.2" **E** 57°7'30.9"

Morphology:

Ah1 – 0–35 cm, *mollic* horizon, silt loam, very dark gray (10YR 3/1), moist to weakly wet, friable, fine subangular blocky and crumbly structure, weak effervescence at 20 cm, densely pierced by fine roots, few coarser roots, few fragments of calcareous rocks of different weathering degree, clear and wavy boundary;

Ah2 – 35–60 cm, humus horizon, silt loam, heterogeneous in color: dark gray (10YR 3/1) and dark yellowish brown (10YR 3/4) mottles, moist, rather firm, subangular blocky structure, visible effervescence, few roots of any diameter, few fragments of calcareous rocks of different weathering degree, clear and wavy boundary;

ABwk – 60–(100) cm, colluvial silt loam, heterogeneous in color: dark gray (10YR 3/1) and dark yellowish brown (10YR 3/4) mottles, moist, rather firm, weak subangular blocky structure, visible effervescence, few fragments of calcareous rocks of different weathering degree.

Table 10. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	0–35	16	7	18	16	7	7	17	17	9	2	SiL
Ah2	35 – 60	13	6	16	17	6	5	16	18	13	3	SiL
ABwk	60–100	7	8	19	17	7	5	14	16	11	3	SiL

Table 11. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	C/N	pH H_2O	$CaCO_3$ [$g \cdot kg^{-1}$]
Ah1	0–35	38	3.5	10.9	7.1	12
Ah2	35 – 60	-	-	-	7.3	18
ABwk	60–100	-	-	-	7.7	31

Table 12. Elemental composition

Horizon	Depth [cm]	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	MnO	TiO_2	K_2O	P_2O_5
		[%]								
Ah1	0–35	53.33	13.08	6.49	14.80	8.52	0.20	0.82	2.28	0.21
Ah2	35 – 60	53.30	12.22	6.84	15.53	7.86	0.15	0.83	2.39	0.20
ABwk	60–100	53.39	13.06	6.98	15.98	6.99	0.14	0.83	2.42	0.18

Climate

The study area is located in the fully humid zone with a long period with snow cover and warm summer (Kottek et al., 2006). Mean annual air temperature equals 1.8ºC, mean temperature of July is +21.6ºC (absolute maximum +37.5ºC), that of January −11.2ºC (absolute minimum –45ºC); the frost-free period lasts 115 days. Mean annual precipitation is equal to 532 mm. The snow cover is preserved during 170 days, and its average depth reaches 60 cm (water reserve in the snow is estimated as 130 mm). Soil is freezing to the depth of 65 cm on average. Strong winds in winter affect the snow cover pattern: sinkholes accumulate snow blown off from the main surface (Kungur Ice Cave…, 2005).

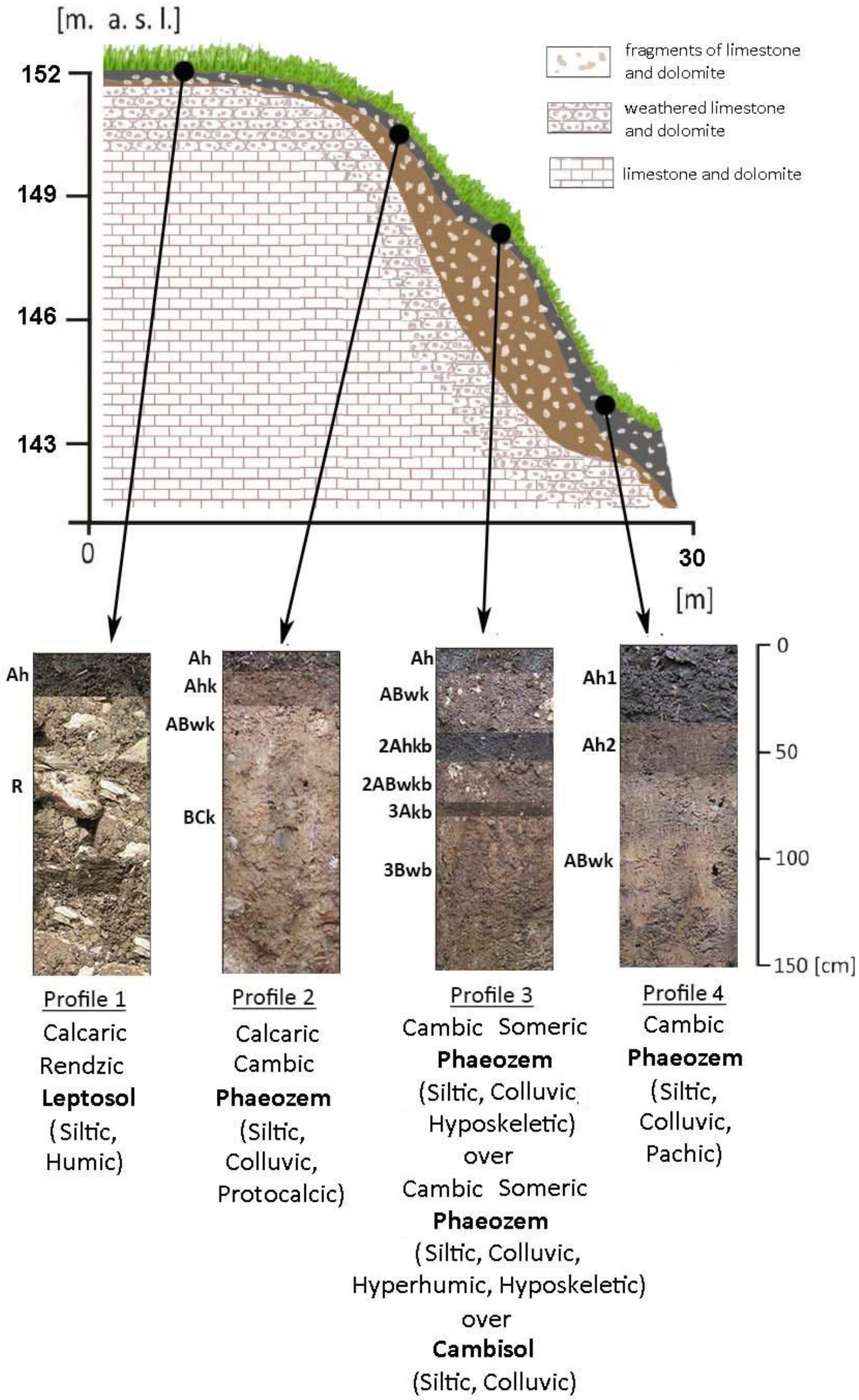


Fig. 2. Toposequence of soils on the slope of karst sinkhole in forest-steppe

Soil genesis and systematic position

Among pedogenic processes that have formed soils in this sinkhole, located in forest-steppe with its **Phaeozems**, **Chernozems** and **Luvisols** (IUSS Working Group WRB, 2015), accumulation of humus is the main process; it is manifested in all soils of the studied sinkhole as a mollic horizon. Slope processes – mass movements within the sinkhole were intensive, so the colluvial material is rather deep, poor in rock fragments and contains well preserved buried soils.

The bulk of soils within the sinkhole – **Phaeozems** – strongly differ of the shallow soil on the main surface on hard calcareous rock: it is rich in humus, has a strong structure, and perfectly fits its definition: ***Rendzic*** **Leptosol** with ***Humic*** and ***Calcaric*** qualifiers.

Soils on the slopes and in the bottom formed on colluvium have deeper profiles, and this may be explained by their parent material on one hand, and by their moisture regime, on the other hand: they receive additional moisture of the melting snow wind-blown down to the sinkhole. The second soil contains limestone fragments and has few elements of cambic horizon (pedogenic structure, although weak, dissolution of calcareous rock fragments; moreover, few secondary carbonates were recorded, testifying to the current character of the dissolution process). However, all these phenomena are not conspicuous, so "cambic" may be applied only as a qualifier for **Phaeozem** RSG, hence, we have ***Calcaric Cambic*** **Phaeozem (*Siltic, Colluvic, Protocalcic*)**. The profile of the third soil is peculiar and comprises three soils: recent ***Someric Cambic*** **Phaeozem (*Siltic, Colluvic, Hyposkeletic*)**, which properties well agree with the image of a humus-accumulative soil with pedogenic modifications of its mineral subsoil. Similar is the first buried soil – ***Cambic Someric*** **Phaeozem (*Siltic, Colluvic, Hyperhumic*, Hyposkeletic)**. The small difference of the recent soils concerns its humus horizon, which has low chroma and depth, as it is common in buried soils (Gennadiev, 1990). The lowermost soil was defined as **Cambisol**; it has a weak humus horizon and, presumably, enough time to become a **Cambisol**. All humus horizons display a weak shift of pH along their profiles. The fourth soil in the sinkhole bottom is also a ***Cambic*** **Phaeozem (*Siltic, Colluvic, Pachic*)**, its deep *mollic* horizon (***Pachic*** qualifier) being in agreement with its accumulative position.

Soil sequence

The diversity of soils in this sequence is not high. Unlike the soil sequence in the karst sinkhole filled with sands in taiga zone (Smirnova and Gerasimova, 2018) here there is "a harmony" of parent material and climate, so the differentiation of the soil cover of the sinkhole is due only to slope processes. They cause either soil burial on less steep, or flattened, parts of the slope, or gradual additions of loamy material modified by pedogenesis to produce **Phaeozems** with more or less prominent cambic features.

The influx of moisture, which generally is not abundant in the forest-steppe, to the sinkhole maintains favorable conditions for the processes of pedogenic modifications of the mineral material, while their intensity is governed by topography and age. Thus, "trapping" of snow by the sinkhole results in catenary differentiation of soil properties: pH values and the content of carbonates decrease down slope parallel to increasing moisture. The most prominent *cambic* features were recorded in the oldest the buried soil.

Formation of ***Rendzic*** **Leptosols** on the outcrops of calcareous rock (without any additions of mineral material) is in good agreement with forest-steppe environment, which may be aggravated by moisture deficit owing to percolation of atmospheric moisture through cavities and cracks in the calcareous rocks. Most favorable conditions for humus accumulation process (*mollic* horizon) fall on the middle part of the slope, since in the bottom part, the hydrothermal regime is recorded as too wet and cold.

References

Andrejchuk, V.N., 1996. Gypsum karst of the pre-Ural region. Int. Journal of Speleology. 25 (3-4). 285–292.

Buzmakov, S.A., Sannikov, P. Yu., 2014. Landscape and biological diversity of protected areas network in Perm Krai. Advances in environmental biology, 8(13), 2014 P. 473–479.

De Waele, J., Plan, L, Audra, L, 2009. Recent developments in surface and subsurface karst geomorphology: An introduction. Geomorphology 106: 1–8.

Ford, D.C., Williams, P.W., 2007. Karst Hydrogeology and Geomorphology. Wiley, Chichester.

Gennadiev, A.N., 1990. Soils and Time: evoluton models. Moscow Univ.Publ., Moscow, 576 pp. (in Russian).

Gorbunova, K. A., Andreychuk, V.N., Kostarev, V.P., Maximovich, N.G., 1992. Karst and caves in the Perm oblast: Perm Univ.Publ. Perm, 232 pp. (in Russian).

IUSS Working Group WRB, 2015. World Reference Base for soil resources 2014, update 2015. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Report No. 106. FAO, Rome.

Kadebskaya, O.I., Naumkin, D.V., 2012. Crucial landscape areas of Kungur island forest-steppe (Perm region) Steppes of Nothern Eurasia. Proceedings of the VI Internationsl Simposium. 142–144

Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F. 2006. World Map of Köppen-Geiger Climate Classification. updated. Meteorol. Z., 15, 259–263.

Kungur Ice Cave: experience of regime observations, 2005. Ed.by V.N.Dublianskiy. Ural Division of RAS, Ekaterinburg, 246 pp. (in Russian).

Smirnova, M., Gerasimova, M., 2018. Soil sequence on sands filling the karst sinkhole in the north of the East European Plain. [in:] Soil Sequences Atlas, (eds.) Świtoniak, M., Charzyński, P., Toruń: 111–120.

Waltham, T. F., Bell, F. M., Culshaw, M., 2005. Sinkholes and Subsidence. Karst and cavernous rocks in engineering and construction. Springer, Chichester, 382 pp.

Soils of an undulating, cultivated loess plateau in North Mezőföld, Central Hungary

Tibor József Novák, Tamás Árendás, Marcin Świtoniak

The study area is located on a lower elevated part of the Mezőföld, one of the largest loess covered plains within the Great Hungarian Plain (Ádám et al., 1959). The elevation of the surface is between 100 and 150 m, and the 15- to 20-m-thick loess layers were deposited mainly during the Saalian and Weichselian glacials (Pécsi, 1995; Horváth, 2001). The typical surface landforms are related to the derasion processes of the loess, and to water erosion. On the slightly undulating, generally cultivated loess plain, erosional and derasional valleys, loess dolines and loess wells can be found (Ádám et al., 1959).

Fig. 1 Localization

Lithology and topography

The parent material of the study area is sandy loess. These aeolian deposits consist mainly of fine sand and silt sized quartz and feldspar grains, having a finely distributed carbonate content up to 8–10 %. The studied catena is located on a gently undulating loess plateau with small elevation differences between 110 and 130 m a.s.l. across a 500-m horizontal distance. On higher elevated slope sections there is visible sheet erosion in lighter coloured soil surfaces. In local depressions the soil surface colour is darker as a result of colluvial accumulation of organic rich topsoil material from the surrounding areas.

Land use

The loess plain and its fertile soils offer advantageous conditions for agriculture, especially cereal production. Therefore, the area has been cultivated since very early times, probably since the Neolithic age. Currently the study area is an experimental field of the Centre for Agricultural Research of the Hungarian Academy of Science where annual crops like corn, wheat, rapeseed and sunflower are cultivated (Kádár, 2015).

Soil conditions

The texture of the soils is slightly variable in topsoil layers, being silty loam, sandy loam or clay loam. In deeper layers it is quite homogeneous and dominantly silty loam. pH is neutral to slightly alkaline (7–8) at the surface. Carbonate content starts in some cases directly on the surface, where it already reaches 13–15%, but mostly it appears only below the organic rich horizons (at a depth of 30–60 cm). The depth of the humus layer varies between 25 and 60 cm, with >1.5% organic carbon on average. According the Hungarian classification they belong to the Chernozems and Chernozems with forest remains (Árendás & Csathó, 2002; Árendás et al., 2004).

Climate

The climate of investigated area is slightly more dry and continental than the surrounding hilly areas. According to Kottek et al. (2006) it is located in the humid zone with warm summer. The average annual temperature is 10.6°C, the average amount of annual precipitation about 560 mm (Ádám et al. 1959).

Profile 1 – Anocalcic **Kastanozem** (Aric, Epiloamic, Katosiltic)

Localization: Loess plateau, summit - upper slope, inclination 4°, arable land, elevation 128 m a.s.l.
N 47°19'56.9" **E** 18°47'36.3"

Morphology:

Apk – 0–30 cm, *mollic* horizon, *calcic* horizon, loam, very dark grayish brown (10YR 5/2, 10YR 3/2), slightly moist, moderate medium and coarse subangular blocky, very strongly calcareous, hard carbonate concretions, very fine and common roots, abrupt and smooth boundary;

Ck – 30–(50) cm, *calcic* horizon, colluvic material, sandy loam, light yellowish brown (2.5YR 7/3, 2.5YR 6/3), dry, medium moderate subangular blocky structure, extremly strongly calcareous, hard carbonate concretions, fine few roots.

Table 1. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	
Apk	0–30	2.3	0.4	1	1.2	7.4	18	18	16	13	25	L
Ck	30–50	0	0	0.3	0.5	4.2	20	26	16	14	19	SiL

Table 2. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	C/N	pH		$CaCO_3$ [$g \cdot kg^{-1}$]
					H_2O	KCl	
Apk	0–30	16.4	0.87	19	8	7.3	218
Ck	30–50	na.	na.	na.	8.3	7.6	310

Profile 2 – Endocalcic **Chernozem** (Aric, Pachic, Anoloamic, Endosiltic, Bathystagnic)
Localization: Loess plateau, local depression, flat, slope inclination 0°, arable land, elevation 119 m a.s.l.
N 53°09'17.8" **E** 17°39'40.1"

Morphology:

Ap – 0–28 cm, *chernic* horizon, clay loam, black (10YR 2/1), slightly moist, medium to fine strong granular and subangular blocky structure, fine and common roots, earthworm channels, clear and smooth boundary;

Ah1 – 28–50 cm, *chernic* horizon, clay loam, black (10YR 2/1), slightly moist, medium-fine strong granular and subangular blocky structure, fine few roots, gradual and smooth boundary;

Ah2 – 50–80 cm, *mollic* horizon, clay loam, very dark grayish brown (10YR 3/2), slightly moist, medium strong subangular blocky structure, fine and medium very few roots, gradual and wavy boundary;

ACk – 80–110 cm, *calcic* horizon, silty loam, light olive brown (2.5Y 5/3), medium moderte subangular blocky structure, strongly calcareous, soft and hard secondary carbonate concretions, pseudomycelia, krotovinas, gradual and smooth boundary;

Ck – 110–135 cm, *calcic* horizon, colluvic material, silty loam, light yellowish brown (2.5Y 6/4), medium moderate subangular blocky structure, strongly calcareous, soft and hard secondary carbonate concretions, clear and smooth boundary;

Cgk – 135–(150) cm, *calcic* horizon, silty loam, light yellowish brown (2.5Y 6/3), *stagnic* colour pattern (5Y 8/1; 10YR 6/8), strongly calcareous.

Table 3. Texture

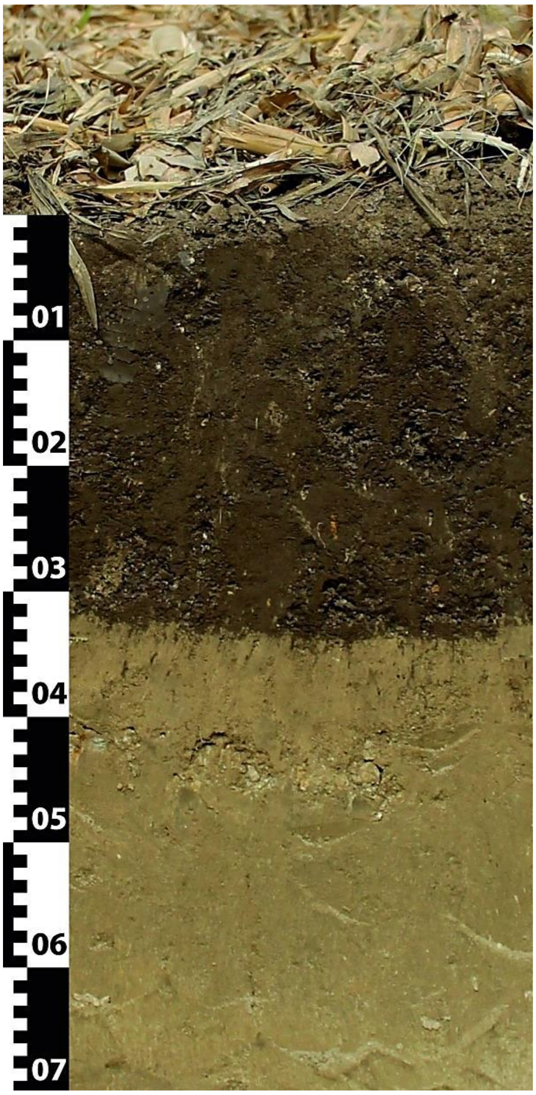
Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm										Textural class
		> 2.0	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.1	0.1-0.05	0.05-0.02	0.02-0.005	0.005-0.002	< 0.002	
Ap	0–28	0.2	0.1	0.2	1.7	10	15	18	14	9	32	CL
Ah1	28–50	0.1	0	0.3	1.5	7.2	14	19	14	10	34	CL
Ah2	50–80	0.1	0.2	0	1.5	9.3	13	19	14	10	33	CL
ACk	80–110	0	0.1	0.5	1.5	7.9	14	21	16	13	26	SiL
Ck	110–135	0.6	0.2	0.2	1	5.6	13	21	19	16	24	SiL
Cgk	135–(150)	0	0	0	0.5	1.5	16	22	24	18	18	SiL

Table 4. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	C/N	pH		$CaCO_3$ [$g \cdot kg^{-1}$]
					H_2O	KCl	
Ap	0–28	16.5	0.102	16	7	6.1	1.13
Ah1	28–50	16.5	0.086	19	7.3	6.1	1.46
Ah2	50–80	13.5	0.072	19	8.2	7.1	1.78
ACk	80–110	6.67	0.037	18	8.4	7.8	26.9
Ck	110–135	na.	na.	na.	8.6	7.9	28.1
Cgk	135–(150)	na.	na.	na.	8.9	8.1	31.7

Profile 3 – Endocalcic **Chernozem** (Aric, Pantoloamic)

Localization: Loess plateau, lower slope positon – slope inclination 2°, arable land, elevation 113 m a.s.l.
N 47°19'45.3" **E** 18°47'31.5"



Morphology:

Ap – 0–35 cm, *chernic* horizon, clay loam, very dark grayish brown (2.5Y 5/2, 2.5Y 3/2), slightly moist, medium moderate granular –subangular blocky structure, fine and very few roots, abrupt and smooth boundary;

BCk2 – 35–60 cm, *protocalcic* properties, loam, light olive brown (2.5Y 5/3), dry, medium-coarse weak subangular blocky structure, moderately calcareous, soft and hard secondary carbonate concretions, pseudomycelia, disperse powdery lime, fine few roots, gradual and smooth boundary;

Ck – 60–(80) cm, *calcic* horizon, colluvic material, sandy loam, light yellowish brown (2.5Y 6/4), slightly moist, medium-coarse weak subangular blocky structure, strongly calcareous, soft and hard secondary carbonate concretions, pseudomycelia, disperse powdery lime.

Table 5. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	0–35	5	0.6	1.5	4	13.9	11	15	14	13	27	CL
BCk	35–60	1.6	0.1	1.7	7.5	29.7	12	9	9	12	19	L
Ck	60–(80)	0	0.1	0.5	5.2	38.2	16	8	7	7	18	SL

Table 6. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	C/N	pH		$CaCO_3$ [$g \cdot kg^{-1}$]
					H_2O	KCl	
Ap	0–35	12.1	0.8	15	8	7.6	136
BCk	35–60	na.	na.	na.	8.6	7.8	222
Ck	60–80	na.	na.	na.	8.7	7.9	208

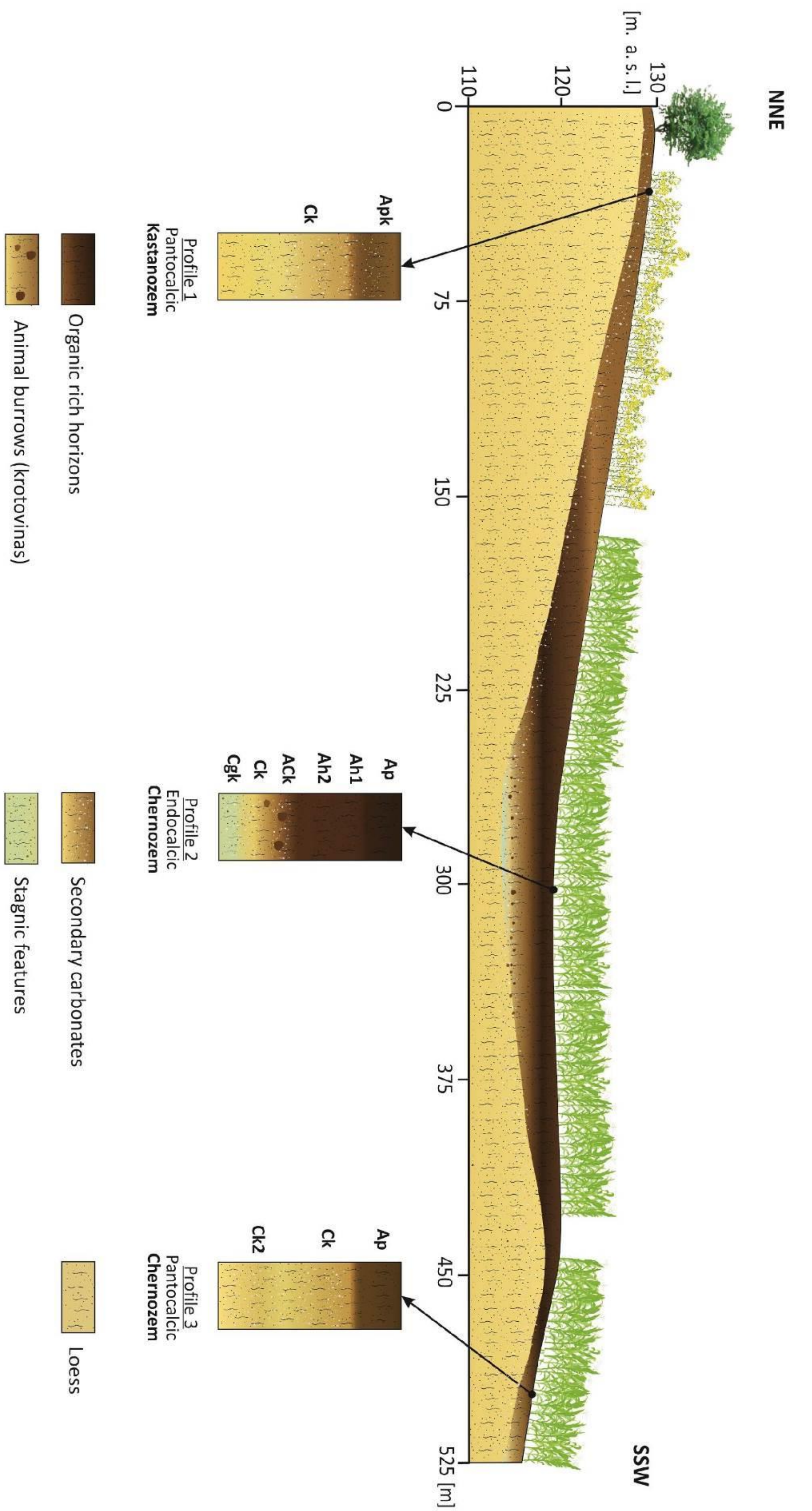


Fig. 2. Toposequence of soils of undulating, cultivated loess plateau in North Mezőföld, Hungary

Soil genesis and systematic position

Profile 1 was classified as **Kastanozem**, since it has *mollic* horizon, and also *calcic* horizon within the required depth below the lower boundary of the *mollic*, but the surface horizon does not fulfil the structure-related criteria for *chernic*. Since the calcic horizon appears not below the *mollic*, but in combination with it, starting directly from the surface, the principal qualifier ***Calcic*** was added, with the ***Panto***- specifier, i.e. ***Pantocalcic***. As the soil, similarly to the other two profiles, is ploughed, the ***Aric*** supplementary qualifier applies. The topsoil has loamic texture in a 30 cm layer, and below 30 cm it changes to silty loam. Therefore the ***Epiloamic*** and ***Katosiltic*** supplementary qualifiers describe the textural character of the profile.

Profile 2 has a very dark and deep *mollic* horizon, with well-developed granular and fine subangular blocky structure, and therefore in this case it also fulfils the criteria for *chernic*. *Calcic* horizon also appears, and directly underlying the *chernic*. Therefore the profile was classified as a ***Chernozem***. Since the *calcic* horizon is not overlapping the *mollic*, i.e. *chernic*, but starting just below that, at a depth of 80 cm, the ***Endocalcic*** principal qualifier was applied. As the profile is cultivated to a depth of 28 cm, the ***Aric*** supplementary qualifier was added, and the ***Pachic*** remains for the very thick (80 cm) *chernic* horizon. The textural characteristics of the profile describe the ***Anoloamic*** and ***Endosiltic*** supplementary qualifiers, being clay loam over 80 cm, and silty loam throughout below that depth. In the deepest described part of the profile a stagnic colour pattern was also recognisable, but because of its deep position within the profile, this qualifier was added with the *bathy* specifier, described with the ***Bathystagnic*** supplementary qualifier.

Profile 3 has also *mollic* horizon, which at the same time fulfils the criteria for *chernic*. It also has *calcic* horizon, starting within 50 cm below the lower boundary of the *chernic*, and therefore this profile is classified as ***Chernozem***. The *protocalcic* properties appear directly below the *chernic* but the *calcic* horizon itself starts at 60 cm depth, and therefore the principal qualifier ***Katocalcic*** applies. Because of the 35-cm-deep ploughed *chernic* horizon, the ***Aric*** supplementary qualifier was also added. The main texture class of the soil profile is loam throughout, but changing from clay loam to sandy loam, and it is described by the ***Pantoloamic*** supplementary qualifier.

Soil sequence

The catena represents a topographic section starting from a locally highest elevated place (Profile 1), crossing a shallow local depression (Profile 2) and ending in a slightly sloping surface. In spite of the small elevation differences (15 m) over a larger distance (ca. 500 m), and the relative low slope gradient (2–4°), the effects of erosion processes are clearly visible comparing the 3 profiles. It is recognisable in the difference of the depth of humus horizon, which is restricted to the ploughed horizon (***Aric***) in the case of the two eroded profiles (Profiles 1 and 3). The erosion was stronger, i.e. more effective in Profile 1, where the material of the underlying parent material was mixed with the topsoil, that its colour becomes lighter than in the other 2 profiles, and the structure has been destroyed to such an extent that it no longer fulfils the criteria for *chernic*, but only for *mollic*. That is why Profile 1 was classified as **Kastanozem**, but Profile 3 – with a very similar eroded profile configuration – was classified as **Chernozem**. In the local depression (Profile 2), where erosion was not even visible, but organic rich material eroded elsewhere was deposited, the **Chernozem** even acquired the ***Pachic*** qualifier, having a >50-cm-thick *mollic* horizon (which is also *chernic* at the same time).

Erosion also affected the vertical position of the *calcic* horizon, or horizons with *protocalcic* properties.It is supposed that it was originally present below the humus horizons, because organic matter accumulation slightly acidifies soil and facilitates the leaching of carbonates, and this process stops below the humus layer. In the case of strongly eroded profiles (Profile 1) the carbonates, which were originally located below the mollic horizon, were mixed due to ploughing into the whole mollic, and therefore the calcic horizon starts from the surface (***Pantocalcic***). In the other eroded profile, *calcic* horizon, or *protocalcic* properties, starts at the depth of 35 cm, which is below the depth of regular ploughing. Therefore it is still not mixed into the cultivated layer, but starts directly below the humus horizon. For this profile the ***Katocalcic*** qualifier applies. In the local depression the calcic horizon lies below the very deep chernic, and it is described with the ***Endocalcic*** qualifier.

The profile in the local depression functions not only as a sink for organic rich topsoil that was eroded elsewhere, but it also acquires some additional moisture from surface or subsurface runoff, which might be periodically faster than the infiltration. This supposed process is recognisable in the *stagnic properties* appearing in a deeper position (>100 cm) of the Profile 2, for which the ***Bathystagnic*** qualifier is used.

The soil sequence is a typical example for soils of the slightly undulating chernozemic landscapes of Central Hungary, which are affected by erosion triggered by long-time agriculture and machinery cultivation, which has changed not only the soil surface characteristics, but also the taxonomic position of the soils.

Acknowledgement

The research sites were maintained with the help of the GINOP-2.3.2-15-2016-00028 project. The work of Novák T. was supported by the János Bolyai Research Scholarship of the Hungarian Academy of Sciences.

References

Ádám, L. Marosi, S., Szilárd, J. 1959: Physical Geography of the Mezőföld. Földrajzi Monográfiák. Akadémiai Kiadó, Budapest, 514. (in Hungarian)

Árendás, T. Csathó, P. 2002. Comparison of the effect of the equivalent nutrients given in the form of farmyard manure or fertilizers in Hungarian long-term field trials. Communications in Soil Science and Plant Analysis 30: 2861-2878.

Árendás, T., Bónis, P., Molnár, D., Sarkadi, J. 2004. Residual effects of phosphorous in chernozem soils with forest remnants in dependence of the carbonate content. Agrokémia és Talajtan 53 (1-2): 111-124. (in Hungarian)

Horváth, E. 2001. Marker horizons in the loesses of the Carpathian Basin – Quaternary International 76/77: 157-163.

IUSS Working Group WRB, 2015. World Reference Base for soil resources 2014, update 2015 International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Report No. 106. FAO, Rome.

Kádár, I. 2015. Correspondences between the soil fertility and nutrient supply. MTA ATK, Talajtani és Agrokémiai Kutatóintézet, Budapest, pp. 389. (in Hungarian)

Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F. 2006. World Map of Köppen-Geiger Climate Classification updated. Meteorol. Z., 15: 259–263.

Pécsi, M. 1995. Loess stratigraphy and quaternary climatic change – Loess in Form 3, Geographical Research Institute, Hungarian Academy of Science: 23-30.

Loess soils of the Trnava Hilly Land

Emil Fulajtár, Martin Saksa

Fig. 1. Location

The Trnava Hilly Land (Trnavská pahorkatina in Slovak) is situated in Western Slovakia and belongs to the Danube Lowland (Podunajská nížina) occupying a large part of Western Slovakia between the Danube and the Western Carpathians. Due to its fertile soils and moderate climate it is the most important agricultural area of Slovakia. It comprises two parts: 1) The Danube Plain, which is the alluvial plain of the Danube and the Váh River and 2) The Danube Hilly Land, comprising several particularly hilly lands separated by the alluvial plains of rivers approaching the Danube from the Carpathians. The Trnava Hilly Land is the westernmost hilly land occupying the area between the alluvial plain of the Váh River and the Little Carpathian Mountains (Malé Karpaty) what is the south-westernmost mountain range of the Western Carpathians.

Lithology and topography

The Trnava Hilly Land, similarly to the whole Danube Lowland, belongs geologically to the Pannonian Basin, which is a large sunken tectonic unit of the Alpine–Himalayan orogenic zone situated between the Carpathians and the Dinarides. It is filled by several-thousand-metre-thick layers of Neogeneous deposits (marine and limnic clays, sands and gravels). This Neogeneous basement is covered by Quaternary deposits. The Danube Plain is covered by up-to-300-m-thick layers of alluvial gravels (Vaškovský, 1977). The Danube Hilly Land is a relatively less sunken periphery of the Pannonian Basin and the Quaternary is represented here only by several-metres- to several-tens-of-metres-thick loess cover.

The main part of Trnava Hilly Land is the flat Trnava Plateau. The loess cover of this area is continuous and several metres thick. Towards the mountains the plateau gradually changes to hilly land. The peripheral part of Trnava Hilly Land along the Little Carpathians is called the Under-Little Carpathian Hilly Land (Podmalokarpatská pahorkatina). Loess deposits are combined here with loess loams (loess-like non-calcareous aeolian loams) and alluvial fans comprising of roughly rounded coarse gravel transported by brooks from nearby mountains.

Climate

According to Köppen-Geiger climate classification (Kottek et al., 2006) the Trnava Hilly Land belongs to Cfb class (i.e. the warm temperate climate, fully humid with warm summer). More detailed characterization of climate is provided by national climate classification (Climatogeographical Types) (Tarábek, 1980). The Trnava Hilly Land has lowland warm or predominantly warm climate with mean annual temperature of 9 – 11°C, average temperature of the warmest month (July) of 19 – 21°C and of the coldest month (January) of -1 to -3°C and the average annual precipitation of 450 - 600 mm.

Profile 1 – Calcic **Chernozem** (Loamic, Aric, Pachic)
Localization: Voderady, flat plateau, arable land, 139 m a.s.l.;
N 48°17'3.98'', **E** 17°33'16.398''

Morphology:

Ap – 0–25 cm, plough *chernic* horizon, silty clay loam, black (10YR 4/2; 10YR 2/2), moist, medium granular to subangular blocky structure, friable consistence, slightly calcareous, few roots, few crop residues, clear and smooth boundary;

A – 25–45 cm, *chernic* horizon, silty clay loam, black (10YR 4/2; 10YR 2/2), moist, fine to medium granular structure, friable consistence, slightly calcareous, few calcareous pseudomycelia, humiferous coatings, few roots, diffuse and smooth boundary;

A2 – 45–65 cm, humus horizon, silty clay loam, black (10YR 4/2; 10YR 5/4-3.5/3), moist, fine to medium granular structure, friable consistence, slightly calcareous, few calcareous pseudomycelia, humiferous coatings, few roots, diffuse and smooth boundary;

ACk – 65–95 cm, transitional horizon, silty clay, black/yellow contrast colours (10YR 4/2; 10YR 5/4-3.5/3), moist, medium angular blocky structure, friable consistence, strongly calcareous, abundant calcareous pseudomycelia, few roots, diffuse and irregular boundary;

Ck – 95–(110) cm, *calcic* horizon (loess), silty clay loam, yellow (10YR 4/2; 10YR 6.5/6), moist, coarse blocky structure in upper part of the horizon, massive structure in lower part, firm consistence, strongly calcareous, abundant pseudomycelia, few small calcareous nodules (2-10 mm), abundant krotovinas, very few roots.

Table 1. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm							Textural class
		2.0-0.63	0.63-0.2	0.2-0.063	0.063-0.02	0.02-0.0063	0.0063-0.002	<0.002	
Ap	0–25	0	1	3	26	28	10	32	SiCL
A	25–45	0	1	3	22	25	11	38	SiCL
ACk	65–95	0	1	2	24	23	10	40	SiC
Ck	95–(110)	0	1	2	25	28	10	34	SiCL

Table 2. Chemical and physicochemical properties

Horizon	Depth [cm]	C_{org} [g·kg^{-1}]	N_t [g·kg^{-1}]	C:N	pH_{CaC}	$CaCO_3$ [g·kg^{-1}]
Ap	0–25	19	2.51	7.7	7.1	05
A	25–45	14	1.78	8.1	7.3	04
ACk	65–95	9	1.28	7.1	7.6	156
Ck	95–(110)	2	0.72	-	7.6	322

Table 3. Content of selected chemical elements

Horizon	Depth [cm]	P	Ca	Mg	K	Na	Fe	Al	Mn
		[mg·kg^{-1}]							
Ap	0–25	973	4142	6595	11764	319	28955	31785	630
A	25–45	653	4195	6414	10371	321	30596	31140	612
ACk	65–95	658	38252	11361	8514	343	26321	15665	457
Ck	95–(110)	440	84349	20500	5786	228	21457	9787	361

Profile 2 – Luvic Calcic **Kastanozem** (Aric, Pachic, Siltic)
Localization: Jaslovské Bohunice, middle part of the long smooth strait slope (2°), arable land, 170 m a.s.l.;
N 48°28'10.579'', **E** 17°37'9.437''

Morphology:

Ap – 0–28 cm, plough *mollic* horizon, silt loam, dark grey-brown (10YR 4/2, 10YR 3/3), slightly moist, massive structure, barely crushable, dense, few roots, clear and smooth boundary;

A – 28–56 cm, *mollic* horizon, silt loam, dark grey-brown (10YR 4/3, 10YR 3/3), moist, 90% complete moderate prismatic structure (5-10 cm diameter), breaking down to 80% complete moderate angular blocky structure (4 cm to few mm diameter), friable consistence, locally slightly firm, blocks coated with dark humus-silt coatings, no carbonate content, common roots, clear and smooth boundary;

Bt – 56–84 cm, *argic* horizon, silt loam, brown (10YR 4.5/2.5-3, 10YR 3-3.5/4), moist, complete moderate prismatic structure (10-15 cm diameter), locally breaking down to 80% complete moderate subangular blocky structure, the rest of prisms massive, friable consistence, well developed clay coatings, no carbonate content, common roots, clear and smooth boundary;

Btk – 84–(110) cm, transitional (*argic* and *calcic*) horizon, silt loam, brown (10YR 6/3, 10YR 5.5/3.5), slightly moist, massive structure, friable consistence, few coatings along discontinuous vertical surfaces and bio galleries, high carbonate content, abundant pseudomycelia, common hard calcareous nodules, krotovinas with various types of infillings, few roots.

Table 4. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm					Textural class
		2-0.25	0.25-0.05	0.05-0.01	0.01-0.001	<0.001	
Ap	0–28	1	12	56	7	24	SiL
A	28–56	1	15	50	12	22	SiL
Bt	56–84	0	11	52	10	27	SiL
Btk	84–(110)	0	16	45	21	18	SiL

Table 5. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	C:N	pH		Cations	CEC	Base saturation [%]
					H_2O	KCl	[meq.100g^{-1}]		
Ap	0–28	10.3	0.952	11	7.8	6.6	15.4	19.0	81
A	28–56	6.8	0.585	12	7.5	7.0	16.3	19.4	84
Bt	56–84	3.0	0.244	12	7.8	6.7	10.9	16.1	68
Btk	84–(110)	2.4	-	-	8.2	7.4	-	12.7	-

Profile 3 – Calcic **Luvisol** (Aric, Cutanic, Ochric, Siltic, Bathystagnic)
Localization: Kočín, slightly inclined slope of wide flat ridge, arable land, 225 m a.s.l.;
N 48°35’35.52’’, E 17°40’28.138’’

Morphology:

Ap – 0–26 cm, plough humus horizon, silt loam, dark brown (10YR 4/3; 10YR 4/4), wet, non-plastic, medium subangular blocky structure, clods of Bt material admixed in lower part of horizon, few roots, abrupt and wavy boundary.

AB – 26–48 cm, transitional horizon, silt loam, few roots, clear and wavy boundary;

Bt – 48–70 cm, *argic* horizon, silt loam, brown (10YR 4/3; 7.5YR 4/4), moist, angular blocky to prismatic structure, friable consistence, abundant clay coatings, abundant krotovinas (humiferous fillings of vertical channels), clear and wavy boundary;

Bt2 – 70–95 cm, *argic* horizon, silty clay loam, brown (10YR 4/3; 7.5YR 4/4), moist, angular blocky to prismatic structure, friable consistence, abundant clay coatings, abundant krotovinas (humiferous fillings of vertical channels), clear and wavy boundary;

Ckg – 95–(120) cm, *calcic* horizon (loess) with *stagnic* properties, silt loam, brown (2.5Y 6/3.5; 10YR 7/4), moist, coarse prismatic to massive structure, friable consistence, few clay coatings, few krotovinas (fillings of vertical channels with decalcified Bt material), strongly calcareous, abundant small calcareous nodules (5-10 mm), abundant pseudomycelia.

Table 6. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm										Textural class
		>2	2-1	1-0.5	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	0–26	1	2	2	1	2	8	35	22	7	21	SiL
AB	26–48	1	1	0	1	1	10	34	24	8	21	SiL
Bt	48–70	0	0	0	1	0	9	35	22	7	26	SiL
Bt2	70–95	1	0	0	0	1	9	29	24	8	29	SiCL
Ckg	95–(120)	0	0	1	1	1	12	29	26	9	21	SiL

Table 7. 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	0–26	13.6	0.69	20	7.4	7.3	159
AB	26–48	5.97	0.25	24	7.5	7.4	88
Bt	48–70	-	-	-	7.4	7.3	33
Bt2	70–95	-	-	-	7.3	7.3	14
Ckg	95–(120)	-	-	-	7.7	7.6	172

Profile 4 – Haplic **Luvisol** (Cutanic, Hypereutric, Ochric, Siltic, Amphiloamic, Bathycalcic)
Localization: Senec – Martin forest, flat plateau, forest, 196 m a.s.l.;
N 48°15'14.181'', **E** 17°20'26.147''

Morphology:

Oi – 3–2 cm, slightly decomposed organic material;

Oe – 2–0 cm, moderately decomposed organic material;

A – 0–10 cm, humus horizon, silt loam, dark brown (10YR 5/3, 10YR 3/3), slightly moist, moderate granular fine to medium structure, common roots, clear and smooth boundary;

ABw – 10–30 cm, transitional horizon, silt loam, brown (7.5YR 6/4, 7.5YR 4/4), slightly moist, strong subangular fine and medium structure, few roots, clear and smooth boundary;

Bt1 – 30–60 cm, *argic* horizon, loam, dark brown (7.5 YR5/4, 7.5YR 3/4), clay coatings, slightly moist, strong angular coarse structure, gradual and smooth boundary;

Bt2 – 60–90 cm, *argic* horizon, loam, yellowish brown (10YR 6/6, 10YR 5/6), clay coatings, slightly moist, strong angular and subangular coarse structure, gradual and smooth boundary;

CBtk – 90–105 cm, *calcareous* transitional horizon with clay coatings, silt loam, brownish yellow (10YR 8/6, 10YR 6/6), angular and subangular medium structure, clear and smooth boundary;

Ck – 105–(130) cm, *calcic* horizon (loess), silt loam, light yellowish brown (2.5Y 7/4, 2.5Y 6/4), angular and subangular medium structure.

Table 8. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm										Textural class
		>2	2-1	1-0.5	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	
Oi	3–2	-	-	-	-	-	-	-	-	-	-	-
Oe	2–0	-	-	-	-	-	-	-	-	-	-	-
A	0–10	1	1	4	6	7	12	25	21	11	13	SiL
ABw	10–30	1	1	3	5	6	13	25	21	8	18	SiL
Bt1	30–60	2	4	4	5	6	9	21	16	8	27	L
Bt2	60–90	3	2	3	6	6	12	22	19	6	24	L
CBtk	90–105	2	1	3	4	4	9	29	20	8	22	SiL
Ck	105– (130)	1	1	1	3	2	9	37	23	9	15	SiL

Table 9. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	N_t [g·kg^{-1}]	C:N	pH		$CaCO_3$
					H_2O	KCl	
Oi	3–2	464	19.2	24	5.5	5.2	-
Oe	2–0	241	14.5	17	6.3	5.8	-
A	0–10	21.0	1.25	17	4.6	3.5	-
ABw	10–30	11.1	0.60	19	5.1	3.6	-
Bt1	30–60	-	-	-	5.7	3.9	-
Bt2	60–90	-	-	-	5.2	4.2	-
CBtk	90–105	-	-	-	7.0	6.8	41.6
Ck	105– (130)	-	-	-	7.6	7.5	269

Vegetation

Before the introduction of agriculture, the original vegetation of Trnava Hilly Land was dominated by oak-hornbeam forests (*Querco robori-Carpinenion betuli*, *Carici pilosae-Carpinenion betuli*) (Michalko et al., 1986). The driest and warmest south-facing slopes of loess hills were occupied by thermophilous oak forests (*Aceri-Quercion*, *Quercetum petraeae-cerris*) (Michalko et al., 1986). Recently, the great majority of Trnava Hilly Land is intensively cultivated. The major crops are maize, winter wheat, spring barley, sunflower, oil rape and sugar beet. Despite of the intensive agricultural exploitation of this area few patches of forest similar to original vegetation remained here. Apart of their ecological roles such as controlling water circulation, influencing microclimate and protecting biodiversity they also preserve the remnants of original soil cover allowing studying the soil genesis and the impact on man on the development of soils.

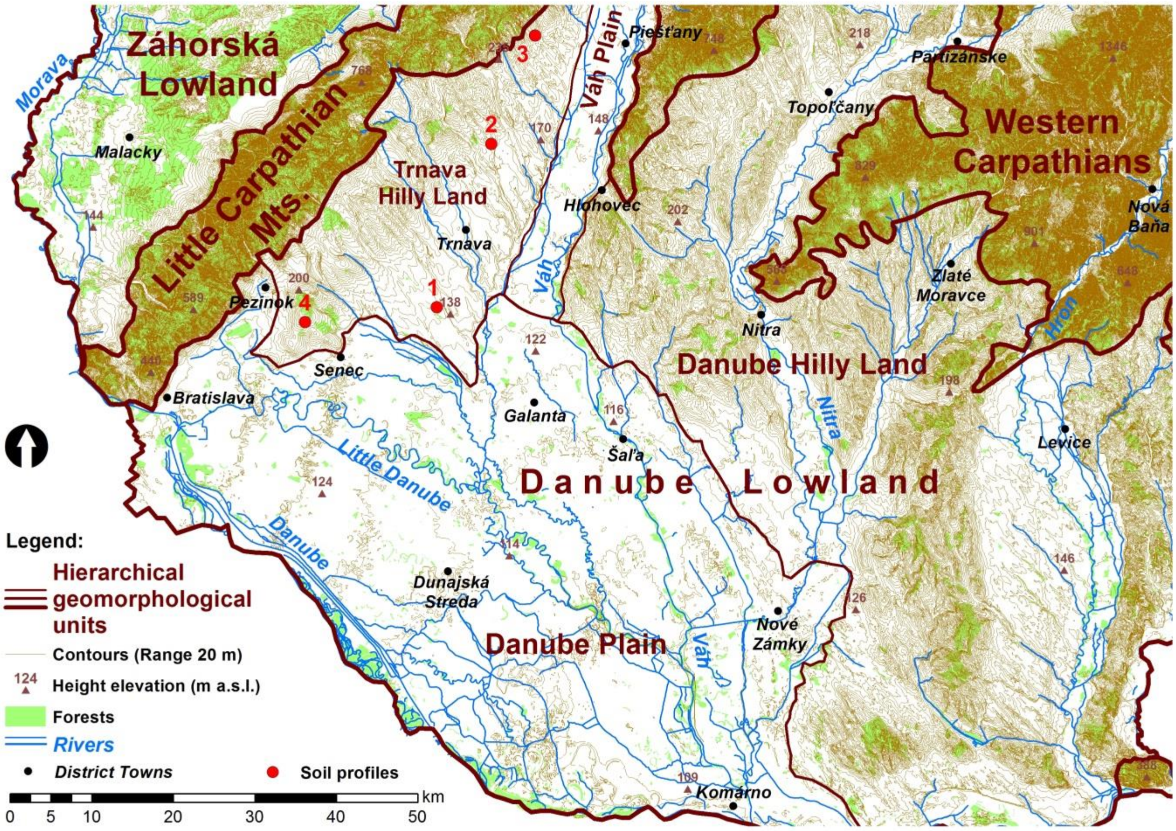


Fig. 2. Localization of Soil profiles

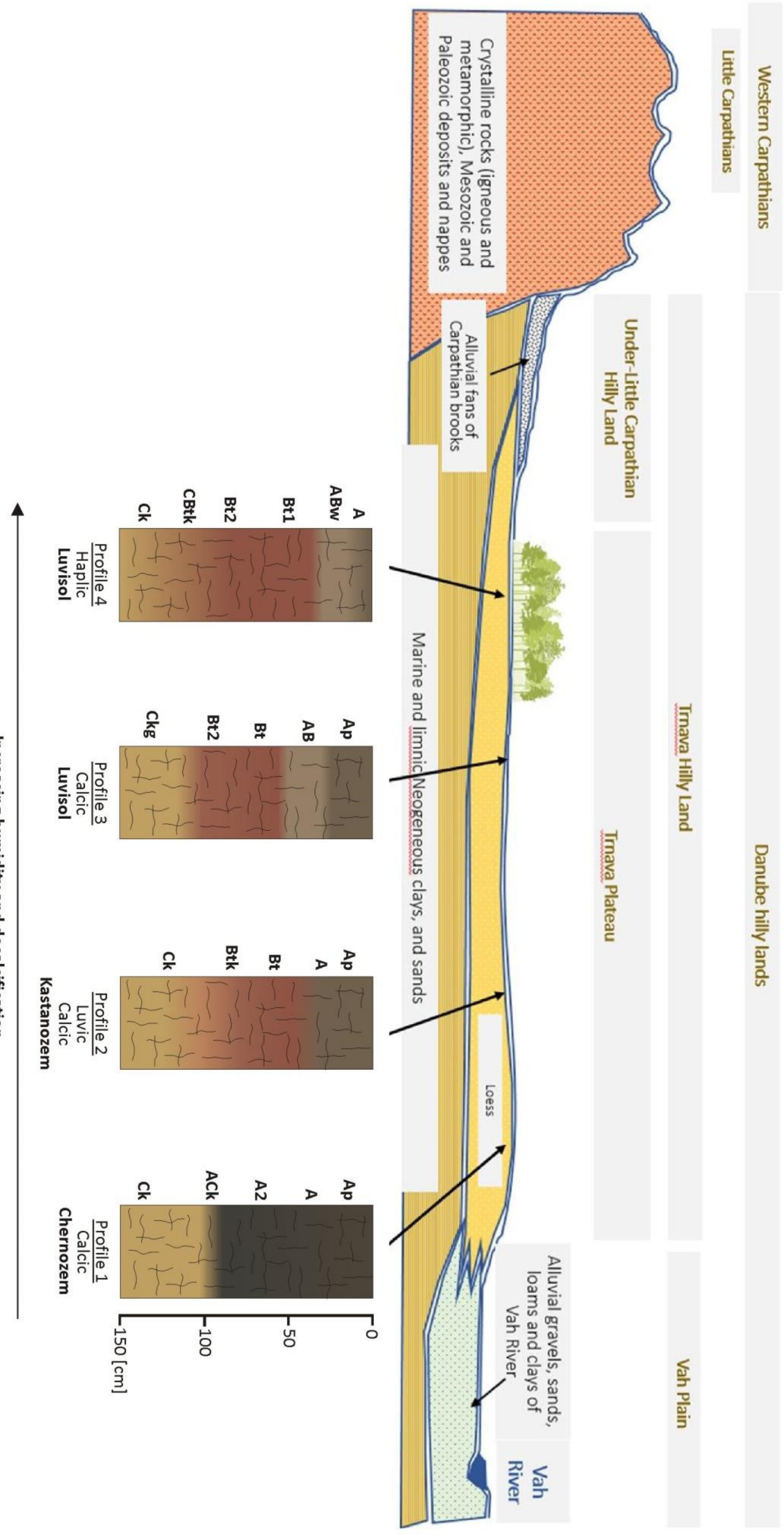


Fig. 3. Soil sequence on loess in Danube Lowland

Soil genesis and systematic position

The soil profiles selected in Trnava Hilly Land represent a typical sequence of soils developed on loess deposits. Loess is very suitable parent material for the development of fertile soils, due to its loamy texture and carbonate content. Soils developed on loess (***Calcic*** **Chernozems**, ***Haplic*** and ***Luvic*** **Kastanozems** and ***Haplic*** or ***Calcic*** **Luvisols**) are, together with soils developed on loamy calcareous alluvial deposits (***Calcaric Fluvic*** **Phaeozems** and ***Calcaric*** **Fluvisols**), the most fertile soils of Slovakia.

The development of loess soil cover began in the early Holocene. During the Pleistocene the loess covers were deposited during several phases, the last of which was the würm III stadial. The soil formation could start only when the deposition of loess stopped and the land surface stabilised. The major soil forming processes active in this area were: 1) formation of soil structure and porosity (by intensive bioturbation and shrinking–swelling caused by the wetting–drying cycle); 2) accumulation of organic matter (formation of *chernic/mollic* horizons); 3) leaching of carbonates (formation of *calcic* horizons); 4) weathering (formation of *cambic* horizons with rusty colour); 5) leaching of clay (formation of *argic* horizons); and 6) weak oxidation-reduction processes in periodically wet subsoil.

The soil development began with the formation of *chernic/mollic* horizons under the steppe vegetation (Hraško, 1966). This phase of pedogenesis can be attributed according to *Blytt-Sernander paleoclimatic classification* to the *Boreal Period*, which was warm, and the driest period of the *Holocene* (Krippel, 1986). It is presumed that at this time soils with a pronounced accumulation of organic matter in the mineral topsoil occupied the whole of Trnava Hilly Land. Later, during the *Atlantic Period*, which was the warmest and most humid period of the *Holocene*, the steppe was replaced by forests. Soils were exposed to higher precipitations and the leaching of carbonates resulted in decalcification of the upper part of the soil profile. This development affected only the more moist peripheral parts of the hilly lands. Decalcification encouraged further processes, such as weathering, clay translocation and degradation of soil organic matter. The *cambic* and *argic* horizons were formed and *chernic/mollic* horizons were transformed to humus horizons with less content of organic matter. In the drier central parts of the hilly land, the *chernic/mollic* horizons were preserved.

During the *Atlantic Period*, agriculture was introduced to the Danube Lowland (Demo et al., 2001). The natural steppe and forest vegetation was replaced by a new ecosystem (the so called "cultural steppe"). This certainly had an influence on the soil genesis, mainly through a changed soil moisture regime. The later *Subboreal* and *Subatlantic* periods were similar to the *Boreal* and the *Atlantic* but their climatic differentiation was less pronounced. The intensity of pedogenesis was lowered and the soil cover stabilised. During the last 1–2 millennia the agricultural exploitation of loess areas significantly increased in intensity and the anthropogenic processes such as tillage and accelerated soil erosion significantly influenced the recent state of the soil cover (Fulajtár, 1993).

The selected soil profiles represent the variability of the loess soil cover. The unifying features for the whole sequence are: 1) the loess parent material, which has an optimal texture (mostly silt loam or silty clay loam); 2) significant carbonate content (originally 10–15%, but carbonates were leached to various extents from the topsoil); and 3) the *calcic* horizons enriched by carbonates leached from above (usually having a carbonate content of 17–26%). The *calcic* horizons are very thick and normally the routine field soil profile descriptions and sampling for basic analyses aimed at the upper 120 cm of the soil profile cannot identify them. Some specialised studies on soil genesis investigating deeper profiles showed that the *calcic* horizons are 1–2 m thick and the carbonate content, which usually reaches 17–26% at a depth of 100–150 cm falls to 10–15% at a depth of 200–300 cm (Fulajtár, 1993). *Calcic* horizons also occur in those soils, which are calcareous from the surface, because all humus horizons are significantly leached in the whole Trnava Hilly Land and even in those areas where they are still calcareous, leaching reduced their carbonate content from the original 10–15% to the recent 2–3%.

The major differentiation features between the soil profiles of the studied topo-lithosequence are the quality humus horizons and the presence or absence of horizons originated by weathering and leaching (*cambic*, *argic* horizons).

The first three profiles are located on cultivated land, and the last is in forest. The first soil profile, situated in a flat plateau position in the southeast of the Trnava Plateau was classified according to the WRB (2015) as ***Calcic*** **Chernozem** (***Loamic***, ***Aric***, ***Pachic***). The main criterion for this reference soil group is the presence of a *chernic* horizon. The *chernic* horizon is a relatively thick, well-structured, very dark-coloured surface horizon, with a high base saturation, high biological activity and a moderate to high content of organic matter. The *chernic* horizon is ploughed to a depth of ≥20 cm from the soil surface and is more than 50 cm thick; therefore, the ***Aric*** and ***Pachic*** supplementary qualifiers were added. This soil has also a *calcic* horizon starting ≤100 cm from the soil surface, in which secondary carbonates have accumulated in a diffuse form of soft concentrations (*pseudomycelia*) and hard nodules; therefore, the ***Calcic*** principal qualifier was added. The soil texture meets the criteria for the ***Loamic*** supplementary qualifier.

The second soil profile, situated on a smooth slope in a central part of the Trnava Plateau is a ***Luvic Calcic*** **Kastanozem** (***Aric***, ***Pachic***, ***Siltic***). It has a humus horizon which does not meet the criteria for a *chernic* horizon. Because of the combination of *mollic* and *calcic* horizons this profile was classified as a **Kastanozem**. It is decalcified and has a well developed *argic* horizon, and is therefore classified as ***Luvic***. The *mollic* horizon is thicker than 50 cm, and ploughed, so the supplementary qualifiers ***Aric*** and ***Pachic*** apply, and the soil texture meets the criteria for the ***Siltic*** supplementary qualifier.

The third soil profile is located on the slightly inclined slope of a wide loess ridge in the northern part of Under-Little Carpathian Hilly Land. It was classified as a ***Calcic*** **Luvisol** (***Siltic***, ***Aric***, ***Cutanic***, ***Ochric***, ***Bathycalcic***, ***Bathystagnic***). Based on the presence of an *argic* horizon with clay content higher than the overlying horizon and which is formed by illuvial accumulation of clay, this soil was classified as a **Luvisol**. The ***Calcic*** principal qualifier was added because this soil contains a *calcic* horizon starting within 100 cm of the soil surface. The *argic* horizon has evidence of illuvial clay – clay coatings; therefore, the ***Cutanic*** supplementary qualifier was added. Surface humus horizon is ploughed (supplementary qualifier: ***Aric***), and it does not fulfil the criteria for *chernic*, *mollic* or *umbric* horizons and does not meet criteria for ***Humic*** supplementary qualifiers, therefore ***Ochric*** supplementary qualifier applies. The profile has also *stagnic* properties and *reducing conditions* at a depth below 100 cm; therefore, the ***Bathystagnic*** supplementary qualifier was added.

The fourth soil profile is located in a flat plateau position in the west of the Trnava Plateau in the forest and was classified as a ***Haplic*** **Luvisol** (***Cutanic***, ***Hypereutric***, ***Ochric***, ***Siltic***, ***Amphiloamic***, ***Bathycalcic***). Like Profile 3, this soil was classified as a **Luvisol** because it has an *argic* horizon with well-developed clay coatings (***Cutanic*** supplementary qualifier). The soil profile has an effective base saturation ≥50% throughout the whole layer between 20 and 100 cm from the mineral surface, and ≥80% in some layers between 20 and 100 cm from the mineral surface; therefore, the ***Hypereutric*** supplementary qualifier was also added. The surface humus horizon is not ploughed and does not fulfil the criteria for *chernic*, *mollic* or *umbric* horizons, nor for the ***Humic*** supplementary qualifier; therefore, only the ***Ochric*** supplementary qualifier was added. The *calcic* horizon starts >100 cm from the soil surface; therefore, the ***Bathycalcic*** principal qualifier was added.

Soil sequence

The intensity of soil forming processes varied across the Danube Hilly Land from lower, warmer and drier lowland landscapes towards the cooler, moister and more elevated peripheral footslopes. This change in geographical conditions and soil forming factors resulted in the formation of various soils with *chernic/mollic* horizons or humus horizons with less mature organic matter, combined with *calcic*, *argic* or *cambic* horizons. They form a soil sequence that can be interpreted as *soil piedmont zonality* (Bedrna, 1966). The major differentiating factors of this special zonal soil sequence is the increase in soil moisture and intensity of percolation from the slightly warmer and drier central part of the lowland towards its slightly cooler and moister peripheries (Bedrna, 1977).

The *piedmont zonality* occurs across the whole Danube Hilly Land but most typically it is developed in the Trnava Hilly Land because this area has the most homogeneous topography and parent material, so the impact of climate is markedly manifest here. The intensity of leaching increases from Vah River towards mountains. In the driest and warmest areas of the Trnava Plateau, soils are calcareous from the surface. They have strongly developed *chernic* horizons and can be classified as **Chernozems**, e.g. Profile 1, ***Calcic*** **Chernozem** (***Aric***, ***Loamic***, ***Pachic***). With increasing intensity of leaching the humus horizon is decalcified and its colour gradually becomes less dark so it does not meet the criteria for a *chernic* horizon, and the **Chernozems** were replaced by **Kastanozems**. In the next stage the decalcification advanced deeper and the decalcified part of the subsoil was affected by weathering, resulting in the formation of the *cambic* horizons, and the ***Calcic*** **Kastanozems** (***Cambic***) were formed. Further, where the leaching was more intensive, the *argic* horizons and ***Luvic Calcic*** **Kastanozems** were formed, e.g. Profile 2: ***Luvic Calcic*** **Kastanozem** (***Aric***, ***Pachic***, ***Siltic***). In more moist areas the conditions are no longer suitable for the formation of *chernic/mollic* horizons. The humus horizons with less content of organic matter occur here and the **Chernozems/Kastanozems** are replaced by ***Haplic*** **or** ***Calcic*** **Luvisols** (***Cutanic***) – Profiles 3 and 4. They can be characterised by several supplementary qualifiers.

References

Bedrna, Z., 1966. Topografický rad pôd výškovej pásmovistosti na Trnavskej pahorkatine [Soil Piedmont Zonality at Trnava Hilly Land]. Náuka o Zemi IV., Pedologica 2, Bratislava.

Bedrna, Z., 1977. Pôdotvorné procesy a pôdne režimy [Soil forming processes and soil regimes]. Veda. Bratislava, 129 p.

Demo, M. et al., 2001. Dejiny poľnohospodárstva na Slovensku [History of Agriculture in Slovakia]. Slovak Agricultural University, Nitra, 662 p.

Fulajtár, E., 1993. Impact of human activity on the development of Chernozems in the loess hilly land north-east of Risňovce, Nitra Department, Slovakia. M.Sc.-thesis, University of Ghent.

Hraško, J., 1964. Černozeme Podunajskej nížiny, problémy ich genézy a klasifikácie [Chernozems of Danube Lowland, problems of their genesis and classification]. Náuka o Zemi III., Pedologica 1, Bratislava.

IUSS Working Group WRB, 2015. World Reference Base for Soil Resources 2014. Update 2015. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Report No. 106, FAO, Rome. http://www.fao.org/3/a-i3794e.pdf.

Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F., 2006. World Map of the Koppen-Geiger climate classification updated. Meteorologische Zeitschrift 15, 259-263. DOI: 10.1127/0941-2948/2006/0130.

Krippel, E., 1986. Postglaciálny vývoj vegetácie Slovenska [Postglacial development of vegetation in Slovakia]. Veda, Bratislava.

Michalko, J., Berta, J., Magic, D., 1986. Geobotanická mapa ČSSR [Geobotanical map of CSSR]. Veda, Bratislava.

Tarábek, K., 1980. Klimtickogeografické typy [Climatogeographical Types], 1: 1 000 000. Atlas of Slovak republic, SAV, SÚGK, Bratislava, 1980, p. 64.

Vaškovský, I., 1977. Kvartér Slovenska [Quarternary of Slovakia]. GÚDŠ, Bratislava.

Differently used soils of the Tribeč mountain range and Nitra valley slope

Michał Jankowski, Vladimir Šimanský, Maciej Markiewicz, Anna Pilichowska, Joanna Michalak

The study area is located in south-western Slovakia, on the border of the Tribeč range, which belongs to the Carpathian Mountains (Western Inner Carpathians) and the Nitra river valley, constituting a part of the Great Danubian Lowland (Podunajskà Nižina), between the city of Nitra and the village of Dràžovce.

Fig. 1. Location

Lithology and topography

The Tribeč range is built of granitoid rocks and a packet of Mesozoic (Triasic) dolomites extending on the edges, forming a low mountain ridge reaching over 800 m a.s.l. The ridge is divided into two parts: 1. the Tribeč part, with the highest peak being Veľký Tribeč (829 m a.s.l.), and 2. the Zobor part, with its culmination on the top of the Zobor mountain (587 m a.s.l.). The studied soil sequence is situated in a dolomitic area of the Zobor part, on a south-western slope of Plieška (393 m a.s.l) and Meškov Vrch (449 m a.s.l.). Slopes of the Tribeč range and higher parts of the Nitra river valley are covered with colluvial deposits built of weathered Carpathian rocks and also with a widespread mantle of Quaternary silty-loamy aeolian loess sediments accumulated in periglacial conditions of the last glaciation (Hreško et al., 2006). The Nitra river floodplain lies ca. 140 m a.s.l. It is built of alluvial sediments with predominating clay or silty-clay texture. The total relative height in the soil sequence does not exceed 260 m.

Land use and topography

The highest parts of the Plieška-Meškov Vrch ridge, at over 300 m a.s.l., are covered with a mosaic of forest–steppe vegetation of natural, but secondary character, which is protected in the "Zoborská lesostep" nature reserve. Some dozens years ago, however, this area was used as pasture land. The steep mountain slopes between 300 and 200 m a.s.l. are inclined ca. 8–30° and overgrown with deciduous forest dominated by Turkey oak (*Quercus cerris*) and maple (*Acer* sp.) with admixture of single pines artificially planted by man. Lower, more gentle parts of slopes (5–15°) lying ca. 200–180 m a.s.l. are managed as vineyards and gardens. The variously flat and undulating surfaces of the loess terrace and colluvial cone spread at 170–150 m a.s.l. are intensively used as arable fields. The Nitra floodplain used to be managed the same way in the past. Nowadays, however, this area is intended for industrial development (a Land Rover factory).

Climate

The study area lies in a zone of moderately warm climate. It is characterised by a long, warm, dry summer and short, slightly warm, dry winter with a low number of snowy days. Mean annual air temperature ranges around 7.5–10°C. July is the hottest month with the mean temperature 16–18°C, and January is the coldest, with temperatures of -2 to -4°C. Snow cover usually exists for 50–80 days of the year. Mean annual precipitation is 550–750 mm (Repa, 2004). It is worth noting that the relatively low height difference between extreme profiles in the sequence (260 m) does not allow for the formation of real vertical bioclimatic zonation.

Profile 1 – Eutric Dolomitic **Leptosol** (Arenic, Humic)

Localization: Plieška-Meškov Vrch ridge, Zobor part of the Tribeč range, upper slope, inclination 8°, forest-steppe, protected area, previously used as a pasture, 360 m a.s.l., **N** 48°21'1,3" **E** 18°4'56,2"

Morphology:

A – 0–7 cm, humus horizon, fine sandy loam, brownish black (10YR 4/2; 10YR 3/2), dry, weak granular fine structure, fine and common roots, gradual and smooth boundary;

AC – 7–15 cm, transitional horizon, loamy coarse sand, dark brown (10YR 5/3; 10YR 3/3), dry, weak granular fine structure, abundant of rock fragments, fine and common roots, clear and smooth boundary;

R – 15–(40) cm, hard bedrock, dolomite.

Table 1. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	0–7	10	8	10	7	6	21	29	14	2	3	SL
AC	7–15	68	41	11	6	4	12	16	8	1	1	LS

Table 2. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	C/N	pH		$CaCO_3$ [$g \cdot kg^{-1}$]
					H_2O	KCl	
A	0–7	55.2	3.6	15	6.3	5.9	-
AC	7–15	22.1	1.9	12	7.3	7.2	3

Profile 2 – Luvic Chernic **Phaeozem** (Loamic)

Localization: Plieška-Meškov Vrch ridge, Zobor part of the Tribeč range, lower slope, inclination 30°, deciduous forest with dominant oak and maple trees, 220 m a.s.l., **N** 48°20'49.5" **E** 18°4'46"

Morphology:

Oi – 7–5 cm, slightly decomposed organic material;

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

A1 – 0–21 cm, humus *chernic* horizon, silt loam, brownish black (10YR 4.5/2.5; 10YR 3/2), slightly moist, moderate granular fine structure, fine and common roots, gradual and smooth boundary;

A2 – 21–33/35 cm, humus horizon, silt loam, dull yellowish brown (10YR 5.5/3.5; 10YR 3/3), slightly moist, moderate granular structure, fine and common roots, gradual and smooth boundary;

Bt – 33/35–63 cm, *argic* horizon, silt loam with common dolomite rock fragments, dull yellowish brown (10YR 6.5/4; 10YR 4.5/3.5), slightly moist, weak blocky angular structure, very few roots, diffuse boundary;

Ck – 63–(100) cm, parent material, silty clay loam, dull yellowish brown (10YR 6.5/3.5; 10YR 4.5/3.5), moist, secondary and primary carbonates, moderate blocky angular structure.

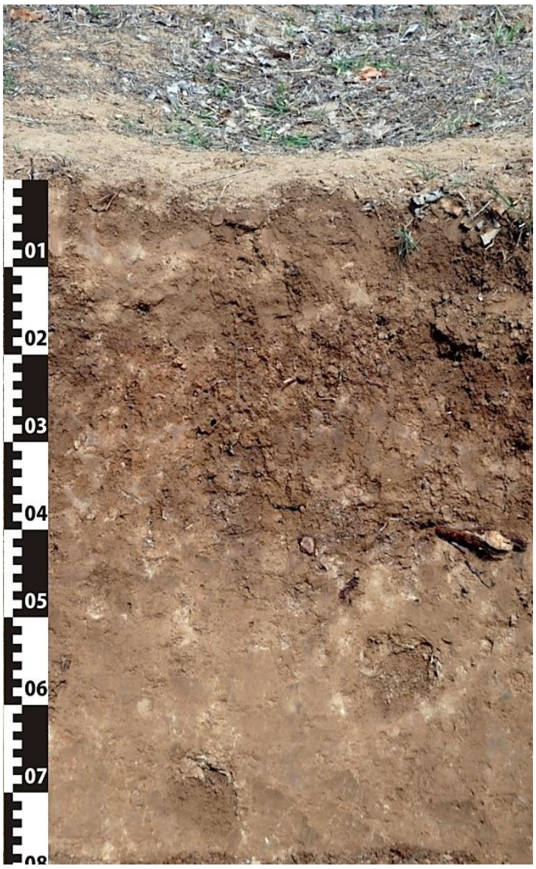
Table 3. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	0–14	2	3	5	4	5	9	27	22	8	17	SiL
A2	14–35	3	4	6	4	6	11	32	20	10	7	SiL
Bt	35–63	10	1	3	3	5	8	27	25	12	16	SiL
Ck	63–100	1	1	1	1	2	9	22	24	13	27	SiCL

Table 4. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	C/N	pH		$CaCO_3$ [$g \cdot kg^{-1}$]
					H_2O	KCl	
Oi	7–5	225	10.6	21	7.1	6.7	35
Oe	5–0	389	14.3	27	6.1	5.7	28
A1	0–14	48.7	4.4	11	7.7	7.1	17
A2	14–35	26.2	2.6	10	8.1	7.2	16
Bt	35–63	10.4	1.1	10	8.2	7.4	29
Ck	63–(100)	9.0	1.2	-	8.4	7.5	118

Profile 3 – Nudiargic **Luvisol** (Cutanic, Hypereutric, Loamic)
Localization: Plieška-Meškov Vrch ridge, Zobor part of the Tribeč range, lower slope, inclination 12°, vineyard, 210 m a.s.l., **N** 48°20’48.4” **E** 18°4’45.2”



Morphology:

AB – 0–10/12 cm, mixed horizon, silt loam, brown (10YR 6.5/4; 10YR 4.5/4), slightly moist, moderate granular medium structure, fine and common roots, clear and smooth boundary;

Bt – 10/12–40 cm, argic horizon, silt loam, brown (10YR 6.5/3.5; 10YR 4.5/3.5), slightly moist, blocky subangular structure, fine and common roots, gradual and smooth boundary;

Ck – 40–(100) cm, parent material, silt loam, dull yellowish brown (10YR 6.5/3.5; 10YR 4.5/3.5), moist, primary and secondary carbonates, massive structure.

Table 5. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	
AB	0–10/12	1	1	2	1	3	9	28	23	11	22	SiL
Bt	10/12–40	1	1	1	1	2	9	27	24	10	25	SiL
Ck	40–(100)	1	1	2	1	2	10	25	25	12	22	SiL

Table 6. 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	
AB	0–10/12	9.4	0.9	10	8.1	7.4	90
Bt	10/12–40	5.3	0.6	9	8.3	7.4	18
Ck	40–(100)	2.8	0.4	-	8.6	7.5	125

Profile 4 – Eutric **Cambisol** (Colluvic, Humic, Loamic)

Localization: Plieška-Meškov Vrch ridge, Zobor part of the Tribeč range, lower slope, inclination 8°, vineyard, 200 m a.s.l., **N** 48˚20'46.8'' **E** 18˚4'8''

Morphology:

A1 – 0–13 cm, humus horizon, silty clay loam, dull yellowish brown (10YR 6/4; 10YR 4/3), slightly moist, moderate granular structure, fine and few roots, gradual and smooth boundary;

A2 – 13–30 cm, humus horizon, silty clay loam, brown (10YR 6/4; 10YR 4/4), slightly moist, moderate granular fine structure, fine and medium common roots, clear and smooth boundary;

AB1 – 30–50 cm, humus horizon, silt loam, dull yellowish brown (10YR 7/4; 10YR 4/3), moist, blocky subangular structure, visible clay and humus coatings, clear and smooth boundary;

AB2 – 50–70 cm, humus horizons, silty clay loam, brown (10YR 6/4; 10YR 4/4), moist, blocky subangular structure, visible clay and humus coatings, clear and smooth boundary;

BC – 70–(100) cm, transitional horizon to parent material, silty clay loam, dull yellowish brown (10YR 7/4; 10YR 5/4), moist, blocky subangular structure, visible clay and humus coatings.

Table 7. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	0–13	1	1	1	1	1	7	27	21	10	31	SiCl
A2	13–30	2	1	1	1	2	6	26	21	9	33	SiCl
AB1	30–50	3	1	2	2	2	12	25	20	10	26	FSiL
AB2	50–70	0	0	1	1	1	8	26	21	8	34	SiCl
BC	70–(100)	0	0	0	1	1	8	27	22	8	33	SiCl

Table 8. 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	
A1	0–13	16.6	0.9	19	8.0	7.3	17
A2	13–30	9.1	1.1	9	8.1	7.4	17
AB1	30–50	9.8	1.1	9	8.2	7.4	39
AB2	50–70	4.5	0.5	9	8.2	7.3	4
BC	70–(100)	3.7	0.3	-	8.1	7.4	3

Profile 5 – Haplic **Calcisol** (Aric, Endochromic, Hypocalcic, Loamic, Ruptic)
Localization: Loess terrace of Nitra valley, inclination 3°, arable land, 170 m a.s.l.,
N 48°20'45'' **E** 18°4'26.9''

Morphology:

Ap – 0–17 cm, humus plough horizon, silt loam, dull yellow orange (10YR 6.5/3; 10YR 5.5/3.5), slightly moist, strong lumpy structure, common concentrations of calcium carbonate, clear and smooth boundary;

Ck1 – 17–30 cm, *calcic* horizon, silt loam, bright yellowish brown (10YR 8/4; 10YR 6.5/5), slightly moist, strong blocky angular structure, common concentrations of calcium carbonate, clear and smooth boundary;

Ck2 – 30–60 cm, *calcic* horizon, silt loam, dull yellow orange (10YR 7.5/5; 10YR 6.5/5), slightly moist, moderate granular structure, common concentrations of calcium carbonate, clear and smooth boundary;

C2B – 60–78 cm, transitional horizon, silty clay loam, orange (7.5YR 7.5/4; 7.5YR 6/6), slightly moist, massive structure, clear and smooth boundary;

2Bto (m)b – 78–(100) cm, buried *argic* horizon with residual accumulation of sesquioxides, clay loam, reddish brown (5YR 5.5/7; 5YR 4.5/7), slightly moist, massive structure, partially hardened.

Table 9. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	0–17	2	2	3	3	3	10	24	18	11	26	SiL
Ck1	17–30	2	2	2	2	3	8	24	21	31	7	SiL
Ck2	30–60	1	1	2	2	2	9	27	22	28	7	SiL
C2B	600–78	1	1	2	2	3	9	25	19	8	31	SiCL
2Bto(m)b	78–(100)	5	5	6	7	8	9	16	10	1	18	CL

Table 10. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	C/N	pH		$CaCO_3$ [$g \cdot kg^{-1}$]
					H_2O	KCl	
Ap	0–17	7.5	1.0	8	8.4	7.5	139
Ck1	17–30	3.0	0.5	-	8.6	7.7	252
Ck2	30–60	2.0	0.4	-	8.7	7.5	165
C2B	600–78	1.9	0.3	-	8.5	7.6	102
2Bto(m)b	78–(100)	1.2	0.3	-	8.5	7.5	46

Profile 6 – Vermic **Chernozem** (Aric, Colluvic, Loamic, Loaminovic, Pachic)
Localization: Loess terrace of Nitra valley, flat, arable land, 172 m a.s.l.,
N 48˚20’39.2’’ **E** 18˚4’27.3’’

Morphology:

Ap – 0–27 cm, humus plough horizon, loam, dull dark brown (10YR 5/3; 10YR 3/3), slightly moist, moderate granular structure, common concentrations of calcium carbonate, abrupt and smooth boundary;

A – 27–63 cm, *chernic* horizon, silt loam, bright brownish black (10YR 5/2.5; 10YR 3/1.5), moist, moderate granular structure, gradual and smooth boundary;

AC – 63–83 cm, transitional horizon, loam, dull yellowish brown (10YR 7/4; 10YR 5/4), moist, moderate granular structure, very gravely, gradual and smooth boundary;

Ck – 83–(100) cm, *calcic* horizon, silt loam, orange (10YR 8/3; 10YR 7/3), moist, few calcium carbonate concentrations, moderate granular structure.

Table 11. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	0-27	4	2	4	4	4	15	23	16	7	25	L
A	27-63	3	1	4	5	3	10	29	16	6	26	SiL
AC	63-83	40	8	9	10	12	13	16	17	4	11	L
Cĸ	83-(100)	17	9	14	14	9	14	13	7	3	17	SL

Table 12. 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	0-27	14.3	0.7	20	7.7	6.4	-
A	27-63	13.6	0.7	20	8.2	8.1	2
AC	63-83	4.5	0.4	11	8.1	7.4	21
Cĸ	83-(100)	-	-	-	8.5	7.8	172

Profile 7 – Ekranic **Technosol** (Eutric, Densic, Gleyic, Loamic, Loaminovic, Mollic, Transportic, Protovertic)
Localization: Floodplain of Nitra valley, flat, industrial area, 140 m a.s.l.,
N 48˚20′11.9′′ **E** 18˚4′14.8′′

Morphology:

Au – 0–27 cm, humus horizon urban origins, silt loam, dark greyish (2.5Y 6.5/2.5; 2.5Y 4.5/2.5), dry, solid structure, abrupt and smooth boundary;

Cu – 27–32 cm, parent material urban origins, clay loam, yellowish brown (2.5Y 7/3; 2.5Y 5.5/3), dark, solid structure, abrupt and smooth boundary;

2Air – 32–81 cm, buried humus horizon with *shrink-swell* cracks and strong reduction, silty clay, dark greyish yellow (2.5Y 6.5/1.5; 2.5Y 4.5/1.5), slightly moist, solid structure, gradual and smooth boundary;

2Cr – 81–(118) cm, parent material with strong reduction, clay loam, greyish yellow (2.5Y 7/1.5; 2.5Y 5.5/2.5), moist, solid structure, ground water level at 110 cm.

Table 13. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	
Au	0-27	3	4	4	4	6	8	21	17	12	24	SiL
Cu	27-32	4	4	3	2	5	9	23	16	8	30	CL
2Air	32-81	1	1	1	3	6	8	14	15	12	40	SiC
2Cr	81-(118)	2	2	2	4	8	8	12	15	11	38	CL

Table 14. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	C/N	pH		$CaCO_3$ [$g \cdot kg^{-1}$]
					H_2O	KCl	
Au	0-27	10.1	1.3	8	8.3	7.4	110
Cu	27-32	3.6	0.5	7	8.6	7.4	48
2Air	32-81	9.9	1.1	9	8.3	7.1	52
2Cr	81-(118)	4.3	0.5	-	8.4	7.1	17

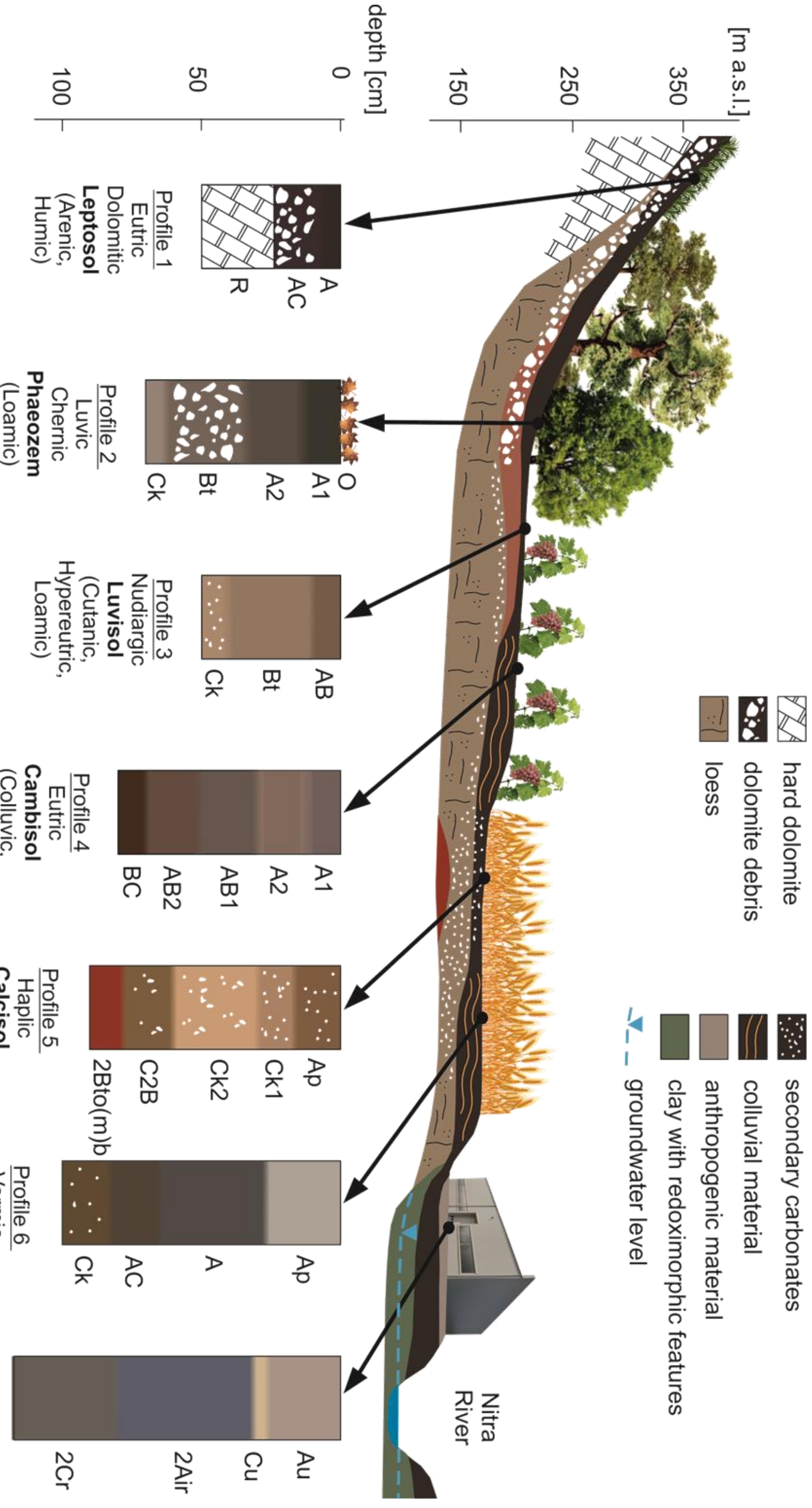


Fig. 2. Landscape transect (land use-litho-toposequence) of soils of the Tribeč mountain range and Nitra valley slope

Soil genesis and systematic position

The analysed soils represent features typical both of the natural bioclimatic conditions of south-western Slovakia and of the numerous effects of transformations caused by land use.

The first profile is located on a deforested summit part of the mountain range. The soil is developed in a very shallow (15-cm-deep) mantle of weathered dolomite material, thus according to the WRB soil classification (IUSS Working Group WRB, 2015) it may be classified as a ***Dolomitic*** **Leptosol**. Due to high pH values (over 6 in H_2O) it is also ***Eutric***. The whole 15 cm deep weathered part of the soil fulfils criteria of *mollic* horizon for earth particles (ø <2 mm), apart from structure, which according to high contents of gravels (10-68%; Table 1) is not developed well enough. Thus, main qualifier ***Rendzic*** may not be used. The loamy sand to sandy loam texture (Table 1) and high content of soil organic matter (5.5% of organic carbon; Table 2) are recorded in the use of the ***Arenic*** and ***Humic*** supplementary qualifiers. The occurrence of such shallow soil forming a mosaic with dolomite rock outcrops on the surface at a relatively low altitude must be an effect of strong erosion initiated by past deforestation of the area for pasturage. Meanwhile, the shallowness of the soil is probably a factor inhibiting the re-succession of forest vegetation and favouring the persistence of steppe grasslands.

Profile 2 represents an afforested section of the mountain slope. The soil does not show any traces of erosion and seems to be a natural one. It has a very well developed humic profile with a 7-cm-deep organic horizon and a humus horizon in the upper 21 cm that is black, silt-loam-textured (Table 3) and organic-carbon-rich (2.6–4.9%; Table 4), and that fulfils the criteria of a *chernic* diagnostic horizon. The soil is also very rich in calcium carbonate (almost 12%) in the Ck horizon; however, this is not enough for the limit established for a *calcic* horizon (15%). In the middle part of the profile abundant clay skins were identified on surfaces of blocky aggregates marking the presence of an *argic* Bt horizon. Such a soil with a *chernic* horizon, which is a more restrictive variant of *mollic*, but without a *calcic* horizon, belongs to the **Phaeozem** Soil Reference Group (SRG). The main qualifiers ***Luvic*** and ***Chernic*** reflect the presence of *argic* and *chernic* horizons. The silt loam texture is reflected in the ***Loamic*** supplementary qualifier. The afforested soil in Profile 2 may be considered the most typical of the study area's soil-forming environment.

The most characteristic feature of the soil in the third profile is the presence of an illuvial horizon Bt *argic* with very well developed clay skins and coatings on aggregate surfaces. Thus, the soil has been classified as a **Luvisol**. It is built of silt clay (Table 5) in the whole profile (***Loamic***). This soil is located in the upper part of a gentle slope managed as a vineyard. Vegetation cover is sparse, which allows for denudation activity. The *argic* horizon starts at the land surface and, in only the upper 10–12 cm, Bt material is mixed with a low amount of organic matter (0.9% of organic carbon in AB; Table 6). According to the lack of eluvial E and humus A horizons that normally overlie an *argic* horizon, the main qualifier ***Nudiargic*** has been applied for this soil. The presence of abundant clay skins is marked in the supplementary qualifier ***Cutanic***. pH values in water exceeding 8.0 through the whole profile (Table 6) allow the use of ***Hypereutric***.

Soil in Profile 4 represents a zone of accumulation of soil material washed from the higher parts of the slope. It does not have any diagnostic horizon, but weak pedogenic transformations and sedimentary features are visible to at least a depth of 100 cm. A brown colour, blocky structure and single clay skins are noted, evidencing *cambic* horizon formation, although its features are masked by the presence of low amounts of organic matter (AB horizons). Due to weak but visible pedogenic transformations, the soil is classified to the **Cambisols** SRG. High pH values over 8.0 in H_2O) are underlined by the ***Eutric*** main qualifier. Down to 70 cm the soil is built of four layers of colluvial deposits transported from the higher part of the slope (Profile 3). These weakly pedogenically transformed sediments contain a low amount of organic carbon (0.5–1.7%; Table 7) and have a texture of silty clay loam (Table 8). The features of that colluvial soil are marked by the supplementary qualifiers ***Colluvic***, ***Humic*** and ***Loamic***.

Profile 5 is situated in an arable field, on a local, gentle elevation on the surface of an undulant loess terrace, at the foot of the Tribeč range and over the Nitra valley. The soil consists of a humus A horizon that is weakly developed, poor in organic matter (0.75%; Table 10) but rich in calcium carbonate (14%), laying over a ***calcic*** horizon containing 16.5–25% of $CaCO_3$. This soil has to be classified as a ***Haplic*** **Calcisol**. Calcisols are not typical soils of the bioclimatic conditions of Central Europe. The analysed profile has to be interpreted as a remnant of primary soil, in which the *calcic* horizon developed as the subsurface horizon but is nowadays exposed on the land surface as an effect of strong erosion and truncation. The current arable land use, reflected in the presence of a plough horizon Ap, allows ***Aric*** to be added, while the loamy texture warrants the (Table 9) ***Loamic*** supplementary qualifier. At a depth of ca. 80 cm, loess material is underlain by red (***Endochromic***), partially hardened, clay loamy material, which is probably a buried relict of old, Tertiary pedogenesis and the formation of the *argic* horizon (2Bto(m)b). The boundary between loess and red loam is clear, evidencing erosional contact (***Ruptic***).

The next profile (No. 6) is situated in the same field as Profile 5, but in a smooth depression. The soil has been classified as a **Chernozem**, due to the presence of two diagnostic horizons. The black-coloured, organic-carbon-rich humus A horizon fulfils the criteria of *chernic*. It is entirely dug by animals and full of zooturbations, which is reflected in the main qualifier ***Vermic***. The Ck horizon starts at a depth of 20 cm below the lower border of the *chernic*. It contains 17% of $CaCO_3$ and is thus a *calcic* diagnostic horizon. The supplementary qualifier ***Aric*** reflects the current agricultural use, and ***Loamic*** the loamy texture (Table 11). Material meeting the criteria of a *mollic* horizon is over 50 cm deep, and thus the ***Pachic*** qualifier has been also used. The primary soil profile is covered with ca.-30-cm-thick, loamy, organic-carbon-rich material (>1%; Table 12) of colluvial origin. Its presence is marked by the qualifiers ***Colluvic*** and ***Loaminovic***.

The last profile (No. 7) is located at the bottom of the Nitra river valley, on a floodplain formerly used as an arable field, but nowadays designed for industrial purposes. The original soil is well preserved, but it is covered with a layer of over 30 cm thick of heavy (silt loam to clay loam), compacted material accumulated by man and forming a weakly permeable geomembrane. According to that, the soil has been classified as an ***Ekranic*** **Technosol**. The "natural" character of the material building the geomembrane is marked by the use of the ***Transportic*** qualifier. Its compaction is expressed by the use of ***Densic***. The original soil below the geomembrane has a well developed *mollic* horizon (***Mollic*** qualifier) and features of strong iron reduction in the whole profile, due to the influence of groundwater (***Gleyic***). Such structure of the original soil allows its classification as a ***Mollic*** **Gleysol**. An additional feature of the humus 2Air horizon is the presence of *shrink–swell* cracks, which is expressed by the use of ***Protovertic***. Both the original soil and the anthropogenic "technical" materials are built generally of loamy material (***Loamic***, ***Loamynovic***; Table 13) that is entirely saturated with base cations, as shown by the high pH values measured in H_2O (>8; Table 14; ***Eutric***).

Soil sequence

The seven soil profiles studied in this work form a sequence that is diverse in terms of environmental and anthropogenic factors. According to the WRB (IUSS Working Group WRB, 2015) the soils have been classified as follows:

1. ***Eutric Dolomitic*** **Leptosol** (***Arenic***, ***Humic***),
2. ***Luvic Chernic*** **Phaeozem** (***Loamic***),
3. ***Nudiargic*** **Luvisol** (***Cutanic***, ***Hypereutric***, ***Loamic***),
4. ***Eutric*** **Cambisol** (***Colluvic***, ***Humic***, ***Loamic***),
5. ***Haplic*** **Calcisol** (***Aric***, ***Endochromic***, ***Hypocalcic***, ***Loamic***, ***Ruptic***),
6. ***Vermic*** **Chernozem** (***Aric***, ***Colluvic***, ***Loamic***, ***Loaminovic***, ***Pachic***),
7. ***Ekranic*** **Technosol** (***Eutric***, ***Densic***, ***Gleyic***, ***Loamic***, ***Loamynovic***, ***Mollic***, ***Transportic***, ***Protovertic***).

To some extent, the distribution of the soils manifests a variability that relates to topography. The ***Dolomitic*** **Leptosol** is located in the summit part of the mountain range. Profiles of the middle part of the sequence mostly show strong accumulation of calcium carbonate (12–25% in Profiles 2, 3, 5, 6), often seen in the formation of a *calcic* horizon (over 15% of $CaCO_3$). Additionally, *argic* Bt horizons occur in soils of lower parts of the Tribeč range slope (Profiles 2 and 3), and *chernic* A horizons in some soils of slopes and loess terraces (Profiles 2 and 6). This allows the study area to be described in as generally being a *zone of overlapping Luvisol and Chernozem formation.* The most characteristic natural features of Profile 7, which constitutes the lowest element of the sequence, are well described by the definitions of ***Gleyic***, ***Mollic*** and ***Protovertic***. This soil developed in the hydromorphous conditions of the valley bottom with some input of vertilisation (*shrink–swell* cracks). Despite the regularity described above, the sequence cannot be named a ***toposequence*** or ***catena*** *sensu stricto* (Milne, 1935, Sommer, Schlichting, 1997). Besides topography, the soil distribution is also dependent on parent material variability and land use.

The upper part of the slope is built of Carpathian dolomites, which are exposed as hard rock (Profile 1) and relocated weathered material (Profile 2). The middle part of the sequence is developed mostly in loess deposits *in situ* (Profiles 3, 5) or relocated by slope processes (Profiles 4, 6). The bottom part of the sequence (Profile 7) is situated in a range of silt-clay alluvial sediments of the Nitra floodplain. From this point of view the whole sequence may be considered a ***topo-lithosequence***.

The natural features of the analysed soils are strongly transformed by intensive land use, mostly agro-denudation. Profiles 1, 3 and 5 in fact represent soils eroded to various degrees: to hard rock (**Leptosol**), *argic* horizon (***Nudiargic*** **Luvisol**) and *calcic* horizon (**Calcisol**). On the other hand, the soils in Profiles 4 and 6 are colluvial soils actually functioning as an entirely new soil (**Cambisol**) or as original soil (**Chernozem**) with aggraded colluvium on a *chernic* horizon. Another form of strong soil cover alteration is the allochtonous material accumulation on the surface of Profile 7, changing a former **Gleysol** into a **Technosol**.

There is also a clear relationship between soil distribution and current vegetation cover. The top part of the sequence with the eroded **Leptosol** is overgrown with secondary, natural forest–steppe vegetation. On the steep mountain slope, deciduous forest protects the best preserved **Phaeozem**. The two short sequences of eroded and aggraded soils are located in the vineyard (Profiles 3 and 4) and in the arable field (Profiles 5 and 6). Profile 7 is situated in an industrial, post-agricultural area.

According to all the natural and anthropogenic factors driving soil variability along the slope of the Tribeč mountain range and Nitra valley, the presented set of soils should be named a ***land use-***

litho-toposequence. Such complex sequences of soils formed by at least three various factors may be named ***landscape transects***.

References

Hreško, J., Pucherová, Z., Baláž, I., 2006. Krajina Nitry a jej okolia, Univerzita Konštantina Filozofa, Nitra.

IUSS Working Group WRB, 2015. World Reference Base for soil resources 2014, update 2015 International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Report No. 106. FAO, Rome.

Milne, G., 1935. Some suggested units of classification and mapping particularly for east African soils. Soil Research 4(3): 183-198.

Sommer, M., Schlichting, E., 1997. Archetypes of catenas in respect to matter – a concept for structuring and grouping catenas. Geoderma: 76, 1-33.

Repa, Š., Šiška, B., 2004. Klimatická charakteristika roka 2003 v Nitre, SPU, Nitra.

Agricultural Soils on Morainic Hills in the Southwest of Latvia

Aldis Karklins, Ilze Vircava

The study area is located on the south-southeast margin of the Lielauce–Kerklinu terrain (LK), the Eastern Kursa Upland, Western Latvia (Fig. 1). The territory was formed by Pleistocene glaciations. The morphology of landforms is related to the last Weichselian glaciation. The inner structure of the Upland consists of a bedrock core that is covered with insular-shaped landforms comprising mainly glacigenic and glaciofluvial/glaciolacustrine sediments (Zelčs, Markots, 2004). According to Ber (2009), the Eastern Kursa Upland covers 3860 km^2 and is the largest radial glaciotectonic insular height upland in Latvia –consisting mainly of interlobate moraines connected with deeper tectonic structures of the basement (Ber, 2009; Zelčs, 2018). The interlobate ridges in the central part of the Eastern Kursa Upland are formed between two ice streams – the Baltic Ice stream and the Riga Ice stream (Lamsters et al., 2018).

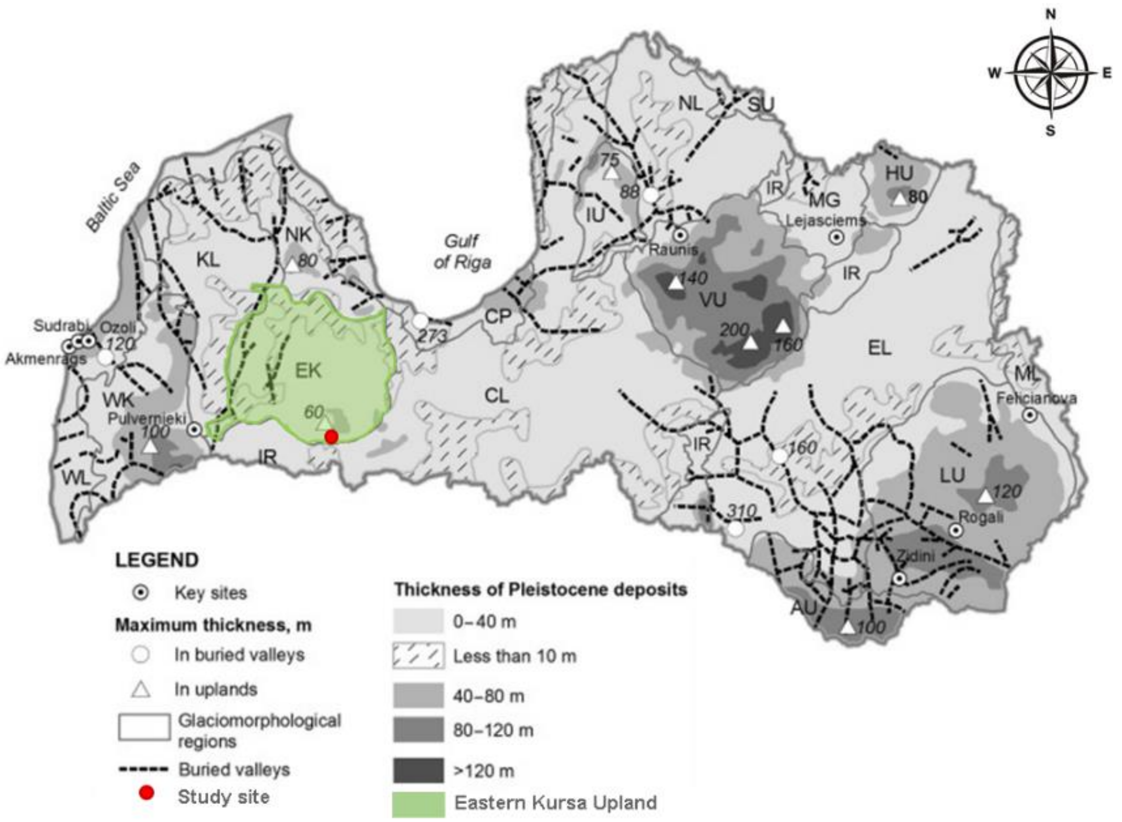


Fig. 1. Location of the study area and the thickness of Quaternary deposits in Latvia (modified from Zelčs et al., 2011)

Glacial lowlands: WL – Western Latvian; KL – Kursa; CL – Central Latvian; NL – Northern Latvian; MG – Middle Gauja; EL – Eastern Latvian; ML – Mudava (Velikoretsky). Glacial uplands: WK – Western Kursa; NK – Northern Kursa; EK – Eastern Kursa; IU – Idumeja; VU – Vidzeme; HU – Alūksne-Haanja; LU – Latgale; AU – Augšzeme; IR – Interlobate ridges.

Lithology and topography

The Lielauce–Kerklinu terrain surrounds the Eastern Kursa Upland from the south and is ~30 km long and 2 km wide. The southern slope of LK marks a margin between the Eastern Kursa Upland and the Vadakste Plain in the Middle Latvian Lowland (Fig. 1). The morphology and altitude above sea level (a.s.l.) of LK is complex and heterogeneous – formed from elongated, hummocky hills and their chains, linear and winding valleys, and cupola hills (Aber, Ber, 2007; Ber, 2007). The highest point in this area is Cīruļkalns – 151.5 m a.s.l. Hummocky hills are situated parallel to the terrain; however, some of them are oriented perpendicularly. The parameters of hummocks are: 200–250 m (less frequently > 500 m) in length, 75–120 m in width, and 10–12 m in height (Strautnieks, 1998). Soil catena used in the current study crossed hypsometrically the lower hummocks, which are characteristic for the LK edge area in its southeast part. These hummocks, elongated and rounded in shape, are 5–8 m high insular accumulative landforms (Zelčs, Markots, 2004) with dome-like morphology, modified by an overriding ice activity (Ber, 2009). Small closed and partly closed depressions are located between the hummocks (Strautnieks, 1998).

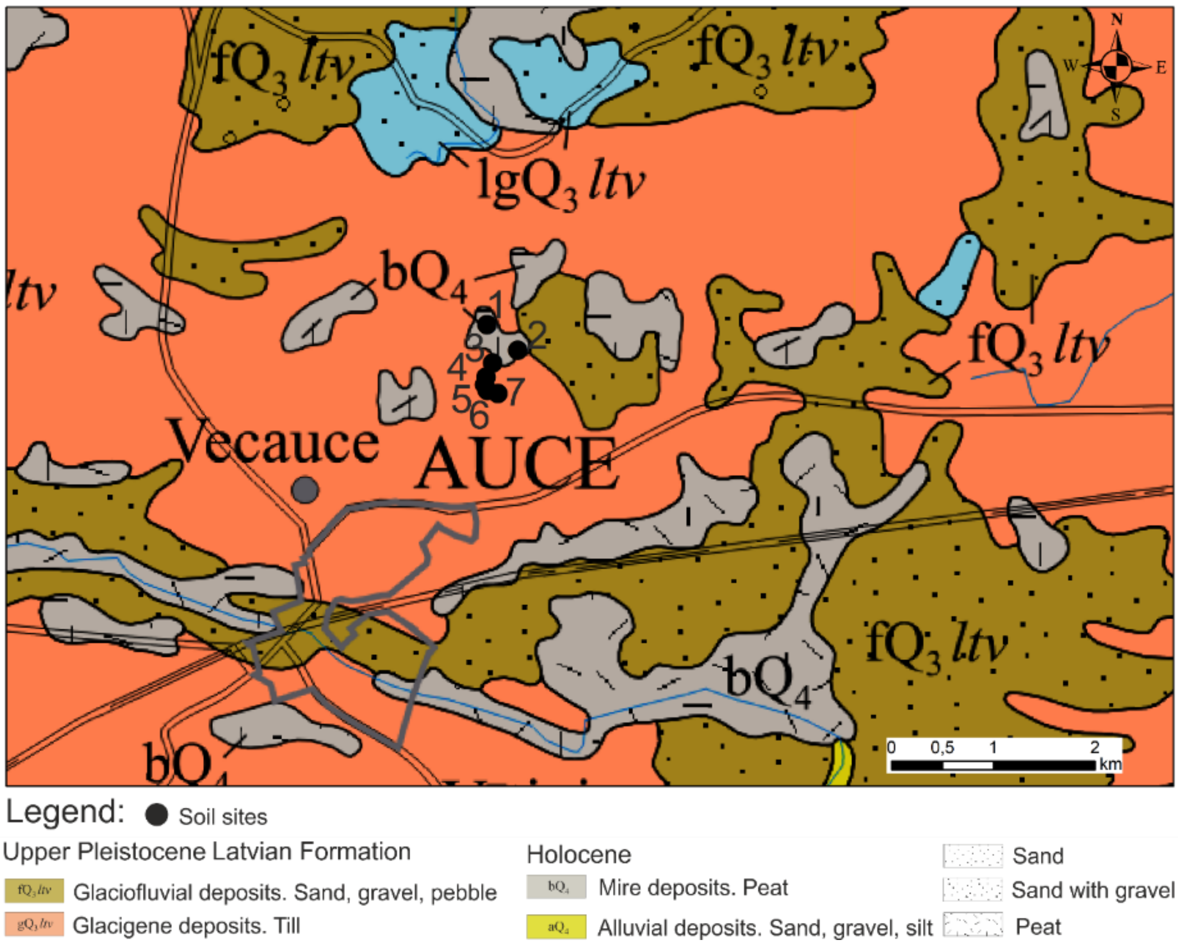


Fig. 2. Location of soil profiles

The LK morphology and orientation correspond to the local uplift of the bedrocks that lower in the southwest direction (Lamsters, 2015). The subsurface under the Quaternary sediments is mostly covered by the Late Permian (Lopingian) Naujakmenes stage (P3nj) limestones (Razynski, Bernadska, 2014). In the study area, the bedrock cover under Quaternary sediments is the Upper Devonian

(Ketleri stage, D3kt) sedimentary rocks. The bedrock elevation and lithology affected the movement of local ice streams, thus affecting the thickness of the Quaternary cover and the non-uniformity of its displacement, as well as promoting the formation of an undulated relief. Glacial sediments are heavily deformed. Older sediments of the Saalian glaciation are found in deflections of the subquaternary surface. Intermoraine glaciofluvial (sand, gravel, pebbles) sediments are displaced in the centre of the terrain, with the average thickness of 5–10 m. They are covered with sandy loam and loam till sediments, 1–2 m thick on hill tops and 15 m thick on the slopes and depressions formed by the last Weichselian glaciation (Fig. 2). At the same time, till in the depressions is covered with a 0.5–0.75-m thick layer of glaciolacustrine sediments (silty sand). These sediments can be covered with younger (Holocene age) sediments – peat and sapropel (Strautnieks, 1998).

Land use

The area where the research was carried out is characterised by a high percentage of agricultural land – 78.2% of the total study area. On average, this parameter is significantly lower for Latvia – only 38.3% of its total territory (Boruks, 2003). Forests (mixed) occupy 9.5% of the total study territory (average for Latvia – 44.5%). Agricultural land is mainly used under crop rotations – 71.3% of the total study territory (average for Latvia – 44.8%). The quality of the region's agricultural land is comparatively high. Areas having a ≥ 4° slope account for less than 5% of the total territory. Erosion-prone areas account for approximately 15% of the agricultural land. Areas where rock fragments are troublesome for soil tillage operations cover approximately 15–20% of the cropland. Soils with very sandy texture and very heavy texture account for 5% and 10% (respectively) of the total cropland area; both are not the best for the main crops grown here. The agricultural land of the study area is assessed at 45–50 points (in the 0–100-point system); average for Latvia is 37.2 points (Boruks, 2003).

Climate

In Latvia, frequent weather variability is associated with intense cyclonic activities and the impact of the Baltic Sea. The mean annual temperature in Latvia is +5.9°C; the warmest month is July (+17.0°C), and the coldest months are January and February (–4.6 and –4.7°C). The average annual precipitation is 667 mm. July and August are months with the largest amount of precipitation, which on average amounts to 78 mm. The least precipitation occurs in February and March – on average 33 mm per month. The average annual relative humidity is 81%. The lowest air moisture content is in May (71%), and the highest in November and December (88%). The sun shines on average for 1790 hours a year, which is about half of the possible sunshine duration (when the sky is clear); the maximum sunshine hours are from May to August, and the minimum sunshine hours are from November through January[1].

The study area is relatively warmer (mean annual temperature is +6.0°C) and dryer (annual amount of precipitations is 600 mm). In general, in Latvia, the snow cover varies considerably in terms of its thickness, duration and the number of days of snow formation. In the Middle Latvian Lowland, snow cover lasts on average for 94 days per year, but the growing season (mean air temperature ≥ 5°C) is 194 days.

[1] Climate of Latvia. https://www.meteo.lv/en/lapas/environment/climate-change/climate-of-latvia/climat-latvia?id=1471&nid=660

Profile 1 – Amphihypercalcic Epimurshic Sapric **Histosol** (Limnic)
Localization: Lower part of till plain, inter-hill depression, limnic deposits on glacial till, arable field, 96 m a.s.l.
N 56°29.201' **E** 22°55.135'

Morphology:

Ha – 0–26 cm, plough horizon, very strongly decomposed organic material (*sapric*), dark gray (5YR 4/1, 5YR 3/1), very dry, amorphous structure, many very fine and fine roots, abrupt and smooth boundary;

He – 26–70 cm, partly plough horizon, moderately strongly decomposed organic material (*hemic*), very dark brown (10YR 2/2, 5YR 2.5/1), very dry, amorphous structure, trans-horizon cracks, many very fine and fine roots, abrupt and smooth boundary;

Lkm – 70–87 cm, *limnic* material (marl), white (10YR 8/1, 10YR 8/2), slightly moist, medium weak prismatic structure, many very fine and few fine roots, clear and smooth boundary;

Lh – 87–98 cm, *limnic* material (marl), fine sandy loam, light gray (10YR 7/1, 10YR 7/2), slightly moist, weak coarse lumpy structure, *gleyic* properties, abundant snail shells, many very fine and few fine roots, clear and smooth boundary;

Lmr1 – 98–110 cm, *limnic* material, clay loam, reddish gray (2.5YR 6/1, 2.5YR 4/2), moist, weak coarse columnar structure, *gleyic* properties and reducing conditions, abundant snail shells, tile drain, few very fine roots, gradual and smooth boundary;

Lmr2 – 110–123 cm, *limnic* material, light gray (5Y 7/1, 5YR 5/2), moist, very weak coarse columnar structure, *gleyic* properties and reducing conditions, abundant snail shells, very few very fine roots, gradual and smooth boundary;

Bkr 123–(250) cm, silt loam, light gray (2.5Y 7/1, 5Y 5/1), moist, massive structure, *gleyic* properties and reducing conditions, very few very fine roots.

Table 1. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm									Textural class
		>2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.10	0.10–0.05	0.05–0.02	0.02–0.002	<0.002	
Ha	0–26	2.7	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
He	26–70	1.7	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Lkm	70–87	0.4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Lh	87–98	4.2	0.4	1.9	7.3	17.0	26.0	17.1	14.8	15.5	FSL
Lmr1	98–110	2.9	0.3	0.9	3.2	6.1	13.2	12.1	27.4	36.9	CL
Lmr2	110–123	0.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Bkr	123–(250)	0.2	0	0	0	0.2	0.5	42.6	34.8	21.9	SiL

Table 2. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	pH		$CaCO_3$ [$g \cdot kg^{-1}$]
			H_2O	KCl	
Ha	0–26	252.0	7.55	7.20	86.4
He	26–70	408.5	7.41	6.93	38.0
Lkm	70–87	38.5	8.10	8.08	915.6
Lh	87–98	73.4	7.60	7.51	246.8
Lmr1	98–110	68.9	7.45	7.30	271.0
Lmr2	110–123	46.3	7.51	7.35	438.2
Bkr	123–(250)	24.1	7.63	7.38	392.7

Profile 2 – Endocalcaric **Arenosol** (Aric, Endoprotocalcic, Ochric, Amphistagnic, Bathygleyic)
Localization: Till plain, foot slope N, very gently sloping < 3°, arable field, 98 m a.s.l.
N 56°29.068' **E** 22°55.431'

Morphology:

Ap – 0–33 cm, plough horizon, loamy sand, brown (10YR 5/3, 7.5YR 4/2), dry, very fine moderate crumbly structure, many fine calcareous residual rock fragments, many very fine and fine roots, abrupt and smooth boundary;

Bs – 33–68 cm, loamy fine sand, very pale brown (10YR 7/4, 7.5YR 5/6), slightly moist, fine very weak columnar structure, *stagnic* properties, common very fine and fine roots, clear and irregular boundary;

Bk – 68–75 cm, medium sand, light yellowish brown (10YR 6/4, 10YR 7/3), moist, porous massive structure, *protocalcic* and *stagnic* properties, few very fine and fine roots, gradual and irregular boundary;

Bg – 75–96 cm, loamy very fine sand, light gray (10YR 7/2, 10YR 6/2), moist, single gain structure, *stagnic* properties, reducing conditions, few very fine roots, gradual and irregular boundary;

Br1 – 96–143 cm, loamy sand, light gray (10YR 7/2, 2.5Y 5/2), moist, medium moderate platy structure, very few very fine soft manganese concretions, *gleyic* properties and reducing conditions, few very fine roots, clear and wavy boundary;

Br2 – 143–(230) cm, loamy sand, gray (2.5Y 6/1, 10Y 3/1), moist, coarse strong platy structure, *gleyic* properties and reducing conditions, few very fine soft manganese concretions.

Table 3. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm									Textural class
		>2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.125	0.125–0.063	0.063–0.02	0.02–0.002	<0.002	
Ap	0–33	8.4	2.4	6.7	15.5	30.0	26.9	5.7	4.4	8.5	LS
Bs	33–68	0.2	0.3	1.5	7.7	28.0	44.4	8.5	3.3	6.7	LFS
Bk	68–75	32.4	9.4	22.7	33.0	16.2	9.2	2.7	1.0	5.8	MS
Bg	75–96	0.2	0.1	0.7	4.3	22.5	55.7	8.7	4.0	4.0	LVFS
Br1	96–143	8.3	1.4	4.0	11.4	29.6	32.3	2.5	10.8	7.9	LS
Br2	143–(230)	12.2	1.2	3.5	12.4	26.0	26.7	11.5	9.1	9.6	FSL

Table 4. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	pH		$CaCO_3$ [g·kg^{-1}]
			H_2O	KCl	
Ap	0–33	18.4	8.0	7.6	70.0
Bs	33–68	1.9	8.4	8.3	86.3
Bk	68–75	1.6	8.5	8.4	286.8
Bg	75–96	1.7	8.6	8.5	166.9
Br1	96–143	4.2	8.0	8.0	199.8
Br2	143–(230)	3.2	8.0	8.2	162.4

Profile 3 – Calcaric Katoluvic Katostagnic **Phaeozem** (Aric, Colluvic, Endoloamic)
Localization: Till plain, lower slope N, complex, gently sloping 3°, arable field, 100 m a.s.l.
N 56˚28.999’ **E** 22˚55.195’

Morphology:

Ap – 0–27 cm, plough *mollic* horizon, partly *colluvic* materials, fine sandy loam, brown (7.5YR 5/2, 7.5YR 3/1), slightly moist, coarse moderate granular structure, many very fine and fine roots, clear and smooth boundary;

Eg – 27–50 cm, *colluvic* material, silt loam, light yellowish brown (10YR 6/4, 7.5YR 6/6), slightly moist, medium moderate prismatic structure, *stagnic* properties, common very fine and medium roots, clear and wavy boundary;

Btg1 – 50–144 cm, *argic* horizon, fine sandy loam, strong pink (7.5YR 7/3, 7.5YR 5/4), moist, medium strong prismatic structure, *stagnic* properties and reducing conditions, common clay coatings, very few fine hard and soft calcareous concretions, few very fine and medium roots, clear and wavy boundary;

Btg2 – 144–(200) cm*,* *argic* horizon, fine sandy loam, pinkish gray (7.5YR 7/2, 7.5YR 5/3), wet, medium strong prismatic structure, common clay coatings, few medium soft ferruginous concretions, pseudomycelium of secondary carbonates, no roots.

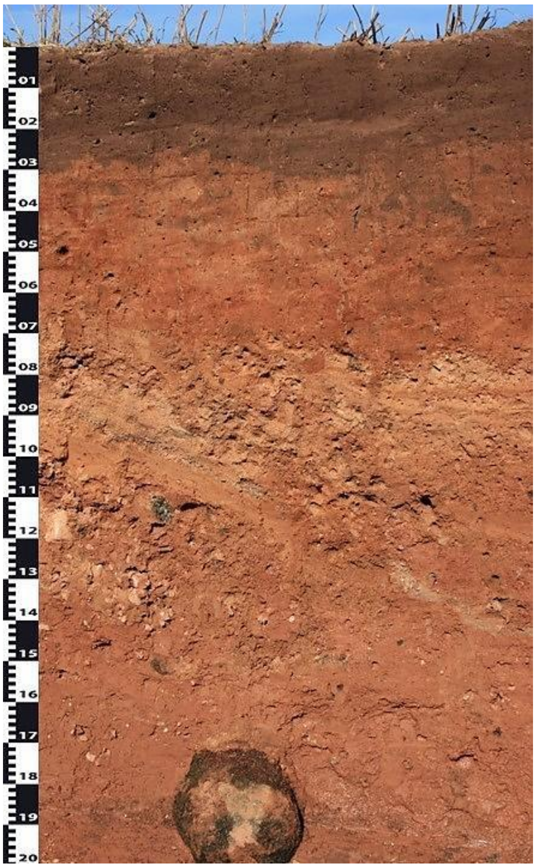
Table 5. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm									Textural class
		>2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.125	0.125–0.063	0.063–0.02	0.02–0.002	<0.002	
Ap	0–27	6.5	1.9	4.5	10.6	21.4	19.0	13.3	29.0	0.3	FSL
Eg	27–50	4.0	1.8	3.7	8.7	17.6	15.4	12.3	40.1	0.4	SiL
Btg1	50–144	10.8	2.5	5.3	12.1	23.7	16.0	11.5	28.7	0.4	FSL
Btg2	144–(200)	14.2	2.6	4.8	11.6	22.1	16.6	10.9	31.1	0.4	FSL

Table 6. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	pH		$CaCO_3$ [g·kg^{-1}]
			H_2O	KCl	
Ap	0–27	29.3	7.9	7.3	26.9
Eg	27–50	2.5	8.2	7.1	32.7
Btg1	50–144	0.9	8.6	7.9	226.3
Btg2	144–(200)	1.3	8.6	8.1	213.2

Profile 4 – Endocalcaric **Cambisol** (Anoarenic, Aric, Drainic, Ochric, Endoraptic, Bathyhypostagnic)
Localization: Till plain, middle slope N, complex, gently sloping 4°, arable field, 102 m a.s.l.
N 56°28.923' **E** 22°55.132'



Morphology:

Ap – 0–30 cm, plough horizon, loamy sand, brown (7.5YR 5/3, 5YR 4/2), slightly moist, medium moderate granular structure, common very fine and fine roots, abrupt and smooth boundary;

EB – 30–56 cm, transitional horizon, loamy sand, light brown (7.5YR 6/3, 7.5YR 6/4), slightly moist, fine moderate prismatic structure, few very fine and fine roots, abrupt and smooth boundary;

Bw – 56–83 cm, *cambic* horizon, loamy sand, light yellowish red (5YR 5/6, 5YR 5/6), slightly moist, fine weak prismatic structure, very few fine calcareous nodules, few fine roots, abrupt and wavy boundary;

2Bk – 83–128 cm, *lithic* discontinuity, *cambic* horizon, medium sand, pink (7.5YR 7/4, 7.5YR 7/4), dry, fine very weak granular structure, common medium calcareous nodules, very few fine roots, abrupt and wavy boundary;

3Btg – 128–157 cm, *lithic* discontinuity, *argic* horizon, fine sandy loam, light brown (7.5YR 6/4, 5YR 5/4), wet, coarse strong platy structure, common medium calcareous nodules, many distinct clay coatings on pedfaces, no roots, abrupt and wavy boundary;

3Ck – 157–(205) cm, fine sandy loam, light brown (7.5YR 6/4, 5YR 5/4), moist, massive structure, common medium calcareous nodules, no roots.

Table 7. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm									Textural class
		>2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.125	0.125–0.063	0.063–0.02	0.02–0.002	<0.002	
Ap	0–30	3.0	2.3	5.4	14.9	27.3	21.8	10.8	17.4	0.2	LS
EB	30–56	2.6	3.6	6.7	17.3	31.6	21.0	8.7	11.1	0.1	LS
Bw	56–83	3.2	1.9	6.4	18.2	33.4	20.9	8.2	10.9	0.1	LS
2Bk	83–128	35.9	7.5	20.5	25.9	26.1	9.2	4.6	6.2	0.1	MS
3Btg	128–157	8.2	1.7	3.8	10.0	23.0	20.6	10.9	29.8	0.3	FSL
3Ck	157–(205)	8.9	2.1	4.7	10.4	21.2	18.1	12.1	31.0	0.3	FSL

Table 8. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	pH		$CaCO_3$ [g·kg^{-1}]
			H_2O	KCl	
Ap	0–30	11.9	6.7	5.9	10.8
EB	30–56	2.5	7.2	6.3	11.0
Bw	56–83	1.6	8.0	7.3	16.5
2Bk	83–128	0.4	8.9	8.6	190.2
3Btg	128–157	0.4	8.8	8.1	239.0
3Ck	157–(205)	0.4	8.8	8.1	219.9

Profile 5 – Calcaric Endoprotocalcic Epiabruptic **Luvisol** (Aric, Cutanic, Epiendoloamic, Ochric)
Localization: Till plain, summit, arable field, 104 m a.s.l.
N 56°28.884' **E** 22°55.122'

Morphology:

Ap – 0–30 cm, plough horizon, fine sandy loam, brown (7.5YR 5/4, 7.5YR 4/3), slightly moist, medium moderate granular structure, many very fine and very fine and medium roots, clear and wavy boundary;

Bh – 30–45 cm, fine sandy loam, light reddish brown (5YR 6/4, 5YR 5/6), slightly moist, medium moderate granular structure, common faint clay and humus coatings on horizontal pedfaces, common medium and few fine roots, clear and wavy boundary;

Bt1 – 45–57 cm, *argic* horizon, abrupt textural difference, clay loam, light reddish brown (5YR 6/3, 5YR 5/4), slightly moist, moderate columnar fine structure, few medium-sized concretions of secondary carbonates, many distinct clay coatings on pedfaces, common fine and medium roots, clear and smooth boundary;

Bt2 – 57–85 cm, *argic* horizon, fine sandy loam, light reddish brown (5YR 6/4, 7.5YR 4/3), slightly moist, moderate platy very coarse structure, many medium-sized concretions of secondary carbonates, *protocalcic* properties, many distinct clay coatings on pedfaces, common fine and medium roots, clear and smooth boundary;

Bk1 – 85–160 cm, fine sandy loam, pink (7.5YR 7/3, 7.5YR 5/4), slightly moist, moderate platy very coarse structure, very few faint clay coatings on pedfaces, very few fine roots, clear and smooth boundary;

Bk2 – 160–(215) cm, fine sandy loam, light brown (7.5YR 6/4, 7.5YR 4/4), slightly moist, moderate columnar fine structure, no roots.

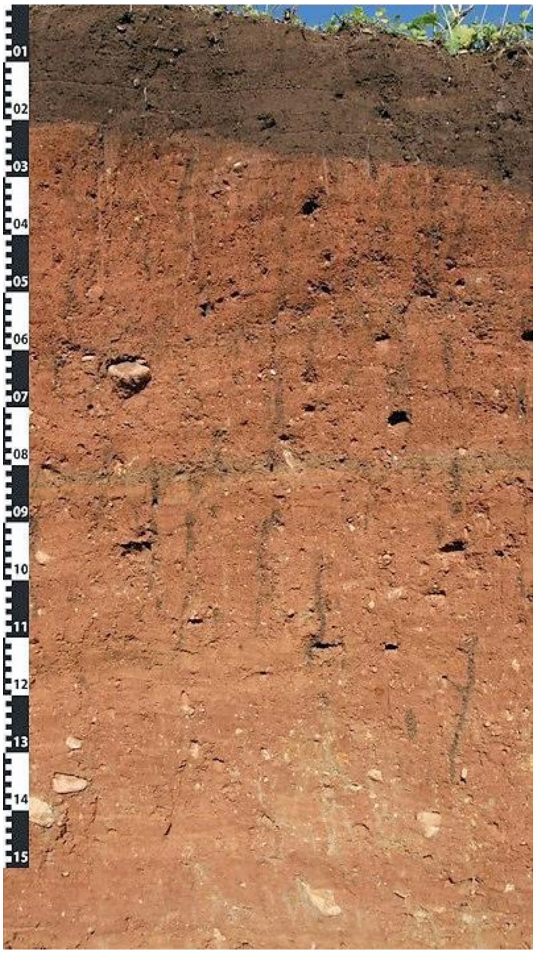
Table 9. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm									Textural class
		>2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.125	0.125–0.063	0.063–0.02	0.02–0.002	<0.002	
Ap	0–30	4.0	1.8	3.8	11.5	20.0	22.2	10.6	11.2	18.8	FSL
Bh	30–45	8.6	1.2	2.8	10.7	20.5	23.9	13.1	14.6	13.3	FSL
Bt1	45–57	5.8	1.2	2.1	7.1	14.0	16.4	13.1	16.9	29.2	CL
Bt2	57–85	8.8	1.2	3.8	10.7	18.9	22.1	13.7	10.5	19.0	FSL
Bk1	85–160	10.5	1.4	4.8	12.7	20.3	24.4	7.3	12.0	17.2	FSL
Bk2	160–(215)	12.5	2.4	5.2	12.5	19.6	23.4	10.5	11.8	14.6	FSL

Table 10. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	pH		$CaCO_3$ [g·kg^{-1}]
			H_2O	KCl	
Ap	0–30	8.8	8.0	7.4	43.2
Bh	30–45	1.7	8.4	7.7	149.1
Bt1	45–57	1.6	8.3	7.6	147.4
Bt2	57–85	0.8	8.6	7.8	210.8
Bk1	85–160	0.9	8.7	8.0	261.7
Bk2	160–(215)	0.9	8.7	8.0	271.5

Profile 6 – Calcaric Amphiluvic Endoprotocalcic **Phaeozem** (Epiabruptic, Aric, Colluvic, Loamic)
Localization: Till plain, middle slope S, complex, gently sloping 5°, arable field, 102 m a.s.l.
N 56°28.854' **E** 22°55.146'



Morphology:

Ap – 0–25 cm, plough *mollic* horizon, partly *colluvic* materials mixed by ploughing, fine sandy loam, brown (7.5YR 5/3, 7.5YR 3/2), slightly moist, medium moderate granular structure, many fine and coarse roots, clear and wavy boundary;

Bt1 – 25–72 cm, *argic* horizon, sandy clay loam, light brown (7.5YR 6/4, 7.5YR 4/4), slightly moist, medium fine and medium subangular prismatic structure, very few medium-sized concretions of secondary carbonates, trans-horizon cracks with humus illuviation, many fine and few coarse roots, clear and wavy boundary;

Bt2 – 72–82 cm, *argic* horizon, loam, pink (7.5YR 7/3, 7.5YR 5/3), slightly moist, medium moderate nutty subangular blocky structure, very few medium-sized concretions of secondary carbonates, trans-horizon cracks with humus illuviation, common fine and medium roots, clear and wavy boundary;

Btk1 – 82–122 cm, *argic* horizon, fine sandy loam, light brown (7.5YR 6/4, 7.5YR 4/4), moist, weak fine subangular prismatic structure, common medium-sized concretions of secondary carbonates, few fine roots, clear and wavy boundary;

Btk2 – 122–166 cm, *argic* horizon, fine sandy loam, light brown (7.5YR 6/4, 7.5YR 4/6), moist, weak fine subangular prismatic structure, common medium-sized concretions of secondary carbonates, very few fine roots, clear and wavy boundary;

Bg1 – 166–181 cm, fine sandy loam, pink (7.5YR 7/3, 7.5YR 5/4), moist, very weak very coarse granular structure, very few very fine roots, clear and wavy boundary;

Bg2 – 181–(207) cm, calcareous parent material, fine sandy loam, pink (7.5YR 7/4, 5YR 5/6), slightly moist, weak fine subangular prismatic structure.

Table 11. Texture

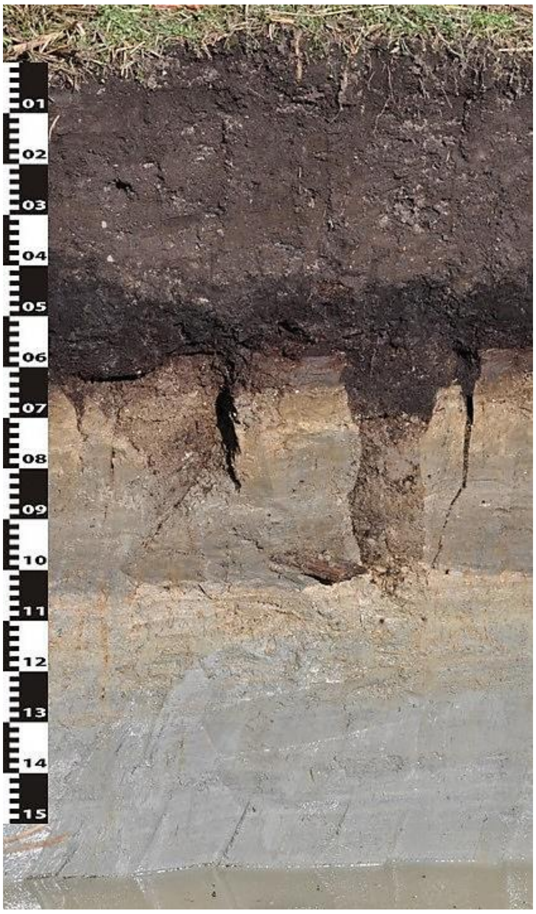
Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm									Textural class
		>2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.125	0.125–0.063	0.063–0.02	0.02–0.002	<0.002	
Ap	0–25	8.9	2.1	5.7	14.8	22.1	23.7	12.5	9.7	9.5	FSL
Bt1	25–72	9.4	1.5	3.2	9.5	17.8	21.1	10.2	15.2	21.6	SCL
Bt2	72–82	9.1	2.5	3.9	7.4	11.2	25.7	13.9	15.6	19.8	L
Btk1	82–122	12.7	1.7	4.2	11.7	20.8	24.3	8.6	11.8	16.9	FSL
Btk2	122–166	7.5	1.9	4.0	9.9	19.2	22.7	10.5	13.0	18.9	FSL
Bg1	166–181	11.7	2.0	5.0	14.3	24.8	27.0	10.5	8.7	7.7	FSL
Bg2	181–(207)	9.6	1.3	3.9	12.0	21.4	24.2	8.8	10.7	17.8	FSL

Table 12. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	pH		$CaCO_3$ [$g \cdot kg^{-1}$]
			H_2O	KCl	
Ap	0–25	13.1	7.6	7.0	10.3
Bt1	25–72	2.4	8.3	7.7	113.9
Bt2	72–82	2.7	8.3	7.5	135.4
Btk1	82–122	1.2	8.5	7.8	150.0
Btk2	122–166	0.8	8.6	7.8	124.3
Bg1	166–181	0.5	8.8	8.2	212.4
Bg2	181–(207)	0.4	8.7	8.0	246.2

Profile 7 – Endohypercalcic Reductigleyic Mollic **Gleysol** (Aric, Colluvic, Drainic, Hyperhumic, Epiloamic, Endosiltic, Raptic)

Localization: Till plain, closed inter-hill depression S, lower part, arable field, 100 m a.s.l.
N 56°28.838' **E** 22°55.249'



Morphology:

Ap – 0–40 cm, plough *mollic* horizon, colluvium, loam, dark gray (7.5YR 4/1, 10YR 3/1), slightly moist, medium moderate granular structure, many fine and very fine and few coarse roots, clear and wavy boundary;

2Ha – 40–50 cm, moderately strongly decomposed peat (*hemic*), black (7.5YR 2.5/1, 10YR 2/1), slightly moist, strong columnar fine structure, very few fine brick fragments, many fine and very fine and very few coarse roots, clear and smooth boundary;

2He – 50–55 cm, strongly decomposed peat (*hemic*), very dark gray (7.5YR 3/1, 10YR 4/3), slightly moist, weak platy medium structure, many fine and very fine roots, clear and smooth boundary;

2Lm – 55–66 cm, *calcic* horizon, *limnic* materials (marl), silty clay loam, light gray (10YR 7/2, 10YR 4/2), moist, very weak columnar fine structure, no roots, gradual and wavy boundary;

2Bkr1 – 66–95 cm, *calcic* horizon, *limnic* materials (marl), silty clay loam, reddish gray (2.5YR 6/1, 2.5Y 5/2), wet, weak subangular prismatic medium structure, very few coarse wood fragments, no roots, abrupt and smooth boundary;

2Bkr2 – 95–123 cm, *calcic* horizon, reducing conditions, silty clay loam, light gray (5Y 7/1, 2.5Y 6/2), very wet, weak subangular prismatic medium structure, no roots, clear and wavy boundary;

2Bkr3 – 123–(180) cm, *calcic* horizon, reducing conditions, silty clay loam, light greenish gray (5GY 8/1, 10G 4/1), very wet, massive structure, no roots.

Table 13. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm									Textural class
		>2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.125	0.125–0.063	0.063–0.02	0.02–0.002	<0.002	
Ap	0–40	3.5	0.4	1.4	3.2	8.5	13.9	20.0	26.3	26.2	L
2Ha	40–50	-	-	-	-	-	-	-	-	-	-
2He	50–55	-	-	-	-	-	-	-	-	-	-
2Lm	55–65	0.2	0.0	0.3	0.9	1.6	7.9	21.3	34.2	33.9	SiCL
2Bkr1	65–95	0.2	0.0	0.3	0.6	2.3	8.5	24.6	35.0	28.7	SiCL
2Bkr2	95–123	0.3	0.0	0.3	0.5	1.8	4.3	18.0	44.5	30.6	SiCL
2Bkr3	123–(180)	0.0	0.0	0.3	0.4	1.4	4.3	16.2	43.7	33.7	SiCL

Table 14. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	pH		$CaCO_3$ [$g \cdot kg^{-1}$]
			H_2O	KCl	
Ap	0–40	163.5	7.6	7.0	32.4
2Ha	40–50	488.0	7.0	6.6	6.3
2He	50–55	298.6	7.2	6.9	33.8
2Lm	55–65	42.4	7.5	7.4	481.7
2Bkr1	65–95	37.2	7.5	7.3	306.6
2Bkr2	95–123	24.9	7.6	7.4	569.8
2Bkr3	123–(180)	16.1	7.6	7.4	429.6

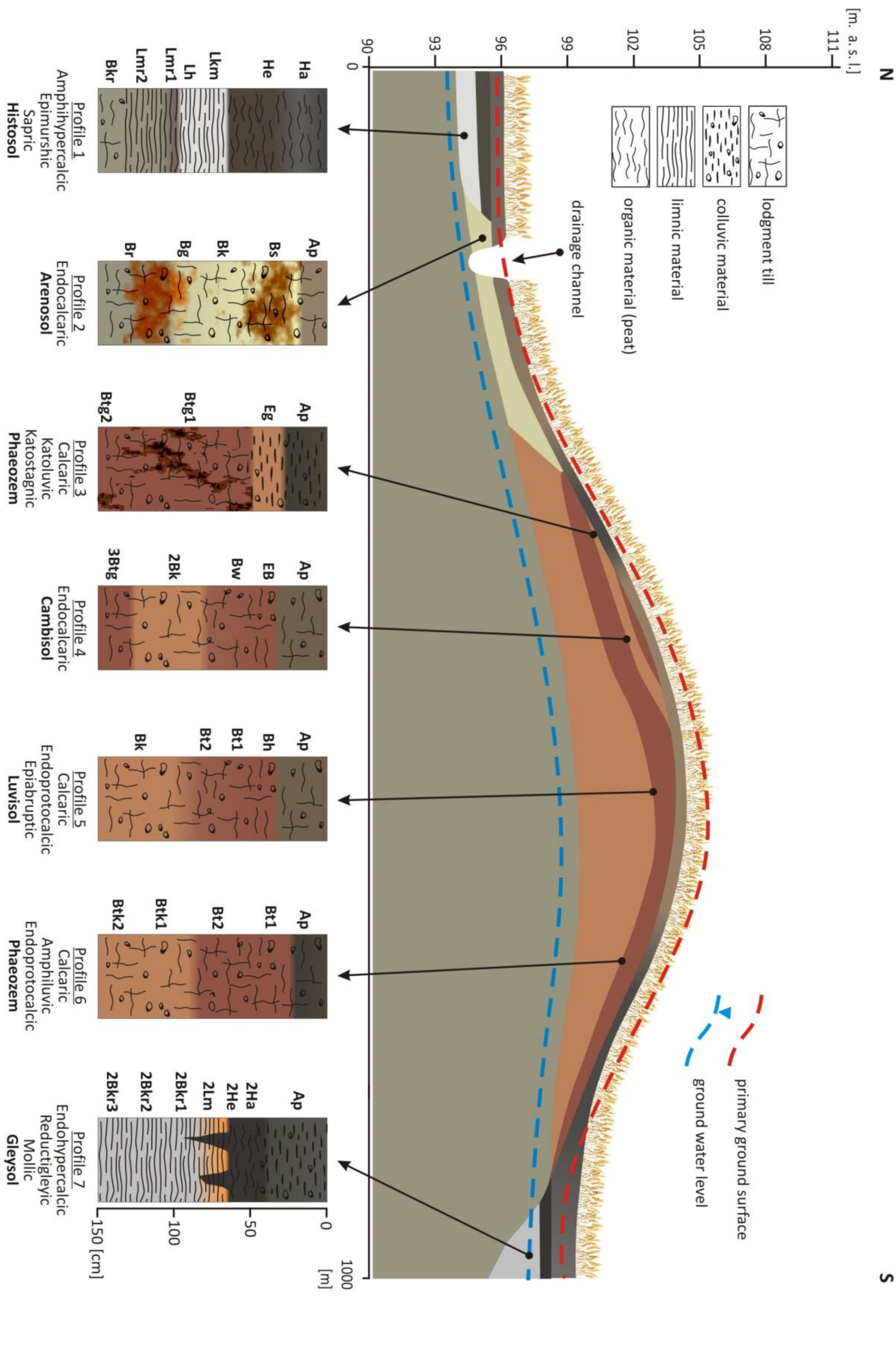


Fig. 3. Lithohydrotoposequence of agricultural soils in morainic landscapes - Southwest Latvia

Soil genesis and systematic position

The investigated soil profiles exhibit a diversity of soil cover within the Central Latvian Lowland in the southern part of Latvia where it borders on the Austrumkursa Upland. The topography of the region represents an undulating morainic plain. The soil catena representing seven profiles is delineated from the northern part of the morainic hill slope (profile 1) to its southern slope (profile 7). The total length of the trajectory (bee line) is 700 m. The first and the last soil profile represent soils at the bottom of the slope. The soil position on the slope and the heterogeneity of the glacial till are the main factors responsible for the diversity of soils in the relatively small area under present study. The taxonomy of all soil profiles was determined using the international methodology (IUSS Working Group WRB, 2015).

Profile 1 is located in the northern part of the selected morainic hill. It is the lowest part of the complex slope, a naturally closed inter-hill depression. During the last century, it was drained by open ditches and tile drains. Despite the drainage installations, water saturation (even ponding) may occur temporarily. The soil has the *histic* diagnostic horizon. The surface layer (0–26 cm) corresponds to *sapric* material, and the subsurface layer (26–47 cm) corresponds to *hemic* material. Because of the presence of soil in the intensive crop rotation with annual soil tillage, peat mineralization is a characteristic feature in such situations. Separate use of such spots is limited due to their small and fragmented areas. Because of the mineralization of peat, the topsoil structure is amorphous (after tillage) or blocky (when dried out), with a relatively high bulk density and cracks, therefore the ***Epimurshic*** qualifier was applied. *Limmnic* materials with snail shells and freshwater lime (***Limnic*** qualifier) are accumulated underneath the peat layer; a strongly gleyed and reduced soil layer is located at a greater depth. This soil is classified as ***Amphihypercalcic Epimurshic Sapric*** **Histosol (*Limnic*)**. Soil properties are presented in Tables 1–2. Obviously, before drainage, such spots were covered with water, forming small permanent or temporal water bodies. Currently, they are part of the field, forming undesirable patchiness in soil cover with contracting properties. This is a characteristic feature of agricultural land having a similar topography.

Profile 2 is located at the footslope, which is a slightly elevated area. The soil has developed from sandy material and, since this place is slightly higher compared to the neighbouring depression, the profile shows typical mineral soil characteristics. Features developed as a result of water saturation are present only at a depth of 80 cm from the soil surface. The soil is rich in calcium carbonate including secondary lime (Tables 3–4). Under such circumstances, a relatively deep A horizon has developed. The soil is classified as ***Endocalcaric*** **Arenosol (*Aric, Endoprotocalcic, Ochric, Amphistagnic, Bathygleyic*)**. On the walls of the profile, heterogeneity of glacial till can be clearly observed. Coarser particles in the form of layers and pockets alternate with finer ones, and the percentage of clay in the soil matrix is low. The temporary high groundwater level in the past and some water stagnation in the 0–80 cm soil layer are clearly evidenced by the oximorphic features of the profile and iron segregation (***Amphistagnic*** qualifier). Since *gleyic* properties start below 75 cm from the soil surface, only the ***Bathygleyic*** qualifier can be used by shifting it to the end of the supplementary qualifiers' list.

Profile 3 is located in the lowest part of the complex slope. Due to colluvial activity, the surface horizon is *mollic*. Colluvium is present also in the next soil horizon, from 27 to 50 cm, having a silt loam texture, which differs from the texture in deeper soil layers (Table 5). In general, soil texture is somewhat finer compared to the previous profile, therefore water stagnation and reducing conditions are evident. Primary carbonates (coarse limestone and dolomite fragments) are present throughout the soil profile, and secondary carbonates in the form of nodules and pseudomycelium occur starting from a depth of 50 cm, which is not enough to qualify this layer as a *calcic* horizon (Table 6).

Groundwater is below 300 cm and does not significantly affect the soil water status, and reducing conditions in some places are due to the surface water stagnation. Intensive weathering of coarse soil fragments is a characteristic feature of soil development. The soil is classified as ***Calcaric Katoluvic Katostagnic*** **Phaeozem (*Aric, Colluvic, Endoloamic*)**. Although colluvium is reworked by ploughing and does not show a clear difference from the material below, it is a characteristic feature of soils in a similar environment.

Profile 4 is located in the middle of a gentle slope. The heterogeneity of the glacial till can also be observed here (Table 7). The Ap horizon is relatively thick due to some colluvial influence. The *Lithic* discontinuity was observed twice: at 83 cm and at 128 cm from the soil surface (the layer of glaciofluvial deposits). Groundwater is deep (> 250 cm) and deposits are relatively loose, therefore some *stagnic* properties were observed only below one metre. In such a situation, only the ***Bathyhypostagnic*** qualifier can be used by placing it at the end of the supplementary qualifiers' list. *Calcaric* soil material starts at a depth of 83 cm and is mainly represented by primary carbonates and partly by secondary ones (Table 8). The *argic* horizon starts deeper, only 128 cm from the soil surface, and its presence does not affect the soil classification. Due to the presence of the *cambic* horizon (56–128 cm), the soil is classified as ***Endocalcaric*** **Cambisol (*Anoarenic, Aric, Drainic, Ochric, Endoraptic, Bathyhypostagnic*)**. Alternatively, it is possible to use also the ***Colluvic*** supplementary qualifier, however, this feature is not very obvious there.

Profile 5 is located in the highest part of the hill. Glacial till with many stones and coarse, boulder-sized fragments is a parent material for the soil. Soil texture is relatively homogeneous within the profile, representing fine sandy loam with a narrow (from 45 to 57 cm) clay loam layer in between (Table 9). Despite its location (the highest point on the hill) and soil tillage, the A horizon is relatively thick. The erosion and the loss of soil material are evidenced by the low content of organic carbon (8.8 g kg^{-1}, Table 10) in the soil. The soil is calcareous at the surface (Table 10); *protocalcic* properties occur starting at 57 cm from the soil surface. At a depth of 45 cm, an abrupt textural difference occurs and a well-developed *argic* horizon starts. Groundwater is deep (> 200 cm), deposits are relatively loose, and surface runoff does not allow soil saturation with water for a long time; therefore, *stagnic* or *gleyic* properties are absent. The soil is classified as ***Calcaric Endoprotocalcic Epiabruptic*** **Luvisol (*Aric, Cutanic, Epiendoloamic, Ochric*)**.

Profile 6 is located on the opposite side of the hill (compared to profiles 1–4). The moraine glacial till, rich in coarse fragments including dolomite, is the parent material for the soil development. Some colluvial activity has led to the accumulation of fine, disperse, humus-rich soil components in the ploughed layer, allowing it to be classified as the *mollic* diagnostic horizon. Groundwater is below 200 cm and many trans-horizon cracks are conducive to water infiltration, therefore some slight *stagnic* properties can be observed only at a depth of 166 cm and deeper (on the surface of pedfaces), which does not affect the soil classification. The calcareous soil material starts at 25 cm, while secondary carbonates start at 32 cm from the soil surface. *Protocalcic* properties are apparent from 82 cm (***Endoprotocalcic*** qualifier). An abrupt textural difference occurs at a depth of 25 cm from the soil surface (***Epiabruptic*** qualifier). The presence of the *mollic* diagnostic horizon keys out the soil as **Phaeozem**, and the addition of all specific features, including primary and secondary carbonates, clay illuviation, deep ploughing, colluvium and soil texture leads to the full soil name: ***Calcaric Amphiluvic Endoprotocalcic*** **Phaeozem (*Epiabruptic, Aric, Colluvic, Loamic*)**. Alternatively, if the A horizon does not meet the criteria of *mollic*, the soil can be classified again as **Luvisol**.

Profile 7, similarly to profile 1, is located in a closed inter-hill depression, but in this case at the southern end of the catena. This is the lowest part of the field surface, a water-receiving area without open discharge channels. Excess-water removal is possible only with the help of a closed tile-drain system. The soil surface horizon (0–40 cm) is formed from decomposed peat with colluvial admixture and is qualified as the mineral (*mollic*) horizon because of the low organic carbon content – 16.5% (Table 14). The threshold for organic soil material is ≥ 20% of organic carbon, which was probably the case some decades ago. Soil organic materials are present at a depth of 40–55 cm. The presence of well-developed *limnic* deposits (55–95 cm) confirms that naturally (before drainage) this part was an open permanent or temporal waterbody. The calcareous material consisting of snail shells and freshwater lime allows the *calcic* horizon (55–180 cm) to be determined. The soil is classified as ***Endohypercalcic Reductigleyic Mollic*** **Gleysol (*Aric, Colluvic, Drainic, Hyperhumic, Epiloamic, Endosiltic*).** Based on the *mollic* diagnostic horizon and reducing conditions directly underneath, this soil can be classified into the **Gleysol** Reference soil group. In this specific case, the definition criteria for *mollic* are marginal. If this diagnostic horizon was thinner, the soil would be keyed out as ***Gleyic*** **Phaeozem**. This might happen in the nearest future if decomposition of organic matter continues. *Gleyic* properties are strongly exposed but lack mottles of oximorphic colours. This means that only reducing conditions are present in this part of the soil profile, therefore the ***Reductigleyic*** qualifier should be applied. The soil is strongly calcareous in the lower part (***Endohypercalcic*** qualifier); deeply ploughed (***Aric***); additions of colluvium in the A horizon (***Colluvic***); drained (***Drainic***); and more than 5% of organic carbon in the fine earth as a weighted average at a depth of 50 cm from the mineral soil surface (***Hyperhumic*** qualifier). The soil has different textures: loam in the surface horizon (***Epiloamic*** qualifier) and silty loam below 55 cm (***Endosiltic*** qualifier) (Table 13).

Soil sequence

The above-described transect shows significant differences in soil cover under slightly undulating topography. The main factors responsible for such diversity are relief position and heterogeneity of morainic deposits. Anthropogenic activity, i.e. formation of large fields, changed the water regime in the whole area, but the soil pattern and properties remained unaffected. This represents some limitation for modern farming, because fertility status, moisture conditions, and soil tillage requirements are different in different parts of the field.

Profiles 1 and 7 represent peculiarities of soils formed in inter-hill depressions, especially in the closed ones. These depressions usually cover less than 25% of the current field area. Water pounding and the formation of limnic deposits and peat have led to the accumulation of organic matter in the surface layer in the past. After drainage and soil cultivation, mineralization of peat has taken place. Also some admixture of colluvium from the neighbouring slopes has changed the soil surface properties. ***Sapric*** **Histosols,** ***Mollic*** **Gleysols** or even ***Gleyic*** **Phaeozems** might be found in such locations. The above-mentioned soils have very contrasting properties compared to other soils found on the slopes and in higher parts of the hills. Therefore, management of the field as a whole unit is burdened.

In this particular region, glacial till is rich in limestone and dolomite, therefore base saturation of soil is high throughout the whole profile and the formation of secondary lime is evident. This explains the occurrence of **Phaeozems** and the use of several principal and supplementary qualifiers, reflecting the presence of primary (***Calcaric*** qualifier) and/or secondary (***Calcic*** qualifier) carbonates in the soil. Weathering of coarse fragments in the soil is intensive, providing plants with calcium, magnesium and potassium and maintaining their high status in the soil.

Profile 2 is located in a relatively flat area and is not affected by erosional or colluvial activity. Glacial till deposits in this part of the area are sandy, leading to the development of ***Endocalcaric* Arenosol.** The influence of the previous (before drainage) groundwater level in the soil is considerable.

In the highest part of the morainic hill, ***Epiabruptic*** **Luvisol** was found. The use of the ***Abruptic*** (also ***Raptic***) qualifier there and elsewhere shows that in many cases the name of the soil depends on the glacial till deposits from which the soil was formed. Heterogeneity of till is significant and was observed in any soil profile pit. Therefore, depending on the occurrence of illuvial clay coatings, soils might be keyed out as **Luvisols** or **Cambisols** (e.g. in profile 4). Due to the high biological activity of soil (calcareous, nutrient-rich parent material, rock weathering), the use of fertilisers, reasonable soil management practice and the relatively gentle slope, soil erosion has not caused serious problems or topsoil degradation.

Profiles 3 and 6 represent soils located on slopes at a similar position. The soil in this location partly receives and partly loses the humus-rich material. In such a situation, **Phaeozems** might be found. If the content of organic matter is too low and the topsoil does not meet colour requirements for the *mollic* diagnostic horizon, the soils can again be classified as **Luvisols** or **Cambisols**.

The above-mentioned soil sequence is typical in a situation when glacial till deposits are carbonatic, rich in fine-sized limestone and/or dolomite fragments. Otherwise, **Retisols** and, in some places, also **Umbrisols** will be the case instead of **Luvisols** and **Phaeozems**. In places where morainic deposits contain more clay and are denser, **Stagnosols** will occur.

References

Aber, J. S., Ber, A., 2007. Glaciotectonism. Developments in Quaternary Science 6. Elsevier, Amsterdam, 246.

Ber, A., 2009. Vertical stress of Pleistocene continental glaciers and its hypothetical evidence in present relief of Northern Europe. Polish Geological Institute Special Papers, 2: 7–12.

Boruks, A., 2003. Dabas apstākļi un to ietekme uz agrovidi Latvijā [Nature conditions and their impact on the agroenvironment of Latvia]. Latvijas Republikas Valsts zemes dienests, Rīga (in Latvian).

Hytteborn, H., Maslov, A.A., Nazimova, D.I., Rysin, L.P., 2005. Boreal forests of Eurasia. In: Andersson F. (ed.) Coniferous forests, Ecosystems of the World, 6, Elsevier, Amsterdam: 23–99.

IUSS Working Group WRB, 2015. World Reference Base for soil resources 2014, update 2015 International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Report No. 106. FAO, Rome.

Lamsters, K., 2015. Subglacial landsystems and dynamics of the Zemgale lobe of the Fennoscandian ice sheet. Summary of Doctoral thesis. Latvia University, Riga: 49–89.

Lamsters, K., Karušs, J., Ošs, R., Ješkins, J., 2018. Glaciotectonic deformation structures and landforms in Western Latvia. Geophysical Research Abstracts, 20, EGU2018–17652, EGU General Assembly.

https://meetingorganizer.copernicus.org/EGU2018/EGU2018-17652.pdf

Raczynski, P., Biernacka, J., 2014. Zechstein in Lithuania–Latvia Border Region. Geologija, 56.2(86): 57–62.

Strautnieks, I., 1998. Austrumkursas augstienes reljefs un tā ģenēze [Relief and its genesis of Austumkursa upland]. Doctoral thesis. Latvia University, Riga (in Latvian).

Zelčs, V., 2018. Zemes virsmas reljefs [Earth's relief]. In: Nikodemus O., Kļaviņš M., Krišjāne Z., Zelčs V. (eds.), Latvija, Zeme, Daba, Tauta [Latvia, Land, Nature, People, Country]. Latvijas Universitāte, Rīga: 89–93 (in Latvian).

Zelčs, V., Markots, A., Nartišs, M., Saks, T., 2011. Pleistocene Glaciations in Latvia. In: Ehlers, J., Gibbard, P.L., Hughes, P.D. (eds.), Quaternary glaciations – extent and chronology. A closer look. In: Developments in Quaternary Science, 15. Elsevier, Amsterdam: 221–229.

Zelčs, V., Markots, A., 2004. Deglaciation history of Latvia. In: Ehlers, J., Gibbard P. L. (eds.), Quaternary Glaciations – Extent and Chronology. Part I: Europe. In: Developments in Quaternary Sciences, 2. Elsevier, Amsterdam: 225–243.

Agricultural areas within hummocky moraine landscapes of north-east Lithuania

Rimantas Vaisvalavičius, Jonas Volungevičius, Vanda Buivydaitė, Virgilija Gregorauskienė

Fig. 1. Location

The investigated area is situated on the marginal glacial formations of the Late Weichselian glaciation Baltija stage, between marginal ridges of the Middle and South Lithuanian Phases (Kudaba, 1983; Guobytė, 2002, 2013). The moraine ridges are dated from 13600 to 14000 years BP. The described territory is situated on the marginal glacial deposits of the interlobate moraine massive between the Siesartis and Šešuola depressions (Basalykas, 1965). To the west, they are linked to the younger moraine ridges of the Middle Lithuanian Phase. As the marginal moraine ridges of the Middle Lithuanian Phase formed under the influence of the diminishing glacier and were exposed in later periods to the ice melting and glaciolacustrine waters, they and the edges of the older South Lithuanian Phase glacial sediments are heterogeneous.

Lithology and topography

Although medium and heavy loam is dominant (Kudaba, 1983), interlayers of outwashed sandy loam and glaciofluvial sediments could be identified, too. The glaciolacustrine sand deposited in the depressions between hills was covered in the Holocene by organogenic peat. The relief of the investigated area could be described as hummocky moraine and is characterised by small (up to 300 m in diameter) and moderately steep hills (according Basalykas, 1967). The hill slopes are complex and composed of slopes of different angles – in the lower part of the slope 5–7° angles are dominant, while in the upper part of the hills the inclination reaches only 2–3°. The primary surface changed during the late glacial and Holocene due to the geodynamic and accumulation processes. The depressions between hills were filled out with peat, so they became more shallow (by nearly one metre). Due to physical erosion during post-glaciation and the agro-industrialisation of the landscape during the last century, the hills in the area sank by about 50 cm and the depressions among hills were filled in with a similar thickness of colluvium (deluvium).

Land use

Lithuania is in a zone of mixed forests (coniferous and mixed broadleaf forest). At the beginning of the Neogen there grew even such trees as beech, chestnut, cypress, magnolia, sequoia and other deciduous species. Following the retreat of the last Valdaj (Vistulian) glacier, tundra vegetation prevailed. Historical data shows that in the past there were forests all over the country's territory. In the 15th century the area of forests began to decrease considerably (Vaičys, 1975).

Profile 1 – Eutric Endocalcaric Endostagnic **Retisol** (Loamic, Aric, Cutanic, Ochric)
Localization: The top of the hill, inclination 0.5 – 1.0°, cropland, 129 m a.s.l.,
N 55°14'25.93", **E** 24°59'55.47"

Morphology:

Ah1 – 0–12 cm, humic horizon, sandy loam, very dark gray (7.5YR 3/1), subangular blocky structure, slightly hard/firm consistency, brick, ceramic, clear and smooth boundary;

Ah2 – 12–30 cm, humic ploughing horizon, sandy loam, brown (7.5YR 4/3), subangular blocky structure, slightly hard/firm consistency, brick, ceramic, clear and smooth boundary;

E/B – 30–60 cm, elluvial/illuvial horizon with albeluvic glossae, sandy loam, E - light brown (7.5YR 6/4), B - strong brown (7.5YR 5/6), subangular blocky structure, hard/very firm consistency, clear boundary;

Bt – 60–65 cm, *argic* horizon, sandy clay loam, brown (7.5YR 4/4), angular blocky structure, hard/very firm consistency, clear boundary;

Btg – 65–105 cm, *argic* horizon with stagnic properties, sandy clay loam, strong brown (7.5YR 5/6), angular blocky structure, hard/very firm consistency, clear boundary;

BCkg – 105–(130) cm, transitional horizon with stagnic properties, sandy clay loam, brown (7.5YR 4/4), with light bluish gray spots (GL2 7/5B), angular blocky structure, hard/very firm consistency.

Table 1. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	0–30	4	4	4	11	22	17	13	12	6	11	SL
E/B	30–60	3	3	4	10	23	17	15	11	5	12	SL
Bt	60–65	1	3	4	10	21	16	7	7	5	27	SCL
Btg	65–105	3	3	3	9	21	16	8	8	5	27	SCL
BCkg	105–(130)	15	3	4	9	20	14	11	10	5	24	SCL

Table 2. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	C/N	pH		$CaCO_3$ [$g \cdot kg^{-1}$]
					H_2O	KCl	
Ah	0–30	11.2	0.55	21	7.0	6.3	traces
E/Bt	30–60	-	-	-	7.4	5.5	traces
Bt	60–65	-	-	-	6.6	5.6	4.2
Btg	65–105	-	-	-	7.1	5.0	3.3
BCkg	105–(130)	-	-	-	8.8	7.7	115

Profile 2 – Endostagnic Endoabruptic **Luvisol** (Epiloamic, Amphiarenic, Aric, Cutanic, Ochric, Raptic,)
Localization: The top of the hill, inclination 0.5 – 1.0°, cropland, 128 m a.s.l.
N 55°14'27.02" **E** 24°59'56.04"

Morphology:

Ah – 0–25 cm, humus horizon, sandy clay loam, reddish brown (5YR 4/4), few strong subangular blocky structure, dry, clay coatings on pedfaces, very few roots, earthworm channels and live earthworms, clear and smooth boundary;

Bt – 25–37 cm, *argic* horizon, sandy clay loam, yellowish red (5YR 4/6), strong subangular blocky structure, dry, few clay coatings on pedfaces, very few roots, earthworm channels and live earthworms, gradual and smooth boundary;

2C1 – 37–42 cm, fine sand, yellowish red (7.5YR 5/6), single grain structure, slightly moist, abrupt and smooth boundary;

2C2 – 42–63 cm, fine sand, reddish brown (7.5YR 5/4), single grain structure, slightly moist, clear and smooth boundary;

3Bt – 63–70 cm, *argic* horizon, sandy clay loam, yellowish red (5YR 4/6), moderate angular and subangular blocky structure, slightly moist, common clay coatings on pedfaces, clear smooth boundary;

3Btg1 – 70–92 cm, *argic* horizon with stagnic properties, sandy clay loam, reddish brown (5YR 5/4), strong angular and subangular blocky structure, slightly moist, common clay coatings on pedfaces, gradual and smooth boundary;

3Btg2 – 92–(100) cm, *argic* horizon with stagnic properties, sandy clay loam, reddish brown (5YR 4/4), strong angular and subangular blocky structure, slightly moist, common clay coatings on pedfaces.

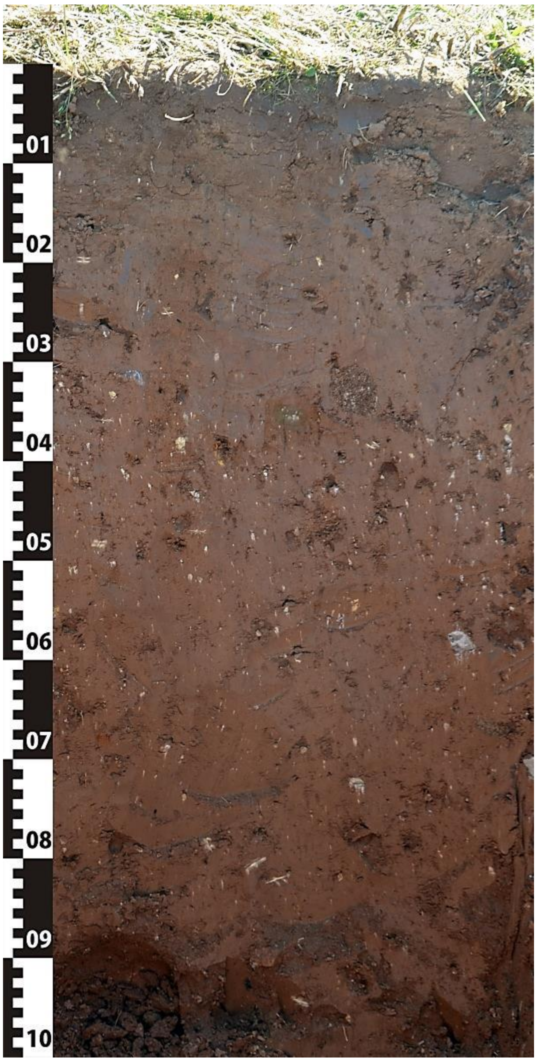
Table 3. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	3	2	4	12	24	17	9	7	5	20	SCL
Bt	25–37	2	1	2	9	33	17	8	6	3	21	SCL
2C	37–63	0	0	2	26	50	12	2	0	0	8	FS
3Bt	63–70	1	1	1	9	36	20	6	3	2	22	SCL
3Btg	70–(100)	1	2	3	9	20	14	8	9	5	30	SCL

Table 4. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	C/N	pH		$CaCO_3$ [$g \cdot kg^{-1}$]
					H_2O	KCl	
Ah	0–25	9.19	0.52	18	6.0	4.6	traces
Bt	25–37	-	-	-	5.7	4.2	traces
2C	37–63	-	-	-	5.9	4.8	traces
3Bt	63–70	-	-	-	6.1	4.5	-
3Btg	70–(100)	-	-	-	6.1	4.5	-

Profile 3 – Epicalcaric Chromic **Luvisol** (Loamic, Cutanic, Ochric)
Localization: gently sloping, north exposition, cropland, 125 m a.s.l.,
N 55°14'27.84" **E** 24°59'56.36"



Morphology:

Ah – 0–15 cm, humus horizon, sandy clay loam, dark reddish brown (5YR 3/2), strong subangular blocky structure, few roots and earthworm channels, gradual and smooth boundary;

Bt – 15–35 cm, argic horizon, sandy clay loam, dark reddish brown (5YR 3/4), strong angular blocky structure, many clay cutans, earthworms channels, diffused boundary;

Btk – 35–80 cm, *argic* horizon, sandy clay loam, dark reddish brown (5YR 3/4), strong angular blocky structure, many clay cutans, diffused boundary;

BCk – 80–(100) cm, transitional horizon, sandy clay loam, subangular and angular structure, reddish brown (5YR 4/4), 7 pH, earhworms channels, common cutans, secondary and primary carbonates.

Table 5. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	0–15	2	2	3	10	21	14	11	7	7	25	SCL
Bt	15–35	1	2	3	9	19	12	10	10	6	29	SCL
Btk	35–80	6	3	3	9	20	13	10	9	7	26	SCL
BCk	80–(100)	7	3	4	9	19	14	10	10	6	25	SCL

Table 6. 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	
Ah	0–15	9.82	0.57	17	6.9	6.2	traces
Bt	15–35	-	-	-	7.3	6.1	traces
Btk	35–80	-	-	-	8.5	7.7	92.0
BCk	80–(100)	-	-	-	7.7	7.8	106.9

Profile 4 – Dystric Rheic Drainic **Histosol** (Colluvic, Epiloamic Umbric)
Localization: foot slope, cropland, 124 m a.s.l.
N 55°14'29.56" **E** 24°59'56.74"

Morphology:

Ah – 0–30 cm, humus horizon, colluvial deposits mixed with decomposed organic material, loam, very dark greyish brown (10YR 3/2), subangular blocky structure, many roots, insect and animals burrows, clear and wavy boundary;

2Ha – 30–60 cm, organic horizon, highly decomposed, light grey (10YR 7/1), subangular blocky structure, very few biological features, gradual and wavy boundary;

2He – 60–100 cm, organic horizon, moderately decomposed, very dark greyish brown (10YR 3/2), platy structure, very few biological features, gradual and wavy boundary;

2Hi – 100–135 cm, organic horizon, weakly decomposed, very dark greyish brown (10YR 3/2), platy structure, no biological features, clear and wavy boundary;

3L – 135–(160) cm, limnic organic horizon, dark reddish brown (5YR 3/2), massive structure.

Table 7. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	0–30	4	2	4	9	19	11	21	11	7	16	L
2Ha	30–60	-	-	-	-	-	-	-	-	-	-	-
2He	60–100	-	-	-	-	-	-	-	-	-	-	-
2Hi	100–135	-	-	-	-	-	-	-	-	-	-	-
3L	135–(160)	1	0	8	10	6	10	21	23	11	11	SL

Table 8. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	C/N	pH		$CaCO_3$ [$g \cdot kg^{-1}$]
					H_2O	KCl	
Ah	0–30	55.2	2.35	23	5.9	5.2	-
2Ha	30–60	399	19.6	20	6.1	5.4	-
2He	60–100	299	18.3	16	5.3	4.7	-
2Hi	100–135	388	20.1	19	5.5	5.0	-
3L	135–(160)	48.5	1.59	30	3.6	3.4	-

Profile 5 – Endocalcaric Mollic **Gleysol** (Loamic, Aric, Colluvic, Drainic, Raptic)
Localization: foot slope, cropland, 126 m a.s.l.,
N 55°14'30.74" **E** 24°59'56.49"

Morphology:

Ah – 0–40 cm, *mollic* horizon, colluvial material, loam, medium moderate subangular blocky structure, dark brown (10YR 3/3), dry, few biological features, clear and wavy boundary;

2Ab – 40–55 cm, buried *mollic* horizon, colluvial material, loam, very dark gray (10YR 3/1), fine moderate subangular and angular blocky structure, dry, very few biological features, clear and wavy boundary;

2Cr – 55–(80) cm, parent material with reducing conditions, silty clay, massive structure, olive gray (5YR 5/2), very few biological features.

Table 9. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	0–40	1	1	2	9	20	16	15	12	10	15	L
2Ab	40–55	0	1	1	4	9	15	15	19	15	21	L
2Cr	55–(80)	0	0	0	0	1	13	15	18	12	41	SiC

Table 10. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	C/N	pH		$CaCO_3$ [$g \cdot kg^{-1}$]
					H_2O	KCl	
A	0–40	13.8	0.7	20	6.6	5.7	traces
2Ab	40–55	34.2	1.15	30	6.4	5.4	-
2Cr	55–(80)	-	-	-	5.7	4.8	-

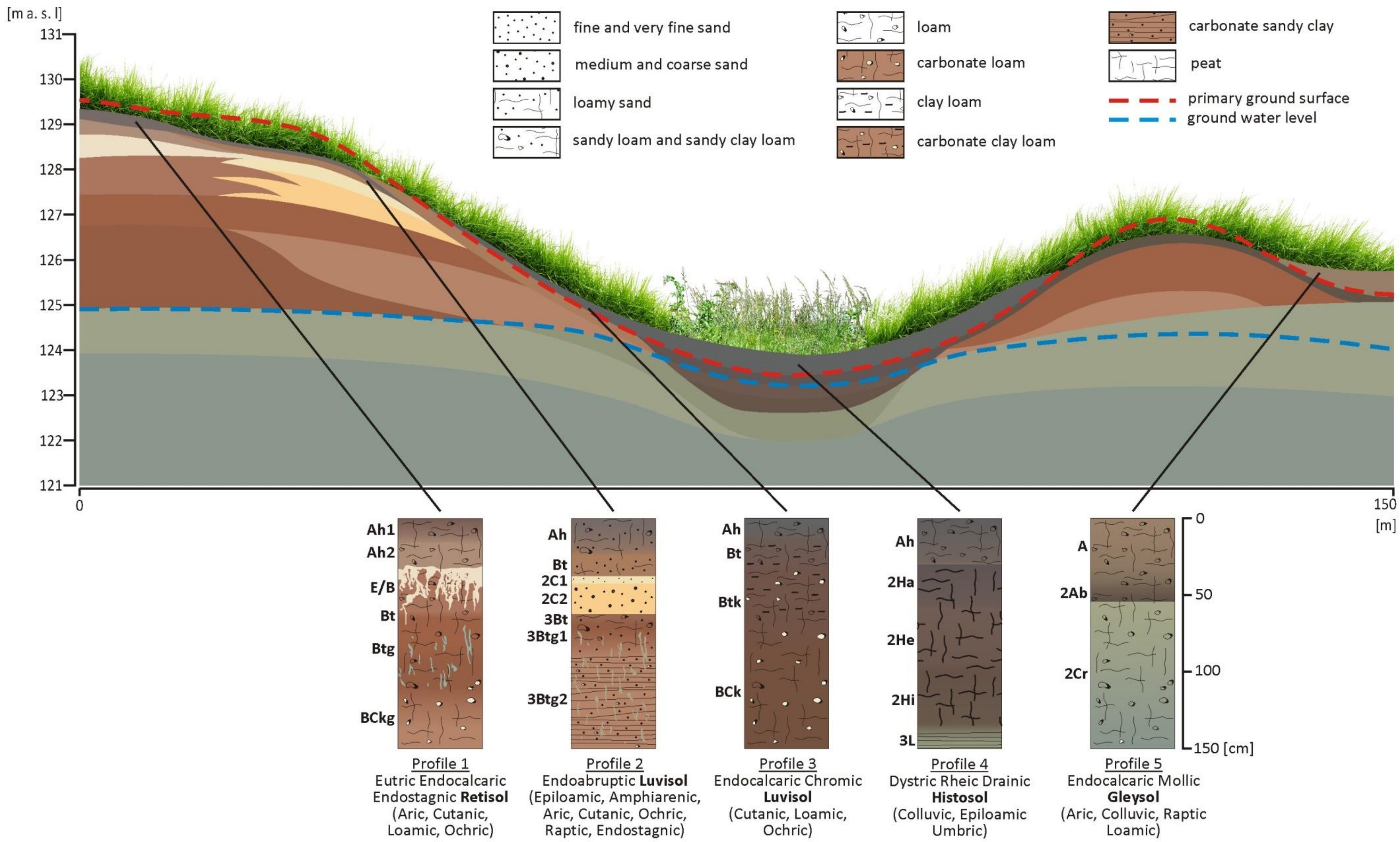


Fig. 2. Hydrolithotoposequence of soils within hummocky moraine Landscapes of north-east Lithuania

At present, due to intensive agriculture development, forest covers only around one-third of the country's area (33.4%), while agricultural areas have expanded to 52.4%. Thus, in general, a very similar proportion of woodland area is currently preserved in the north-east of Lithuania, since the dominant land-use type here is agriculture, with cropland as the main component. However, as an alternative for the conventional farming, ecological (organic) farming has been consistently practised in the particular area of investigation since 1998. The reason for this solution was the idea of conservation tillage, such as no-till or minimum tillage, which has come out of local farmers' sustainable approach to farming conditions – the soils are of medium fertility and the area's landscape being hilly puts it at increased risk of erosion. Currently, Spelt (*Triticum spelta*), winter rye, caraway, timothy and white clover are widely grown in crop rotation. Nevertheless, a certain disadvantage under the current conditions of minimum tillage is that various species of weeds are spreading in the fields. It was assessed that *Chenopodium album* L., *Stellaria media* (L.) Vill. and *Poa annua* L. were the most common species among the annual weeds, while *Elytrigia repens* (L.) Nevski, *Rumex crispus* L., *Artemisia vulgaris* L. were found to be the dominating perennial weed species (Genys et al., 2017).

Climate

The study area belongs to the Pietryčių aukštumų (i. e., southeast highlands) climatic region and the Aukštaičių sub-region (Bukantis, 2016). The average annual temperature is 6.1–6.7°C. The average temperature of the coldest month (January) is –4.8 to –3.8°C, while the warmest month is July (17.7–18.0 °C). Mean annual amount of precipitation is about 610–690 mm. Snow cover persists is 90 – 105 days, meanwhile, the sunshine duration is one of the shortest in Lithuania – 1690–1770 hours.

Soil genesis and systematic position

The investigated soil profiles are formed in marginal moraine structures, while the prevailing inherent natural soil processes, included weak podzolisation, hydromorphism, peat formation and organic matter accumulation. In the meantime, in the recent anthropogenic transformation of the uplands, peat formation processes have stopped and hydromorphism is strongly reduced. However, intense erosion accompanied by the accumulation of slope colluvium and organic matter mineralisation and leaching are beginning. The common feature of the hummocky moraine landscapes of north-east Lithuania is the extensive occurrence of **Luvisols** and **Retisols** – which are the typical soils of the region (Jankauskas et al., 2001).

Profile 1 is located in an upper part of the moraine ridge. This soil was previously formed in a woodland landscape in a cold, wet climate. At the beginning of the landscape agrogenisation, forests were cut down, and ploughing of the land started. As at the moment, soils here are undergoing erosion. This is evidenced by the soil profile's unidentified thin E horizon. Also, quite high up (at a depth of 105 cm), the superposition of a calcareous BCkg horizon begins. At this age of deposits, superposition of carbonates should occur at least 20–30 cm deeper (Guobytė and Satkūnas, 2011). That fact suggests that the examined soil was previously exposed to erosion. Later on, due to changes in land use the erosion stopped, and the accumulation of humus substances started in the Ah horizon. This process became more intensive at the very beginning of the 21st century, at first, after the introduction of minimum tillage agriculture. This could be confirmed by the topsoil Ah horizon's differentiation into the subhorizons Ah1–Ah2. This soil (Profile 1) illustrates that, in Lithuania's climatic conditions, the inherent soil processes in the marginal moraine structures include leaching and weak podzolisation. Also, in comparison with the other agrarian territories, here, the accumulation of organic matter and humification is quite intense.

The discussed soil profile has a well-expressed *argic* diagnostic horizon starting within 100 cm of the mineral soil surface and having CEC of ≥24 $cmol_c$ kg clay throughout, as well as *interfingering* (at a depth of 30–60 cm) of coarser-textured *albic* material into a finer-textured *argic* horizon. ***Stagnic*** properties are present in a ≥25-cm-thick layer that starts between 50 and 100 cm from the mineral soil surface and the material containing ≥2% of *primary carbonates* started at a depth of 105 cm. The pH values measured within 100 cm indicated that the soil could have high enough base saturation (>50%) to be expressed using the ***Eutric*** qualifier. Taking into account all the aforementioned considerations, Profile 1 was finally classified as a ***Eutric Endocalcaric Endostagnic*** **Retisol** (IUSS Working Group WRB, 2015).

Profiles 2 and 3 are in a south-westward slope of a moraine ridge. In genetic terms, these two soil profiles are formed in heterogeneous parent material formations from previous **Retisol**. The main factor leading to their formation is soil erosion because of intensive ploughing in the 20th century. Those assumptions are supported by the absence of inherent genetic and diagnostic horizons that are usually common in zonal soils of this region and the high beginning of the superposition of the calcareous BCkg horizon. Profile 2 illustrates inherent erosion processes common in agrarian moraine hilly heights. By contrast, Profile 3 is formed in material that was transported by water down from the eroded south-westward slope of the investigated catena. This origin of the soil parent material is presented in greyish brown horizons with a high concentration of limestones in the soil. Profile 2 is located at a higher elevation than Profile 3, however, both investigated soils meet the main requirements of **Luvisols** (IUSS Working Group WRB, 2015) since they have a higher clay content in the subsoil than in the topsoil, as a result of pedogenetic processes (especially clay migration) leading to an *argic* subsoil horizon. An abrupt textural change is present in Profile 2 (indicated with the qualifier ***Endoabruptic***) and ***Stagnic*** properties are observable in a layer of ≥25 cm thick that starts between 50 and 100 cm from the mineral soil surface. For the next profile (No. 3) the ***Chromic*** and ***Epicalcaric*** principal qualifiers were justified.

Profile 4 is typical of hydromorphic depressions of cold humid climate at moraine formations hilly highlands relief. In general, such soil profiles are shallow **Histosols** which are very often covered by slope colluvial deposits. The investigated soil profile reflects climate and landscape changes, and because of that, changes in soil formation conditions: there has been a gradual drying and warming of the climate. Moreover, this is also evidenced by the increasing degree of peat (turf) fragmentation while investigating from the deeper to the upper layers of the soil profile. The signs of natural previous soil formation here are recorded only looking down from the 60 cm depth, while the above present layers are formed in the cultivated landscape. After drainage was installed, the mineralisation of peat in the highlands increased. Therefore, this **Histosol** (Profile 4) is identified by the highly mineralised, 30- to 60-cm-thick peat (turf) layer. The investigated soil profile morphology is typical of all **Histosols** that are formed in the hydromorphic depressions of the agro-highlands in Lithuania.

Profile 5 occupies an intermediate position between the eroded slopes and peaty depressions. It is characterised by the hydromorphic and reductomorphic processes and accumulation of slope colluvial fans. Since the examined soil has a well expressed continuous greenish grey 2Cr horizon (i.e., ***Gleyic*** properties are present), it was identified as a **Gleysol**. In general, such soils in Lithuania are formed around the edges of relatively well drained parts at higher elevations or lower-level hydromorphic peaty depressions.

Soil sequence

The above-described transect shows both the natural evolution of soil cover in the agrarian hilly highlands and the impact of agricultural activities on soils, and particularly thatthat in most cases they were artificially drained during the second half of the 20th century. In general, three main phases of the evolution of rural hilly upland soils are reflected in the investigated catena: the result of natural conditions (up to the 19th century); an intensive and extensive of agriculture (in the early-20th and the 21st centuries, respectively). Those phases are most visible in the soil profiles' morphology and changes in amount of organic carbon. Natural processes specific to moraine hilly landscapes (leaching, gleyification and peat formation) are clearly visible in the ***Eutric Endocalcaric Endostagnic*** **Retisol**, ***Endocalcaric Mollic*** **Gleysol** and ***Dystric Rheic Drainic*** **Histosol** (soil Profiles 1, 5 and 4, respectively). Soil erosion processes (soil formation on hills eroded by water and slope alluvial-deluvial fans) caused by intensive agriculture illustrates ***Endostagnic Endoabruptic*** **Luvisol** and ***Epicalcaric Chromic*** **Luvisol** (soil Profiles 2 and 3, respectively). As a characteristic feature of the farming approach in the vicinity, the effect of extensive farming activities is visible in soil Profile 1.

References

Basalykas, A., 1965. Lietuvos TSR fizinė geografija [Physical geography of the Lithuanian SSR]. Fiziniai geografiniai rajonai [Physical geographic regions]. Vol. II. Vilnius: Mintis. 495 pp. (in Lithuanian).

Bitinas, A., 2012. New insights into the last deglaciation of the south-eastern flank of the Scandinavian Ice Sheet. In: Quaternary Science Reviews, Vol. 44: 69–80.

IUSS Working Group WRB. 2015. World Reference Base for Soil Resources 2014, update 2015 International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome.

Jankauskas, B., Mažvila, J., Prapiestienė, R., Šleinys, R., Vaičys, M. 2001. Main soil groups of Lithuania, their properties and distribution. In: Soils of Lithuania. Monograph. Lietuvos mokslas [Science and Arts of Lithuania], Vilnius, Book 32: 409–689 (in Lithuanian with English Summary).

Gaigalas, A., 2001. Viršutinio (vėlyvojo) pleistoceno stratigrafija ir geochronologija [Stratigraphy and geochronology of the upper (late) Pleistocene]. In: Baltrūnas, Vilnius. (Ed.), Akmens amžius Pietų Lietuvoje [The Stone Age in South Lithuania]. Institute of Geology, Vilnius: 7–24 (in Lithuanian).

Genys, V., Marcinkevičienė, A., Pupalienė, R., 2017. Piktžolių kontrolės sistema V. Genio ekologiniame ūkyje [Weed control system at V. Genys organic farm]. In: Herbology 2017 [electronic resource]: Lietuvos laukų piktžolėtumo problemos: mokslinė-praktinė konferencija [Weed control problems of Lithuania: scientific-practical conference]. Aleksandras Stulginskis University, Lithuanian Herbology Society. Akademija: 19-21.

Guobytė, R., 2004. A brief of the Quaternary of Lithuania and the history of its investigations. In: Ehlers, J., Gibbard, P.L. (Eds.), Quaternary Glaciations – Extent and Chronology. Elsevier: 245–250.

Guobytė, R., 2013. Geomorfologinis žemėlapis [Geomorphological map]. Vilnius. Geological Survey of Lithuania. (in Lithuanian).

Guobytė, R., 2002. Kvartero geologinis žemėlapis [Quaternary Geology Map]. Vilnius. Geological Survey of Lithuania (in Lithuanian).

Guobytė, R., Satkūnas J. 2011. Pleistocene Glaciations in Lithuania. In: Ehlers, J., Gibbard, P.L and Hughes P.D. (Eds.), Quaternary Glaciations – Extent and Chronology. A closer Look. Elsevier: 231–246.

Kudaba, Č. 1983. Lietuvos aukštumos [Highlands of Lithuania]. Vilnius: Mokslas. 186 pp. (in Lithuanian).

Vaičys, M., 1975. Pietų pabaltijo miškų dirvožemių genezė ir savybės [Genesis and properties of forest soils in the southern part of the Baltic area]. Vilnius: Mintis, 411 pp. (in Russian with summaries in Lithuanian, English and German).

Soils of the agricultural lands of the Horatskaya Plain

Viktar Tsyrybka, Hanna Ustsinava, Marcin Świtoniak, Przemysław Charzyński

The Horatskaya Plain is located in north-eastern Belarus (Fig. 1). This territory is a ravine-riddled landscape formed in the interglacial conditions after the retreat of the last glaciation (Makhnach, 2001).

Fig. 1. Location

Lithology and topography

The Horatskaya Plain is a region of undulating plateau-like plains heavily dissected by river and stream valleys and a dense network of deep ravines with moraine ridges rising in a number of places in the form of small hills. The relief of the plain consists of thick loess and loess-like silt loams and sandy loams. The loess covers the watersheds and slopes of elevated parts of the territory devoid of forest vegetation (Yakushko et al., 2011).

A characteristic feature of the relief is the formation of a large number of suffusion depressions – "saucers". Numerous depressions on the plain are due to the leaching of carbonate soils by thawed snow and rainwater, the washing out of clay particles and subsequent subsidence of the surface. The depth of the valleys is 1–1.5 m, the diameter is 50–80 m. In the spring, the depressions are filled with snow water, and in the summer they overgrow with shrubs and grass vegetation. Many of them have today been transformed into regularly shaped artificial reservoirs. Absolute heights are in the range of 150–200 m above sea level. In the plain there are a number of rivers, the largest being the Pronya (Yakushko et al., 2011).

Land use and vegetation

Loess deposits have favourable natural physical conditions and fertile soils are formed on them, which has resulted in the intensive use of these lands in agriculture (approximately 51% is occupied by arable land). Forests occupy a limited space. The most common spruce forests (*Picea abies*) and secondary deciduous (*Betula pendula*, *Populus tremula*) (Miasnikovich, 2002).

Climate

In the climatic relation, the plain enters the central moderate-moist thermal zone of Belarus - its eastern sub region. According to Kottek et al. (2006) the region is located in the snow, fully humid climate with warm summer. The average annual air temperature is 5-7 degrees. The average temperature in January is -7.5 ° C to -8 ° C, in July - from 17.5 ° C to 18 ° C. The length of the growing season is about 185 days, and the frost-free period is up to 150 days. The amount of precipitation varies within 650 mm per year. The main part of precipitation falls in the summer period of the year. The most humid month is July, but in May, moisture is sometimes not enough. In some years, rains do not fall for more than a month. In winter, a fifth of the annual amount of precipitation falls. This is approximately 30 centimetres of snow cover (Loginov, 1996).

Profile 1 – Endolamellic **Luvisol** (Aric, Cutanic, Pantosiltic, Ochric)
Localization: flat and vast summit (inclination 2˚), arable land, 186 m a.s.l.,
N 54°14′13″ **E** 31°7′5″

Morphology:

Ap – 0–22 cm, ploughed humus horizon, silt loam, brownish-gray with brown spots (10YR 4/3), granular structure, moist, compacted, inclusions of organic (manure); few roots, abrupt and smooth boundary;

Ap2 – 22–34 cm, humus horizon ploughed in the past, silt loam, pale brown (10YR 6/3), granular structure, slightly moist, compacted, worms, few roots; abrupt and smooth boundary;

EBg – 34–39 cm, discontinuous transitional horizon, stagnic properties, silt loam, pale brown (2.5YR 7/4), fine weak subangular structure, slightly moist, crotovinas, clear and broken boundary;

Bt – 39–71 cm, *argic* horizon, silt loam, reddish brown (5YR 4/4), with whitish veins, medium moderate subangular structure, slightly moist, many clay coatings, gradual boundary;

BC – 71–128 cm, transitional horizon, silt loam, reddish brown (5YR 4/4) illuvial lamellaes and pale and light-gray interlamellaes material, medium moderate subangular structure, slightly moist, compacted, gradual boundary;

C – 128–(140) cm, parent material, silt loam, light yellowish brown (10YR 6/4), medium moderate subangular structure, compacted, slightly moist.

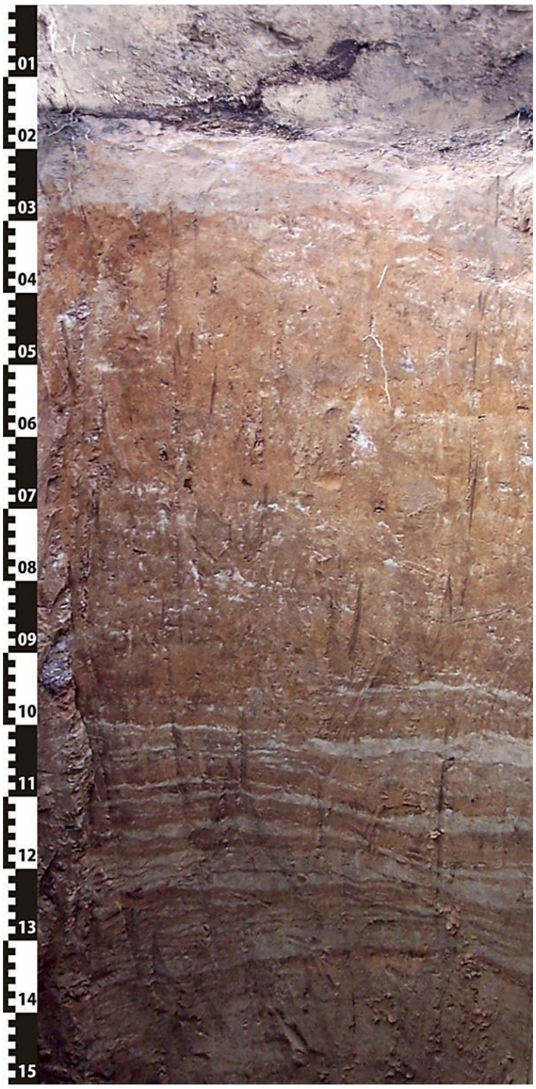
Table 1. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm							Textural class
		1–0.5	0.5–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001	
Ap	0–22	–	0	18	60	8	4	10	SiL
Ap2	22–34	–	0	24	54	4	8	10	SiL
EBg	34–39	–	0	27	55	6	6	6	SiL
Bt	39–71	–	0	24	54	6	8	8	SiL
BC	71–128	–	0	22	52	8	3	15	SiL

Table 2. Agrochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	pH KCl	P_2O_5	K_2O	Ca	Mg
				[g·kg^{-1}]			
Ap	0–22	26.9	5.9	4.49	3.76	14.91	1.17
Ap2	22–34	15.5	4.6	2.72	3.12	10.60	1.07
EBg	34–39	4.0	5.0	2.33	0.32	8.90	1.22
Bt	39–71	3.1	4.5	1.97	0.63	15.93	2.79
BC	71–128	1.9	4.0	3.11	0.44	8.95	1.96

Profile 2 – Stagnic **Luvisol** (Aric, Cutanic, Pantosiltic, Ochric, Bathylamellic)
Localization: upper slope (inclination 8°), arable land, 182 m a.s.l.,
N 54°14′15″ **E** 31°7′1″



Morphology:

Ap – 0–22 cm, ploughed humus horizon, silt loam, brownish-gray with brown spots (10YR 4/3), granular structure, moist, compacted, inclusions of organic (manure); few roots, abrupt and smooth boundary;

ABp – 22–28 cm, humus horizon ploughed in the past, some inclusions of material from illuvial horizon with cutans, silt loam, pale brown (10YR 6/3), granular structure, slightly moist, compacted, worms, few roots; abrupt and smooth boundary;

Bt(g) – 28–63 cm, *argic* horizon, silt loam, reddish brown (5YR 4/4), with whitish veins, medium moderate subangular structure, slightly moist, weakly developed stagnic properties, many clay coatings, gradual boundary;

Btg – 63–113 cm, *argic* horizon with stagnic properties, silt loam, reddish brown (5YR 4/4), with whitish veins and common fine reductimorphic mottles (5Y 5/4), medium moderate angular blocky/platy structure, compacted, moist, common clay coatings, gradual boundary;

BC – 113–(150) cm, transitional horizon, silt loam, reddish brown (5YR 4/4) illuvial lamellaes and pale and light-gray interlamellaes material, medium moderate subangular structure, moist, compacted.

Table 3. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm							Textural class
		1–0.5	0.5–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001	
Ap	0–22	–	1	12	67	6	7	7	SiL
ABp	22–28	–	0	23	53	5	5	14	SiL
Bt(g)	28–63	–	0	15	56	8	7	14	SiL
Btg	63–113	–	0	15	54	9	6	16	SiL
BC	113–(150)	-	1	15	55	8	6	15	SiL

Table 4. Agrochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	pH KCl	P_2O_5	K_2O	Ca	Mg
				[g·kg^{-1}]			
Ap	0–22	23.6	4.8	2.33	4.19	15.45	2.14
ABp	22–28	6.5	5.8	5.52	1.94	14.23	2.23
Bt(g)	28–63	3.2	4.3	2.55	0.56	13.18	1.87
Btg	63–113	3.6	3.8	2.94	0.60	12.12	2.28
BC	113–(150)	2.6	4.0	2.94	0.46	8.55	1.67

Profile 3 – Stagnic **Luvisol** (Aric, Cutanic, Pantosiltic, Ochric, Bathylamellic)
Localization: middle slope (inclination 8°), arable land, 178 m a.s.l.,
N 54°14′17″ **E** 31°6′58″

Morphology:

Ap – 0–20 cm, ploughed humus horizon, silt loam, light brownish gray (10YR 6/7), some inclusions of material from illuvial horizon with cutans, granular structure, moist, compacted, inclusions of organic (manure), few roots, abrupt and smooth boundary;

Bt(g) – 20–60 cm, *argic* horizon, silt loam, reddish brown (5YR 4/4), with whitish veins, medium moderate subangular/platy structure, moist, weakly developed stagnic properties, many clay coatings, clear and smooth boundary;

Btg – 60–105 cm, *argic* horizon with stagnic properties, silt loam, reddish brown (5YR 4/4), with whitish veins and common fine reductimorphic mottles (5Y 5/4), medium moderate angular blocky/platy structure, compacted, moist, common clay coatings, clear and smooth boundary;

BC – 105–(150) cm, transitional horizon, silt loam, reddish brown (5YR 4/4) illuvial lamellaes and pale and light-gray interlamellaes material, medium moderate subangular structure, moist, compacted.

Table 5. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm							Textural class
		1–0.5	0.5–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001	
Ap	0–20	–	1	17	57	6	7	12	SiL
Bt(g)	20–60	–	0	17	54	8	7	14	SiL
Btg	60–105	–	0	16	53	9	6	16	SiL
BC	105–(150)		0	15	52	10	6	17	SiL

Table 6. Agrochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	pH KCl	P_2O_5	K_2O	Ca	Mg
				[$g \cdot kg^{-1}$]			
Ap	0–20	12.5	4.69	1.76	3.47	8.21	1.35
Bt(g)	20–60	4.5	3.97	2.11	0.66	9.49	0.88
Btg	60–105	4.0	3.84	3.09	0.63	10.50	1.81
BC	105–(150)	3.8	4.56	1.64	0.64	8.89	2.30

Profile 4 – Eutric **Stagnosol** (Aric, Colluvic, Humic, Pantosiltic)
Localization: toe slope (inclination 3°), arable land, 178 m a.s.l.,
N 54°14′18″ **E** 31°6′55″

Morphology:

Ap – 0–25 cm, ploughed humus horizon, colluvial material, silt loam, dark grayish brown (2.5Y 4/2), very few fragmented cutans (papules), granular structure, moist, compacted, inclusions of organic (manure), few roots, abrupt and smooth boundary;

Ag1 – 25–40 cm, humus horizon with stagnic properties, colluvial material, silt loam, grayish brown (2.5Y 5/2), common whitish reductimorphic material and oximorphic rusty spots, very few fragmented cutans (papules), granular structure, moist, compacted, abrupt and smooth boundary;

Ag2 – 40–90 cm, humus horizon with stagnic properties, colluvial material, silt loam, olive brown (2.5Y 4/3), common oximorphic rusty spots, very few fragmented cutans (papules), granular structure, moist, compacted, clear and smooth boundary;

Ag3 – 90–105 cm, humus horizon with stagnic properties, colluvial material, silt loam, dark bluish gray (GLEY 2 5PB 4/1), common oximorphic rusty spots, very few fragmented cutans (papules), granular structure, moist, compacted, clear and smooth boundary;

2Agb – 105–123 cm, buried humus horizon, silt loam, bluish black (GLEY 2 5PB 2.5/1), granular structure, moist, compacted, clear and wavy boundary;

2Bg – 123–(150) cm, illuvial horizon with reducing conditions, silt loam, olive gray (5YR 5/2) and yellowish red (5YR 4/6) spots, massive structure, wet.

Table 7. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm							Textural class
		1–0.5	0.5–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001	
Ap	0–25	–	0	17	57	8	5	13	SiL
Ag1	25–40	–	0	15	58	8	6	13	SiL
Ag2	40–90	–	0	13	60	7	6	14	SiL
Ag3	90–105	–	0	13	57	8	6	16	SiL
2Agb	105–123	–	0	13	55	10	7	15	SiL
2Bg	123–(150)	–	0	11	53	11	8	17	SiL

Table 8. Agrochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	pH KCl	P_2O_5	K_2O	Ca	Mg
				[$g \cdot kg^{-1}$]			
Ap	0–25	30.6	5.7	2.61	4.19	15.03	3.28
Ag1	25–40	14.4	5.4	1.24	2.28	9.80	1.85
Ag2	40–90	11.5	5.0	0.60	1.23	8.03	1.65
Ag3	90–105	14.8	4.7	0.85	2.18	7.89	1.55
2Agb	105–123	29.9	4.3	0.47	2.24	13.00	1.57
2Bg	123–(150)	7.1	4.0	1.09	0.59	9.74	0.84

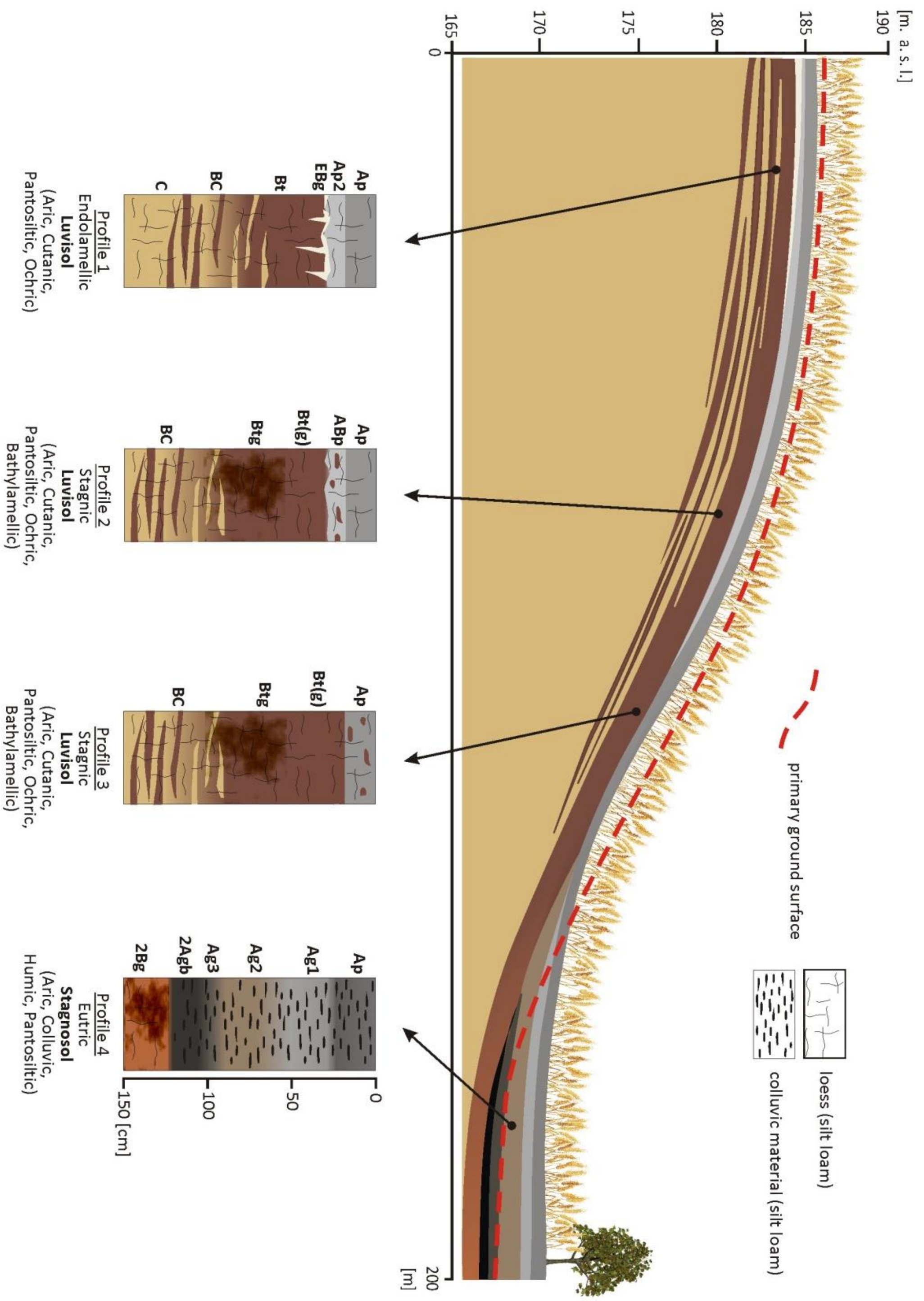


Fig. 2. Toposequence of soils of the agricultural lands of the Horatskaya Plain

Soil genesis and systematic position

All studied soils had two common features: they were ploughed to a depth 20 cm of more and developed from material with a silt loam texture. Accordingly, the ***Aric*** and ***Pantosiltic*** qualifiers were used in all cases.

The region's humid climate, with relatively high mean annual effective rainfall, favours the lessivage process and clay translocation (Arkley, 1967; Quénard et al., 2011). Moreover, the silt loam texture of the loess maintains the perfect conditions for the vertical downwards flux of water (Quénard et al., 2011; Cornu et al., 2014). The above factors led to the development of Bt *argic* horizons with abundant illuvial clay coatings and infillings in most investigated soils (Profiles 1–3). The common presence of illuvial clay forms was expressed by the ***Cutanic*** supplementary qualifier. These pedons had no other diagnostic horizons and no *retic* properties, and were characterised by: (i) more-or-less homogenous vertical texture (lack of *abrupt textural difference*), (ii) high-activity clays, and (iii) high base status. All of these features allowed them to be classified as **Luvisols** (IUSS Working Group, 2015). In all three cases the upper part of the *argic* is homogenous, but the form of the lower section has many clearly visible illuvial lamellae changing gradually into parent material. In Profile 1 the lamellae start at 71 cm from the mineral surface of the soil, which has been marked by the ***Endolamellic*** principal qualifier. In the second and third pedons the depth of lamella occurrence is higher than 100 cm, and they are thus expressed only in the supplementary subqualifier ***Bathylamellic***. *Argic* horizons in Profiles 2 and 3 had higher content of clay fraction than Bt in Profile 1. This resulted in their low permeability and was probably the main cause of distinct stagnic properties (***Stagnic*** principal qualifier). The stagnation of water was also reflected in some features of the EB horizon in the first profile but it was not thick enough (only 5 cm) to use this qualifier. The humus horizons of the described Luvisols were not dark enough to fit the requirements of *Mollic* or *Umbric*. However, having organic carbon content higher that 0.2% (Table 2) with total depth more than 10 cm, they fit with the requirements of the ***Ochric*** qualifier.

The last pedon was developed as a result of accumulation of young slope deposits (***Colluvic***) which have visible vertical zonation associated with a varied content of humus (e.g., Świtoniak, 2015). These colluvial mineral deposits have too light a colour for any of the diagnostic surface horizons (*mollic*, *umbric*, etc.) but have significant stocks of organic carbon – high enough for the ***Humic*** qualifier. The discussed soil was located in a depression, resulting in its substantial moisture. Reductimorphic and oximorphic mottles are common from a depth of 25 cm. The shallow occurrence of stagnic properties led to the profile being classified as a **Stagnosol**. The effective base saturation in the major part between 20 and 100 cm from the mineral soil surface is higher than 50%, as emphasised by the ***Eutric*** principal qualifier.

Soil sequence

All studied soils located within the summit and slopes are formed on the same parental material – loess (with silt loam texture), which is the most prone to erosion (Chernysh, et al., 2009). The same climatic conditions influenced the soil-forming factors in the whole catena, so the key factor determining the features of the described soils is their location in different parts of the slope. Intensive agricultural use led to intensive erosional processes (e.g., Papendick and Miller, 1977; Jankauskas et al., 2003; Van Oost et al., 2003; De Alba et al., 2004; Marcinek and Komisarek, 2004; Leopold and Völkel, 2007; Dreibrodt et al., 2010; Świtoniak, 2014).

All investigated profiles showed strong alterations associated with slope processes (Chernysh et al., 2009).

The first pedon is located on an almost flat summit and was slightly changed by truncation. The primeval eluvial horizon was partially washed away and/or mixed with humus horizon by ploughing. Currently it forms only discontinuous and fragments between the Ap2 and Bt horizon. The second **Luvisol** is characterised by almost total lack of an eluvial zone. The surface humus horizons contain coarser material, primarily from the E horizon, which was completely mixed by ploughing with Ap horizons. Moreover, some of the material from the Bt horizon is incorporated into the lower part of the plough layer (ABp). In this stage of truncation, soil can be classified as moderately eroded (Świtoniak, 2014). In the strongly eroded Profile 3 the whole material from the eluvial horizon was removed by erosion and the pedon become texturally homogeneous. Surface horizons include illuvial material from the *argic* horizon (Bt).

The changes in the degree of erosion are connected with the character of the parental material, the length and steepness of the slope, and many other factors. In the conditions of the investigated territory, the steepness of the slope plays the greatest role. The soils that form are non-eroded on the slopes with a steepness of less than 1°, slightly eroded on the slopes of gradient 1–3°, medium-eroded on the slopes of 3–5°, strongly eroded on slopes of 5–7°, and strongly and moderately eroded on steeper soils (Chernysh, 2005).

Strong erosion processes led to accumulation of thick colluvium in foot-slope and toe-slope positions. This was confirmed by Profile 4, where slope deposits were more than 1 m thick. The low permeability of these deposits led to the development of **Stagnosol**. Colluvial material also contains remains of Bt horizons comprising material from slope erosion in the form of fragmented cutans (papules) that were partially destroyed when the material was transported down the slope (Brewer, 1976; Kemp, 1998; Świtoniak et al., 2016).

To prevent soil degradation and reduce the intensity of erosion processes, it is necessary to introduce soil protection systems in agriculture and, first of all, to increase the areas of perennial grasses.

References

Arkley, R.J., 1967. Climate of soil great soil groups of the western United States. Soil Science 103, 6: 389–400.

Brewer, R., 1976. Fabric and mineral analysis of soils. Krieger, New York.

Chernysh, A.F., (ed), 2005. Design of anti-erosion complexes and use of erosion-hazardous lands in different landscape areas of Belarus: recommendations / Institute for Soil Science and Agrochemistry, Minsk, 52 pp. (in Russian).

Chernysh, A.F., Ustsinava, H.M., Radzyuk, H.E, Yukhnavets, A.V., 2009. Morphology and basic properties of eroded sod-pale-podzolic soils developing on loess and loess-like loams (according to the results of monitoring observations), Soil Science and Agrochemistry, No. 2 (43), 32-42 (in Russian).

Cornu, S., Quénardb, L., Cousinb, I., Samouëlianc, A., 2014. Experimental approach of lessivage: Quantification and mechanisms. Geoderma 213, 357–370.

De Alba, S., Lindstrom, M., Schumacher, T.E., Malo, D.D., 2004. Soil landscape evolution due to soil redistribution by tillage: a new conceptual model of soil catena evolution in agricultural landscapes. Catena 58: 77 – 100.

Dreibrodt, S., Lubos, C., Terhorst, B., Damm, B., Bork H.-R., 2010. Historical soil erosion by water in Germany: scales and archives, chronology, research perspectives, Quaternary International, 222: 80–95.

IUSS Working Group WRB, 2015, World Reference Base for soil resources 2014. International soil classification system for naming soils and creating legends for soil maps. Update 2015. World Soil Resources Report 106. FAO, Rome, 188 pp.

Jankauskas, B., Jankauskiene, G., Fullen, M.A., 2003. Erosion-preventive crop rotations and water erosion rates on undulating slopes in Lithuania. Can. J. Soil Sci. 84: 177–186.

Kemp, R.A., 1998. Role of micromorphology in paleopedological research. Quaternary International 51/52, 133–141.

Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F. 2006. World Map of Köppen-Geiger Climate Classification updated. Meteorol. Z., 15: 259–263.

Leopold, M., Völkel, J., 2007. Colluvium: definition, differentiation, and possible suitability for reconstructing Holocene climate data. Quaternary International, 162, 163, 133–140.Lowrance, R., McIntire, S., Lance, C., 1988. Erosion and deposition in a field estimated using cesium-137 activity. Journal of Soil and Water Conservation 43, 195–199.

Loginov, V. F. (ed.), 1996. Climate of Belarus / Acad. Sciences of Belarus, Com. on hydrometeorology Ministry of Emergency Resp. Belarus, Minsk, 235 pp. (in Russian).

Marcinek, J., Komisarek, J., 2004. Anthropogenic transformations of soils of Poznań Lakeland as a results of intensive agricultural farming. AR. Poznań (in Polish with English summary).

Miasnikovich M. V. (ed.), 2002, National Atlas of Belarus [maps] / Belkartagrafiya, Minsk, 292 pp. (in Belarusian).

Makhnach A. S. (ed.), 2001. Geology of Belarus / Nat. acad. Sciences of Belarus, Institute of Geology sciences, Minsk, 814 pp. (in Russian).

Papendick, R.I., Miller, D.E., 1977. Conservation tillage in the Pacific Northwest. Journal of Soil and Water Conservation 32: 49 – 56.

Quénard, L., Samouëlian, A., Laroche, B., Cornu, S., 2011. Lessivage as a major process of soil formation: A revisitation of existing data. Geoderma, 167-168: 135–147.

Świtoniak, M., 2014. Use of soil profile truncation to estimate influence of accelerated erosion on soil cover transformation in young morainic landscapes, North-Eastern Poland, Catena, 116: 173–184.

Świtoniak, M., 2015. Issues relating to classification of colluvial soils in young morainic areas (Chełmno and Brodnica Lake District, northern Poland). Soil Science Annual. 66. 2: 57–66.

Świtoniak M., Mroczek P., Bednarek R., 2016. Luvisols or Cambisols? Micromorphological study of soil truncation in young morainic landscapes — Case study: Brodnica and Chełmno Lake Districts (North Poland). Catena 137: 583–595.

Van Oost, K., Van Muysen, W., Govers, G., Heckrath, G., Quine, T.A., Poesen, J., 2003. Simulation of the redistribution of soil by tillage on complex topographies. European Journal of Soil Science 54: 63–76.

Yakushko, O. F., Emelyanov, Yu. N., Ivanov, D. L, 2011. Geomorphology, Minsk, 317 pp. (in Russian).

Agricultural areas in the moraine plateau with glacial curvilineations (Dobrzyń Lakeland, Poland)

Michał Dąbrowski, Renata Bednarek, Anna Piziur, Michał Wilk

The young morainic area of Northern 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 Dobrzyń Lake District represents young glacial landscapes from the Kuyavian-Dobrzyń subphase. This area features a complex suite of bedforms consisting of elongate and sinuous sediment ridges occurring within an anabranched network of tunnel channels terminating at a former ice margin marked by extensive glaciofluvial fans. These ridges have traditionally been termed drumlins (Nechay, 1927; Jewtuchowicz, 1956; Liberacki, 1961; Lamparski, 1972; Wysota, 1994; Olszewski, 1997; Głębicki and Marks, 2009), while in recent studies they are referred to as glacial curvilineations (Lesemann et al., 2010, 2014).

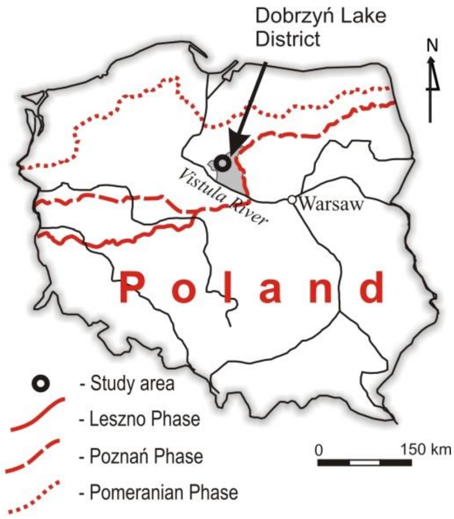


Fig. 1. Location

Lithology and topography

The presented soils were located in the north-eastern part of the Dobrzyń Lake District in a moraine plateau with glacial curvilineations. These landforms occur within tunnel valleys forming a complex anabranched network and consist of a series of parallel ridges extending for as much as 5 km. Throughout their length, these ridges are parallel to till ridges and to tunnel valley margins. The internal composition consists of glacial till with sand and gravel distributed randomly within ridges and intervening troughs. The maximum inclinations of slopes reach about 10–20°. Denivelations are relatively high and in many places reach 10–15 m.

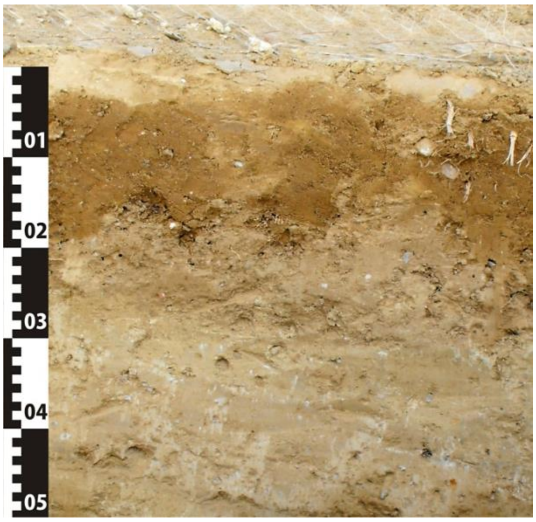
Land use

Because of a relatively high fertility of soils, the vast majority of them was converted into arable lands. Other areas are fallows or ecological sites with organic sediments deposited in depressions between glacial curvilineations.

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 7.3°C. The warmest month is July (17.6°C). The mean air temperature in January (the coldest winter month) is –3.3°C. The average annual precipitation is 521 mm. July is the wettest month with average precipitation of 92 mm (Wójcik and Marciniak, 1987a, b, 1993).

Profile 1 – Pantocalcaric **Regosol** (Aric, Pantoloamic, Ochric)
Localization: glacial curvilineation, summit, 15°, arable field, the corn stubble, 103 m a.s.l.
N 53°02'02", **E** 19°08'31"



Morphology:

Apk1 – 0–20 cm, plough humus horizon, *calcaric* material, sandy loam, very pale brown (10YR 7/3; 10YR 5/4), dry, moderate granular medium structure, fine and common roots, very few stones, clear and smooth boundary;

Apk2 – 20–30 cm, plough humus horizon, *calcaric* material, sandy loam, pale brown (10YR 6/3; 10YR 4/3), dry, moderate granular medium structure, fine and common roots, abrupt and wavy boundary;

Ck – 30–(50) cm, *calcaric* parent material, loam, very pale brown (10YR 7/4; 10YR 5/4), slightly moist, very fine and very few roots, few and fine reductimorphic mottles, common fine rounded soft concentrations and pseudomycelium of secondary carbonates, moderate angular coarse structure.

Table 1. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	
Apk1	0–20	6	3	4	14	24	13	11	8	6	17	SL
Apk2	20–30	7	2	4	11	27	11	11	9	6	19	SL
Ck	30–(50)	3	2	4	9	21	13	11	11	9	20	L

Table 2. 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	
Apk1	0–20	4.5	0.47	10	8.3	7.8	86
Apk2	20–0	4.2	0.47	9	8.4	7.9	96
Ck	30–(50)	1.1	0.15	7	8.6	7.7	109

Profile 2 – Endocalcaric **Luvisol** (Aric, Cutanic, Hypereutric, Loamic, Ochric)
Localization: glacial curvilineation, upper slope 8°, arable field, the corn stubble, 100 m a.s.l.
N 53°02’01”, **E** 19°08’31”

Morphology:

Apk1 – 0–16 cm, plough humus horizon, *calcaric* material, sandy loam, dark yellowish brown (10YR 4/4; 10YR 3/3), slightly moist, moderate granular medium structure, fine and common roots, diffuse and smooth boundary;

Apk2 – 16–34 cm, plough humus horizon, *calcaric* material, sandy loam, yellowish brown (10YR 5/4; 10YR 3/4), slightly moist, moderate granular medium structure, abrupt and smooth boundary;

Bt – 34–70 cm, *argic* horizon, sandy clay loam, yellowish brown (10YR 5/4; 7.5YR 3/4), slightly moist, moderate subangular coarse structure, common faint clay coatings, few fine reductimorphic mottles, clear and smooth boundary;

Ck – 70–(100) cm, *calcaric* parent material, sandy loam, pale brown (10YR 6/3; 10YR 4/3), slightly moist, moderate subangular coarse structure, common fine rounded soft concentrations and pseudomycelium of secondary carbonates.

Table 3. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	
Apk1	0–16	4	1	4	12	36	14	8	7	3	15	SL
Apk2	16–34	2	1	3	12	35	14	8	7	4	16	SL
Bt	34–70	2	2	4	13	31	13	8	6	3	20	SCL
Ck	70– (100)	2	1	3	12	31	17	10	8	4	14	SL

Table 4. 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	
Apk1	0–16	6.8	0.72	9	8.3	7.6	43
Apk2	16–34	8.1	0.83	10	8.3	7.4	34
Bt	34–70	2.1	0.28	8	8.3	6.9	2
Ck	70– (100)	1.9	0.19	10	8.5	7.5	69

Profile 3 – Eutric Albic Glossic **Retisol** (Abruptic, Epiarenic, Cutanic, Katoloamic, Ochric, Raptic)
Localization: glacial curvilineation, middle slope 4°, arable field, the corn stubble, 95 m a.s.l.
N 53°02’00”, **E** 19°08’30”

Morphology:

Ap – 0–17 cm, plough humus horizon, loamy fine sand, grayish brown (10YR 5/2; 10YR 2/3), slightly moist, moderate granular medium structure, fine and common roots, clear/abrupt and irregular boundary;

E – 17–36 cm, eluvial horizon with *albic* material, loamy fine sand, light gray (10YR 7/2; 10YR 5/4), slightly moist, moderate granular medium structure, gradual and irregular boundary;

E/B – 36–65 cm, *glossic* transitional horizon, sandy loam, pale brown (10YR 6/3; 7.5YR 4/4), slightly moist, moderate granular medium structure, gradual and irregular boundary;

2Bt – 65–85 *argic* horizon, sandy loam, light yellowish brown (10YR 6/4; 7.5YR 4/4), slightly moist, moderate subangular coarse structure, common faint clay coatings, few fine reductimorphic mottles, diffuse and smooth boundary;

2C – 85–(100) cm, parent material, sandy loam, yellowish brown (10YR 5/4; 7.5YR 4/4), slightly moist, moderate subangular coarse structure.

Table 5. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	0–17	1	1	4	16	42	15	10	5	3	4	LFS
E	17–36	2	1	3	12	39	21	10	5	4	5	LFS
E/B	36–65	2	1	3	13	36	15	8	7	3	14	SL
2Bt	65–85	1	1	3	11	34	18	8	7	3	15	SL
2C	85–(100)	1	1	3	12	36	16	8	7	3	14	SL

Table 6. 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	0–17	8.2	0.64	13	5.1	4.2	-
E	17–36	1.1	0.13	8	6.0	4.5	-
E/B	36–65	1.4	0.18	8	6.6	4.6	-
2Bt	65–85	0.9	0.14	6	6.9	5.0	-
2C	85–(100)	1.1	0.14	8	7.0	5.1	3

Profile 4 – Eutric Colluvic Endogleyic **Regosol** (Aric, Humic, Pantoloamic, Endoraptic)
Localization: glacial curvilineation, toe slope 2°, arable field, the corn stubble, 93 m a.s.l.
N 53°02’00”, **E** 19°08’32”

Morphology:

Apk1 – 0–25 cm, colluvic material, plough humus horizon, *calcaric* material, sandy loam, yellowish brown (10YR 5/4; 10YR 4/4), slightly moist, moderate granular medium structure, fine and common roots, gradual and smooth boundary;

A2 – 25–47 cm, colluvic material, humus horizon, sandy loam, gray (10YR 5/1; 10YR 2/2), slightly moist, moderate granular medium structure, very fine and very few roots, few fine reductimorphic mottles, gradual and wavy boundary;

A3 – 47–65 cm, colluvic material, humus horizon, sandy loam, yellowish gray (2.5Y 5/1; 2.5Y 3/2), moist, moderate granular medium structure, few fine reductimorphic mottles, clear and irregular boundary;

2Cl – 65–(110) cm, parent material, sandy loam, light gray (2.5Y 7/1; 2.5Y 4/2), moist, moderate granular medium structure, common medium reductimorphic mottles.

Table 7. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	
Apk1	0–25	2	1	5	15	34	17	9	5	4	10	SL
A2	25–47	1	1	3	13	40	16	10	7	5	5	SL
A3	47–65	3	1	4	14	37	15	12	8	5	4	SL
2Cl	65–(110)	5	1	4	15	36	15	9	7	4	9	SL

Table 8. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	C/N	pH		$CaCO_3$ [$g \cdot kg^{-1}$]
					H_2O	KCl	
Apk1	0–25	11.4	1.03	11	8.0	7.4	22
A2	25–47	9.1	0.79	13	5.9	4.9	-
A3	47–65	6.2	0.44	14	6.3	5.1	-
2Cl	65–(110)	2.1	0.23	9	6.3	5.0	-

Profile 5 – Eutric Colluvic Endogleyic **Regosol** (Aric, Geoabruptic, Loamic, Ochric, Endoraptic)
Localization: glacial curvilineation, toe slope (bottom) 1°, boundary between arable field and fallow, 92 m a.s.l., **N** 53°01′15″, **E** 19°08′05″

Morphology:

Ap1 – 0–25 cm, colluvic material, plough humus horizon, sandy loam, light brownish gray (10YR 6/2; 10YR 3/3), slightly moist, moderate granular medium structure, fine and few roots, diffuse and smooth boundary;

A2 – 25–45 cm, colluvic material, humus horizon, sandy loam, light brownish gray (10YR 6/2; 10YR 3/3), slightly moist, moderate granular medium structure, fine and few roots, abrupt and smooth boundary;

Ck – 45–57/45 cm, *calcaric* parent material, sandy loam, pale brown (10YR 6/3; 10YR 4/4), slightly moist, moderate subangular coarse structure, very fine and very few roots, few and fine reductimorphic mottles, common fine rounded soft concentrations of secondary carbonates, abrupt and smooth boundary;

A3 – 57/45–60 cm, colluvic material, humus horizon, sandy loam, light brownish gray (10YR 6/2; 10YR 4/2), slightly moist, moderate granular medium structure, clear and irregular boundary;

2Ab – 60–70 cm, buried humus horizon, sandy loam, light gray (10YR 6/1; 10YR 3/1), slightly moist, moderate granular medium structure, clear and irregular boundary;

2Cl1 – 70–75 cm, parent material, sandy loam, light gray (10YR 6/1; 10YR 3/2), moist, moderate granular medium structure, common medium reductimorphic mottles, clear and smooth boundary;

2Cl2 – 75–(90) cm, parent material, loamy fine sand, light brownish gray (10YR 6/2; 10YR 3/2), moist, moderate granular medium structure, common medium reductimorphic mottles.

Table 9. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	0–25	3	2	5	12	31	20	8	10	5	7	SL
A2	25–45	5	3	5	15	32	15	9	8	5	8	SL
Ck	45–57/45	11	5	5	13	26	13	10	9	4	15	SL
A3	57/45–60	3	2	6	14	31	17	10	8	4	8	SL
2Ab	60–70	1	2	5	15	30	18	10	10	4	6	SL
2Cl1	70–75	1	1	4	12	31	21	10	7	4	10	SL
2Cl2	75–(90)	3	2	4	14	32	23	9	8	4	4	LFS

Table 10. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	C/N	pH		$CaCO_3$ [$g \cdot kg^{-1}$]
					H_2O	KCl	
Ap1	0–25	11.3	0.91	12	8.0	7.4	4
A2	25–45	7.8	0.65	12	7.7	7.4	9
Ck	45–57/45	3.6	0.31	12	8.0	7.5	61
A3	57/45–60	10.9	0.68	16	7.5	6.9	4
2Ab	60–70	17.1	0.94	18	7.1	6.4	trace
2Cl1	70–75	7.2	0.52	13	6.9	6.2	-
2Cl2	75–(90)	6.2	0.52	12	6.8	6.1	-

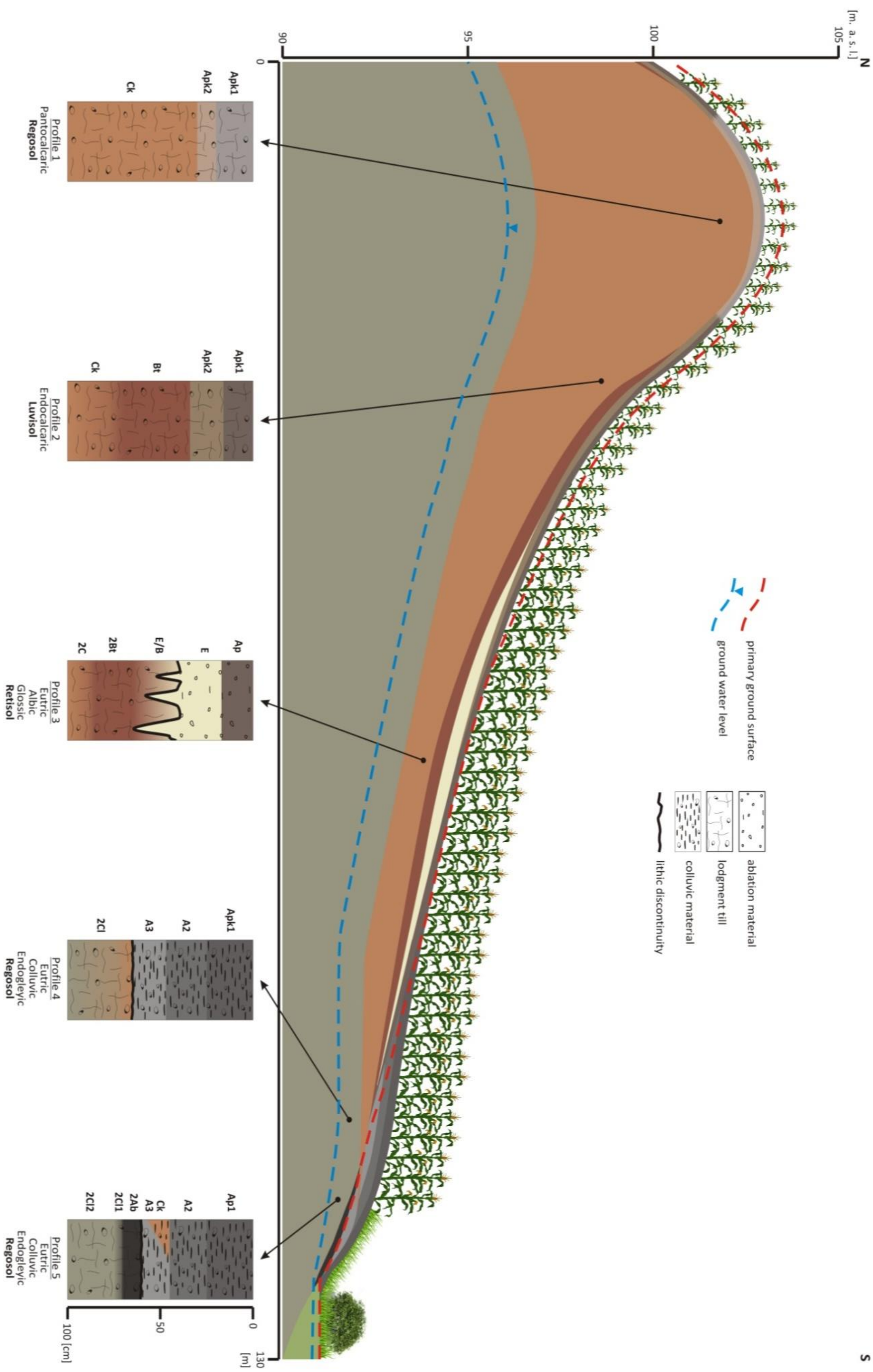


Fig. 2. Toposequence of soils within agricultural areas of moraine plateau with glacial curvilineations

Soil genesis and systematic position

The summit of the glacial curvilineation is covered with a weakly developed pedon classified as **Regosol** (IUSS Working Group WRB, 2015). The solum of the discussed soil is limited to a poorly developed humus ploughing horizon (***Aric*** supplementary qualifier). It is divided into two subhorizons – Apk1 and Apk2 as a result of ploughing up to varied depths in the past (20 and 30 cm). The colour of these subhorizons is similar to the colour of the parent material, which results from the low organic matter content (Table 2). Neither of them met the criteria of a *mollic* or *umbric* horizon (***Ochric*** supplementary qualifier). Directly below the plough layer, there is *calcaric* parent material Ck. The total erosion of original soil horizons is evidenced by the presence of a significant quantity of calcium carbonates even at their surface. Materials from all horizons effervescences strongly with 1 M HCl, which permits the use of the ***Pantocalcaric*** principal qualifier. More than 8% of calcium carbonates in the humus horizon and more than 10% in parent material as well as high pH values indicate extremely high base saturation. This soil is entirely built from glacial deposits slightly transformed by pedogenesis. The texture in the entire soil profile is typical of bottom glacial sediments – sandy loam and loam (Table 1). It allows the use of the ***Pantoloamic*** supplementary qualifier. Forms of this type could have originated only in the parent material of primarily occurring, fully developed soils –**Luvisols** or **Retisols** (Świtoniak, 2014).

In the upper slope of the glacial curvilineation, **Luvisol** occurs with the Apk1-Apk2-Bt-Ck sequence. Lack of eluvial horizons resulted from the partial truncation of this soil. Morphologically, it is very similar to **Cambisols**. The previous studies carried out within glacial curvilineations in the Dobrzyń Lake District (Karasiewicz et al., 2011, 2014) confirmed the illuvial nature of B horizons. The occurrence of eroded **Luvisols**, morphologically similar to **Cambisols** in a young glacial landscape, was also described in Brodnica and Chełmno Lake Districts (Szrejder, 1998, Świtoniak, 2016) or Świecie Plateau (Bednarek et al., 2009, Świtoniak et al. 2015). Both the humus subhorizons and parent material (Ck) have a *clacaric* character with the content of calcium carbonates of more than 3% (Table 3), which permits the use of the ***Endocalcaric*** principal qualifier. High pH values (Table 3) indicate extremely high base saturation in all horizons (***Hypereutric*** supplementary qualifier). The ploughing humus horizon of the described pedon is divided into two subhorizons – Apk1 and Apk2 as a result of ploughing into different depths in the past (***Aric*** supplementary qualifier) and the transport of *colluvic material* on the slope surface (16 and 34 cm). Neither of them met the criteria of a *mollic* or *umbric* horizon (***Ochric*** supplementary qualifier). The presence of common faint clay coatings in the Bt *argic* horizon was noted by the ***Cutanic*** supplementary qualifier. The texture of sandy loam and sandy clay loam throughout the soil allows the use of the ***Loamic*** supplementary qualifier (Table 4).

Profile 3 with the sequence Ap-E-E/B-2Bt-2C is located on the middle slope of the glacial curvilineation. This pedon has the interfingering of the *albic* material (***Albic*** principal qualifier) into the *argic* horizon and was classified as **Retisol** with *retic* properties. The ploughing humus horizon with 17 cm thickness did not meet the criteria of a *mollic* or *umbric* horizon (***Ochric*** supplementary qualifier). Values of pH 6.0 and higher in H_2O (Table 6) between 17 and 100 cm from the mineral soil surface indicate high base saturation (***Eutric*** principal qualifier). The *glossic* transitional horizon E/B with *albeluvic glossae* (***Glosssic*** principal qualifier) starts about 40 cm from the soil surface. Clear textural differentiation from loamy fine sand to sandy loam (***Abruptic***, ***Epiarenic*** and ***Katoloamic*** supplementary qualifiers) with the surface clay-depleted horizons is a dominant feature (Table 5). The subsurface 2Bt *argic* horizon indicates a pedogenic accumulation of the clay fraction in the form of clay coatings (***Cutanic*** supplementary qualifier). The ***Raptic*** supplementary qualifier reflects the presence of *lithic discontinuity*. The textural difference between sandy and loamy horizons is reinforced by the eluviation-illuviation (lessivage) process, but mainly was inherited from the parent material (ablation sandy cover on lodgement till). This is confirmed by studies in morainic landscapes in neighbouring young glacial regions, like e.g. Brodnica Lake District (Świtoniak 2008).

The toe slope of the glacial curvilineation (Profile 4 and 5) is covered with soil, the properties of which evolved under conditions of a strong erosion process. The soil material is an effect of accumulation of the thick colluvium at foot-slope and toe-slope positions (***Colluvic*** principal qualifier). The loamy texture of slope deposits (Tables 7 and 9), the amount of organic carbon higher than 0.6% (Tables 8 and 10) and the well-developed structure allow the humus horizons to be classified as *mollic*. However, it did not meet the criteria of a colour change when comparing with the underlying horizon in these profiles, that is why these profiles were classified as **Regosols**. High pH values (Tables 8 and 10) indicate high base saturation in all horizons of both profiles (***Ereutric*** principal qualifier). Colluvic humus horizons in profile 4 have exactly 1% of organic carbon as a weighted average to a depth of 50 cm (***Humic*** supplementary qualifier) and 0.9% in profile 5 (***Ochric*** supplementary qualifier). Surface humus horizons of both pedons (0–25 cm) have a ploughing character (***Aric*** supplementary qualifier). Common medium reductimorphic mottles below 50 cm from the soil surface of both pedons are an effect of a strong influence by ground water (***Endogleyic*** principal qualifier). The ***Endoraptic*** supplementary qualifier of both soils reflects the presence of *lithic discontinuity* as a boundary between *colluvic* material of A horizons and parent material of 2Cl horizons deeper than 50 cm. The texture in profile 4 is typical of bottom glacial sediments (***Pantoloamic*** supplementary qualifier). The *colluvic* material of profile 5 was deposited over buried soil (perhaps **Gleysoil**) with the buried 2Ab horizon. The content of total organic carbon in this horizon is higher than 1.7% (Table 10). The parent material of this soil is divided into two subhorizons with textural differentiation from sandy loam in 2Cl1 (***Loamic*** supplementary qualifier) to loamy fine sand in 2Cl2 (***Geoabruptic*** supplementary qualifier). The plough humus horizon in Profile 4 (Apk1) and a lens of glacial till in Profile 5 (Ck) have a *calcaric* character with the content of calcium carbonates of more than 2% (Tables 8 and 10).

Soil sequence

All profiles are located within a glacial curvilineation and form a catenal system, which shows a variability of soil cover and is related to the progress of slope processes as a result of agricultural activity (Fig. 2). This occurrence has been defined as anthropogenic denudation (Sinkiewicz, 1998). The development stage and properties of the investigated soils are strongly associated with the topographic position. The presented pedons form a kind of soil **toposequence**. The most intensive erosion zone occurs on summits within the tops of the glacial curvilineation. The soil degradation in this area led to complete truncation (**Regosols** – Profile 1) of primarily well-developed pedons. The upper part of slope positions occupies soils with strong truncation (**Luvisols** without eluvial horizon – Profile 2). **Retisols** (Profile 3) with a well-preserved sequence of genetic horizons are located only in the middle part of the slope. **Regosols** have developed from colluvial deposits in the toe-slope position of the glacial curvilineation (Profiles 4 and 5). The widespread occurrence of highly eroded soils with the lessivage process, developed from sandy cover on lodgement till like **Luvisols** or **Retisols** and the deposition of colluvic materials in young morainic agricultural landscapes of Poland was recently described by Smolska (2002), Bednarek and Szrejder (2004), Marcinek and Komisarek (2004), Podlasiński (2013), Świtoniak et al. (2013), Kobierski et al. (2015). This soil sequence is typical for the agricultural landscape in Dobrzyń Lakeland with these unique forms as glacial curvilineations.

References

Bednarek, R., Dąbrowski, M., Świtoniak, M., 2009. Anthropogenic transformations of soil cover in the chosen types of the young glacial relief on the basis of Jeżewo District. Zesz. Probl. Post. Nauk Roln. 540: 139-146 (in Polish with English summary).

Bednarek, R., Szrejder, B., 2004. Soil cover structure of the representative catchment of Struga Toruńska river In: M. Kejna, J. Uscka (Eds.), Zintegrowany Monitoring Środowiska Przyrodniczego. Funkcjonowanie i monitoring geosystemów w warunkach narastającej antropopresji. Bibl. Monitor. Środow., Toruń: 243-252 (in Polish with English summary).

Głębicki, P., Marks, L., 2009. The origin of drumlins at Zbójno, Central Poland. Geologija 51: 131–138.

IUSS Working Group WRB, 2015. 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.

Jewtuchowicz, S., 1956. Drumlin structures near Zbójno. Acta Geogr. Lodz. 7 (in Polish with French and Russian summary).

Karasiewicz, M.T., Hulisz, P., Świtoniak, M., 2014. Effect of denudation processes on properties of sediments filling the intra-glacial curvilineations troughs in Zbójno vicinity (Dobrzyń Lakeland). Landform Analysis 25: 29–42 (in Polish with English summary).

Karasiewicz, M.T., Noryśkiewicz, A.M., Noryśkiewicz, B., Hulisz, P., Stachowicz-Rybka, R., Bendych, M., 2011. Postglacial and holocene changes in in the evironmental near Zbójenko in Dobrzyń Lakeland. In: M.T. Karasiewicz, P. Hulisz, A.M. Noryśkiewicz (Eds.), Człowiek i jego wpływ na środowisko przyrodnicze w przeszłości i czasach historycznych. Państwowy Instytut Geologiczny-Państwowy Instytut Badawczy, Warszawa: 95–105 (in Polish).

Kobierski, M., Kondratowicz-Maciejewska, K., Kociniewska, K., 2015. Soil quality assessment of Phaeozems and Luvisols from the Kujawy region (central Poland). Soil. Sci. Annual 66, 3: 111-118.

Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F. 2006. World Map of Köppen-Geiger Climate Classification updated. Meteorol. Z. 15: 259–263.

Lamparski, Z., 1972. Origin of drumlines near Zbójno (Dobrzyń Lakeland). Acta Geologica Polonica 22: 139–158 (in Polish with English summary).

Liberacki, M., 1961. Drumlins near Zbójno. In: R. Galon (Ed.). From the Baltic to the Tatras: guide-book of excursion. Pt. 1, North Poland: area of the last glaciation. INQUA Interantional Association on Quaternary Research VIth Congress, Toruń: 115-117.

Lesemann, J.-E., Piotrowski, J.A.,Wysota, W., 2010. ‘Glacial curvilineations’: new glacial landforms produced by longitudinal vortices in subglacial meltwater flows. Geomorphology 120: 153–161.

Lesemann, J.-E., Piotrowski, J.A.,Wysota, W., 2014. Genesis of the ‘glacial curvilineation’ landscape by meltwater processesunder the former Scandinavian Ice Sheet, Poland Sedimentary Geology 312: 1–18.

Marcinek, J., Komisarek, J., 2004. Anthropogenic transformations of soils of Poznań Lakeland as a results of intensive agricultural farming. AR. Poznań (in Polish with English summary).

Marks, L., 2012. Timing of the Late Vistulian (Weichselian) glacial phases in Poland. Quaternary Science Reviews 44: 81–88.

Nechay, W., 1927. Glacial sediments in the Dobrzyń region. Spraw. Państw. Inst. Geol. 4: 61–144 (in Polish with French summary).

Olszewski, A., 1997. Drumlins of the northwestern Dobrzyń Moraine Plateau, location, structure and morphogenesis. Quaternary Studies in Poland 14: 71–83.

Podlasiński, M., 2013. Denudation of anthropogenic impact on the diversity of soil cover and its spatial structure in the agricultural landscape of moraine. West Pomeranian University of Technology. Szczecin (in Polish with English summary).

Sinkiewicz, M., 1998. The development of anthropogenic denudation in central part of northern Poland. UMK, Toruń (in Polish with English summary).

Smolska, E., 2002. The intensity of soil erosion in agricultural areas in North-Eastern Poland. Landform Analysis 3: 25–33.

Szrejder, B., 1998. Some properties and taxonomic position of soils evolved as a result of anthropogenic denudation in Koniczynka on the Chełmno Moraine Plateau. Zesz. Probl. Post. Nauk Roln. 460: 499-511 (in Polish with English summary).

Świtoniak, M., 2008. Classification of young glacial soils with vertical texture-contrast using WRB system. Agrochimija i Gruntoznawstwo, Charkiw 69: 96–101.

Świtoniak, M., 2014. Use of soil profile truncation to estimate influence of accelerated erosion on soil cover transformation in young morainic landscapes, North-Eastern Poland. Catena 116: 173–184.

Świtoniak, M., Dąbrowski, M., Łyszkiewicz, A., 2015. The Influence of human-induced erosion on the soil organic carbon stock in vineyards of Fordon Valley, Polish J. of Soil Sci. 48, 2: 197–211.

Świtoniak, M., Markiewicz, M., Bednarek, R., Paluszewski, B., 2013. Application of aerial photographs for the assessment of anthropogenic denudation impact on soil cover of the Brodnica Landscape Park plateau areas. Ecological Questions 17: 101–111.

Świtoniak, M., Mroczek, P., Bednarek, R., 2016. Luvisols or Cambisols? Micromorphological study of soil truncation in young morainic landscapes — Case study: Brodnica and Chełmno Lake Districts (North Poland). Catena 137: 583–595.

Wójcik, G., Marciniak, K., 1987a. Thermal conditions in central part of the North Poland in the years 1951-1970. AUNC. Geogr. 20: 29–50 (in Polish).

Wójcik, G., Marciniak, K., 1987b. Precipitations in central part of the North Poland in the years 1951-1970. AUNC. Geogr. 20: 51–69 (in Polish).

Wójcik, G., Marciniak, K., 1993. Precipitations in Lower Vistula Valley in the years 1951-1980. In: Churski, Z. (Eds.), Environmental and socio-economic development of the Lower Vistula Valley. IG UMK. Toruń: 107–121.

Wysota, W., 1994. Morphology, internal composition and origin of drumlins in the southeastern part of the Chełmno–Dobrzyń Lakeland. Sedimentary Geology 91: 345–364.

Soils of undulating glacial moraine in Poznań Lakeland (Poland)

Waldemar Spychalski, Łukasz Mendyk, Tomasz Kaczmarek

The study area is located in the eastern part of the Pozań Lakeland mesoregion, at the boundary between two microregions: the Owińska-Kiekrz Hills in the south and the Szamotuły Plain in the north (Krygowski, 1961; Kondracki 2009). The relief was mainly formed during the Poznań phase of the Weichselian glaciation (20–19 kyr BP; Fig. 1; Choma-Moryl et al., 1989; Marks, 2012; Marks 2015). It represents a young glacial landscape, specific to this region.

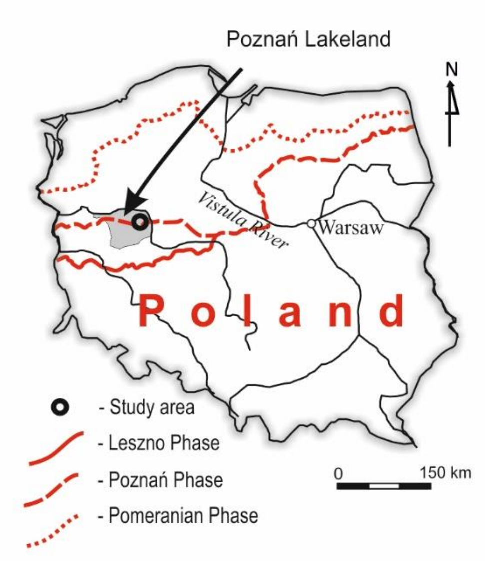


Fig. 1. Location

Lithology and topography

The Owińska-Kiekrz Hills are morainic hills connected with the Poznań phase, with the highest point of the Morasko Hill (153 m a.s.l). They border on the Szamotuły Plain in the north, which is a relatively flat morainic plateau divided by several tributaries of the Warta River (Samica, Sama and Ostroga; Kondracki 2009). The study site is located in the contact zone of the terminal moraine hills built of glacial tills (about 100 m a.s.l.) in the south, fluvioglacial sands covering the lower parts of the slopes (about 95 m a.s.l) and a longitudinal intra-moraine depression filled with sandy loams in the north (about 93 m a.s.l.; Krygowski, 1961; Skompski, 1993; Topographic Map of Poland, 1:10 000, WMS server, geoportal.gov.pl).

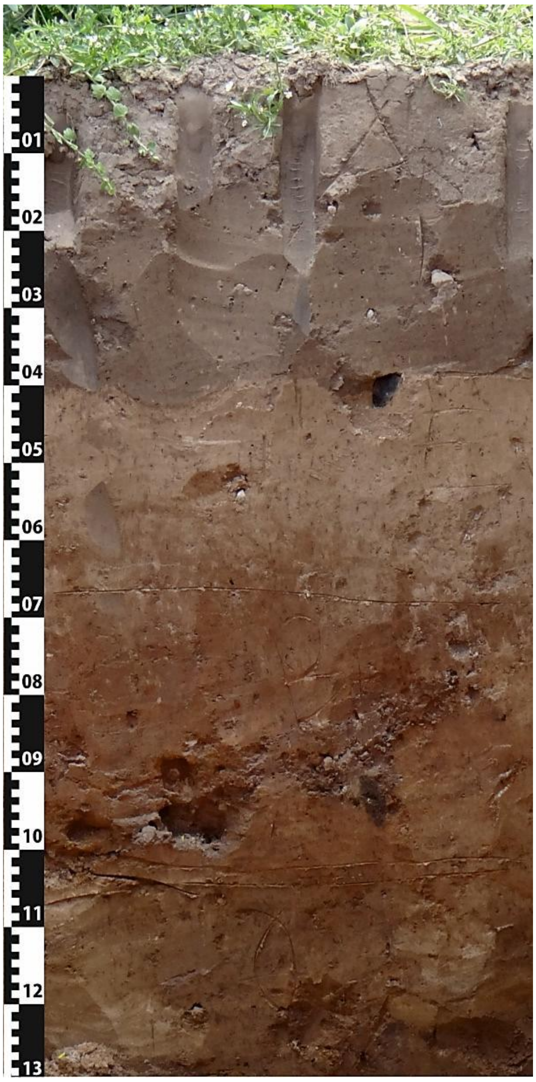
Land use

Nowadays, the study area is used mainly as arable land. The main crops cultivated on loamy soils are e.g. oilseed rape, wheat, corn or triticale, sometimes other plants like blue tansy (*Phacelia tanacetifolia*) used as a cover crop and bee plant. Sandy soils at lower slopes are covered with rye, while toe slopes and bottoms of the depressions are covered with some grasslands or blue tansy and even rushes dominated by common reed (*Phragmites australis*). The potential natural vegetation in this area are middle European hornbeam forests (*Galio-Carpinetum*; Matuszkiewicz 2008).

Climate

According to Kottek et al. (2006), the region is located in the temperate warm climate zone, fully humid with warm summer. The average annual temperature is 8.1 °C. The average temperature of the coldest month (January) is –2.6°C, while the warmest month is July – 17.9°C. The average annual precipitation is 534 mm. February is the driest month (25 mm), while the highest precipitation is recorded in July – 73 mm (1982–2010, climate.data.org).

Profile 1 – Albic Abruptic **Luvisol** (Anoarenic, Aric, Cutanic, Endoloamic, Ochric)
Localization: undulating moraine, middle slope - inclination 5°, arable land, 102 m a.s.l.
N 52°30'13.8" **E** 16°49'20.3"



Morphology:

Ap – 0–38 cm, plough humus horizon, sand, dark yellowish brown (10YR 4/4, 10YR 3/4), slightly moist, medium to coarse weak granular structure, abrupt and wavy boundary;

E – 38–67 cm, eluvial horizon with *albic* material, sand, very pale brown (10YR 7/2, 10YR 7/3), slightly moist, single grain structure, gradual and wavy boundary;

Bt – 67–103 cm, *argic* horizon, sandy loam, brown (7.5YR 6/4, 7.5YR 4/6), slightly moist, coarse strong angular structure, many clay coatings, gradual and smooth boundary;

Ck – 103–(130) cm, *calcaric* parent material, sandy loam, light yellowish brown (10YR 4/4, 10YR 6/6), dry, medium and coarse angular structure, common soft concretions of secondary carbonates.

Table 1. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	0–38	4	7	38	31	12	2	2	1	3	4	S
E	38–67	5	9	32	35	13	1	1	1	3	5	S
Bt	67–103	2	3	14	27	15	6	4	6	15	10	SL
C	103– (130)	2	3	15	26	15	6	7	8	18	2	SL

Table 2. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	C/N	pH		$CaCO_3$ [$g \cdot kg^{-1}$]
					H_2O	KCl	
Ap	0–38	5.0	0.48	10	6.7	6.1	-
E	38–67	0.4	0.04	10	7.1	6.5	trace
Bt	67–103	1.1	0.11	10	7.8	6.9	trace
C	103–(130)	-	-	-	8.2	7.5	56

Table 3. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	TEB	HA	CEC	BS [%]
		[$cmol(+) \cdot kg^{-1}$]							
Ap	0–38	3.79	1.28	0.55	0.15	5.77	0.82	6.59	88
E	38–67	1.83	1.11	0.22	0.09	3.25	0.73	3.98	82
Bt	67–103	6.39	2.37	0.35	0.12	9.23	0.59	9.82	94
C	103–(130)	5.31	2.14	0.32	0.10	7.87	0.52	8.39	94

Profile 2 – Abruptic **Luvisol** (Aric, Cutanic, Pantoloamic, Ochric)
Localization: undulating moraine, upper slope - inclination 5°, arable land, 103.5 m a.s.l.
N 52°30'16.8" **E** 16°49'18.1"

Morphology:

Ap – 0–30 cm, plough horizon, sandy loam, grayish yellow brown (10YR 5/2, 10YR 4/2), slightly moist, fine moderate granular structure, abrupt and wavy boundary;

Bt – 30–47 cm, *argic* horizon, sandy loam, yellowish brown (7.5YR 5/3, 7.5YR 4/4), slightly moist, medium moderate to strong angular structure, gradual and smooth boundary;

C – 47–(120) cm, parent material, sandy loam, yellowish brown (10YR 5/4, 10YR 4/6), slightly moist, medium weak angular structure.

Table 4. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	0–30	2	4	12	17	27	18	5	4	5	8	SL
Bt	30–47	5	3	11	13	23	14	8	2	7	19	SL
C	47–(120)	3	4	9	17	21	15	8	4	5	17	SL

Table 5. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	C/N	pH		$CaCO_3$ [$g \cdot kg^{-1}$]
					H_2O	KCl	
Ap	0–30	6.5	0.46	14	6.5	5.8	-
Bt	30–47	0.7	0.06	12	6.0	5.1	-
C	47–(120)	-	-	-	6.7	5.2	-

Table 6. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	BS [%]
		[$cmol(+) \cdot kg^{-1}$]							
Ap	0–30	3.22	0.53	0.36	0.09	4.20	1.55	5.75	73
Bt	30–47	5.22	0.78	0.41	0.07	6.48	2.36	8.84	73
C	47–(120)	4.65	0.65	0.35	0.08	5.73	2.25	7.98	72

Profile 3 – Dystric **Arenosol** (Aric, Ochric)

Localization: intra moraine shallow longitudinal depression, lower slope - inclination 8°, arable land, 95.5 m a.s.l., **N** 52˚30'27.9'' **E** 16˚49'09,1''

Morphology:

Ap – 0–42 cm, plough horizon, sand, dark grayish brown (7.5YR 4/3, 7.5YR 4/2), slightly moist, fine to medium weak granular structure, abrupt and smooth boundary;

C1 – 42–120 cm, parent material, sand, yellowish brown (10YR 6/5, 10YR 5/4), slightly moist, very fine weak granular and single grain structure, gradual irregular boundary;

C2 – 120–(140) cm, parent material, sand, light yellowish brown (10YR 7/4, 10YR 6/4), slightly moist, single grain structure.

Table 7. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	0–42	0	1	11	47	29	4	3	3	1	1	S
C1	42–120	0	3	17	46	31	1	0	1	1	0	S
C	120–(140)	0	2	15	48	32	1	1	1	0	0	S

Table 8. 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	0–42	4.9	0.47	10	5.5	4.5	-
C1	42–120	-	-	-	5.3	4.1	-
C	120–(140)	-	-	-	5.2	4.7	-

Table 9. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	BS [%]
		[cmol(+)·kg^{-1}]							
Ap	0–30	1.92	0.29	0.23	0.05	2.49	2.80	5.29	47
C1	30–47	0.03	0.02	0.06	0.03	0.14	0.51	0.65	22
C	47–(120)	0.02	0.02	0.04	0.02	0.10	0.60	0.70	14

Profile 4 – Endogleyic **Phaeozem** (Aric, Colluvic, Pantoloamic, Pachic)
Localization: intra moraine shallow longitudinal depression, toe slope - inclination 2°, arable land, 93,5 m a.s.l., **N** 52°30'30.6" **E** 16°49'07.3"

Morphology:

Ap – 0–30 cm, *mollic* horizon, colluvic material, sandy loam, dark grayish brown (10YR 3/3, 10YR 2/2), moist, medium moderate granular structure, abrupt and smooth boundary;

A – 30–58 cm, *mollic* subhorizon, colluvic material, sandy loam, dark grayish brown (10YR 4/2, 10YR 3/2), moist, medium moderate granular structure, clear and wavy boundary;

Ab – 58–75 cm, buried humus horizon, *mollic* subhorizon, sandy loam, dark grayish brown (10YR 3/3, 10YR 3/1), moist, fine and medium weak to moderate granular structure, fine and medium very few roots, clear and irregular boundary;

AC – 75–95 cm, transitional horizon with gleyic properties, sandy loam, grayish olive (2.5Y 6/2, 2.5Y 5/3), moist, medium moderate subangular structure, infilled burrows, gradual and wavy boundary;

Ckl – 95–(120) cm, parent material, sandy loam, yellowish brown and light olive gray (oxymorphic: 10YR 6/8, 10YR 5/6; reductimorphic: 2.5GY 7/1), moist, medium weak subangular structure.

Table 10. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	0–30	0	2	12	17	24	15	7	8	6	9	SL
A	30–58	0	3	11	18	24	14	9	9	5	7	SL
Ab	58–75	0	1	8	14	21	18	6	14	9	9	SL
AC	75–95	0	1	9	13	25	15	5	12	8	12	SL
Ckl2	95–(120)	0	1	11	16	22	15	5	11	9	10	SL

Table 11. 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	0–30	18.5	1.91	10	7.6	6.9	trace
A	30–58	9.8	0.92	11	7.7	7.2	trace
Ab	58–75	10.1	0.96	11	7.5	6.8	trace
AC	75–95	2.3	0.30	8	7.9	7.4	23
Ckl2	95–(120)	0.5	0.06	8	8.3	7.5	46

Table 12. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	TEB	HA	CEC	BS [%]
		[cmol(+)·kg^{-1}]							
Ap	0–30	8.61	0.65	0.42	0.07	9.75	1.23	11.0	89
A	30–58	5.68	0.72	0.41	0.06	6.87	1.58	8.45	81
Ab	58–75	5.52	0.57	0.35	0.06	6.50	1.14	7.64	85
AC	75–95	6.57	0.64	0.31	0.04	7.56	0.95	8.51	88
Ckl2	95–(120)	5.93	0.61	0.24	0.05	6.83	0.65	7.48	92

Profile 5 – Mollic **Gleysol** (Humic, Anoloamic)
Localization: bottom of the intra moraine shallow longitudinal depression, grassland, 93 m a.s.l.
N 52°30'31.4" **E** 16°49'05.5"

Morphology:

Ap – 0–40 cm, *mollic* horizon, sandy loam, very dark grayish olive (2.5Y 3/1, 2.5Y 2/1), moist, medium moderate granular structure, very fine and fine common roots, gradual and smooth boundary;

AC – 40–60 cm, transitional horizon, sandy loam, yellowish brown and light olive gray (oxymorphic: 10YR 6/4, 10YR 5/4; reductimorphic: 5GY 7/1, 2.5GY 7), moist, fine to medium moderate subangular structure, very fine and fine few roots, gradual and wavy boundary;

Cr – 60–(90) cm, parent material, sandy loam, light olive gray (5GY 7/1, 2.5GY 7), wet, fine and medium weak granular structure, coarse very few dead roots.

Table 13. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	0–40	0	2	8	20	31	11	10	4	6	8	SL
AC	40–60	0	1	8	22	32	10	12	6	2	7	SL
Cr	60–(90)	0	1	6	15	28	14	10	9	2	15	SL

Table 14. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	C/N	pH		$CaCO_3$ [$g \cdot kg^{-1}$]
					H_2O	KCl	
Ap	0–40	26.8	2.68	10	7.7	6.9	trace
AC	40–60	9.8	0.96	10	7.5	7.2	trace
Cr	60–(90)	-	-	-	8.2	7.5	21

Table 15. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	HA	CEC	BS [%]
		[$cmol(+) \cdot kg^{-1}$]							
Ap	0–40	7.33	2.62	0.75	0.45	11.2	1.12	12.2	91
AC	40–60	6.81	1.69	0.55	0.25	9.30	0.91	10.2	91
Cr	60–(90)	6.49	1.91	0.52	0.15	9.07	0.72	9.77	93

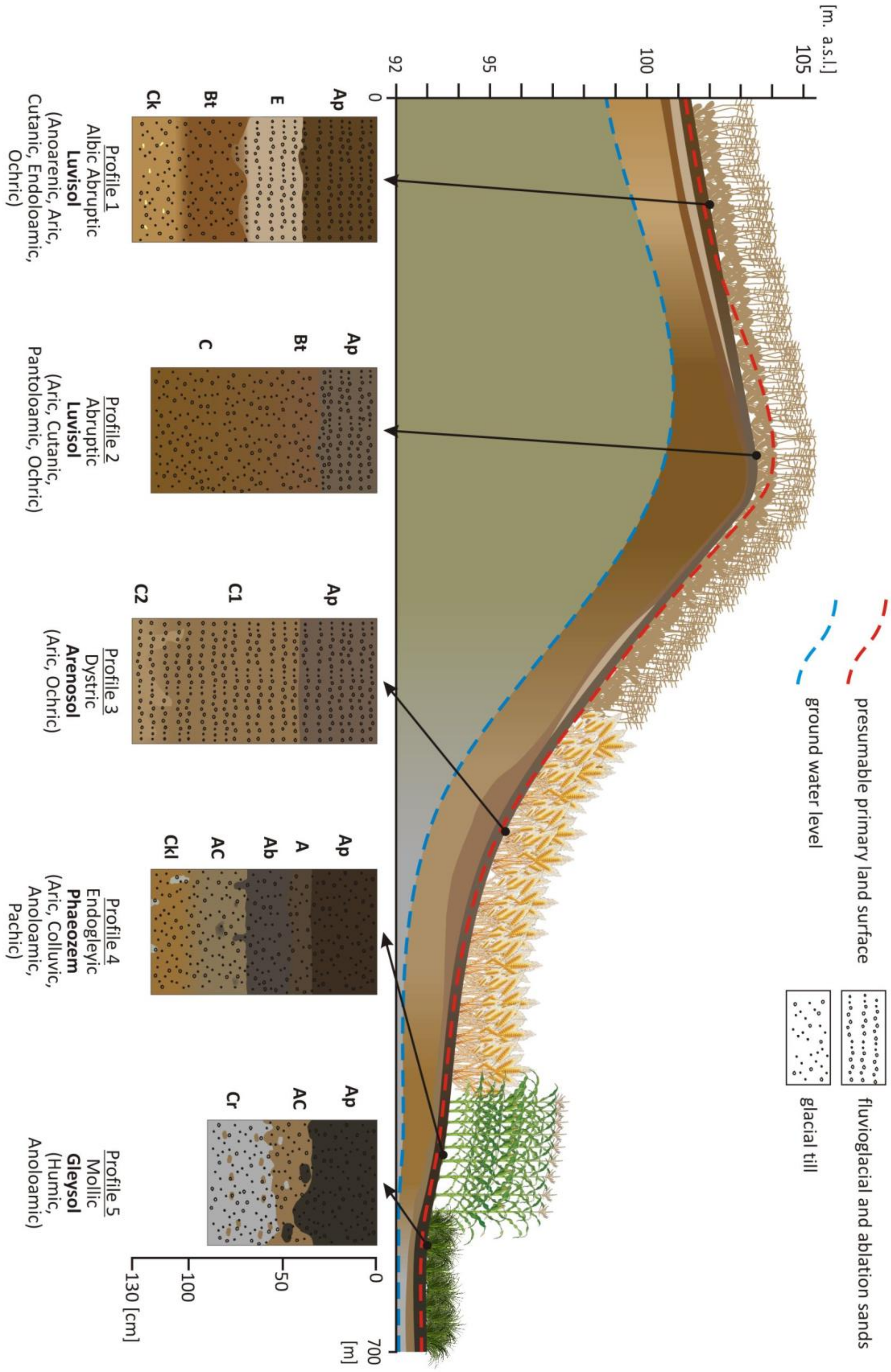


Fig. 2. Hydrolithotoposequence of soils of undulating glacial moraine in the Poznań Lakeland near Złotniki

Soil genesis and systematic position

The investigated soils represent rather typical heterogeneity of soil cover within the young-glacial moraine landscape. High variability of glacial sediments, including the diversity of glacial till dominating in this region (characterised by a high content of sand and very often covered with ablation sands; Kaczmarek et al. 2007) is one of the most important reasons for these conditions. In addition, the dynamically changing relief is a response to fluctuations in the ground water level in the area as well as to erosion and accumulation processes remodelling the developed soil profiles.

Profile 1 is located in the middle part of a gentle moraine slope. It has developed from sand laying on sandy loam. Due to the presence of *argic* Bt, it was classified as **Luvisol** (IUSS Working Group WRB, 2015). This diagnostic horizon was identified based on the presence of clay coatings on ped faces formed under conditions typical of the *lessivage* process (Quénard et al., 2011; Świtoniak et al. 2018). The ***Albic*** primary qualifier was used to express the light colour of the material in the eluvial E horizon, meeting the criteria for *albic material.* The *Abrupt textural difference* between these two above-mentioned horizons (E and Bt) is emphasized by the ***Abruptic*** qualifier. The list of supplementary qualifiers used to describe this profile starts with ***Anoarenic,*** which provides information on sandy texture, from the mineral soil surface to a depth between 50 and 100 cm. The next qualifier – ***Aric*** – is used for soils ploughed to a depth of at least 20 cm from the soil surface. The loamy texture in the bottom part of the soil profile is highlighted with the ***Endoloamic*** supplementary qualifier (Table 1). The abundance of clay coatings mentioned at the beginning of the description of this profile is the feature required for the application of the ***Cutanic*** qualifier. The last qualifier – ***Ochric*** – provides information on properties of the humus horizon. It is used when there are no circumstances to identify the ***Mollic*** or ***Umbric*** horizons and the ***Humic*** qualifier cannot be used, but the content of organic carbon has to be at least 0.2% from the mineral soil surface to a depth of 10 cm (Table 2).

Profile 2 was also classified as **Luvisol** based on the presence of the ***Argic*** Bt diagnostic horizon. The main difference between profiles 1 and 2 is lack of the eluvial E horizon due to the truncation of the profiles as a result of the human-induced erosion process. This is a typical scenario in the case of agriculturally used **Luvisols** located in the upper part of the slopes in many agricultural young glacial moraine areas in Poland (e.g. Sinkiewicz, 1998; Marcinek and Komisarek, 2004; Kobierski, 2013; Podlasiński, 2013; Świtoniak, 2014; Świtoniak et al., 2015; Świtoniak et al., 2016). Similarly to profile 1, the ***Abruptic*** qualifier was used to indicate the *abrupt textural difference;* in this case it was observed between A and Bt horizons. Also the list of supplementary qualifiers is similar to profile 1 (***Aric, Pantoloamic, Cutanic, Ochric***). ***Aric, Cutanic*** and ***Ochric*** were used for the same reasons. The only difference in relation to the texture-related qualifiers is the depth of these features. ***Pantoloamic*** reflects the loamy texture starting at the soil surface, with a lower limit at a depth of 100 cm or more (Table 4).

Profile 3 has developed from glaciofluvial sandy sediments (Table 7) at the lower topographic position of the slope. The absence of any diagnostic horizons and the dominant sandy texture determined the systematic position of this profile, which was classified as **Arenosol** (IUSS Working Group WRB, 2015). The ***Dystric*** principal qualifier was used to indicate that the effective base saturation is below 50% (Table 9). Features of the plough humus horizons in this soil profile allowed us to use ***Aric*** and ***Ochric*** supplementary qualifiers, like for the previously described soils. Due to the specific colour of the surface horizon, which is significantly redder than the parent material, we can assume that this profile may have been a ***Brunic*** **Arenosol** in the past. Later, it was probably partially eroded and deep ploughing resulted in the incorporation of the Bw horizon into the humus horizon.

The ***Brunic*** principal qualifier can be applied when the Bw horizon meets criteria 2–4 for the ***Cambic*** diagnostic horizon and does not consist of albic material.

Profile 4 was located on the toe slope of the intra-moraine depression. The main attribute taken into account in the classification of this soil was the very deep ***Mollic*** diagnostic horizon. This led us to classify the soil as **Pheaozem** (IUSS Working Group WRB, 2015). Due to the presence of *Gleyic properties* at a depth of 75 cm, the ***Endogleyic*** principal qualifiers were used. Other features recognized in this soil profile were emphasized by the supplementary qualifiers. The soil was ploughed to a depth of more than 20 cm (***Aric***). The morphology and variability of the organic carbon content in the ***Mollic*** horizon, as well as the soil profile topographic position (in relation to eroded soil in the upper parts of the slopes) are characteristic of the soils under a considerable influence of colluvial processes (e.g. Orzechowski 2008, Świtoniak 2014, Markiewicz et al. 2015). We recognized that Ap and A subhorizons of the ***Mollic*** horizon were developed from the colluvium, that is why the ***Colluvic*** qualifier was used. The texture of all identified horizons was sandy loam (from the soil surface to a depth of more than 100 cm), which is expressed by using the ***Pantoloamic*** subqualifier (Table 10). As the thickness of the ***Mollic*** horizon was more than 50 cm, the last supplementary qualifier is ***Pachic.***

Profile 5 was located at the bottom of the depression – the lowermost position in the studied soil sequence. Due to the high ground water level connected with the topographic position, G*leyic properties* were recognized at a depth of less than 40 cm, which led us to classify this soil profile as **Gleysol.** The presence of the ***Mollic*** diagnostic horizon is emphasized by using the ***Mollic*** principal qualifier. The relatively high content of organic carbon (Table 14) allowed us to use the ***Humic*** supplementary qualifier. Similarly to the previous soil, this profile also developed from sandy loam (Table 13), but it was investigated only to a depth of 90 cm due to the ground water level. That is why the ***Anoloamic*** subqualifier was used.

Soil sequence

The above-described soil transect has developed through several different soil forming and geomorphologic processes. The first two profiles are **Luvisols** developed from glacial tills and sands as a result of the ***lessivage*** process and later remodelled by erosion processes (profile 2). The third one (**Arenosols**) developed from sandy fluvioglacial sediments influenced by pedogenic in situ concentration of Fe sesquioxides. These three profiles were also transformed by tillage process (deepened humus horizons). Profiles 4 (**Phaeozem**) and 5 (**Gleysol**) developed as a result of organic carbon accumulation and gleyic processes connected with a high ground water level. In addition, profile 4 was modified by the process of colluvic material accumulation. Due to different groundwater table levels in the profiles, relatively large variability of soil materials and different topographic positions influencing the geomorphological processes (human induced erosion), the presented catena is a good example of the **hydro-litho-toposequence.**

References

Choma-Moryl, K., Czerwonka, J., Krzyszkowski, P., Moryl, J., 1989. Genesis and stratigraphy of cenozoic sediments within the Oborniki Wielkopolskie sheet. Centralne Archiwum Geologiczne Państwowego Archiwum Geologicznego, Warszawa (in Polish).

IUSS Working Group WRB, 2015. World Reference Base for soil resources 2014, update 2015 International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Report No. 106. FAO, Rome.

Kaczmarek, Z., Gajewski, P., Owczarzak, W., Grzelak, M., Some physical and water properties of Luvisols formed from the bottom moraine loams (Würm). Roczniki Gleboznawcze – Soil Science Annual 58 (1/2): 45–52 (in Polish with English summary).

Kobierski, M., 2013. Morphology, properties and mineralogical composition of eroded Luvisols in selected morainic areas of the Kujavian and Pomeranian Province. University of Technology and Life Sciences. Bydgoszcz.

Kondracki, J., 2009. Regional geography of Poland. PWN, Warsaw (in Polish).

Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F. 2006. World Map of Köppen-Geiger Climate Classification updated. Meteorol. Z., 15, 259–263.

Krygowski, B., 1961. Physical Geography of the Greater Poland Lowland. Poznańskie Towarzystwo Przyjaciół Nauk, Poznań (in Polish).

Marcinek, J., Komisarek, J., 2004. Anthropogenic transformations of soils of Poznań Lakeland as a results of intensive agricultural farming. AR. Poznań (in Polish with English summary).

Marks, L., 2012. Timing of the Late Vistulian (Weichselian) glacial phases in Poland. Quaternary Science Reviews 44, 81–88.

Marks, L., 2015. The last deglaciation of northern continental Europe. Cuadernos de Investigación Geográfica 41(2), 279–293.

Matuszkiewicz, J.M., 2008. Potential natural vegetation of Poland. IGiPZ PAN, Warszawa, available at: https://www.igipz.pan.pl/tl_files/igipz/ZGiK/opracowania/roślinność_potencjalna/B2.png.

Markiewicz, M., Mendyk, Ł., Gonet, S.S., 2015. Soil organic matter status in agrucultural soil sequence of former shoreline of dissappearing Sumowskie Lakes, North-Eastern Poland. Polish Journal of Soil Science 48 (1): 65–78.

Orzechowski, M., 2008. The properties of eroded and deluvial soils in the Mazurian Lakeland and the Sępopolska Plain. Roczniki Gleboznawcze – Soil Science Annual 59 (3/4): 236–242 (in Polish with English summary).

Podlasiński, M., 2013. Denudation of anthropogenic impact on the diversity of soil cover and its spatial structure in the agricultural landscape of moraine. West Pomeranian University of Technology. Szczecin (in Polish with English summary).

Quénard, L., Samouëlian, A., Laroche, B., Cornu, S., 2011. Lessivage as a major process of soil formation: A revisitation of existing data. Geoderma, 167–168: 135–147.

Skompski, S., 1993. Explanations for the Detailed Geological Map of Poland, 1:50 000, Oborniki Wielkopolskie Sheet. Polish Geological Institute, Warsaw (in Polish).

Sinkiewicz, M., 1998. The development of anthropogenic denudation in central part of northern Poland. UMK, Toruń (in Polish with English summary).

Świtoniak, M., 2014. Use of soil profile truncation to estimate influence of accelerated erosion on soil cover transformation in young morainic landscapes, North-Eastern Poland. Catena 116: 173–184.

Świtoniak, M., Dąbrowski, M., Łyszkiewicz, A., 2015. The influence of human-induced erosion on the soil organic carbon stock in vineyards of the Fordon Valley. Polish Journal of Soil Science 48, 2: 197-211.

Świtoniak, M., Mroczek, P., Bednarek, R., 2016. Luvisols or Cambisols? Micromorphological study of soil truncation in young morainic landscapes — Case study: Brodnica and Chełmno Lake Districts (North Poland). Catena 137: 583–595.

Post-agricultural soils of kettle-holes within an outwash plain (Brodnica Lake District, Poland)

Marcin Świtoniak, Bartłomiej Wojtczak

The investigated transect of soils is located on the slope of a kettle-hole within the East-Brodnica outwash plain (Niewiarowski, 1986). According to Kondracki (2001) the study area is located in the middle of the Brodnica Lake District mesoregion. Within this region, the West and East Brodnica outwashes were formed of glaciofluvial sediments deposited by meltwater during the youngest, Pomeranian phase of the Weichselian glaciation (16–17 kyr BP; Fig.1; Roszko, 1968; Marks, 2012).

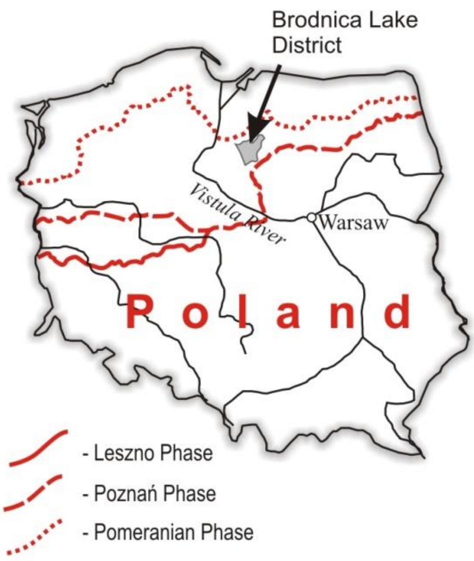


Fig. 1. Location

Lithology and topography

The outwash plains (also called sandurs) of the region are several dozen kilometres in length and were formed by meltwaters that flowed out from the ice sheet to the south. Initially, the outwashes had the character of flat plains separated by "islands" of morainic plateaus. During warm phases of the late-glacial period, mostly in the Alleröd, blocks of ice buried under glaciofluvial deposits melted. This diversified the outwash surface and resulted in "pitted" outwash developing with several deep kettle-holes. The outwash deposits were lodged in the surface of older glacial tills and their thickness varies from about 2 to 10 m (Niewiarowski, 1986). The texture of the outwash sediments is sandy with domination of poorly selected coarse and medium sand fractions mixed with gravels in proximal (north) parts of sandurs and well selected fine and very fine sands in their distal (south) zone. Mineral composition is dominated by quartz and they are non-carbonate, acid sediments.

Land use

Pine plantations are the main form of land use within the Brodnica outwash plains. Only small parts of them, in particular at the border with morainic plateaus, have been transformed into arable areas. The time of the earliest cultivation is unknown. Agricultural areas in the region had the largest range in the first half of the 20th century. From the 1990s, they were reforested and converted into fallows with grass vegetation, as was the case with the studied slope.

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 – Dystric Lamellic **Arenosol** (Aric, Ochric)

Localization: Kettle-hole within outwash plain, crest - inclination 2°, fallow, dense grass vegetation, 99 m a.s.l. **N** 53°22’16.7” **E** 19°22’98.5”

Morphology:

A(p) – 0–25 cm, humus horizon ploughed in the past, fine sand, brown (10YR 6/3; 10YR 4/3), dry, weak granular fine/single grain structure, fine and medium common roots, abrupt and smooth boundary;

C – 25–(100) cm, parent material, fine sand, yellowish brown (10YR 6/4; 10YR 5/4), slightly moist, single grain structure, few fine sand and brown (7.5 YR 5/6; 7.5 YR 4/4) clay-sesquioxides lamellaes.

Table 1. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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(p)	0–25	0	1	2	13	55	22	3	1	1	2	FS
C	25–(100)	0	0	7	40	50	2	1	0	0	0	FS
lamellae	------	0	0	1	19	67	4	1	1	0	7	FS

Table 2. 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	
A(p)	0–25	6.3	0.30	21	5.2	4.2	-
C	25–(100)	-	-	-	6.2	4.6	-
lamellae	------	0.5	0.08	6	6.6	5.0	-

Profile 2 – Dystric Lamellic **Arenosol** (Aric, Ochric)

Localization: Kettle hole within outwash plain, upper slope - inclination 7°, fallow, dense grass vegetation, 98 m a.s.l., **N** 53°22’17.1” **E** 19°23’00.8"

Morphology:

A(p) – 0–28 cm, humus horizon ploughed in the past, fine sand, brown (10YR 6/3; 10YR 4/3), slightly moist, weak granular fine/single grain structure, fine and medium common roots, abrupt and smooth boundary;

C – 28–100 cm, parent material, fine sand, yellowish brown (10YR 6/4; 10YR 5/4), slightly moist, single grain structure, common sandy loam and strong brown (7.5 YR 6/6; 7.5 YR 4/6) clay-sesquioxides lamellaes.

Table 3. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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(p)	0–28	0	1	2	14	54	19	4	1	1	4	FS
C	28–(100)	0	0	0	8	34	49	5	1	0	3	FS
lamellae	-------	0	0	1	3	35	36	5	2	1	17	SL

Table 4. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	C/N	pH		$CaCO_3$ [$g \cdot kg^{-1}$]
					H_2O	KCl	
A(p)	0–28	9.3	0.30	31	5.3	4.1	-
C	28–(100)	-	-	-	5.8	4.1	-
lamellae	-------	1.0	0.13	8	6.1	4.4	-

Profile 3 – Epidystric Endoeutric Endobrunic **Arenosol** (Aric, Colluvic, Humic, Bathylamellic)
Localization: Kettle hole within outwash plain, middle slope - inclination 20°, fallow, dense grass vegetation, 92 m a.s.l., **N** 53°22'18.5" **E** 19°23'01,7"

Morphology:

A(p)1 – 0–30 cm, humus horizon ploughed in the past, colluvic material, loamy fine sand, dark grayish brown (10YR 5.5/2; 10YR 4/2), slightly moist, weak granular fine/single grain structure, fine and medium common roots, abrupt and smooth boundary;

A(p)2 – 30–56 cm, humus horizon ploughed in the past, colluvic material, loamy fine sand, dark gray (10YR 5/2; 10YR 4/1), slightly moist, weak granular fine/single grain structure, fine and medium few roots, abrupt and smooth boundary with black remnants of older humus horizon;

2Bwb – 56–120 cm, *brunic* material, concentration of sesquioxides, fine sand, dark yellowish brown (10YR 6/4; 10YR 4/4), slightly moist, weak granular very fine/single grain structure, fine and medium few roots, single sandy loam and strong brown (7.5 YR 6/6; 7.5 YR 4/6) clay-sesquioxides lamellaes, gradual and wavy boundary;

2C – 120–(160) cm, parent material, fine sand, light olive brown (10YR 7/3; 2.5YR 5/3), slightly moist, single grain structure, common sandy loam and strong brown (7.5 YR 6/6; 7.5 YR 4/6) clay-sesquioxides lamellaes.

Table 5. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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	0	1	2	9	46	26	9	1	1	5	LFS
Ap2	30–56	0	1	3	14	39	27	10	2	1	3	LFS
2Bwb	56–120	0	6	10	18	41	17	5	1	1	1	FS
2C	120–(160)	0	1	1	2	43	46	6	0	1	0	FS

Table 6. 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	
A1	0–30	12.7	0.58	22	5.2	4.1	-
A2	30–56	8.7	0.34	26	5.2	4.2	-
2Bwb	56–120	2.3	0.11	21	5.7	4.7	-
2C	120–(160)	-	-	-	6.6	4.9	-

Profile 4 – Dystric **Arenosol** (Aric, Colluvic, Humic, Bathythaptobrunic)

Localization: Kettle-hole within outwash plain, lower slope - inclination 5°, fallow, dense grass vegetation, 89 m a.s.l., **N** 53°22'20,4" **E** 19°23'04,0"

Morphology:

A**(p)1** – 0–28 cm, humus horizon ploughed in the past, colluvic material, loamy fine sand, dark yellowish brown (10YR 5/4; 10YR 3/4), slightly moist, weak granular fine structure, fine and medium common roots, clear and smooth boundary;

A(p)2 – 28–52 cm, humus horizon ploughed in the past, colluvic material, loamy fine sand, dark yellowish brown (10YR 5/3; 10YR 3/4), slightly moist, weak granular fine structure, fine few roots, abrupt and smooth boundary;

A(p)3 – 52–72 cm, humus horizon ploughed in the past, colluvic material, loamy fine sand, brown (10YR 5/3; 10YR 4/3), slightly moist, weak granular fine/single grain structure, fine very few roots, abrupt and smooth boundary;

A(p)4 – 72–96 cm, humus horizon ploughed in the past, colluvic material, loamy fine sand, dark yellowish brown (10YR 5/4; 10YR 3/4), slightly moist, weak granular fine structure, fine very few roots, abrupt and smooth boundary;

A(p)5 – 96–110 cm, humus horizon ploughed in the past, colluvic material, loamy fine sand, dark yellowish brown (10YR 5/3; 10YR 3/4), slightly moist, weak granular fine/single grain structure, fine few roots, abrupt and smooth boundary;

A(p)6 – 110–134 cm, humus horizon ploughed in the past, colluvic material, loamy fine sand, dark brown (10YR 5/3; 10YR 3/3), slightly moist, weak granular fine structure, fine very few roots, clear and smooth boundary;

2A(b) – 134–144 cm, buried humus horizon ploughed in the past, loamy fine sand, dark grayish brown (10YR 5/2; 10YR 4/2), slightly moist, weak granular fine structure, fine very few roots, common charcoals, abrupt and smooth boundary;

2Bwb – 134–180 cm, concentration of sesquioxides, fine sand, strong brown (2.5 YR 5/6; 2.5YR 4/6), single grain structure, gradual boundary;

2BC – 180–232 cm, transitional horizon, sandy loam, light olive brown (2.5YR 6/6, 2.5Y 5/6), weak granular structure, diffuse boundary;

2Cl – 232–(260) cm, parent material, gleyic properties, common iron concentrations and oximorphic mottles, loamy fine sand, light yellowish brown (2.5YR 7/4, 2.5Y 6/4), single grain structure.

Table 7. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in 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(p)1	0–28	1	1	2	12	47	19	9	4	3	3	LFS
A(p)2	28–52	2	1	3	16	47	18	5	3	2	5	LFS
A(p)3	52–72	0	1	3	13	50	12	15	3	1	2	LFS
A(p)4	72–96	1	1	3	16	48	13	13	3	1	2	LFS
A(p)5	96–110	0	1	3	13	49	20	6	4	2	2	LFS
A(p)6	110–134	0	0	2	10	44	25	8	7	3	1	LFS
2A(b)	134–144	0	0	1	5	49	31	8	3	0	3	LFS
2Bwb	144–180	0	0	0	5	51	33	7	2	1	1	FS
2BC	180–232	0	0	0	3	32	31	18	6	2	8	SL
2Cl	232–(260)	0	0	1	7	44	28	12	4	1	3	LFS

Table 8. 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	
A(p)1	0–28	19.0	0.80	24	5.6	4.4	-
A(p)2	28–52	14.6	0.59	25	5.9	4.5	-
A(p)3	52–72	12.4	0.40	31	5.4	4.2	-
A(p)4	72–96	07.3	0.24	30	5.4	4.2	-
A(p)5	96–110	10.3	0.29	36	5.3	4.1	-
A(p)6	110–134	16.0	0.47	34	5.2	4.2	-
2A(b)	134–144	15.2	0.36	42	5.1	4.3	-
2Bwb	144–180	6.0	0.19	32	5.3	4.7	-
2BC	180–232	2.1	0.13	16	6.2	4.8	-
2Cl	232–(260)	-	-	-	6.4	4.9	-

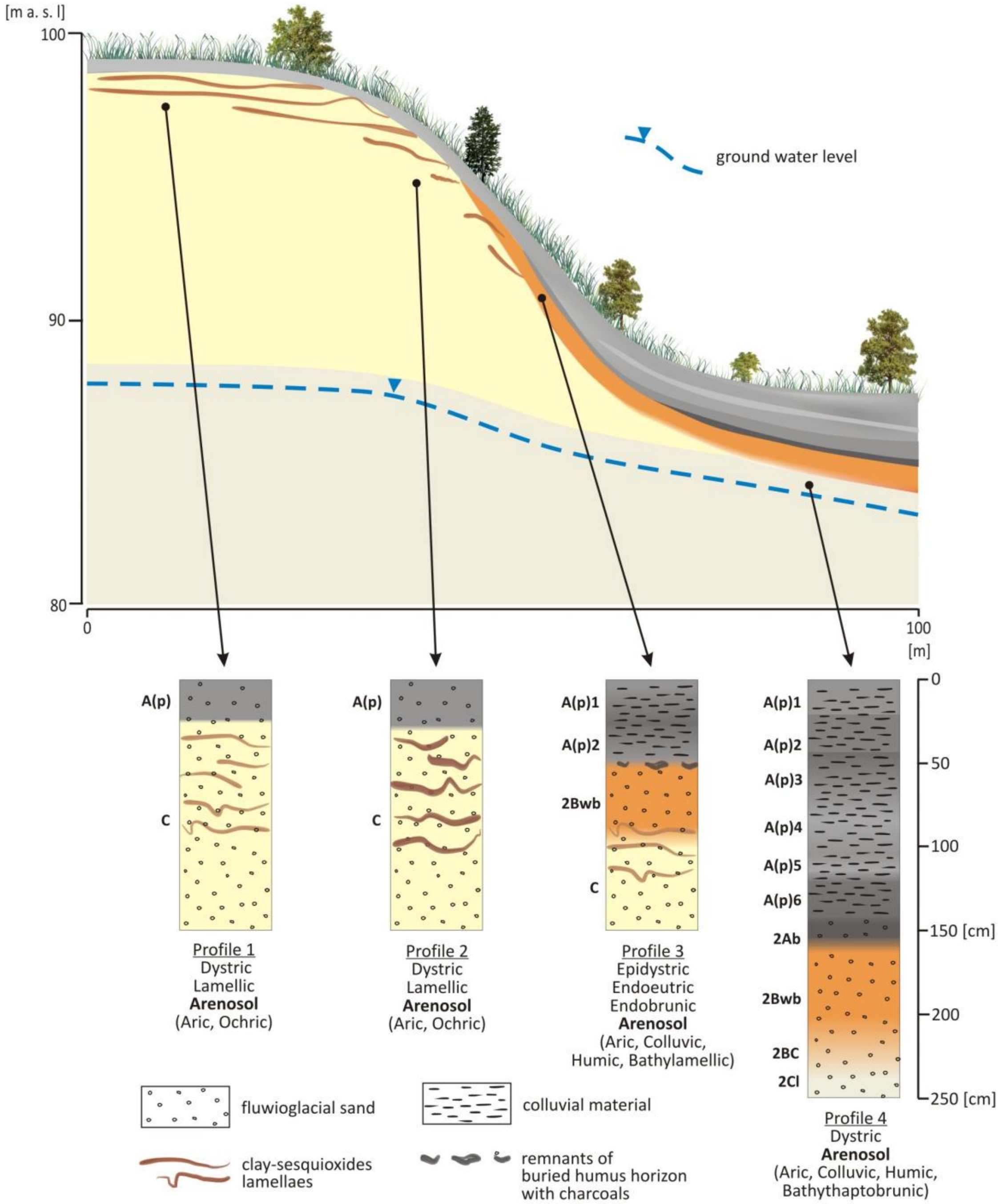


Fig. 2. Toposequence of the soils on slopes of kettle-hole within outwash plain, Brodnica Lake District

Soil genesis and systematic position

The investigated sequence of soils represents the diversity of soil cover on the slopes and bottom of a kettle-hole within an outwash plain that was previously used for agriculture. Because these soils were developed in fluvioglacial deposits (reworked by slope processes in lower part of slopes), a mutual feature for them is sandy texture.

Pedons 1 and 2 located on the summit and upper part of the slope had a similar morphology. Both of pedons had a simple A–C sequence of horizons. The humus epipedons were weakly developed and did not have a diagnostic character. The entire profiles of these soils were built of sandy material in which 0.25- to 0.1-mm fraction dominates (Table 1 and 3). Given the above (coarse texture and lack of diagnostic horizons) they have been classified as **Arenosols.** Humus horizons were not dark enough to meet the criteria of *mollic* or *umbric.* The only possibility to express the presence of these A horizons in the name of soil was to apply the ***Ochric*** supplementary qualifier. Weak development of A horizons is common for soils derived from fluvioglacial sands that are strongly permeable (low moisture) and poor in minerals (quartz mostly) (e.g. Plichta, 1981; Bednarek, 1991; Bednarek and Michalska, 1998). Moreover, the primary stocks of humic substances in these horizons were reduced by erosional processes (Świtoniak and Bednarek, 2014). Surface horizons were partially shallower as a result of soil truncation and some amounts of non-humic parent material were incorporated into A horizons as a result of ploughing. The homogeneous nature of A horizons at 0–25 cm and 0–28 cm from the mineral surface in Profiles 1 and 2, respectively, and their abrupt lower boundary are typical features of arable soils (***Aric***) and in this case may be inherited from past agricultural use of the described pedons (Bednarek and Michalska, 1998; Sewerniak et al., 2014). Despite the presence of the above-mentioned “tillage” features, the “p” designation was used in brackets because the studied soils have not been ploughed for many years. The state of vegetation indicates that the last agricultural treatments (ploughing) took place several years before the soil pits were made.

Directly below the humus horizons parent material occurs with stratified concentrations of iron sesquioxides and clay fraction. These illuvial concentrations are clearly visible in the form of brown lamellae. These bands have a pedogenic character (Prusinkiewicz et al., 1998) and are mainly the result of downwards translocation of iron and clay within the soil profile, together with percolating rain water. These lamellae have a positive impact on the ecological value of these sandy soils due to the clearly higher content of clay fraction (Uggla and Uggla, 1979). In both cases the pedons meet the diagnostic criteria of the ***Lamellic*** qualifier (IUSS Working Group WRB, 2015). Furthermore they are acidic, and the low pH values lead to the assumption that effective base saturation is <50% in the whole material, which allows the use of the ***Dystric*** qualifier.

The third and fourth profiles also had sandy texture and a lack of diagnostic horizons (**Arenosols**). The humus horizons of these soils were much thicker (56 cm for Profile 3, and 144 cm for Profile 4), exceeding the depth of the ploughing layer. The distinctive feature of these horizons was their clear division into subhorizons that differ both in colour (dark yellowish brown to dark gray) and in content of organic matter (19.0 – 7.3 OC $g \cdot kg^{-1}$). Moreover, the content of humus changes irregularly with depth. These features are typical for *colluvial material*, whose occurrence in systematic position was expressed by the ***Colluvic*** supplementary qualifier. In both cases some residues of the original humus horizons were found under the *colluvium.* In Profile 3 it was visible in the form of discontinuous black lenses at a depth of 56 cm. In the last profile the buried 2Ab horizon was 10 cm thick and continuous in character. The numerous charcoals made it possible to determine the age of this horizon by the radiocarbon method. This 2Ab horizon in Profile 4 was probably buried 205 ± 20 years BP, which indicates a very young age of *colluvial material.* Under the humus horizons there were zones enriched in iron and aluminium compounds designated as 2Bwb horizons. Significant *in situ* concentration of Fe and Al sesquioxides is shown by the brown and orange colouring of the fluvioglacial material. This accumulation is mainly the result of biochemical weathering of fluvioglacial sands (Bednarek, 1991) but the foot slope position of Profile 4 also enables the accumulation of allochthonous iron compounds, migrating with flowing downslope subsurface waters (Jankowski, 2013). In both cases the presence of 2Bwb horizons could be highlighted by the use of the ***Brunic*** qualifier (***Endobrunic*** in Profile 3 – Bw at a depth 56–120 cm and ***Bathythaptobrunic*** in Profile 4 – Bw at a depth of 134–180 cm and under a buried humus horizon) because, in view of the sandy texture, they failed criterion 1 of a *cambic* horizon (other criteria of *cambic* were met – IUSS Working Group WRB, 2015). The low pH values imply low base saturation (lower than >50%) in the upper (56 cm) part of Profile 3 and to a depth of 144 cm in Profile 4, which resulted in the use of ***Epidystric*** and ***Dystric***, respectively. The pH values and BS rose at a depth of 56 100 cm of Profile 3, which was marked by use of the ***Endoeutric*** qualifier. The soil organic carbon as a weighted average to a depth of 50 cm from mineral soil surface was >1%, which was highlighted by the ***Humic*** supplementary qualifier in both cases. The colour of the soil matrix in parent material (hue 2.5Y) with a combination of common oximorphic brown and orange iron mottles indicated the influence of ground water in the last profile at depth >232 cm. The qualifier ***Aric*** refers to homogenisation of uppermost A horizons as a result of ploughing in the past.

Soil sequence

The presented profiles form a kind of soil **lithotoposequence**. The development stage and the properties of particular pedons are strongly associated with the topographic position. Although all the studied soils were classified as **Arenosols**, their properties differ significantly as a result of the accelerated erosion impact. All investigated profiles showed strong transformations connected with slope processes. The most intensive erosion zone occurs on the upper, convex parts of slopes (Profile 1 and 2). The soil degradation led to complete truncation of primarily well-developed pedons – probably ***Brunic*** **Arenosols**. This is confirmed by the research of other authors (e.g., Bednarek, 1991). Currently, in these soils there are not even remnants of Bw horizons, which were destroyed by erosion and transported and mixed with humus down the slopes to accumulate as *colluvic* materials. Pedons with well-preserved Bw horizons buried by thick colluvial deposits occupy only the middle slope and bottom positions. "Colluvial" **Arenosols** developed from the slope 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 of North Poland has been about 2–2.5 mm yr^{-1} over the last 150–300 years. This value is less than half the data obtained – 1,340 mm of colluvial deposits were accumulated during the last 200 years. These differences in estimating the rate of erosion will be even higher if we consider a higher rate of slope processes (slopes were covered by dense grass vegetation after abandonment of cultivation). The fast rate of erosion also led to the mixing of humus material with the light-coloured eroded parent material (Profiles 1 and 2). As a result, the colluvial material does not meet the colour criterion for *umbric* or *mollic* – despite the high content of OC and well developed soil structure (Świtoniak, 2015).

References

Bednarek, R., 1991. Wiek, geneza i stanowisko systematyczne gleb rdzawych w świetle badań paleopedologicznych w okolicach Osia. Rozprawy. UMK, Toruń.

Bednarek ,R., Michalska, M., 1998. Wpływ rolniczego użytkowania na morfologię i właściwości gleb rdzawych w okolicach Bachotka na Pojezierzu Brodnickim, Zesz. Probl. Post. Nauk Roln., 460: 487–497 (in Polish).

Intergovernmental Panel on Climate Change (IPCC), 2006. IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4. Egglestone, H.S., L. Buendia, K. Miwa, T. Ngara and K. Tanabe (Eds). Intergovernmental Panel on Climate Change (IPCC), IPCC/IGES, Hayama, Japan.

IUSS Working Group WRB, 2015. World Reference Base for soil resources 2014, update 2015. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Report No. 106, FAO, Rome.

Jankowski, M., 2013. Gleby ochrowe. Pozycja w krajobrazie, właściwości, geneza i miejsce w systematyce. Wydawnictwo Naukowe UMK (in Polish).

Kondracki, J., 2001. Regional geography of Poland. PWN, Warsaw (in Polish).

Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F. 2006. World Map of Köppen-Geiger Climate Classification updated. Meteorol. Z., 15: 259–263.

Marks, L., 2012. Timing of the Late Vistulian (Weichselian) glacial phases in Poland. Quaternary Science Reviews 44: 81–88.

Niewiarowski, W., 1986. Morphogenesis of the Brodnica outwash on the background of ther glacial landforms of Brodnica Lake District. AUNC Geogr. 19 (60): 3–30 (in Polish with English summary).

Plichta, W., 1981. Zagadnienia genezy, właściwości i klasyfikacji próchnicy mor. UMK. Rozprawy. Toruń (in Polish).

Prusinkiewicz, Z., Bednarek, R., Kośko, A., Szmyt, M., 1998. Paleopedological studies of the age and properties of illuvial bands at an archaeological site. Quaternary International, 51–52: 195–201.

Roszko L., 1968. Recession of last inland ice from Poland's territory. In: Last Scadinavian glaciation in Poland. Geographical Studies. 74: 65-100 (in Polish with English summary).

Sewerniak, P., Sylwestrzak, K., Bednarek, R., Gonet, S., 2014. Gleby porolne w lasach. [in:] Świtoniak, M., Janowski, M., Bednarek R. (eds.) Antropogeniczne przekształcenia pokrywy glebowej Brodnickiego Parku Krajobrazowego. Toruń, 43–55 (in Polish).

Sinkiewicz, M., 1998. The development of anthropogenic denudation in central part of northern Poland. UMK, Toruń (in Polish with English summary).

Świtoniak, M., 2015. Issues relating to classification of colluvial soils in young morainic areas (Chełmno and Brodnica Lake District, northern Poland). Soil Science Annual. 66. 2: 57-66.

Świtoniak, M., Bednarek, R., 2014. Anthropogenic denudation. [in:] Anthropogenic transformations of soil cover of Brodnica Landscape Park.[eds.] Świtoniak M., Jankowski M., Bednarek R., Wydawnictwo Naukowe UMK, Toruñ: 57–84 (in Polish).

Uggla, H., Uggla, Z., 1979. Forest Soil Science. PWRiL, Warszawa: 577 pp (in Polish).

Wójcik, G., Marciniak, K., 1987a. Thermal conditions in central part of the North Poland in the years 1951-1970. AUNC. Geogr. 20: 29–50 (in Polish).

Wójcik, G., Marciniak, K., 1987b. Precipitations in central part of the North Poland in the years 1951-1970. AUNC. Geogr. 20: 51–69 (in Polish).

Wójcik, G., Marciniak, K., 1993. Precipitations in Lower Vistula Valley in the years 1951-1980. In: Churski, Z. (Eds.), Environmental and socio-economic development of the Lower Vistula Valley. IG UMK. Toruń: 107–121.

Contributors

Tamás Árendás
MTA-ATK Agricultural Institute,
Centre for Agricultural Research
Hungarian Academy of Science
Martonvásár, **Hungary**
arendas.tamas@agrar.mta.hu

Renata Bednarek
Department of Soil Science and Landscape Management
Faculty of Earth Sciences
Nicolaus Copernicus University
Toruń, **Poland**
bednarek@umk.pl

Vanda Buivydaitė
Institute of Agroecosystems and Soil Science
Faculty of Agronomy
Aleksandras Stulginskis University
Kaunas distr., **Lithuania**
vanda.buivydaite@gmail.com

Przemysław Charzyński
Department of Soil Science and Landscape Management
Faculty of Earth Sciences
Nicolaus Copernicus University
Toruń, **Poland**
pecha@umk.pl

Michał Dąbrowski
Department of Soil Science and Landscape Management
Faculty of Earth Sciences
Nicolaus Copernicus University
Toruń, **Poland**
michal.dabrowski@op.pl

Michał Dudek
Institute of Soil Science and Environmental Protection
Wroclaw University of Environmental and Life Sciences
Wrocław**, Poland**

Emil Fulajtár
Soil Science and Conservation Research Institute
Bratislava**, Slovakia**
e.fulajtar@vupop.sk

Maria Gerasimova
Department of Landscape Geochemistry and Soil Geography
Lomonosov Moscow State University
Moskow, **Russia**
maria.i.gerasimova@gmail.com

Virgilija Gregorauskienė
Subdivision of Contamination Assessment
Division of Hydrogeology
Lithuanian Geological Survey
Vilnius, **Lithuania**
virgilija.gregorauskiene@lgt.lt

Piotr Hulisz
Department of Soil Science and Landscape Management
Faculty of Earth Sciences
Nicolaus Copernicus University
Toruń, **Poland**
hulisz@umk.pl

Michał Jankowski
Department of Soil Science and Landscape Management
Faculty of Earth Sciences
Nicolaus Copernicus University
Toruń, **Poland**
mijank@umk.pl

Cezary Kabała
Institute of Soil Science and Environmental Protection
Wroclaw University of Environmental and Life Sciences
Wrocław**, Poland**
cezary.kabala@upwr.edu.pl

Tomasz Kaczmarek
Department of Soil Science and Land Protection
Poznań University of Life Sciences
Poznań, **Poland**
tomekkaczmarek92@gmail.com

Bartłomiej Kajdas
Department of Mineralogy, Petrology and Geochemistry
Institute of Geological Sciences
Jagiellonian University
Krakow**, Poland**
bartlomiej.kajdas@uj.edu.pl

Rusudan Kakhadze
Michail Sabashvili Institute of Soil Science
Agrochemistry and Melioration
Agricultural University of Georgia
Tblilisi, Georgia

Aldis Karklins
Institute of Soil and Plant Sciences
Latvia University of Life Sciences and Technologies
Jelgava, **Latvia**
aldis.karklins@llu.lv

Ilia Kunchulia
Michail Sabashvili Institute of Soil Science
Agrochemistry and Melioration
Agricultural University of Georgia
Tblilisi, Georgia
ikunc2014@agruni.edu.ge

Tamar Kvrivishvili
Michail Sabashvili Institute of Soil Science
Agrochemistry and Melioration
Agricultural University of Georgia
Tblilisi, Georgia

Magdalena Lazarus
University Of Gdańsk
Faculty Of Biology
Department Of Plant Taxonomy And Nature Conservation
magdalena.lazarus@biol.ug.edu.pl

Maciej Markiewicz
Department of Soil Science and Landscape Management
Faculty of Earth Sciences
Nicolaus Copernicus University
Toruń, **Poland**
mawicz@umk.pl

Ryszard Mazurek
Department of Soil Science and Soil Protection
Institute of Soil Science and Agrophysics
University of Agriculture in Krakow
Krakow**, Poland**
r.mazurek@ur.krakow.pl

Łukasz Mendyk
Department of Soil Science and Land Protection
Poznań University of Life Sciences
Poznań, **Poland**
mendyk.geo@gmail.com

Joanna Michalak
Department of Soil Science and Landscape Management
Faculty of Earth Sciences
Nicolaus Copernicus University
Toruń, **Poland**
joanna.michalak8@interia.pl

Tibor József Novák
Department of Landscape Protection
and Environmental Geography
University of Debrecen
Debrecen**, Hungary**
novak.tibor@science.unideb.hu

Anna Pilichowska
Department of Soil Science and Landscape Management
Faculty of Earth Sciences
Nicolaus Copernicus University
Toruń, **Poland**

Anna Piziur
Department of Soil Science and Landscape Management
Faculty of Earth Sciences
Nicolaus Copernicus University
Toruń, **Poland**

Blaž Repe
Department Of Geography, Faculty Of Arts
University Of Ljubljana
Ljubljana, **Slovenia**
blaz.repe@ff.uni-lj.si

Martin Saksa
Soil Science and Conservation Research Institute
Bratislava, **Slovakia**
m.saksa@vupop.sk

Vladimir Šimanský
Department of Soil Science
Slovak University of Agriculture in Nitra
vladimir.simansky@uniag.sk

Maria Smirnova
Department of Landscape Geochemistry and Soil Geography
Lomonosov Moscow State University
Moskow, **Russia**
summerija@yandex.ru

Waldemar Spychalski
Department of Soil Science and Land Protection
Poznań University of Life Sciences
Poznań, **Poland**
spychal@up.poznan.pl

Marcin Świtoniak
Department of Soil Science and Landscape Management
Faculty of Earth Sciences
Nicolaus Copernicus University
Toruń, **Poland**
swit@umk.pl

Viktar Tsyrybka
Republican Scientific Subsidiary Unitary Enterprise
Institute For Soil Science And Agrochemistry
Minsk, **Belarus**
m029@yandex.by

Giuli Tsereteli
Michail Sabashvili Institute of Soil Science
Agrochemistry and Melioration
Agricultural University of Georgia
Tblilisi, **Georgia**

Tengiz Urushadze
Michail Sabashvili Institute of Soil Science
Agrochemistry and Melioration
Agricultural University of Georgia
Tblilisi, **Georgia**

Hanna Ustsinava
Republican Scientific Subsidiary Unitary Enterprise
Institute For Soil Science And Agrochemistry
Minsk, **Belarus**

Rimantas Vaisvalavičius
Institute of Agroecosystems and Soil Science
Faculty of Agronomy
Aleksandras Stulginskis University
Kaunas distr., **Lithuania**
rimantas.vaisvalavicius@asu.lt

Ilze Vircava
Institute of Soil and Plant Sciences
Latvia University of Life Sciences and Technologies
Jelgava, **Latvia**
Ilze.Vircava@llu.lv

Jonas Volungevičius
Department of Geography and Land Management
Institute of Geosciences
Faculty of Chemistry and Geosciences
Vilnius University, **Lithuania**
jonas.volungevicius@gmail.com

Jarosław Waroszewski
Institute of Soil Science and Environmental Protection
Wroclaw University of Environmental and Life Sciences
Wrocław**, Poland**
jaroslaw.waroszewski@upwr.edu.pl

Michał Wilk
Department of Soil Science and Landscape Management
Faculty of Earth Sciences
Nicolaus Copernicus University
Toruń, **Poland**

Bartłomiej Wojtczak
Department of Soil Science and Landscape Management
Faculty of Earth Sciences
Nicolaus Copernicus University
Toruń, **Poland**

Tomasz Zaleski
Department of Soil Science and Soil Protection
Institute of Soil Science and Agrophysics
University of Agriculture in Krakow
Krakow**, Poland**
t.zaleski@ur.krakow.pl

ISBN 978-83-951878-2-7