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Gleysols on sandy deposits of the Litorina Sea underlain by Histosol formations of Ancylus Lake age in western Estonia

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Abstract. Two bisequal Gleysol profiles were studied in western Estonia to characterize pedogenetic features on aqueous sediments of the Litorina Sea and Ancylus Lake in similar topographical and geological situations. The development of Gleysols during the Late Holocene has been uniform and depends on the composition and sediment structure of both sandy and silty parent materials. Saturated R_2O_3-humic-fulvic organic matter of hydromorphic origin has increased the specific surface area and exchange properties during all stages of the Holocene while the textural-chemical properties of deposits in groundwater regimes have been preserved from Ancylus Lake time up to the present.

Key words: Gleysols on aqueous deposits, Holocene pedogenesis.

INTRODUCTION

One of the prime interests of natural scientists around the Baltic Sea is to detect the environmental changes in the shifting coast of the sea basin. Already since the Stone Age people have adapted themselves to the fluctuating sea level. It means that terrestrial processes during different stages of the Baltic Sea have great geological, pedogenetic, and archaeological importance. During the last few years we have studied several multisequal soil sections in the area of ancient human settlements in western Estonia. The development of Histosols and/or Molli-Histic Gleysols on calcareous till as well as on Baltic Ice Lake sediments during the Yoldia stage have been reported (Reintam & Moora 1998; Reintam et al. 2001). Automorphic Podzols and Arenosols have developed of sandy deposits of Ancylus and/or Litorina stages on the top of many outcrops. The lowermost part of the Lemmejõgi outcrop became the first section, at least in Estonia, which was sampled directly from the top of strongly gleyed till (Reintam et al. 2001). The Paikuse and Pulli outcrop sections were the first ones which had pedological interpretations (Reintam & Moora 1998) in addition to the geologist's indefinite qualification as "organic sediments".

This paper deals with the materials concerning contemporary gleyic formations of different age on Litorina fine sand underlain by peats on Ancylus silty sediments. The presence of bisequal hydromorphic soil profiles, some of which developed more than 7000 BP and others within the past centuries or even during the last decades, has become possible due to the relatively low altitude and permanently high level of the groundwater table.

MATERIAL AND METHODS

Site, topography, geology, and sampling

The main stages in the Baltic Sea history have been known since the beginning of the last century, but have never been properly defined as stratigraphical units whose boundaries between different water bodies are time transgressive. In this paper the boundary between the Baltic Ice Lake and the Yoldia Sea is given as 10 300 yr BP, between the Yoldia Sea and the Ancylus Lake 9300 yr BP, between the Ancylus Lake and the Litorina Sea 8000 yr BP, and between the Litorina Sea and the Limnea Sea 4000 yr BP (Raukas 1997).

Two pits in similar topographical and geological situation were chosen for detailed investigation (Table 1). Both of them have archaeological significance. The first site (Figs 1 and 2) was located in the courtyard of the modern Lihula Central Townstore (58°41′ N, 23°48′ E) at an altitude of 14.86 m a.s.l. Asphalt and gravel covered a 52-cm layer of silty Anthrosol, which evidently had been transported from some other place at the time of

Table 1. General characterization of the pits

Location	Material	Horizon and depth, cm	Colour	Characteristics	Thickness, cm
Lihula	Debris fill, till	A_{terric} 0–52	10YR2/2	Debris fill, anthric	52
58°41′ N,	Limnea Sea fine sand	A 52–68	10YR2/2	Mollic, weakly rooted	16
23°48′ E		Bw 68–78	10YR4/3	Slightly cambic	10
		IG 78–108	10YR7/3	Quicksand, grey	30
	Beach gravel	IIG 108–126		Coarse gravelly sand	18
	Ancylus-age, peaty	AH 126–137	10YR1/1	Molli-histic	11
	Very compact sand	IIIG 137–147	5G5/1	Silty, aleuritic	10
	Calcareous till	>147		Under groundwater	
Ilpla–Reo	Litorina Sea sand	A 0–8	10YR2/1	Mollic, well-rooted	8
58°19′ N,		Bwg 8–24	10YR6/2	Rusty, weakly cambic	16
22°40′ E		Cg 24–45	10Y8/1	Whitish-grey, fine	21
		CG 45–69	10Y8/1	Striped, silty stripes	24
		ACa 69–85	10Y7/2	Humously striped	16
		IIG 85–92	5GY4/3	Plastic clay, steely grey	7
	Ancylus-age, peaty	H3 92–117	N1.5/0	Molli-histic	25
		AH 117–127	10YR2/2	Mollic, clayey	10
	Ancylus-age sand	IIIG 127–143	5GY6/3	Fine silty sand	16
	Gravelly shingle sand	IVG 143–155		Coarse, calcareous	12
	Limestone	>155			

village restoration about 1300. A Eutric Gleysol profile (Fig. 3a), which developed after the Litorina regression, began at an altitude of 14.34 m a.s.l., and a Molli-Histic Gleysol, which developed during Late Ancylus time, started at an altitude of 13.60 m a.s.l. Calcareous reworked till with limestone gravel and pebble material begins at an altitude of 13.39 m a.s.l. Probably that till was reworked during the deep Yoldia Sea regression, however, Ancylus Lake activity cannot be excluded. A thin layer of highly compacted fine sand seems to have accumulated in the nearshore zone of Ancylus Lake before the start of terrestrial paludification. The underlying peat contains residues of woody material.

The second pit was excavated on the Island of Saaremaa (Figs 1 and 4) between the villages of Ilpla and Reo (58°19′ N, 22°40′ E) near a gravel quarry which was exhausted in 1976. On the basis of a large-scale soil map (Fig. 5) compiled in 1987–1988, it is possible to conclude that a Eutri-Gleyic Arenosol profile formed on fine Litorina Sea sand and is only about 24 years old as it tends to be developed during the time after the retreat of the Litorina Sea. This profile covers a problematic thin Fluvisol formation underlain by a Histosol on an Ancylus sandy deposit (Fig. 3b). Silurian limestone lies at a depth of 155 cm and is overlain by a coarse sandy layer (12 cm) containing both calcareous gravel and shingle from limestone bedrock.

The ^{14}C data from the outcrop allow us to specify the time of the maximum Litorina Sea transgression in the precincts of Ipla–Reo Kilbumägi but also the age of the Kõnnu Stone Age settlement (Fig. 4) located nearby. Artifacts from the settlement belong to the Early Neolithic Period. The amount of charcoal collected during the excavations of the settlement in 1976–1978 was not sufficient for analysis. Settlement history is really a special field of geographic research. Archaeologists, whose research is based on material finds, cannot describe the formation and development of their forefathers in the Prehistoric Period without involving palaeogeographic disciplines. Pedologic information plays an important role in the study of the development of natural environments in the past.

The morphological description and the sampling of both profiles were carried out in a traditional soil science way (FAO 2006) to the depth of calcareous till and/or underlying limestone. Holocene stratigraphy was established by Raukas et al. (1995). Microimpactites with an age of over 7000 ^{14}C yr BC were discovered at Ilpla–Reo, which may have originated from the explosion that generated the meteoritic craters at Kaali (Fig. 4).

Analyses

Analytical techniques on air-dry soil were carried out by a research assistant Raja Kährik in the laboratories of the Department of Soil Science and Agrochemistry, Estonian University of Life Sciences (former name Estonian Agricultural University). Fine earth with grain size less than 2 mm was used. Samples for the determination of particle size were treated with sodium pyrophosphate to break down aggregates. Sands were sieved and fractions finer than 0.05 mm were determined by pipette analysis (*Pipette Apparatus Table Model 7 Samples*). Total chemical analysis was carried out after alkaline fusion treatment. Iron and aluminium were ascertained by means of sulphosalicylic acid and aluminone, respectively; alkaline earths, potassium, and sodium were determined by flame photometry. Carbonates were determined acidometrically for recalculation of measurement data. The results obtained are expressed for ignited noncalcareous material (Arinushkina 1970; van Ranst et al. 1999). Previously the reliability of these techniques was verified by atomic absorption spectrometry.

Cation exchange capacity (CEC) and exchangeable bases were measured by percolation of a sample with ammonium acetate at pH 7.0 and expressed in cmol kg^{-1}. The total amounts (g kg^{-1}) of organic carbon and nitrogen were measured by the Tyurin and Kjeldahl volumetric methods, respectively (Ponomareva 1957). The Anne' method (van Ranst et al. 1999) is equivalent to the Tyurin method used. The group and fractional compositions of humus were measured by the alternate acid-alkaline treatment according to the volumetric method of Tyurin–Ponomareva (Ponomareva 1957). The results are expressed as a percentage of organic carbon. Group composition represents humic acids (H.a.), fulvic acids (F.a.), and humins known as the insoluble residue. Humic and fulvic acids altogether are humus acids. The fractions within the groups are the following: 1a – free fulvic acids (only within the group of fulvic acids); 1 – humic and fulvic acids bound with mobile Fe_2O_3 and Al_2O_3; 2 – humic and fulvic acids bound with Ca and Mg; 3 – humic and fulvic acids bound with immobile sesquioxides and clay.

The humic : fulvic ratio is an integral parameter of the maturity and mobility of humus as well as of humicity (>1) and/or fulvicity (<0.7). The ratio of the first to the second fraction demonstrates the relationship of the brown humic-fulvic complexes, bound with mobile sesquioxides, to the grey (black) complexes bound with alkaline earths. Decalcification with 0.05 M sulphuric acid represents a part of humus fractination, which permits determination of the second and the third fractions as well as the hydrolysate of 0.5 M sulphuric acid by extracting humus substances from the crystal structure of clay minerals (Ponomareva 1957). Dithionite-extractable (total non-siliceous) iron, oxalate-extractable iron, aluminium, and silica were measured after Coffin and Tamm, respectively; iron activity was calculated after Schwertmann (van Ranst et al. 1999). The pH of both water and 1 M KCl suspensions (1 : 2.5) was measured potentiometrically with the pH-meter *Jenway 3071*. The specific surface area (SSA) was measured after Puri and Murari using water absorption from the steam-saturated atmosphere above 41% sulphuric acid (Kitse & Rooma 1984). The results are expressed as $m^2 g^{-1}$.

The soils were named according to the *World Reference Base for Soil Resources* (FAO 2006). Requirements for the accuracy of sampling, laboratory techniques and measurements were satisfied as for any reference profile (Batjes & van Engelen 1997).

RESULTS AND DISCUSSION

Organic matter

The lack of any mollic and/or histic formation on both calcareous till and limestone bedrock (Figs 3a and 3b) demonstrates that the sites studied were dry land of islands or islets during the regressions of the Baltic Ice Lake and the Yoldia Sea. In the Pre-Boreal about 9300 BP thin silty-sandy sediments of the Ancylus Lake transgression covered till at Lihula and the limestone in the Ilpla–Reo area. The Histosol profile is dated to 7732 ± 118 BP (Tln-2554) in the lower part and 7368 ± 68 BP (Tln-2558) in the upper part of the histic horizon at Ilpla–Reo, and to 7459 ± 56 BP (Tln-2731) for wood within peat at Lihula. If we suppose that shallow water of Ancylus Lake rapidly retreated from islet-like bedrock and till hillocks, the duration of hydromorphic pedogenesis there must have been at least 2000 years until Litorina transgression once again buried soils under a sandy carpet. The Late Ancylus pedogenesis in the Boreal Chronozone resulted in the formation of Eutric Histosols during about two millennia or even for some hundred years less. The average annual increment in organic carbon appears to be about 10–11 g m^{-2} yr^{-1} in the layer of 25–35 cm, being about 3–4 times higher in the upper part of the histic horizon than in the lower one. This situation is quite similar to that in Molli-Histic Gleysols of Pre-Ancylus stages (Reintam et al. 2001).

The R_2O_3-humic humus, saturated with alkaline earths, is also characteristic of molli-histic epipedons of Late Ancylus–Early Litorina age (Tables 2 and 3). Although the total amount of organic carbon is a little less at Lihula, there are no differences in the principal composition of humus between the two sites. Only Ca-humic-fulvic complexes are better preserved in the high groundwater conditions at Lihula. This is also reflected in the composition of decalcinate. In spite of large differences in the age of Gleysols (Table 2 modern soil, Table 3 Limnea age soil) and total amount of organic carbon, the composition of humus is quite similar. Based on previous

Table 2. Composition of organic matter in percentage of organic carbon, Ilpla–Reo, Island of Saaremaa

Characteristics	Horizon and depth, cm					
	Modern soil		Litorina	Ancylus age, 7732 ± 118–7368 ± 68 BP		
	A 0–8	Bw 8–24	IIG 85–92	H3 92–105	H3 105–117	AH 117–127
Organic C, g kg^{-1} of soil	81.0	1.9	12.2	337.9	93.3	33.1
Nitrogen, g kg^{-1} of soil	4.2	0.2	0.2	17.9	4.1	2.1
C : N	19.3	9.5	61.0	18.9	22.8	15.8
Humic acids						
1	8.3	11.2	4.8	9.0	6.8	3.8
2	6.1	7.9	0.0	5.2	15.6	5.0
3	5.2	6.7	15.6	9.7	11.3	22.9
Total	19.6	25.8	20.4	23.9	33.7	31.7
Fulvic acids						
1a	4.9	18.6	0.7	3.7	6.2	7.0
1	2.9	0.0	5.3	0.1	0.1	0.0
2	7.3	25.2	0.0	4.7	9.6	14.4
3	3.8	0.0	11.7	2.7	5.1	8.9
Total	18.9	43.8	17.7	11.2	21.0	30.3
Hydrolysate of 0.5 M H_2SO_4	5.4	8.3	10.7	6.4	6.1	5.3
Total soluble	43.9	77.9	48.8	41.5	60.8	67.3
Insoluble residue	56.1	22.1	51.2	58.5	39.2	32.7
Humic : fulvic ratio	1.04	0.59	1.15	2.13	1.60	1.05
1st fraction : 2nd fraction	0.84	0.34	10.10	0.92	0.27	0.20
Decalcinate, g kg^{-1}						
Fe	7.3	1.5	2.9	3.7	3.5	4.0
Al	1.6	0.9	0.9	0.2	1.9	2.0
Ca	0.7	0.4	19.6	0.6	0.1	11.3
Mg	0.4	1.1	2.7	0.2	0.1	1.7

Table 3. Composition of organic matter in percentage of organic carbon, Lihula, Lääne County

Characteristics	Horizon and depth, cm					
	Covering Terric Anthrosol (14.86 m above sea level)			Limnea age*	Ancylus age 7459 ± 56 BP (13.6 m above sea level)	
	0–13	13–26	26–52	A 52–68	AH 126–131	AH 131–137
Organic C, g kg^{-1} of soil	36.9	27.7	27.7	12.3	154.7	47.2
Nitrogen, g kg^{-1} of soil	2.4	4.4	2.0	0.9	7.5	3.7
C : N	15.4	6.3	14.3	13.7	20.6	12.8
Humic acids						
1	8.7	8.3	9.6	11.2	14.2	17.7
2	9.9	14.0	10.0	20.0	8.9	14.1
3	4.3	8.6	6.2	4.7	8.1	6.8
Total	22.9	30.9	25.8	35.9	31.2	38.6
Fulvic acids						
1a	2.8	2.1	2.1	11.4	1.3	1.6
1	6.2	10.4	11.2	7.0	3.3	4.4
2	4.9	6.0	4.9	15.0	6.4	9.5
3	7.7	4.6	4.9	5.9	2.8	2.8
Total	21.6	23.1	23.1	39.3	13.8	18.3
Hydrolysate of 0.5 M H_2SO_4	10.1	12.7	8.2	6.2	3.5	2.5
Total soluble	54.6	66.7	56.1	81.4	48.5	59.2
Insoluble residue	45.4	33.3	43.9	18.6	51.5	40.8
Humic : fulvic ratio	1.06	1.34	1.17	0.91	2.26	2.10
1st fraction : 2nd fraction	1.01	0.94	1.40	0.52	1.14	0.93
Decalcinate (g kg^{-1})						
Fe	0.5	0.2	0.4	0.6	1.7	1.1
Al	2.4	1.6	2.8	0.0	6.3	3.1
Ca	21.7	16.0	20.7	7.0	12.4	4.9
Mg	23.3	22.9	24.4	3.5	3.6	2.0

* Eutric Gleysol on Litorina sand.

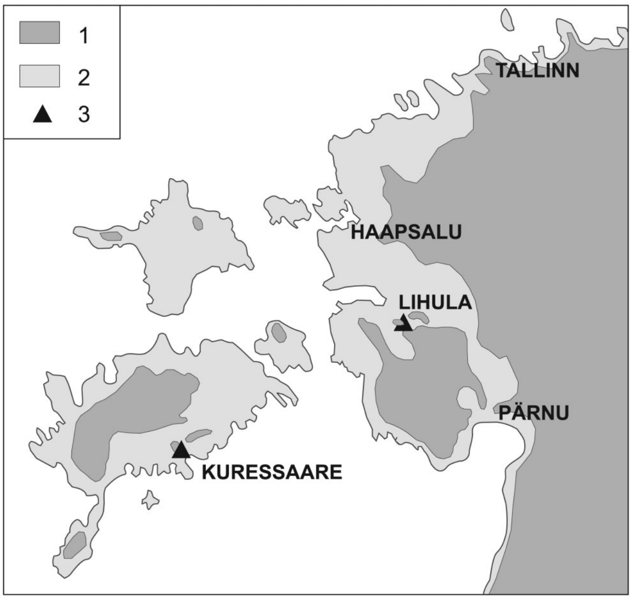

Fig. 1. The shoreline of the Litorina Sea transgression in West Estonia and location of the investigated sites: 1, shoreline of the Litorina Sea; 2, present shoreline of the Baltic Sea; 3, investigated sites.

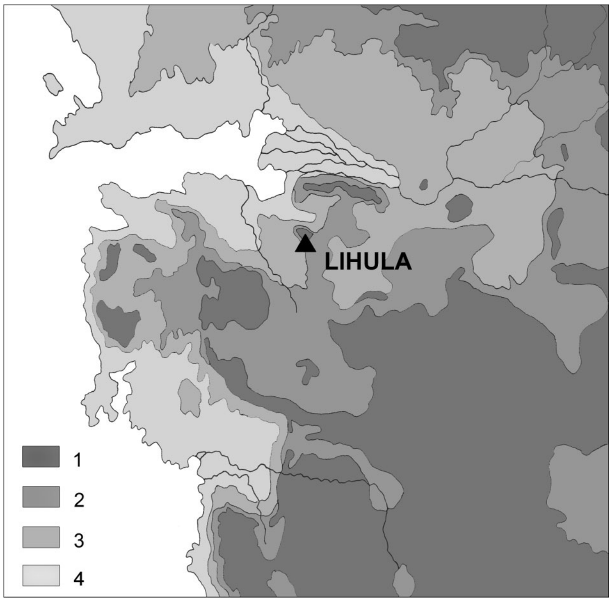

Fig. 2. Retreat of the Baltic Sea in the Lihula area: 1, areas higher than the Litorina transgression maximum; 2, 3, 4, most important shorelines of the retreating Litorina and Limnea seas.

(a)

(b)

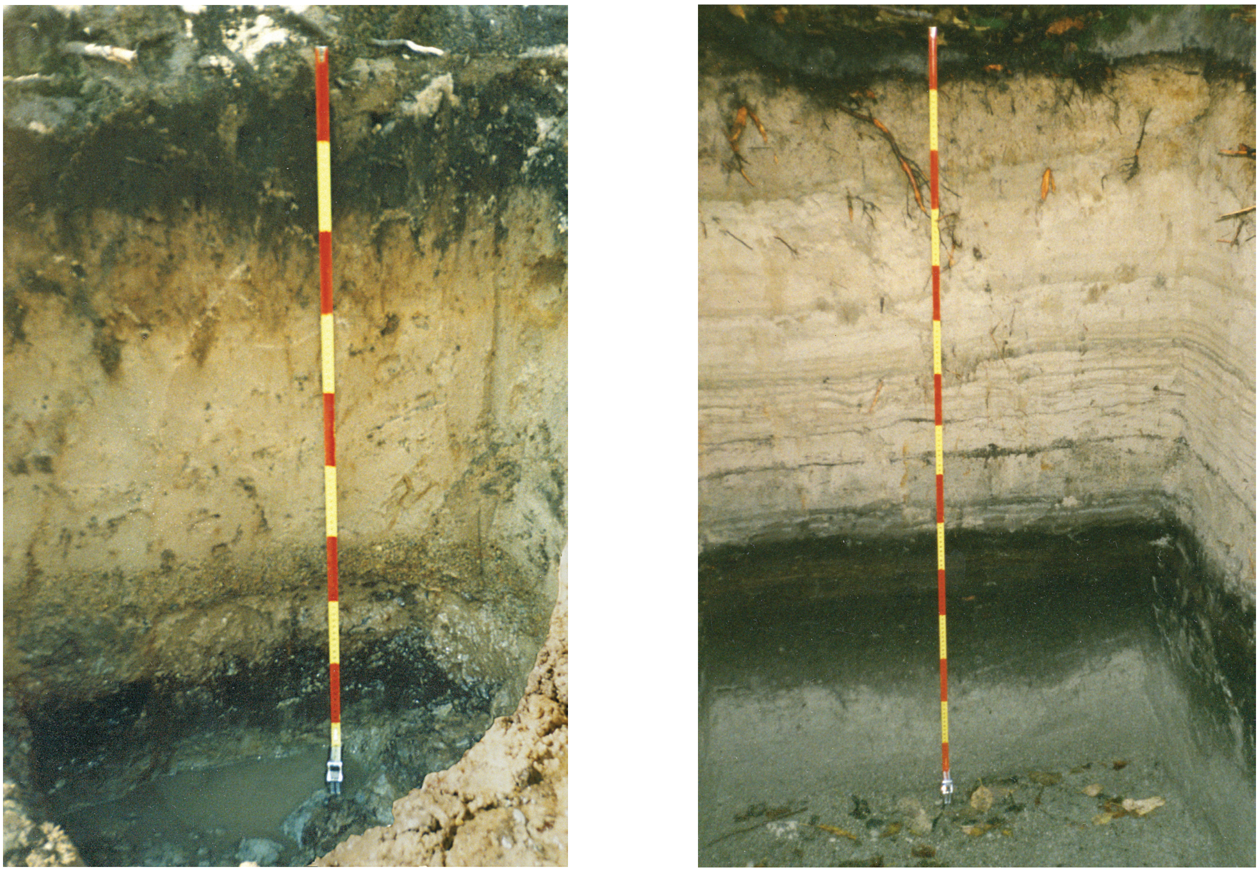

Fig. 3. Bisequal soil profiles (a) at Lihula and (b) at Ilpla–Reo. The bars on the tape = 10 cm.

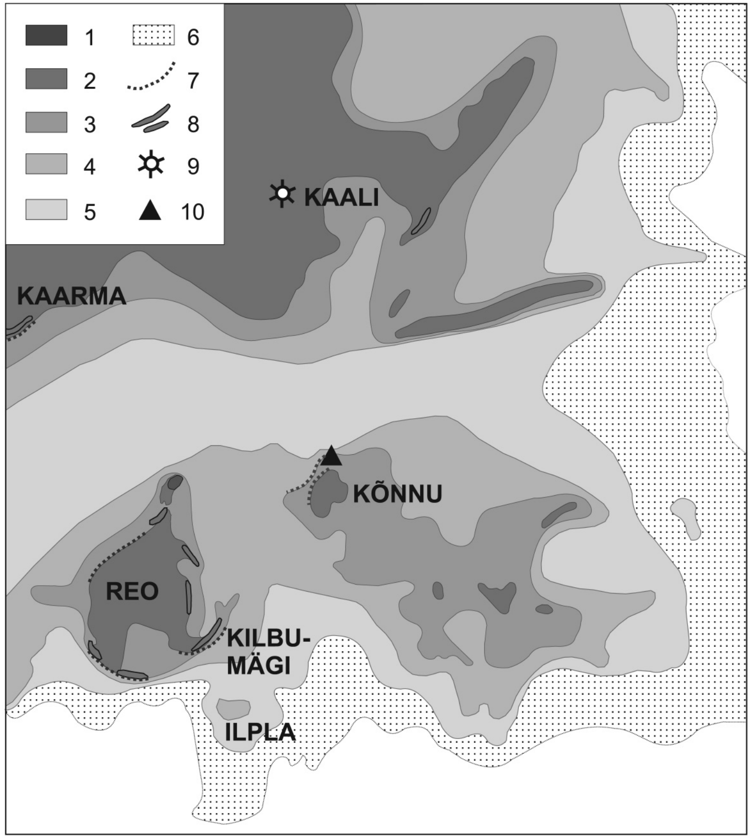

Fig. 4. Retreat of the Baltic Sea in the Ilpla–Reo area: 1, 2, retreat of Ancylus Lake; 3, areas of maximum transgression of the Litorina Sea; 4, 5, 6, most important shorelines of the retreating Litorina Sea and the shoreline of the Limnea Sea; 7, coastal scarps of the Litorina Sea maximum; 8, beach barriers of the Litorina Sea maximum transgression; 9, Kaali meteorite impact crater; 10, early Neolithic Kõnnu settlement.

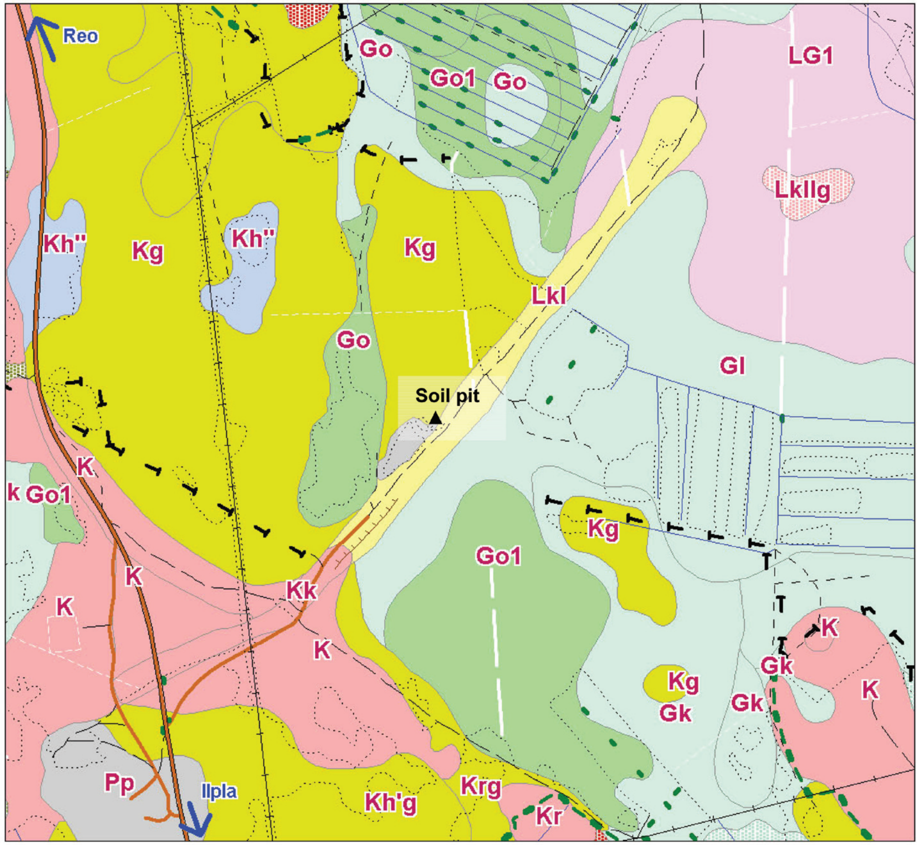

Fig. 5. Soil map (1 : 10 000) of the Ilpla–Reo site from 1987–1988. LkI, sandy Arenosol; Go, sandy Eutric Gleysol; Go1, Molli-Histic Gleysol; Kk, K, Rendzic Leptosol on the bottom of a gravel quarry; Kg, Rendzi-Gleyic Leptosol; Gk, Rendzic Gleysol; Kh″, Kh′g, Rendzic Leptosol on limestone; LkIIg, Gleyic sandy Arenosol; LG1, Histi-Gleyic Podzol; GI, Luvic Gleysol; Kr, Skeleti-Rendzic Leptosol; Krg, Skeleti-Gleyic Leptosol.

studies of several other soil units, we conclude that the main qualitative characteristics of humus status form during early stages of pedogenesis. Further quantitative development appears to result in only negligible changes in qualitative properties. Therefore saturated R_2O_3-humic-fulvic humus of different-aged Gleysols is preserved even in the conditions of an increase in total solubility and impoverishment in decalcinate (Table 3). A similar result occurs in the striped Fluvic formation at a depth of 85–92 cm (Table 2). Organic matter seems to have accumulated here in shallow brackish water of the Litorina Sea (enriched in exchangeable Na^+, Table 4), however, there are no differences in humus composition compared to those above. Only the C : N ratio is extremely large.

The colluvial material deposited at Lihula appears to be from mollic epipedons of Rendzinas of calcareous till origin from the neighbouring areas. It is possible that part of the calcium both in decalcinate (Table 3) and the exchangeable complex (Table 4) of underlying layers could have originated from this material as a result of the weathering of carbonates and leaching of products.

Exchange properties and texture

Against the background of neutral to slightly alkaline reaction, the accumulation of organic carbon resulted in an increase in the specific surface area as well as in cation exchange capacity (Table 4).

The temporal influence is absent in the development of exchange properties of modern and Limnea-age Gleysol. Everywhere the impact of organic matter is prevalent. Calcium is the dominant exchangeable cation.

Pedogenetic textural differentiation is lacking in all Ancylus and Post-Ancylus sediments (Table 5). Common uniformity is also characteristic of the covering Anthrosol of silty sandy till origin. Textural stratification of Post-Ancylus sandy material tends to be due to the coastal activities during its formation at a depth of 107–117 cm at Lihula, but possibly also at a depth of 127–143 cm in the region of Ilpla–Reo. The weathering of sand particles is weak in the top of the uppermost Gleysol profiles, especially within the modern profile at Ilpla–Reo, as a result of which only a slight accumulation of clay and silt can be found.

Table 4. pH, exchange properties, and specific surface area (SSA)

Location	Soil	Horizon and depth, cm	pH_{H2O}	pH_{KCl}	Ca^{2+}	Mg^{2+}	K^+	Na^+	CEC	SSA, m^2g^{-1}
					cmol kg^{-1}					
Ilpla–Reo	Eutri-Gleyic Arenosol	A 0–8	6.7	6.5	52.31	3.27	0.18	0.32	56.18	105
		Bw 8–24	7.0	6.6	3.03	0.13	0.01	0.00	3.17	9
		C 24–45	7.1	6.7	2.71	0.09	0.00	0.00	2.80	7
		$C_{stratif.}$ 45–69	7.7	7.5	19.36	0.24	0.02	0.00	19.62	12
	Fluvisol?	ACa 69–85	7.5	7.5	19.75	0.20	0.00	0.00	19.95	6
		IIG 85–92	7.2	7.1	32.95	0.99	0.10	0.02	34.04	23
	Molli-Histic Gleysol (Histosol)	H3 92–105	6.1	5.8	85.26	6.63	0.15	0.80	92.84	420
		H3 105–117	6.7	6.5	66.32	4.86	0.09	0.32	71.60	141
		AHG 117–127	7.4	7.0	42.84	1.98	0.10	0.09	45.01	72
		IIIG 127–143	7.8	7.4	21.69	0.40	0.04	0.00	21.13	13
		IVG 143–155	7.4	7.2	20.69	0.23	0.03	0.00	20.96	10
Lihula	Terric Anthrosol (14.86 m a.s.l.)	A_{terric} 0–13	7.4	7.2	21.70	3.08	0.96	0.32	26.06	86
		A_{terric} 13–26	7.4	7.1	20.65	2.86	1.20	0.37	25.08	89
		A_{terric} 26–39	7.4	7.0	20.65	2.97	1.52	0.37	25.51	96
		A_{terric} 39–52	7.3	6.8	17.59	2.54	1.40	0.37	21.90	77
	Eutric Gleysol (14.34 m a.s.l.)	A 52–68	7.2	7.1	15.61	2.04	1.04	0.03	18.73	52
		Bw 68–78	7.5	7.3	4.08	0.54	0.27	0.12	5.01	19
		G 78–93	7.9	7.6	1.18	0.24	0.10	0.08	1.61	5
		IG 93–107	8.0	7.6	0.82	0.17	0.08	0.05	1.11	4
		107–117	7.9	7.4	3.94	0.74	0.24	0.13	5.03	19
		IIG 117–126	7.9	7.4	1.37	0.26	0.09	0.06	1.79	5
	Molli-Histic Gleysol (13.6 m a.s.l.)	(A)H 126–131	6.9	6.7	46.39	13.63	1.44	0.13	61.59	259
		AH 131–137	7.1	6.6	23.84	8.36	1.68	0.72	34.61	118
		IIIG 137–147	7.8	7.4	6.43	0.79	0.36	0.12	7.70	10

Table 5. Granulometric composition, g kg^{-1}

Location	Soil	Horizon and depth, cm	Fractions, µm				
			2000–500	500–250	250–50	50–2	<2
Ilpla–Reo	Eutri-Gleyic Arenosol	A 0–8	13	99	680	184	24
		Bw 8–24	4	30	954	12	0
		C 24–45	4	14	964	15	3
		$C_{stratif.}$ 45–69	5	25	916	37	17
	Fluvisol?	ACa 69–85	1	8	954	37	0
		IIG 85–92	8	18	934	216	27
	Molli-Histic Gleysol (Histosol)	H3 92–105	0	0	0	0	0
		H3 105–117	0	0	0	0	0
		AHG 117–127	9	51	601	316	23
		IIIG 127–143	33	129	620	202	16
		IVG 143–155	9	50	593	348	0
Lihula	Terric Anthrosol (14.86 m a.s.l.)	A_{terric} 0–13	113	272	484	131	0
		A_{terric} 13–26	105	239	483	174	0
		A_{terric} 26–39	115	243	405	225	12
		A_{terric} 39–52	99	285	442	171	0
	Eutric Gleysol (14.34 m a.s.l.)	A 52–68	118	241	514	93	34
		Bw 68–78	54	147	771	10	18
		G 78–93	32	58	901	5	4
		IG 93–107	25	75	887	11	2
		107–117*	485	173	295	47	0
		IIG 117–126	35	195	755	15	0
	Molli-Histic Gleysol (13.6 m a.s.l.)	AH 126–131	133	196	436	225	10
		AH 131–137	58	88	550	220	84
		IIIG 137–147	15	18	781	158	28

The simple uniformity of exchange properties and texture of different-aged Gleysols and mineral subsoils of Histosols confirm the former generalization that no pedogenetic differentiation takes place under aquic groundwater regimes and the layering of the solum depends on former geologic conditions and sedimentation.

Chemical characterization

Practically the same can be said about the chemical properties (Tables 6 and 7). Slight accumulation of non-siliceous substances has taken place in the horizons of organogenic origin as well as in the Bw-horizons of the weathering of sand-size alumosilicates (Table 6). The only exception is once again the coastal layer at a depth of 107–117 cm at Lihula. Naturally, iron activity has increased everywhere in the topsoil, but is quite high throughout both underlying Molli-Histic profiles. Amorphous aluminium is low due to the high pH value and base saturation. The amount of amorphous silica can be explained with the gleying in the conditions of alkaline reaction.

Chemical composition appears to be quite homogeneous among the different-aged sediments (Table 7). Slight impoverishment in iron of all weathered gley(ic) horizons is due to the mobilization of ferrous compounds during the gleying and the seasonal fluctuation of the groundwater table. No traces of illuvial and/or in situ accumulation of sesquioxides are observed. Layer differences of alkaline earths are explained by the specifics of Holocene sediments. Molecular ratios repeat the chemical uniformity of the Holocene and contemporary Gleysol formations.

CONCLUSIONS

Archaeological, palaeogeographical, and stratigraphical information is of great importance to study the trends and rates of pedogenesis and the evolution of soils. Gleysol formation during the Holocene on different-aged

Table 6. Content of pedogenetic nonsiliceous substances, g kg^{-1}

Location	Soil	Horizon and depth, cm	Total non-siliceous Fe	Amorphous			Iron activity, %
				Fe	Al	Si	
Ilpla–Reo	Eutric Arenosol	A 0–8	2.8	2.7	0.6	0.9	96
		Bw 8–24	2.2	0.5	0.4	0.9	23
		C 24–45	0.9	0.2	0.3	0.3	22
		$C_{stratif.}$ 45–69	0.4	0.3	0.2	1.4	75
	Fluvisol?	ACa 69–85	0.7	0.7	0.3	0.1	100
		IIG 85–92	0.6	0.5	0.4	0.9	83
	Molli-Histic Gleysol (Histosol)	H3 92–105	2.3	2.2	0.3	0.6	96
		AH3 105–117	1.7	1.6	0.9	0.8	94
		AHG 117–127	1.6	0.3	0.7	0.4	19
		IIIG 127–143	0.3	0.1	0.5	0.8	33
		IVG 143–155	0.3	0.2	0.2	0.3	67
Lihula	Terric Anthrosol (14.86 m a.s.l.)	A_{terric} 0–13	4.7	3.4	0.1	1.4	72
		A_{terric} 13–26	3.6	3.6	0.1	0.6	100
		A_{terric} 26–39	3.9	3.4	0.1	1.0	87
		A_{terric} 39–52	3.6	3.1	0.1	0.9	86
	Eutric Gleysol (14.34 m a.s.l.)	A 52–68	3.6	1.8	1.7	0.3	50
		Bw 68–78	2.5	2.3	1.2	0.0	92
		G 78–93	1.2	0.3	0.1	0.3	25
		IG 93–107	0.8	0.3	0.3	0.4	38
		107–117*	6.4	3.1	0.1	0.6	48
		IIG 117–126	2.2	0.6	0.0	0.5	27
	Molli-Histic Gleysol (13.6 m a.s.l.)	AH 126–131	7.0	6.9	0.3	1.2	99
		AH 131–137	7.7	3.6	0.2	1.5	47
		IIIG 137–147	5.4	2.4	0.1	1.5	44

Table 7. Chemical composition of Eutric Arenosol on Litorina sands underlain by Molli-Histic Gleysol of Ancylus age, g kg^{-1} of ignited noncalcareous material

Constituents	Modern Eutri-Gleyic Arenosol, cm				Fluvisol?, cm		Ancylus-age Mollic Gleysol, cm		
	A 0–8	Bw 8–24	C 24–45	C 45–69 stratified	ACa 69–85	IIG 85–92	AHG 117–127	IIIG 127–143	IVG 143–155
Si	391.5	401.5	472.2	393.9	399.2	399.3	404.5	417.3	392.1
Fe	15.9	7.5	8.1	10.1	8.7	17.4	20.1	12.3	14.6
Al	47.5	40.2	38.8	40.3	38.4	47.1	49.9	45.8	43.7
Ti	2.0	1.2	1.0	1.3	1.6	2.1	3.0	1.7	2.3
P	2.6	1.8	3.2	1.5	2.6	2.8	2.6	2.9	2.3
Ca	40.3	7.3	7.3	47.7	68.3	96.3	87.4	177.2	157.5
Mg	8.5	2.8	2.4	7.1	7.6	13.4	16.5	14.3	17.1
K	21.3	16.5	15.9	15.8	16.5	19.2	20.5	20.4	17.6
Na	5.5	7.0	6.0	5.8	6.7	5.0	4.9	3.8	2.6
Mn	0.2	0.2	0.2	0.6	0.5	0.6	1.2	0.3	0.3
Si/Fe+Al	6.84	8.81	10.66	8.41	9.04	6.94	6.55	7.78	5.34
Si/Fe	49.24	106.72	116.30	78.16	91.98	45.86	40.24	67.75	38.47
Si/Al	7.86	9.60	11.74	6.70	10.03	8.18	7.82	8.79	6.20
Al/Mg	4.97	7.01	12.83	5.04	4.49	3.13	2.69	2.85	2.27

aqueous sediments is highly uniform and dependent on the composition and layer structure of parent sediments. As a result of hydromorphic humus accumulation, the large amount of active organic matter as the driving force for pedogenesis tends to create a rapid increase in the specific surface area and exchange properties but preserves the stable textural-chemical properties of the sandy-silty deposits from the Ancylus stage up to modern times.

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Antsülusjärve-aegsetel soomuldadel lasuvatel Litoriinamere liivadel kujunenud gleimullad Lääne-Eestis

Loit Reintam, Tanel Moora ja Anto Raukas

On uuritud kahe kahekorruselise glei- ja soomulla profiili Lääne-Eestis Litoriinamere ning Antsülusjärve setetel, selgitamaks hüdromorfse mullatekke eripära sarnastes ajaloolistes, topograafilistes ja geoloogilistes tingimustes. Sõltumata ajalistest erinevustest on gleimuldade areng Hilis-Holotseenis ühesugune ja oleneb liivase ning tolmja veesettelise lähtekivimi koostisest ja sedimentaalsest ehitusest. Alustest küllastunud R_2O_3-humaat-fulvaatne hüdromorfses keskkonnas tekkinud orgaaniline aine on suurendanud Holotseeni mis tahes ajajärgul muldade eripinda ja neelamismahutavust. Antsüluse-aegsed soo- ja turvastunud gleimullad on rikkad humiinhapetest ning suhte C : N järgi otsustades märkimisväärselt täiusliku huumusega. Põhjaveest küllastatud keskkonnas on granulomeetrilis-keemiline seisund Antsülusjärve ajast tänaseni püsinud üpris stabiilsena. Seetõttu on erivanuseliste gleimuldade profiil huumus-akumulatiivne, kuid mehaaniliselt ja keemiliselt diferentseerumata.