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PROPERTIES AND CLASSIFICATION OF SOILS DEVELOPED FROM AEOLIAN AND FLYSCH MATERIALS IN THE WIELICZKA FOOTHILLS (SOUTHERN POLAND)

Abstract. The paper is focused on the properties of soils developed from relatively shallow loess mantles overlying flysch weathered materials and the role of resulting lithological discontinuities within parent material in shaping soil properties in the marginal area of the Carpathian Foothills. The studied soils were located under mixed forest vegetation in varied geomorphologic context – on relatively flat hilltops and on slopes with varying inclination. The performed analyses comprised the determination of soil texture, also on clay-free basis, pH, content of organic carbon and carbonates as well as the determination of cation exchange capacity and base saturation. The soils were described and classified following the WRB system.

Most of the studied soils show properties resulting from the process of lessivage, expressed in the formation of clay coatings (cutans), changes in soil colour and structure, leading to the origin of fragic horizons. The role of redoximorphic processes related to the high rainfall is also well visible, especially at the boundary of E and Bt horizons and on the contact of loess and flysch regolith, along a lithological discontinuity. The occurrence of lithological discontinuities is detected predominantly based on changes in soil texture and particularly visible when the contents of sand and silt fractions are calculated on the clay-free basis. This shows a marked homogeneity of loess in contrast with a great textural diversity of weathered flysch. Apart from the main discontinuity between loess and weathered flysch, it is also possible to discern textural discontinuities between flysch-derived slope materials (cover beds) and underlying, weathered flysch (regolith) in situ, as well as within the weathered flysch itself. The slope materials (cover beds) occurring under loess mantles and above flysch bedrock owe their genesis to slope processes, predominantly solifluction in the Pleistocene. The existing lithological discontinuities influence also soil physicochemical and chemical properties such as pH, content of carbonates, cation exchange capacity and base saturation, so they have a significant ecological impact.

In the investigated area soil formation and, consequently, taxonomic position depends predominantly on two factors – the thickness of loess material and the inclination of slope. With decreasing slope inclination and increasing thickness of loess soils change from Stagnic Cambisols (Ruptic) through Haplic Stagnosols (Ruptic) and Haplic Stagnosols (Ruptic, Episiltic) to Stagnic Albeluvisols (Ruptic), and where soil profiles are developed entirely in loess materials – Stagnic Albeluvisols.

Key words: *Carpathian Foothills, loess, flysch, lithological discontinuities, soil classification, WRB.*

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СВОЙСТВА И КЛАССИФИКАЦИЯ ПОЧВ, РАЗВИВАЮЩИХСЯ ИЗ ЭОЛОВЫХ И ФЛИШЕВЫХ МАТЕРИАЛОВ В POGÓRZE WIELICKIE (ЮЖНАЯ ПОЛЬША)

В статье фокусируется внимание на свойствах почв, которые были развиты из относительно мелких лессовых слоев, перекрывающих флишевые реголиты в краевой области польского предгорья Карпат. Исследованные почвы покрыты пологом смешанных лесов и располагаются в различных геоморфологических ситуациях. Проведенный анализ включал определение гранулометрического состава почвы, расчет гранулометрии почв с исключением илистой фракции, pH, содержания органического углерода и карбонатов, определения емкости катионного обмена и степени насыщенности основаниями.

Почвы были описаны и классифицированы в соответствии с системой WRB. Большинство исследуемых почв показывают свойства, которые являются результатом лессиважа, в том числе и образования фраджипенового горизонта, со значительной выраженностью окислительно-восстановительных процессов.

Появление литологических разрывов обнаружено преимущественно на основе изменений гранулометрического состава почвы. Помимо основного разрыва между лесом и выветрившимся флишем, выделялись разрывы между склоновым материалом флишевого происхождения и подстелающим выветрившимся флишем in situ, а также в сомом выветренном флише. Литологические разрывы влияют на физико-химические и химические свойства почвы, в частности на pH, содержание карбонатов и емкость катионного обмена, создавая значительное экологическое воздействие.

На исследуемой территории почвообразование, а, следовательно, и систематическое положение почв зависит преимущественно от двух характеристик – толщины лессовых пород и крутизны склона. С уменьшением наклона и увеличением толщины лессовых пород, почвы изменяются от Stagnic Cambisols (Ruptic) через Haplic Stagnosols (Ruptic) и Haplic Stagnosols (Ruptic, Episiltic), в Stagnic Albeluvisols (Ruptic), а в местах, где почвенный профиль полностью развился на лессовых материалах – Stagnic Albeluvisols.

Ключевые слова: *предгорье Карпат, лесс, флиш, литологические разрывы, классификация почв, WRB.*

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ВЛАСТИВОСТІ І КЛАСИФІКАЦІЯ ГРУНТІВ, ЩО РОЗВИВАЮТЬСЯ З ЕОЛОВИХ І ФЛІШОВИХ МАТЕРІАЛІВ У POGÓRZE WIELICKIE (ПІВДЕННА ПОЛЬЩА)

У статті фокусується увага на властивостях грунтів, що розвинулись з відносно дрібних лесових верств, які перекривають флішові вивітрені матеріали в крайовій області польського передгір'я Карпат. Досліджені грунти вкриті пологом мішаних лісів та розташовувалися в різних геоморфологічних ситуаціях. Проведений аналіз включав визначення гранулометричного складу грунту, розрахунок гранулометрії грунту з виключенням вмісту мулу, pH, вмісту органічного карбону і карбонатів, визначення ємності катіонного обміну та ступеня насиченості основами. Грунти були описані і класифіковані відповідно з системою WRB.

Більшість досліджуваних грунтів показують властивості, які є результатом лесиважу, в тому числі і утворення фраджіпенового горизонту, зі значним вираженням окисно-відновних процесів. Поява літологічних розривів виявлена переважно на основі змін гранулометричного складу грунту.

Крім основного розриву між лесом і вивітреним флішом, виділялися розриви між схиловим матеріалом флішового походження (cover beds) і підстеляючим вивітреним флішом in situ, а також в самих реголітах.

Літологічні розриви впливають і на фізико-хімічні та хімічні властивості грунту, зокрема на pH, вміст карбонатів і ємність катіонного обміну, тому вони мають значний екологічний вплив.

На досліджуваній території, грунтоутворення, а отже і систематичне положення грунтів залежить переважно від двох характеристик – товщини лесових порід і крутизни схилу. Зі зменшенням нахилу і збільшенням товщини лесових порід, грунти змінюються від Stagnic Cambisols (Ruptic) через Haplic Stagnosols (Ruptic) і Haplic Stagnosols (Ruptic, Episiltic), до Stagnic Albeluvisols (Ruptic), а в місцях де грунтовий профіль повністю розвинувся на лесових матеріалах – Stagnic Albeluvisols.

Ключові слова: *передгір'я Карпат, лес, фліш, літологічні розриви, класифікація грунтів, WRB.*

INTRODUCTION

The Wieliczka Foothills (Pogórze Wielickie) is a part of the Carpathian Foothills, being the northernmost geographical unit of the Carpathians in Poland. It is built of folded, sedimentary, flysch rocks on most of the region's area covered with carbonate-free loess sediments of varying thickness. At the regional scale, the soil cover of the Carpathian Foothills is fairly uniform, dominated by Luvisols and Albeluvisols (Skiba and Drewnik, 2003, Szymański et al., 2012b). The Wieliczka Foothills is an area where intensive soil research has been carried out for several decades, dealing with the mechanisms of the lessivage process (Zasoński, 1981, 1983, 1989), soil geography and structure of soil cover (Skiba, 1992, Skiba et al., 1998, 2002), and, most recently, on the formation and degradation of fragipan horizons (Szymański et al., 2011, 2012a). Most of the research has focused on the soils developed from loess materials, although the influence of flysch bedrock in certain parts of the Wieliczka Foothills was also indicated (Kacprzak et al., 2010).

The aim of this paper is to present the results of a study focused on the properties of soils developed from relatively shallow loess mantles overlying flysch weathered materials (regolith) and the role of resulting lithological discontinuities within parent material in shaping soil properties. The importance of lithological discontinuities and soil layering has been getting increasing recognition worldwide over recent years, as reviewed by Schaetzl and Anderson (2005) or Phillips and Lorz (2008). Also their ecological role has been emphasized (Lorz and Phillips, 2006). This phenomenon is particularly important in the mountains, where most soils are formed in slope materials (cover beds). In the Carpathians the role of lithologically discontinued slope materials in soil formation has been investigated in the Bieszczady Mts (Kacprzak and Skiba, 2001, Kacprzak 2003) and in the Pieniny Mts (Kacprzak and Derkowski, 2007). Another goal of this paper is to discuss the classification of the studied soils according to the World Reference Base (WRB) system (IUSS Working Group WRB, 2007), in which lithological discontinuities are recognized as one of diagnostic properties.

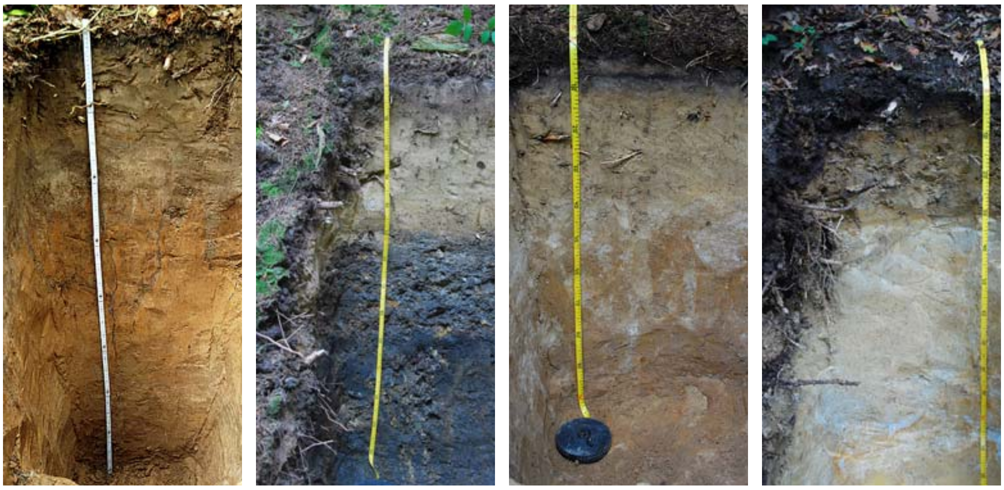
DATA AND METHODS OF RESEARCH

The studied area is situated in the marginal zone of the Wieliczka Foothills, south-east of the town of Bochnia. The elevation above sea level is between 200 and 350 m. The characteristic elements of the landscape are broad, flat hilltops and interfluves, as well as wide, flat-bottomed valleys. The altitude of hills increases to the south and so does the inclination of slopes. Hilltops and slopes in the northern part are completely covered by loess, whereas in the southern part outcrops of flysch rocks occur in the steepest slope sections, exposed mainly due to the action of landsliding or fluvial erosion. The mean annual temperature is 6 to 8 °C and the mean annual precipitation is 700–900 mm (Hess, 1965). Most of the area is under agricultural use with forests occurring solely on the steepest slopes or valley sides and adjacent strips of hilltops.

Soil profiles were described and classified using the WRB system (IUSS Working Group WRB, 2007). Particle size distribution was determined using a modified Casagrande method (Bednarek et al., 2004) and the relative contents of the sand and clay fractions were also calculated on the clay-free basis. Soil pH was measured potentiometrically in distilled water with a soil/solution ratio 1:1 and 0,01M $CaCl_2$ solution (1:2) (USDA NRCS, 2004). Organic carbon content was measured using a modified Tyurin method (Bednarek et al., 2004) and the content of carbonates was determined using the Scheibler volumetric method (Bednarek et al., 2004). Soil exchangeable acidity was determined using the Sokołow method and the sum of exchangeable bases using the Kappen method (Oleksynowa et al., 1987) The colours of soil material were described using the Munsell scale. The content of coarse fractions (> 2 mm) was evaluated in the field.

RESULTS AND THEIR DISCUSSION

The studied soils (Fig. 1) were all located under mixed forest vegetation (Tillio – Carpinetum) in varied geomorphologic context – on relatively flat hilltops (profiles 1 and 4) and on slopes with varying inclination (profiles 2, 3, 5). The important factor taken into consideration was the varied thickness of loess cover (profiles 2–5).



A B C D

Figure 1. **Morphology of the studied soils:**
A – profile 1; B – profile 3; C – profile 4; D – profile 5

Profile 1 is a soil developed entirely in loess material, representing a typical situation for most of the area (Skiba et al., 1998, Szymański et al., 2012b). The morphological properties of the studied soils are presented in Table 1.

Except profile 5, all studied soils show properties resulting from the process of lessivage i.e. clay illuviation, expressed in the formation of clay coatings (cutans), changes in soil colour and structure, leading to the origin of fragic horizons with prismatic soil structure (profiles 1 and 4). The role of redoximorphic processes related to the high rainfall is also well visible, especially at the boundary of E and Bt horizons (profiles 1 and 4) and on the contact of loess and flysch regolith (profiles 2 and 3). Soil horizons developed in loess material are devoid of coarse fraction, whereas its content in horizons developed in flysch regolith can be as high as more than 50 % (profile 3).

Particle size distribution in the studied soils (Table 2), particularly in the upper parts of their profiles, is dominated by the silt fraction, constituting 40–79 % of fine earth in the majority of horizons. Except profile 5, a marked increase in the content of clay can be observed between Ah or E horizons (2–15 %) and Bt or B(t)g horizons (16–23 %), caused

Table 1

Field description of the studied profiles

Depth [cm]	Horizon	Colour (moist)	Colour (dry)	Coarse fractions [% vol]	Soil structure	Consistence	Cutans	Roots	Horizon boundary
1	2	3	4	5	6	7	8	9	10
Profile 1. Stagnic Cutanic Fragic Albeluvisol (Abruptic, Orthoeutric, Siltic) N 49°58’00,5’’ E 20°29’06,9’’, 265 m a.s.l., hilltop – inclination 0°									
0-3	Oe	moderately decomposed forest litter							
3-8	Ah	10YR 3/2	10YR 5/2	0	granular	friable	-	++	clear
8-35	E	10YR 6/4	10YR 7/2	0	subangular blocky	firm	-	++	clear
35-55	Btx	10YR 5/3	10YR 7/3	0	prismatic	extremely firm	+++	+	clear
55-105	Btg	10YR 5/4	10YR 7/4	0	prismatic	very firm	++	+	gradual
105-125	BC1	10YR 5/4	10YR 7/4	0	angular blocky	firm	+	+	gradual
125-150	BC2	10YR 5/6	10YR 8/6	0	angular blocky	firm	+	-	-
Profile 2. Haplic Stagnosol (Ruptic, Epidystric) N 49°56’49,9’’ E 20°29’39,2’’, 295 m a.s.l., slope – inclination 25°									
0-3	Ah	10YR 3/1	10YR 4/2	0	granular	friable	-	++	abrupt
3-20	E	10YR 6/4	10YR 8/3	0	subangular blocky	friable	-	++	gradual
20-40	B(t)g	10YR 6/4, 7,5YR 5/6	10YR	15	subangular blocky	very firm	+	+	clear
40-55	2BC	2,5Y 6/3	2,5Y 8/2	15	angular blocky	firm	-	+	clear
55-60	3Cg1	2,5Y 4/2	2,5Y 6/3	25	massive	firm	-	+	clear
60-95	3Cg2	2,5Y 4/2	2,5Y 7/3	25	massive	very firm	-	+	gradual
95-145	3Cg3	2,5Y 4/1	2,5Y 7/2	25	massive	very firm	-	-	-
Profile 3. Haplic Stagnosol (Ruptic, Epidystric, Episiltic) N 49°57’05,7’’ E 20°31’08,0’’, 262 m a.s.l., slope – inclination 25°									
0-2	Oi	weakly decomposed forest litter							
2-7	Oe	moderately decomposed forest litter							
7-18	Ah	10YR 4/2	10YR 5/3	0	granular	firm	-	++	clear
18-45	Eg	10YR 7/4	10YR 8/3	0	subangular blocky	firm	-	+	clear
45-55	B(t)g	10YR 7/3, 2,5Y 5/2	10YR	5	subangular blocky	very firm	+	+	abrupt
55-65	2BC	2,5Y 5/2, 10YR 7/3	2,5Y 7/2,	60	massive	firm	-	+	abrupt
65-90	2Cg1	2,5Y 4/3	2,5Y 6/2	60	massive	very firm	-	+	abrupt
90-140	2Cg2	2,5Y 3/2	2,5Y 6/3	50	massive	very firm	-	+	-

Table ending

1	2	3	4	5	6	7	8	9	10
Profile 4. Stagnic Cutanic Fragic Albeluvisol (Abruptic, Ruptic, Alumic, Siltic) N 49°56’36,2’’ E 20°30’03,0’’, 320 m a.s.l., hilltop – inclination 0-3°									
0-3	Oe	moderately decomposed forest litter							
3-12	Ag	10YR 4/2	10YR 5/3	0	granular	firm	-	++	abrupt
12-38	Eg	10YR 7/6	10YR 8/3	0	subangular blocky	firm	-	+	clear
38-50	Btx	10YR 5/4	10YR 7/4	0	prismatic	extremely firm	+++	+	gradual
50-75	Btg	10YR 5/6	10YR 7/6	0	angular blocky	very firm	+++	+	gradual
75-90	BC	10YR 6/6, 7,5Y 5/6	10YR 7/6,	5	angular blocky	very firm	++	-	clear
90-105	2Cg	7,5YR 5/6, 10YR 6/6	7,5YR 7/6,	25	massive	very firm	-	-	-
Profile 5. Stagnic Cambisol (Endoeutric, Ruptic) N 49°56’39,3’’ E 20°30’00,1’’, 295 m a.s.l., slope – inclination 35°									
0-1	Oe	moderately decomposed forest litter							
1-5	Ah	7,5YR 2/2	7,5YR 4/2	0	granular	friable	-	+++	clear
5-15	Bwg	10YR 6/6	10YR 7/3	10	subangular blocky	firm	-	++	gradual
15-35	2BC	10YR 6/4	10YR 8/3	30	subangular blocky	firm	-	+	abrupt
35-110	2Cg	2,5Y 7/4, 10YR 7/6	2,5Y 8/2,	0	single grained	very firm	-	-	-

by the process of clay illuviation. There are, however, prominent differences in soil texture resulting not from soil-forming processes but from the occurrence of lithological discontinuities within soil material. The texture of the upper parts of profiles, developed in loess material, is slit loam.

Table 2

Particle size distribution in the studied soils

Depth [cm]	Horizon	Particle size distribution [diameter in mm]									Soil texture	Clay-free	
		2,0-0,1	0,1-0,05	0,05-0,02	0,02-0,006	0,006-0,002	<0,002	sand 2-0,05	silt 0,05-0,002	clay <0,002		sand	silt
Profile 1. Stagnic Cutanic Fragic Albeluvisol (Abruptic, Orthoeutric, Siltic)													
0-3	Oe	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
3-8	Ah	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
8-35	E	9	12	45	23	5	6	21	73	6	SiL	22	78
35-55	Btx	5	13	40	17	3	22	18	60	22	SiL	23	77
55-	Btg	5	15	40	19	3	18	20	62	18	SiL	24	76
105-	BC1	3	18	46	17	2	14	21	65	14	SiL	24	76
125-	BC2	5	14	49	17	1	14	19	67	14	SiL	22	78
Profile 2. Haplic Stagnosol (Ruptic, Epidystric)													
0-3	Ah	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
3-20	E	8	6	36	27	8	15	14	71	15	SiL	16	84
20-40	2B(t)g	31	6	11	21	8	23	37	40	23	L	48	52
40-55	2BC	28	6	18	19	6	23	34	43	23	L	44	56
55-60	3Cg1	11	0	35	22	8	24	11	65	24	SiL	14	86
60-95	3Cg2	11	10	11	21	27	20	21	59	20	SiL	26	74
95-	3Cg3	3	1	9	23	20	44	4	52	44	SiC	7	93
Profile 3. Haplic Stagnosol (Ruptic, Epidystric, Episiltic)													
0-2	Oi	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
2-7	Oe	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
7-18	Ah	15	4	54	21	4	2	19	79	2	SiL	19	81
18-45	Eg	5	10	45	25	6	9	15	76	9	SiL	16	84
45-55	B(t)g	6	11	40	22	3	18	17	65	18	SiL	21	79
55-65	2BC	29	10	25	15	4	17	39	44	17	L	47	53
65-90	2Cg1	56	6	15	8	3	12	62	26	12	SL	70	30
90-	2Cg2	41	2	12	15	10	20	43	37	20	L	54	46
Profile 4. Stagnic Cutanic Fragic Albeluvisol (Abruptic, Ruptic, Alumic, Siltic)													
0-3	Oe	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
3-12	Ag	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
12-38	Eg	9	4	42	30	7	8	13	79	8	SiL	14	86
38-50	Btx	7	5	43	24	5	16	12	72	16	SiL	14	86
50-75	Btg	5	7	44	21	4	19	12	69	19	SiL	15	85
75-90	BC	17	12	29	17	5	20	29	51	20	SiL	36	64
90-	2Cg	70	7	8	3	1	11	77	12	11	SL	87	13
Profile 5. Stagnic Cambisol (Endoeutric, Ruptic)													
0-1	Oe	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
1-5	Ah	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
5-15	Bwg	38	12	23	13	3	11	50	39	11	SL	56	44
15-35	2BC	64	12	10	5	3	6	76	18	6	SL	81	19
35-	2Cg	78	3	9	5	2	3	81	16	3	LS	84	16

The texture of deeper horizons is varied – in the lowermost horizons of soils developed entirely in loess material it is silt loam (profile 1), but the texture of BC and C horizons developed in flysch regolith ranges from loamy sand (profile 5), through sand loam (profile 4), loam (profile 3) to silty clay (profile 2), depending on the lithology of bedrock. The occurrence of lithological discontinuities is particularly visible when the contents of sand and silt fractions are calculated on the clay-free basis. This procedure shows a marked homogeneity of loess (76–78 % silt in profile 1, 85–86 % silt in profile 4) corresponding with the data given by Szymański et al. (2011) and standing in contrast with a great textural diversity of weathered flysch. Apart from the main discontinuity between loess and flysch regolith (profiles 2–4), it is also possible to discern textural discontinuities between flysch-derived slope materials and underlying weathered flysch in situ (profiles 2 and 5), as well as within the weathered flysch itself (profiles 2 and 3). The observed, large textural diveristy of flysch-derived slope materials and weathered flysch material in situ has two causes. Firstly, it is a result of the gravity-driven transportation of material from upper parts of slope, predominantly by solifluction in the Pleistocene (Kacprzak et al., 2010). Secondly, it results from the geological layering of flysch bedrock consisting of interbedded sandstones, mudstones and shales. The occurrence of lithological discontinuities was reflected in the application of arabic numerals (2, 3) in front of the designations of horizons developed in material of varied origin (FAO, 2006).

In the studied soils organic carbon, apart form litter O horizons, is concentrated in relatively thin (less than 10 cm thick) Ah horizons, where its content can exceed 5 % (Table 3). Soil reaction in the most of horizons is acidic, with the values of pH in H_2O lower than 5,5, usually between 4,1–4,8. The content of organic carbon is higher and the pH values lower than reported for the soils of the area (e.g. Szymański et al. 2011, 2012b) but this is a natural phenomenon when forest soils are compared with these under agricultural use (Skiba et al., 1998). Markedly higher pH values are observed in C horizons formed in weathered flysch bedrock (profile 3 and 5), where the occurrence of carbonates is observed (Table 3). The rest of the investigated soil horizons is devoid of carbonates. The determined cation exchangeable capacity (T) ranges from 2,40 to 45,90 $cmol^{(+)}/kg$ (Table 3). This significant variability is also a result of the occurrence of lithological discontinuities – the smallest values were recorded in sandy layers of flysch regolith or silty eluvial horizons, while the highest values are a characteristic of horizons developed in clay-rich material originated due to weathering of flysch shales. The determined values of base saturation in soils with lithological discontinuities do not exceed 50 % in horizons developed in loess materials and cover beds, whereas in these formed in flysch regolith in situ they are markedly higher, ranging from 55 to 100 % (Table 3). The differences in cation exchange capacity and base saturation have an ecological impact. Although most roots are observed in the upper soil horizons developed in acidic horizons developed in loess mantle, tree roots reach to more euthrophic horizons formed in cover beds and weathered flysch layers.

The studied soils were classified using the latest version of the WRB system (IUSS Working Group 2007). Soils situated on flat hilltops covered with loess material (profiles 1 and 4) developed as Albeluvisols. The presence of thick (> 25 cm) albic horizons, abundant clay coatings (cutans) and fragic properties in the upper sections of Bt horizons allow to classify them as Stagnic Cutanic Fragic Albeluvisols. As their profiles are typified by the occurrence of abrupt textural change i.e. doubling of clay content at the boundary of E and Bt horizons, the suffix Abruptic has to be used, and, because of the dominant texture of silt loam, the suffix Siltic is also applicable. In the cases where the thickness of loess material is smaller, as in profile 4, a lithological discontinuity between loess and flysch regolith is observed, so the soils have to be classified with the suffix Ruptic.

Soils occupying slopes, where the thickness of loess material does not exceed 50 cm and the B horizons do not meet the criteria for the argic horizon (profiles 2 and 3) have to be classified as Haplic Stagnosols. They are typified by the presence of pale-coloured E horizons, meeting the criteria for the albic horizon, and the occurrence of stagnic colour pattern in most of the soil volume, being best expressed in B(t)g horizons on the contact of loess material and flysch regolith. The redoximorphic features result from a periodic excess of water due to subsurficial throughflow parallel to the slope surface. This lateral flux of water also accounts for the initial stage of the development of illuvial horizons, as colloids are to a large extent transported not vertically but laterally, down the slope. As there is a lithological discontinuity between the loess material and flysch regolith, the soils are classified with the suffix Ruptic, and in the cases where the loess cover is thicker than 30 cm, the suffix Episiltic is applicable.

Table 3

Selected chemical properties of the studied soils

Depth [cm]	Horizon	C_{org} [%]	pH		equiv. $CaCO_3$ [%]	S	H	H_H	H_{Al}	H_{Al} [%]	T $cmol^{(+)}$/kg	V [%]
			H_2O	$CaCl_2$		$cmol^{(+)}/kg$						
Profile 1. Stagnic Cutanic Fragic Albeluvisol (Abruptic, Orthoeutric, Siltic)												
0-3	Oe	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
3-8	Ah	4,25	4,1	3,7	0,00	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
8-35	E	0,68	4,7	4,0	0,00	0,0	4,0	0,1	3,8	95,	4,00	0,0
35-55	Btx	0,19	5,3	4,3	0,00	8,6	1,5	0,1	1,4	88,	10,20	84,5
55-	Btg	0,10	5,4	4,6	0,00	8,4	1,0	0,1	0,8	83,	9,50	88,9
105-	BC1	0,10	5,3	4,6	0,00	6,6	0,8	0,1	0,7	80,	7,50	88,3
125-	BC2	0,10	5,3	4,6	0,00	6,6	0,7	0,0	0,6	87,	7,30	90,4
Profile 2. Haplic Stagnosol (Ruptic, Epidystric)												
0-3	Ah	6,23	3,8	3,5	0,00	2,6	8,4	0,7	7,7	91,	11,00	23,6
3-20	E	0,36	3,9	3,5	0,00	3,2	13,	4,3	8,7	66,	16,30	19,6
20-40	2B(t)	0,19	4,1	3,5	0,00	3,8	16,	8,4	8,5	50,	20,80	18,3
40-55	2BC	0,15	4,6	4,0	0,00	6,4	7,3	1,2	6,1	83,	13,80	46,5
55-60	3Cg1	n.a.	4,5	4,0	0,00	7,8	6,3	1,0	5,2	83,	14,10	55,3
60-95	3Cg2	n.a.	4,5	4,0	0,00	10,	6,3	2,1	4,2	66,	17,10	63,2
95-	3Cg3	n.a.	4,4	4,1	0,00	16,	4,9	1,0	3,8	78,	21,70	77,4
Profile 3. Haplic Stagnosol (Ruptic, Epidystric, Episiltic)												
0-2	Oi	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
2-7	Oe	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
7-18	Ah	4,07	3,5	3,1	0,00	0,4	12,	1,8	10,	85,	12,90	3,1
18-45	Eg	0,47	3,7	3,6	0,00	0,6	9,3	0,4	8,9	95,	10,00	6,0
45-55	B(t)g	0,22	4,2	3,9	0,00	5,1	8,3	0,3	7,9	95,	13,40	38,0
55-65	2BC	n.a.	6,8	6,7	1,05	21,	0,0	0,0	0,0	0,0	21,50	100,
65-90	2C1	n.a.	7,6	7,4	1,52	32,	0,0	0,0	0,0	0,0	32,40	100,
90-	2C2	n.a.	8,0	7,5	2,94	45,	0,0	0,0	0,0	0,0	45,90	100,
Profile 4. Stagnic Cutanic Fragic Albeluvisol (Abruptic, Ruptic, Alumic, Siltic)												
0-3	Oe	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
3-12	Ag	0,53	n.a.	n.a.	0,00	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
12-38	Eg	0,17	4,3	3,9	0,00	3,6	16,	0,1	15,	98,	19,70	18,3
38-50	Btx	0,10	4,4	3,8	0,00	3,4	9,1	0,3	8,7	96,	12,50	27,2
50-75	Btg	0,06	4,4	3,8	0,00	0,8	12,	3,3	8,9	72,	13,10	6,1
75-90	BC	0,01	4,4	3,8	0,00	0,6	12,	4,2	8,4	66,	13,20	4,5
90-	2Cg	n.a.	4,4	3,8	0,00	0,0	6,1	0,1	5,9	97,	6,10	0,0
Profile 5. Stagnic Cambisol (Endoeutric, Ruptic)												
0-1	Oe	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
1-5	Ah	3,42	4,1	3,5	0,00	1,2	9,8	0,7	9,1	92,	11,00	10,9
5-15	Bwg	0,33	4,2	3,7	0,00	2,2	7,1	0,2	6,9	96,	9,40	23,5
15-35	2BC	0,19	4,8	4,1	0,00	1,7	2,5	0,0	2,4	96,	4,20	40,1
35-	2Cg	0,03	5,7	5,1	0,48	2,4	0,0	0,0	0,0	0,0	2,40	100,

On the steepest slopes soils developed predominantly in weathered flysch layers an flysch-derived slope materials (cover beds) with only an admixture of loess material (profile 5), possibly resulting from slope transportation driven by gravity and movement of water. The influence of water is visible in the stagnic colour pattern observed in their profiles and they are classified as Stagnic Cambisols. As lithological discontinuities, based on textural differences, occur between slope materials and in situ regolith, the suffix Ruptic is applicable.

On the basis of the investigated soil profiles a general model of soil diversity in the studied area of the Carpathian Foothills can be presented. Soil formation and, consequently, taxonomic position depends predominantly on two characteristics – the thickness of loess material and the inclination of slope. With a decreasing slope inclination and an increasing thickness of loess soils change from Stagnic Cambisols (Ruptic) through Haplic Stagnosols (Ruptic) and Haplic Stagnosols (Ruptic, Episiltic) to Stagnic Albeluvisols (Ruptic), and where soil profiles are developed entirely in loess materials – Stagnic Albeluvisols.

CONCLUSIONS

In the investigated area of the Wieliczka Foothills morphology and properties of soils are to a large degree controlled by the occurrence of lithological discontinuities between loess mantles, slope deposits and in situ weathered flysch (regolith). The presence of lithological discontinuities can be detected from significant textural changes and they influence soil morphology, structure and chemical properties as well as throughflow of water. The impact of discontinuities is particularly important in the case of soils occurring on steep slopes, where the thickness of loess is smallest. Soils developed entirely in loess material or where its thickness reaches 1 m are classified as Albeluvisols, whereas soils occurring on slopes are classified as Stagnosols or Cambisols.

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