УДК 631.44

CLASSIFICATION OF YOUNG GLACIAL SOILS WITH VERTICAL TEXTURE-CONTRAST USING WRB SYSTEM

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The objective of this publication is presentation of taxonomy position of vertical texture-contrast soils developed from bottom moraine material covered by fluvioglacial or ablation sandy layers in young glacial landscapes. Studied soils were classified as 5 different Reference Soil Groups according to WRB system: Luvisols, Albeluvisols, Alisols, Umbrisols and Arenosols. Several proposals for modifications in the WRB classification have been suggested for a more complete description of investigated soils properties.
Key words: vertical-texture contrast, lessivage process, lithological discontinuity.

Introduction. Coarse-over-fine vertical texture-contrast (VTC) is common feature of soils in a variety of environmental settings [10, 12, 14, 20, 21, 22, 25]. Increasing in clay content within a limited depth range is an effect of many processes. Explaining the genesis of VTC is vital goal for soil researchers because it is very useful to elucidate principles of soil-forming processes [1, 6, 11, 21, 23]. Former pedological investigations on Brodnica Lake District (northeastern Poland), evaluated parent material effects on soil genesis in the young glacial landscapes [27]. In all investigated cases VTC is inherited from the parent material – sandy ablation or fluvioglacial layer (thickness about tens centimeters) covering the more heavy lodgment till [18, 19]. Despite of morphological similarity of investigated vertical texture-contrast soils (VTCs), two main different directions of soil-forming processes were observed [27, 28]. In most pedons primary, geological VTC was increased by eluviation-illuviation (lessivage) process. In some cases features characteristic for clay illuviation were not present. Problems with classification of VTCs are induced by various pedogenesis. The aim of the present paper is determination of VTCs systematic position according to World Reference Base for Soil Resources classification (2006) [9] with special regard to appraise the usefulness of the WRB classification for the describing these soils features.

Object and Methods. Nineteen VTC-s profiles developed on ground moraine deposits were described and sampled in southeastern part of Brodnica Lake District, Poland (fig. 1). The relief of this area is typical for hummocky moraine plateau landscapes. Fifteen pedons were under mixed forests, whereas in four cases soils were situated in the arable areas. Apart from soil pits, 567 augerholes to the depth of 200 cm were made.

The samples were taken from the particular soil horizons. Standard soil analyses were performed according to the methods as follows:

- organic carbon content – by sample oxidation in the mixture of $K_2Cr_2O_7$ and H_2SO_4;
- total nitrogen content – Kjeldahl method;
- $CaCO_3$ content – Scheibler volumetric method;
- grain size distribution – by pipette and sieve method;
- pH of soil-to-solution ratio of 1:2,5 using 1M KCl and H_2O as the suspension medium;
- hydrolytic acidity by Kappen method;
- exchangeable cations content by leaching with 1M ammonium acetate;
- colour has been described according to Munsell [17].

In order to micromorphological investigations 36 samples with undisturbed structure were taken according to Mroczek [15]. Thin sections (55x75 mm) were prepared according to Lee and Kemp [13]. Description of micromorphological features was made according to Mroczek [15] based on nomenclature by Bullock et al. [2] with Stoops [26] modifications. Thin section and their description were made by Przemysław Mroczek from Maria-Curie Sklodowska University in Lublin, Poland.

The soils were classified according to WRB (1998 and 2006) [8, 9] and Systematics of Polish Soils [24]. Symbols of soil horizons were given after Guidelines for Soil Description [7].

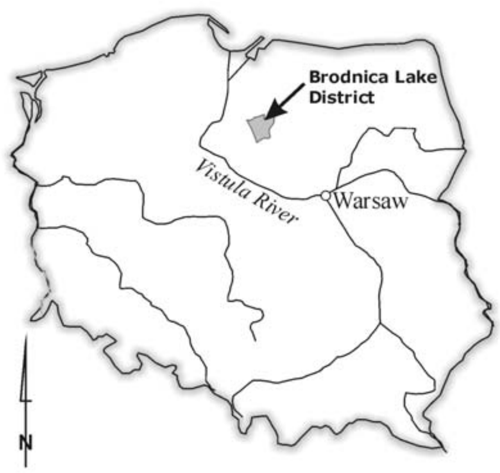

Fig. 1. Localization of study area

Results and their discussion. Investigated soils have generally two different sequences of the genetic horizons (fig. 2).

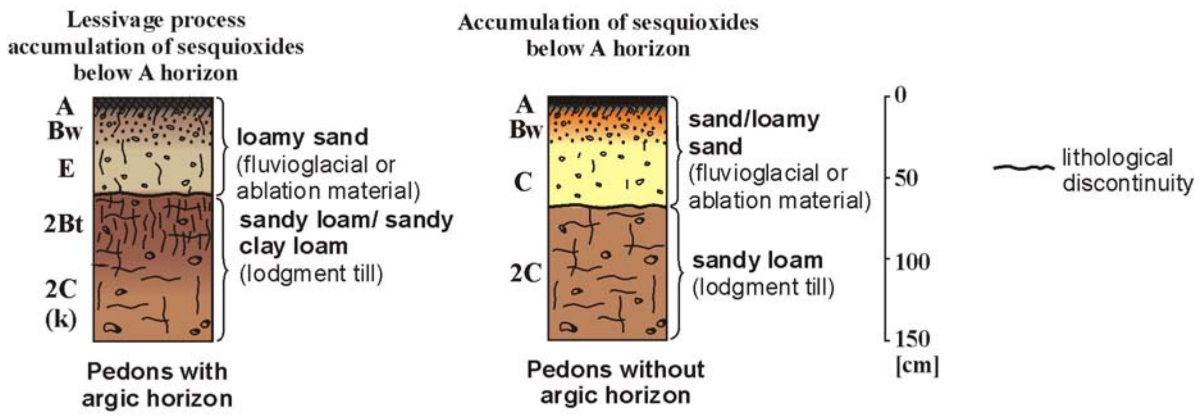

Fig. 2. Different sequences of genetic horizons in investigated VTCs

Eluviation-illuviation process (lessivage) has traditionally been perceived as the major pedogenetic mechanism leading to develop VTCs [22]. Effect of an illuvial accumulation of clay in subsoil is development of argic horizon. All investigated profiles (19) have VTC – but only in 12 of them argic horizon was recognized. Primary content of clay fraction in the surface fluvioglacial or ablation sandy materials was a major factor leading to two different ways of pedogenesis [27].

Different soil-forming processes were determined by primary heterogenity of parent material. In all cases sandy ablation or fluvioglacial layer was covering the finer lodgment till. The lessivage process occurred in rocks where ablation or fluvial layer was primarily richer in clay fraction. When sandy cover primarily contained low amount of clay fraction (only few percent) – clay translocation structures (lessivage) were not observed. Additionally almost all investigated profiles had directly under A horizons, visible “minimum B-horizons” [4]. Transformation of soil material is evident from brownish discoloration which is caused by accumulation of iron sesquioxides. Lack of Bw horizons (A2, A10, A11, A12 Profiles) is caused by truncation (tab. 1).

VTC soils with argic horizons. The illuvial character of an *argic* horizons was established by using thin section (micromorphology method). Other criteria couldn’t be used because of the presence of lithological discontinuity between sandy and loamy materials. Lithological discontinuity was identified by the percentage change (calculated on a clay-free basis) greater than 20% of immobile fractions 1,0-0,5; 0,5-0,25; 0,25-0,1; 0,1-0,05; 0,05-0,002 mm (tab. 1).

1. Relative change [%] of immobile fraction content calculated on clay-free basis between E and Bt horizons

Profile No.	Relative change [%] of immobile fraction content between E and Bt horizons calculated on clay-free basis				
	1,0-0,5 [mm]	0,5-0,25 [mm]	0,25-0,1 [mm]	0,1-0,05 [mm]	0,05-0,002 [mm]
A1	8	0	32*	7	43*
A2	29*	9	3	2	16
A3	19	6	2	22*	8
A4	51*	29*	13	9	3
A5	44*	21*	4	11	10
A6	12	12	6	16	30*
A7	4	1	10	7	13
A8	3	12	26*	7	42*
A9	26*	40*	8	12	26*
A10	8	10	7	15	18
A11	11	17	10	58*	100*
A12	2	31*	20	2	150*

** values confirmed lithological discontinuity*

In two cases (profile B2, C1) lithological discontinuity was clearly observed in field. Sandy (fluvioglacial) overlaying horizons (E) contains rounded pebbles, underlying loamy horizons developed from lodgment till (Bt) has angular rock fragments and the boundary between them was sharp.

Basic criterion used to distinguish *argic* horizon was the presence of illuvial forms of clay concentration (clay coatings and clay infillings). Oriented clays covered more than 1% of the entire thin sections prepared from undisturbed material sampled from Bt horizons (fig. 3).

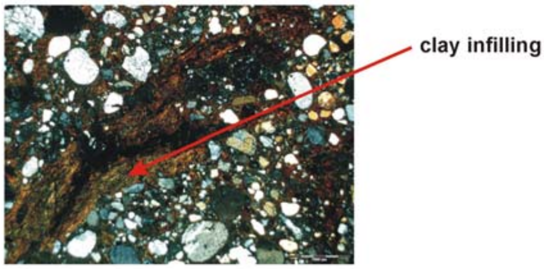

Fig. 3. Illuvial forms of clay concentration in argic horizon of studied soil example (crossed nicols light)

Pedons with clay-enriched subsoil can be classified to five RSGs according to WRB system: Albeluvisols, Alisols, Acrisols, Luvisols, Lixisols [9]. Studied soils with *argic* horizons represent three of them (tab.2). In the Systematics of Polish Soils all profiles were classified as one type (basic unit) – Soils Lessivès [24].

Most common are Luvisols – 10 profiles (tab. 2). All these profiles have an argic horizon with CEC above 24 ($cmol_c kg^{-1} clay^1$) and a base saturation of more than 50 percent in the major part between 50 and 100 cm from soil surface. Occurrence of soils developed from bottom moraine sediments which have high-activity clays throughout the argic horizon and high base saturation at certain depths, is typical in young glacial landscapes.

Profile A11 was classified as Albeluvisol – between horizons E and Bt occurred albeluvic tonguing boundary.

One profile with *argic* horizon was described as Alisol. It was caused by low base saturation in the depth from 50 to 100 cm. Generally, Alisols occur in humid (sub-) tropical and warm temperate regions and contain soluble inorganic Al in toxic quantities [4]. Some authors regard all clay illuviation horizons in Alisols as relics from a distant past [4, 5]. Studied soils occur in humid temperate regions and are developed from young moraine deposits which do not contain toxic quantities of Al. Profile A9 do not fulfill criteria of Alic properties according to older version of Key (WRB 98) in the major part between 25 and 100 cm from the soil surface: silt/clay ratio is more than 0,6 (in studied soil 0,9) and Al-saturation is less than 50% (low base saturation is caused by the high content of hydrogen ions). Taking into consideration chemical characteristics and genesis of Profile A9 it seemed to be necessary to restore criterion of Alic properties as indispensable to distinguish Alisols. It would give the possibility to properly describe such soils as Luvisols.

2. Reference Soil Groups of studied soils with argic horizon

Profile No.	Sequence of horizons	Depth of the boundary E/Bt* [cm]	Thickness of Bt [cm]	Albeluvic tonguing	Base status [%]**	Activity of clay in Bt [CEC $cmol_c$ $kg^{-1}clay^{1}$]	RSG (WRB 2006)
A1	A-Bw-E-2Bt-2Ck	60	50	-	65	67	Luvisol
A2	A-E-2Bt-2Ck	20	30	-	100	55	Luvisol
A3	A-Bw-E-2Bt-2Ck	45	65	-	80	77	Luvisol
A4	A-Bw-E-2Bt-2Ck	55	25	-	95	75	Luvisol
A5	A-Bw-E-2Bt-2C	75	60	-	56	50	Luvisol
A6	A-Bw-BE-2Bt-2C	58	40	-	75	52	Luvisol
A7	A-Bw-E-2Bt-2C	52	38	-	54	30	Luvisol
A8	A-BwE-2Bt-2Ck	40	35	-	88	61	Luvisol
A9	A-AB-Bw-E-E/2B-2Bt-2C	80	30	-	42	55	Alisol
A10	Ap-E-E/2B-2Bt-2Ck	45	35	-	100	60	Luvisol
A11	Ap-E-2Bt-2C	65	35	+	76	38	Albeluvisol
A12	Ap-E-2Bt-2Ck-3Ck	40	50	-	100	74	Luvisol

** depth of lithological discontinuity*
*** Base saturation in the major part between 50 and 100 cm*

General overview of properties that was used as a diagnostic criteria for describing second level of WRB classification of VTCs with *argic* horizon is given in Table 3. Cutanic is most common prefix qualifier (tab. 3). Only in one case (Profile A11) this qualifier could not be used because the qualifier list for RSG Albeluvisols does not contain it. Occurrence of clay coatings is obvious in some part of *argic* horizon. Ii is not necessary to use qualifier that duplicate criteria for distinguish RSG, therefore this qualifier should be remove from the qualifier list for Alisols and Luvisols.

For soils with concentrations of secondary carbonates (present as soft nodules that occupy more than 5% of the soil volume) starting within 100 cm of the soil surface (A1, A2, A8, A12) prefix calcic was used. Occurrence of spheroidal aggregates and concentrations of $CaCO_3$, at first translocated by percolating soil solution from upper to lower part of pedons is normal in soils developed from moraine deposits. New (in comparision to old WRB Key) suffix qualifier Ruptic is related to differences of lithology of described soils. Another frequently used suffix qualifier Abruptic enhance vertical-texture contrast formed by litho- and pedogenesis. Varied base saturation in the upper part of profiles is caused by primary mineralogical and chemical differentiation of ablation sandy layer. Therefore various suffix qualifiers releted to chemical characteristic of CEC were used: Epidystric, Hyperdystric, Hypereutric (tab. 3).

Most of the studied soils have, directly below A horizons, horizon with properties allowing usage of Brunic qualifier, shoving evidence of colour alternation relative to the underlying horizons (tab. 3). This material can be treated as analogous with the *cambic* diagnostic horizon of Cambisols [1, 3]. This is a result of pedogenic accumulation of iron sesquioxides in upper part of E horizons. In author’s opinion the addition of Brunic to the qualifiers list for Albeluvisol and Luvisols would create the possibility for the more complete description of their properties and would improve the classification system for VTCs. Qualifier Brunic should be placed in Prefix qualifiers list as an intergrade qualifier between Luvisols and Brunic Arenosols.

3. Second level of classification of studied soils with argic horizon

Profile No.	Depth of Bw [cm]	Colour		Depth of litholo-gical discon-tuinity [cm]	Texture class (percent of clay)		$CaCO_3$ [%]	BS 20-50cm [%]	Second level units (WRB 2006)
		Bw	E		E	Bt			
A1	10-45	10YR 4/5	10YR 5/4	60	LS (6)	SCL (28)	5,7	15	Calcic Cutanic Luvisol (Abruptic, Ruptic, Epidystric)
A2	-	-	-	20	LS (5)	SL (17)	6,9	100	Calcic Cutanic Luvisol (Abruptic, Ruptic, Hy-pereutric)
A3	10-25	10YR 5/4	10YR 5,5/4	45	LS (3)	SL (19)	4,7	17	Cutanic Luvisol (Abrup-tic, Ruptic, Epidystric)
A4	15-25	10YR 4/5	10YR 5/4	55	LS (2)	SL (11)	0,6	12	Cutanic Luvisol (Abrup-tic, Ruptic, Epidystric, Arenic)
A5	12-55	10YR 4/4	10 YR 5/4	75	LS (6)	SL (18)	-	7	Cutanic Luvisol (Abrup-tic, Ruptic, Epidystric, Profondic, Arenic)
A6	15-48	10YR 6/4,5	10YR 6/3	58	LS (7)	SL (17)	-	18	Cutanic Luvisol (Abrup-tic, Ruptic, Epidystric, Profondic, Arenic)
A7	10-42	10YR 4/4	10YR 6/3	52	LS (6)	SL (17)	-	18	Albic Cutanic Luvisol (Abruptic, Ruptic, Epidystric, Profondic)
A8	12-20	10YR 4/4	10YR 5/4	40	LS (6)	SCL (28)	13,0	20	Calcic Cutanic Luvisol (Abruptic, Ruptic, Epidystric)
A9	30-45	10YR 4/4	10YR 4,5/4	80	LS (5)	SL (13)	-	4	Cutanic Alisol (Ruptic, Hyperdystric, Profondic, Arenic)
A10	-	-	-	45	LS (6)	SL (18)	3,0	100	Cutanic Luvisol (Rup-tic)
A11	-	-	-	65	LS (7)	SL (19)	-	21	Albeluvisol (Abruptic, Ruptic, Epidystric)
A12	-	-	-	40	LS (4)	SL (12)	6,1	100	Calcic Cutanic Luvisol (Abruptic, Ruptic, Hy-pereutric)

VTC soils without argic horizons. According to the Systematics of Polish Soils [24] all studied VTCs without *argic* horizon were classified as one type – Rusty soils (uncompleted). According to WRB [9] profiles B1 and B2 were classified as Umbrisols because they have a thick, dark-coloured, base-depleted surface *umbric* horizons. Other surface A horizons of VTCs without *argic* horizon can not be classified as *Umbric* because of too small thickness (B4, B5, B6), not sufficient content of organic carbon (B7) or far to enough thickness between the soil surface and the lower boundary of the solum (B3). These soils fulfill criteria of Arenosols: have a weighted average texture of loamy sand and sand to a depth of 100 cm contains less than 40 percent (by volume) of gravels or coarser fragments and has no other diagnostic horizons (tab. 4).

Accumulation of sesquioxides in upper part of the sandy layer is expressed on second level of systematic position in all the investigated VTCs without *argic* horizon by using qualifier Brunic (tab. 5). It is not clear why in the case of Umbrisol this qualifier is on the suffix list whereas for Arenosol the same qualifier was put in the prefix list.

4. Reference Soil Groups of studied soils without argic horizon

Profile No.	Sequence of horizons	Thickness of A horizon [cm]	Content of Corg in A horizon [%]	BS in A horizon [%]	Thickness of solum [%]	Average texture to the depth 100 cm	Content of gravels [%]	RSG (WRB 2006)
B1	A(p)-Bw-C-2C	20	1,48	8,2	45	S	0,3	Umbrisol
B2	A-Bw-C-2C	25	2,37	9,6	45	LS	9,0	Umbrisol
B3	A-Bw-BwC-C-2C	20	0,69	6,5	80	S	9,4	Arenosol
B4	A-Bw-2C	15	1,33	6,8	74	LS	7,4	Arenosol
B5	A-Bw-C-C2-2C	10	1,41	6,6	25	LS	6,9	Arenosol
B6	A-ABw-Bw-C-2C	10	1,44	4,7	55	LS	5,9	Arenosol
B7	Ap-Bw-C-C/2C-2Ck	35	0,49	6,9	55	LS	4,6	Arenosol

Accumulation of sesquioxides is basic pedogenic process in all described VTCs without *argic* horizon. It seems to be proper to differentiating a new diagnostic horizon in the WRB classification – *brunic* (criteria according to actual criteria of Brunic properties) – and a new soil group, namely Brunisols. The definition of Brunisols would be based on the changed definition of Cambisols using *brunic* horizon instead of *cambic* horizon. Similar suggestion was earlier proposed by Charzyński [3].

5. Second level of classification of studied soils without *argic* horizon

Profile No.	Bw depth	Colour		ATC* [cm]	Texture class (percent of clay)		Second level units (WRB 2006)
		Bw	C		C	2C	
B1	20-45	10YR 4/6	10YR 5,5/4	95	S (1)	LS (7)	Haplic Umbrisol (Anthric, Brunic, Arenic)
B2	25-45	2,5Y 4/4	2,5Y 6/3	70	LS (3)	SL (9)	Endogleyic Umbrisol (Brunic)
B3	20-55	10YR 4/4	10YR 5/4	100	S (2)	SL (15)	Brunic Hypoluvic Arenosol (Dystric)
B4	15-74	10YR 4/4	10YR 5/6,5	74	LS (2)	SCL (29)	Brunic Hypoluvic Arenosol (Dystric)
B5	10-25	10YR 3/4	10YR 4/4	110	LS (2)	SL (10)	Brunic Arenosol (Dystric)
B6	27-55	10YR 4/4	10YR 4,5/4	77	LS (3)	SL (13)	Brunic Hypoluvic Arenosol (Epidystric)
B7	35-55	10YR 4/6	10YR 5/4	80	LS (3)	SL (11)	Brunic Hypoluvic Arenosol (Epidystric)

**depth of abrupt texture change.*

Sharp increase in clay content within a soil profile of Umbrisols and Arenosols is very important feature because it has big influence on the ecological value of these soils [28]. Abrupt textural change is especially crucial in Arenosols. Underlying, finer (sandy loam) material decreases permeability of these soils and enlarges their water and nutrient storage capacity. In this connection, all examinated Arenosols with VTC have high ecological quality as they are eutrophic habitats of decidous forests [28]. For Arenosols only one prefix qualifier Hypoluvic describing higher content of clay in underlying parts of pedons. Application of Hypoluvic in Arenosols suggest, that these soils are intergrade soils to the Luvisols what is not true (lack of oriented illuvial clay coatings and infillings). Using this qualifier seems not to be correct. In the case of Umbrisol there is no possibility to express VTC. Addition of Abruptic and Ruptic to the suffix qualifiers list for Umbrisols and Arenosols will become more precise in describing the characteristic and use value of these soils.

Conclusions. On the basis of the investigated VTCs systematic position, author have evaluated whether the WRB classification system reflected the most important properties of such soils. Presented research results and proposals of WRB Key modifications would enable optimal classification of VTCs from young glacial landscapes. The following changes are suggested:

- differentiating a *brunic* diagnostic horizon, the definition of which would be based on the definition of material with Brunic properties, and creating a new soil group - Brunisols;

- including the *brunic* horizon into the list of those horizons which may be found in Luvisols;
- restoring criterion of Alic properties as indispensable to distinguish Alisols;
- accepting the Brunic prefix qualifier for the soil unit of Luvisols and Ruptic and Abruptic suffix qualifiers for Umbrisols and Arenosols
- removing the Cutanic prefix qualifier from the soil units containing *argic* horizon.

The suggestions for amendments in the WRB classification system given above, may improve its usefulness of the describing of VTCs.

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КЛАСИФІКАЦІЯ МОЛОДИХ ГЛЯЦІАЛЬНИХ ҐРУНТІВ ІЗ ВЕРТИКАЛЬНОЮ ТЕКСТУРНОЮ КОНТРАСТНІСТЮ З ВИКОРИСТАННЯМ СИСТЕМИ WRB

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Предметом публікації є презентація таксономічного розташування ґрунтів із вертикальною текстурною контрастністю, розвинених на моренному матеріалі, покритому флювіогляціальними або абляційними піщаними шарами молодих гляціальних ландшафтів. Досліджувані ґрунти класифіковані як 5 різних реферативних ґрунтових груп згідно системи WRB: лювісолі, альбелювісолі, алісолі, умбрісолі та ареносолі. Деякі пропозиції для модифікацій в системі WRB сформульовані для повнішого опису властивостей досліджуваних ґрунтів.
Ключові слова: вертикальний текстурний контраст, процес лесиважу, літологічна неоднорідність.