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RELIC CRYOGENIC INDICATORS OF DIAGNOSTIC HORIZONS IN RUSTY AND PARABROWN SOILS IN EUROPEAN LOWLAND

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A b s t r a c t. In the last Vistulian glacial period, the profiles of periglacial perstructions and the profiles of old cryosols were formed in the extra glacial and gradually released from retreating continental glacier regions, originally in conditions of over 6-8 ka existing arctic desert before approximately 14.5 ka, and then from 14.5 to 10.5 ka BP, in the changing short rhythms of glacier deserts, shrub and park tundras as well as in short lasting pine-birch and birch forests. The whole profile thickness of the remaning periglacial horizons of the pleistocene paleosoils at the earth surface consists of a sequence or series of periglacial frost perstruction zones. In the cryogenic perstruction process of surface and subsurface sediment layers in the periglacial environment there were diagnostic horizons - cryosideric - crBv, cryoargillic - crBt, and cryospodic - crBk formed. Their localisation in the perstruction profile, in the soil horizons profile and the grain size profile, with readily recognisable associations of cold climate characteristics, may be used for quantification and diagnosis of rusty and parabrown paleosoils in the framework of superordinate taxonomic unit of paleocryosols.

K e y w o r d s: periglacial perstruction zones, relic cryosols, diagnostic horizons, permafrost, cryopedogenesis.

INTRODUCTION

The respetitive climatic-ecological cycles in the Quaternary period, according to Iwersen [21], from glacial period through interglacial to the next glacial period were the following chain cycles of the glacial and periglacial sedimentation processes of the deposit, the old soils formation and denudation and the younger soils development in the warmer interglacial periods. The soils in that environment could develop only when the morphogenetic processes were not too active for the minimum topostabilisation which conditioned the appearance of the soil profile consisting of horizons. Morphogenetic-pedogenic balance in the changing environments, according to Tricart [82], consisted in the permanent interference between morphoand pedogenesis in those conditions. This state may be reached due to the development of flora, conditioning so-called phytostabilisation of the earth's surface [2]. The earth's surface is formed by erosion and deposition and it is in the unstable phase in which soils may develop but only having passed to the next stable phase of ground formation [9] or pedomorphic surface [87].

Topostabilisation of the contemporary soil landscape, according to the justified opinions of geomorphologists, has its assumptions in the decaying Pleistocene phase. Therefore, in the mosaic of recent soil cover, there are sets of remaining morphological and pedogenetic characteristics, coming from the stabilisation period of the earth's surface and the soil development in glacial and periglacial environments of the last glaciation at least. In the Holocene, the local denudation of soils, sometimes only of their surface horizons or their whole profile as well as the soil covered with diluvial sediments caused a great increase in the soil mosaics. In this way in the soil cover mosaic, besides the old soils of Pleistocene origin, there appeared young Holocene soil associations of various age and development stage with the new distinguishing characteristics [10,25,45,47].

Starting with the appearance of living organisms on the Earth's surface the pure abiotic weathering process ceased to exist. In natural conditions of terrestrial and semihydric ecosystems the weathering and soil development processes have been running simultaneously since that moment [27,43,50,58], however, with its intensification changing over time and space. It is difficult to imagine that at the contact point of the lithosphere with the atmosphere, the hydrosphere and the cryosphere, at any earth surface unit there was no biosphere and the sterile weathering process occurred without the participation of living organisms and dead organic substances. Therefore, one should doubt the opinion that the periglacial perstruction zones are not the result of pedogenesis, but exclusively that of lithogenesis [3]. If soil and weathering covers exist in one horizon the intrasoil weathering is an important factor in the development of soil.

Krezencew [30] aptly draws attention to the fact that in the origination of cryogenic soils, in the association of soil development factors, the main role is performed by the climate, which also decides the geographical location of those soils. In their profiles there is a determined rhythm of frost soil climate repeatedly passing through the zero temperature point, forming the soil properties in the horizontal and vertical range of the active frost zone. In connection with this fact, it is essential to recall the interpretation of the soil development factors stated by Terlikowski [81]: "*independently from the contemporary activity of the particular soil development factors in the given state of soil development, one of them, or* sometimes two, may exert more decisive influence, whereas the role of the others may oc*cur to be* *less clear in the development of the given soil*". The periglacial perstruction zones in the recent soils of Central Europe are inert relics of the results operating in the systems of soil development factors in the periglacial environment of the final Pleistocene phase. Those paleosoils are animated by the changing systems of soil development factors during the period of the Holocene warm climate. Both the existence of paleocryogenesis characteristics and their significance in the development of the recent soil properties and ecological conditions for organisms, have defined diagnostic value and taxonomic rank, which implies the possibility of classifying them to the unit of paleocryosoils [50, 65] in the soil region range [13].

The relative age differentiation of the deposit and earth surface is connected with the rhythm of climatic-ecological Pleistocene cycles, conditioning the possibility of initiating and developing pedomorphic processes and determining the soil age below the defined time limit marked by the continental glacier stage and recession phases. There is a unity between the soil development space, in which the systems of soil development factors operate, and the time on the macroscale of geographical space. However, on the geographical space mezoscale there exists a common temporal mosaic of soil areas [48] with its typical paleocryogenic microtopography preserved in the postglacial areas [88].

In the European Lowland region, there are at least 14 belts with their latitudinal directions in the middle part, passing to meridional at the western and eastern edges, depending on the rhythm and range of the Scandinavian continent glaciers` activities in the Pleistocene (Fig. 1). Those belts are limited by end moraine sequences of glaciers stages, the ages of which range from max 500 ka in the south to 10.25 ka in the north. Within each belt, there are areas of ancient and recent soils mosaics, the ages of which range from the maximal one, corresponding to the age of maximal limit of a given glacier front, to the recent age. Strongly denuded belts of older glaciations - South Poland and Central Poland - may also contain the remains of soils of the older Pleistocene glaciations and the soils of the Tertiary period in the soil mosaics.

Despite copious and frequently detailed scientific researches on soils, no synthesis has been done to determine the geographical indicators and distinguishing soil pedogenetic characteristics in particular belts.

PERIGLACIAL PERSTRUCTION ZONES

The occurrence of permafrost [28,51,52] is closely connected with extraglacial and periglacial zones. In the area of the youngest glaciation, the climate

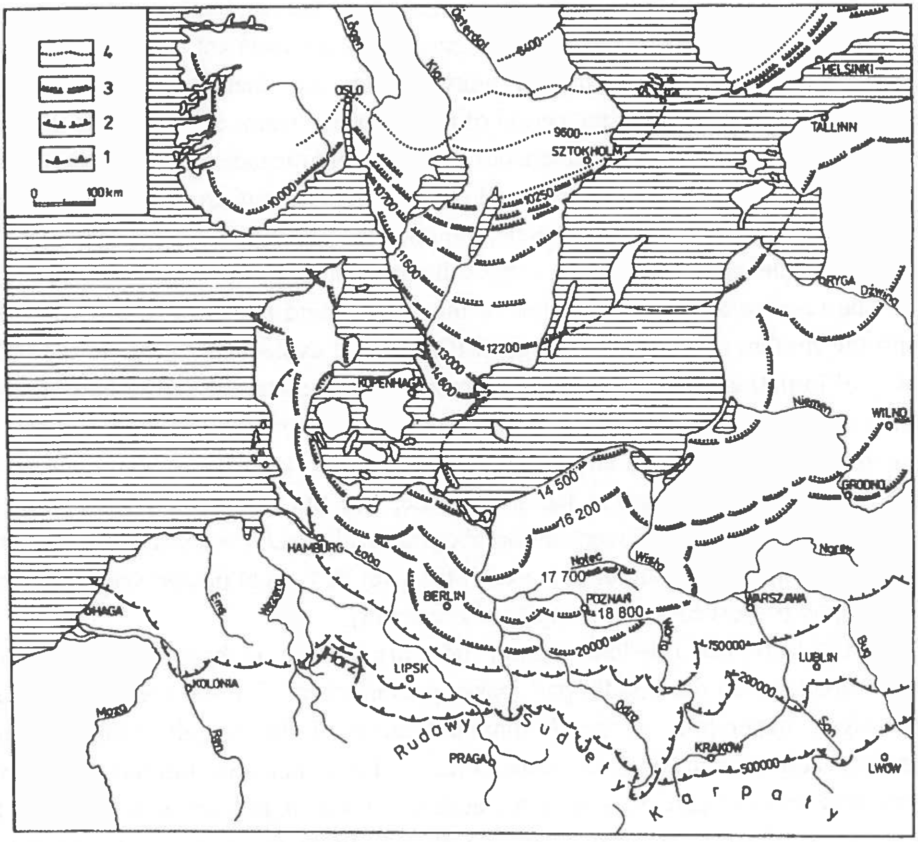

Fig. 1. The main latitudinal belts of the Scandinavian continental ice sheet stages limited by end moraine forehands and their age in Middle Europe. 1 - San glaciation, 2 - Middle Poland glaciation, 3 - Vistulian, 4 - Holocene stages of Scandinavian glacier.

contributed to the the development of permafrost during the top pleniglacial and cold phases of late Vistulian [14,17,23,28,32,51,54,76,83]. With this is connected the active layer of highly diversified thickness from 0.4 to 1.8 m and the poligonal network of permafrost cracks and tetragonal or paraorthogonal to pentagonal wedges nets [4,14,18,51,52,75,77,83] in the basal loams and periglacial terraces deposits.

For the soil development, the depth of the bottom permafrost range is not so important but its thickness and continuity as well as the thickness and humidity of the active layer in their top part in the stage of its functioning (Fig. 2). Those properties depend on the deposit grain size and on the macro- and microclimatic conditions of the periglacial landscape. According to many researchers [7,16,19,28,41,52,64,69, 84,86], nowadays, the thickness of the active layer in the northern hemisphere depends mainly on the annual average air temperatures, namely:

- from -9 to -5 °C there occurs the active layer of thickness 0.4-0.6 m over the continuous permafrost with large thickness from 100 to 800 m (sometimes to 1500 m), with minimal temperature from -13 to -1 °C at a depth of 10-20 m,
- from -8.5 to -4 °C the active layer reaches a depth of 1.8 m in sand and 0.6-0.8 m in clay and loam over the non-continuous permafrost with thickness from 25 to 100 m, rarely 200-300 m with minimal temperatures from +1 to -9 °C at the depth of 10-20 m,
- from -5 to -1 °C the active layer reaches the depth of 1.8 to 6 m in sand and gravel and 1.8 to 2.5 m in clay and loam over the insulated lobes of permafrost with the slight thickness from 15 to 100 m, sometimes to 100-200 m with minimal temperatures from -1 to +4 °C at the depth of 10-20 m. In the isle permafrost top, the temperatures range from -0.1 to -1.4 °C in summer to the depth of 50 cm from its surface [1,38,40,41].

Within the active layer, depending on its thickness, three distinct sublayers are morphologically distinguished, which are characterised by the activities of the daily and seasonal (annual) temperature amplitude, moisture conditions, physical and chemical litho- and pedogenic processes connected with the cryosphere:

- top sublayer with variable thickness from 30 to 60 cm, with higher moisture in the range of daily temperature amplitudes [60], with daily freezing and melting cycles, especially during the transitory yearly seasons [11] with the highest intensification of frost-dynamic processes, finally homogenising the colour, the mineral and organic components distribution at the whole depth;
- middle sublayer, with highly diversified thickness, depending on the depth of the permafrost occurrence, the driest one, characterised by the even temperatures within the year with slight fluctuations and also slight perstruction in the mineral material lithological assemblage,
- floor sublayer, with the thickness of 20-60 cm directly above the permafrost roof, within the range of periodical temperature variations and under the influence of the cold front in the bottom, with the greatest humidity and the essential frost perstructions in its mineral deposit range, giving them the new cryogenetic morphology and properties. Depending on the deepening stages of the active layer range, in its bottom range section there may occur two or more floor sublayers.

The above mentioned active sublayers, formed during the extension of the arctic desert and periglacial tundra and forest-tundra with the forest, in the depth range of daily and seasonal temperature amplitudes form the separate and at the same time complexly connected active subsystems of various cryogenic and pedogenic processes. Between them, there is a constant exchange of matter and energy. Those sublayers are characterised by the determined thickness variation, limited by surface forms of their separation, which were named by Rode [71] as "internal relief". The surfaces, e.g. between sand and clay layers, have a definite influence on the velocity and direction of temperature dynamics and on the horizontal water migration with the dissolved substances, independent of when and where they were formed. Therefore, in the active frost layer, there developed three sublayers possessing their own characteristic limits, whereas their degree of development as well as the sets of cryogenetic characteristics depended on the depth of the permafrost roof occurrence and the grain size of the primary material.

The notions of *perstruction profile* (Perstruktionsprofil) and *perstruction zones* (Perstruktionszonen) introduced to the literature of pedology by Kopp [34,35] and terminologically justified by Jäger [24,25] refer to the diversification of so-called *horizon* profile, substrate profile, grain size profile, humus profile, totally creating *state profile* (Befundsprofil) in the vertical cross-section. All those profiles form together a *pedomorphogenetic soil profile* developed in definite time as an entity with its own development history in a given geographical environment.

The perstruction profile, with a series of three perstruction zones located over the unchanged substrate of sedimentary rocks, formed in the periglacial environment, has a vast European literature [8,15,31,35-37,42,46,70,73,74]. It has found its reflection in the soil systematics of Poland (1974, 1989) and Germany (1994, 1998), however, in its practical application, it finds some difficulties due to the lack of separate specifications of cryogenic and pedogenic properties. There will be cryogenetic properties specified below, the origin of which is connected with the active frost layer from the Vistulian glaciation.

1. Periglacial cover zone - δ zone (top cryogenic horizon) with the thickness of 30-50 cm, parallel to the earth surface, with the homogenized earth material containing the skeletal parts non-uniformly located, uniform colour. On the surface of rounded quartz sand grains there are eolic (up to 30%) and water lateral transportation properties as well as cryogenic exfoliation properties. On the surface of fine grains (<0.01 mm), there are stable humus-iron cutans with yellow-brown colour. In relation to the zone located below, it differs by:

- the abundance of stones and gravel in the bottom; arranged the long axis parallel to the earth surface, partially with eolic treatment properties (eologliptoliths and ventifacts);
- abrupt changes in the mechanical composition - in sands enriched with silt uniformly located, in loam - enriched sand with skeletal parts uniformly located over the top of loam layer, become impoverished in silt and floatable parts;
- abrupt changes in the mineralogical and chemical composition;
- a lack of brown bands and streaks as well as cryogenic structures;
- clear and gradual passage in sand on the line enriched in skeletal parts or below it; in loam by sharp passage - usually on uneven tongue or wedge like surface.

In this zone, there usually occurs a diagnostic relic sideric crBv horizon yellow-brown in colour characteristic for rusty soils of periglacial origin.

2. Periglacial transient zone-top part - ε zone (in the middle part of the active frost layer) with the thickness of 40 to 60 cm parallel to the earth surface, decalcified, in deep sand or loam in the substrate. In relation to the above and below located zones it differs:

- in sand, by irregularly scattered small periglacial perstructions, brown-yellow and yellow-brown in colours, laid upon the sediment structures with the unchanged substrate colour, with rounded, semirounded and edged quartz sand grains depending on the sediment genesis;
- in loam, by uniform grain size and brown colour of earth parts, with a higher content of colloidal loam, with skeletal parts nonuniformly scattered, in the top part by numerous cryogenic pseudomorphs in the form of tongues, wedges and sand pockets, with rare frost wedges cutting vertically the whole thickness of decalcified loam with the primary sand filling from the cover zone, the passage in the top sharp and uneven and gradual in the bottom.

In sand, that zone is characterised by relic transitional horizon crCBv of periglacial rusty soils, in loam by diagnostic relic argillic horizon crBt (crBt1) of brown soils of periglacial genesis, contemporarily unjustly classified to parabrown soils.

3. Periglacial transient zone - bottom part - ξ zone (in the floor of the active frost layer) with the thickness of 20 to 40 cm, decalcified, in the bottom part there are carbonate traces, directly located on the unchanged substrate (η-etha zone), under ε zone or frequently directly under - δ zone. In relation to the zone below it differs:

- in sand, by the frost segregation structures with thicker fractions (gravel, stones) creating the garland shape of flow sometimes with deep stone wedges, by a lack of sediment structures with a higher content of silt and floatable

parts, by a higher and increasing content of humus and iron to its floor colour ranging from yellow to brown, red and black, stick and partially cemented, with sharp passage in the floor clear and gradual one in the top;
- in loam by a lack of structure, enriched in silt and floatable parts and humus, compact, dark brown to grey brown in colour, by floor fork-like or pocket-like ends of spreading wedges filled with sand from the cover zone, a sharp passage.

In sand that zone is characterised by diagnostic relic transient cryospodic horizon crCBk of periglacial rusty soils, in loam by diagnostic relic cryogenic argillic horizon crBt (crBt2) of periglacial brown soils.

4. Unchanged substrate zone - η - with sedimentary structures, a lack of cryogenic properties, carbonate, on the perigalcial transient zone enriched with washed in carbonates in the form of powdering, pseudomycelium, concretions or coatings in pores. In the cryogenic soils, independent of their moisture, above permafrost, there frequently develops a horizon with $CaCO_3$ of meal form not confirmed in the relic profiles of cryogenic soils in European Lowland.

ENVIRONMENTAL CONDITIONS OF PEDOGENESIS DURING VISTULIAN GLACIATION

In the Vistulian deglaciation areas in the warmer periods of climatic fluctuations proceeding from South to North, in the period from 20 ka to 10 ka, from 3 to 1 generation vast tetra-, penta-, hexa- and orthogonal frost polygonal systems developed with syngenetic and epigenetic ice wedges with primary sand filling. Those forms are indices of permafrost existence in arctic continental deserts. Fossil forms of those wedges together with the deflation pavement on their surfaces were noticed in the soil cover by Bogdański and Kijowski [4], Kozarski [51,52], Goździk [18] and other researchers in the Great Poland and Pomerellen regions, by Fränzle [14], Jakob and Lamp [23], Hassenpflug [20] and Ehlers [12] in Schlezwik-Holstein and by Svensson [76,77] in South Scandinavia. However, in the above mentioned period, in the Vistulian sediments in southern Holland and northern Belgium, there were at least 2-3 generations of cracks and frost involutions, showing the existence of arctic desert with the intensified denudation processes and permafrost [83]. In the central part of the Russian Uplands, there are vast systems of ground wedges up to 4 m deep, formed in the cold and arid climate [88].

The vast area of cold and dry desert is likewise proved by the development of 3 generations of frost wedges and ventifact layers in the Vistulian loess, sedimented in the period from 19 to 15 ka on the northern border of the Rheinisch

Schiefergebirge, on the forelands of Vistulian glacier [5]. In the younger upper loess LMg, sedimented in the period between from 28 to 15 ka BP, in the area of uplands and submountain regions of South Poland, there are pseudomorphoses of large ice wedges, 1.0-1.5 m wide and 4.0-5.0 m high, forming the polygons with sides 20-25 m belonging to the largest ones [55].

Just before of the Vistulian maximum [55,57], permafrost is developed in a continuous range, in the conditions characterised by the highest stability of climate continentality, the driest and most unfavourable for chemical weathering in the glaciation cycle. Four stages of its development are eliminated by Goździk [18]. According to the above mentioned researcher, the occurrence of frost wedges in the plenivistulian, approximately 20 ka BP, in different sediments and topographic situations in central and southern Poland is the indication of the continuous permafrost in that period, the range of which was noticed over 300 km in southern Poland. Then, the glacier of the Leszno Phase thrust upon the network of permafrost wedges, which became partially degraded. In the Pomeranian Phase ~ 15.2 ka BP, discontinuous permafrost developed in the youngest deglaciated areas with the glacial desert. Before the Oldest Dryas ~ 14 ka BP, the permafrost functioned with the deep active layer, and a possibility to develop talics on the whole area in front of the ice-sheet. The strong degradation of the permafrost marked its existence in the period from 12 to 10 ka BP, with its insular and sporadic occurrence. In the South from the maximum ice-sheet range, there were numerous thermokarst depressions, whereas in the North there were thermokarst depressions, numerous buried massive ground ice floats and frozen earth blocks. According to Maruszczak [57], ice melting in the wedges in loess began approximately 14-15 ka BP. The complete disappearance of the permafrost, according to Kozarski [52] began probably in Alleröd, so ~ 11.8-10.9 ka BP. According to Nowaczyk [67] the dead ice block melting may have taken place even in the Preboreal and the Boreal.

Strong and long lasting deflation processes in the regions of Vistulian deglaciation caused the appearance and regeneration of desert gravel-stone covers with eologliptoliths, at least 3 times in the period from 20 to 14.5 ka. In the period from 14.5 to 10 ka the 4-fold repetition processes of deflation, rinsing and gelifluction coupled with the development of eolic covers and dune fields caused the roofing the gravel-stones pavement with eolic-delluvial sand layer coming from the washed out and blowing soils on which pleistocene rusty soils ultimately originated. Those processes periodically perstructed both the earth surface and the evolving mosaic of soil cover in that region (Fig. 2). In the period of existence over 5.5 thousand years of desert and then the following park and shrub tundra, at

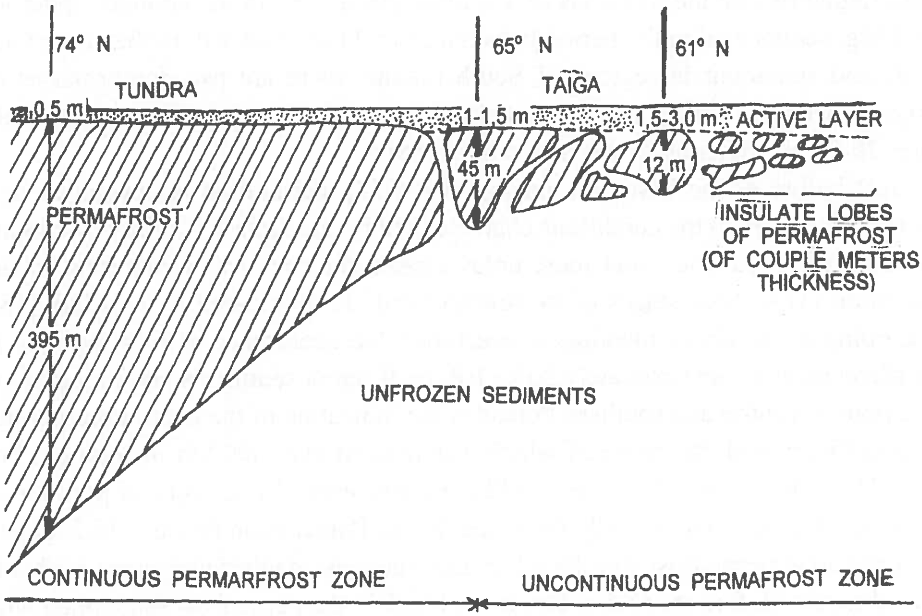

Fig. 2. Southern cross-section of permafrost in North Canada (after Washburn [84], changed).

least for 4.5 thousand years, the earth's surface was not stabilized. Depending on the intensity of the frost processes, the surface deflation and washing out as well as eolic accumulation, was frequently subjected to lowering - degradation or raising - aggradation. In that period, the deflation and washing out processes transported the top part of the soil profile, whereas the shallow desert and tundra soils gradually diffused into the lower sediment and weathering layers. The consequence of this phenomenon was likewise the lowering of floor of the active frost layer. In areas where the transported soil material accumulated, the covered soils entered the fossil state, and were frequently incorporated with the permafrost agradation range. In this way the timing - transgressive chronosequences of more or less developed primitive desert fossil soils - cryosols and pedoliths was formed, the knowledge of which concerning postglacial regions is still slight (Table 1).

The period from ~20 ka to 14.5 ka in the Vistulian area was cold, dry and very dry [52,83] with very high thermal gradients air/soil substrate and permafrost in the soil substrate [52]. In that period the record must have been formed in the shape of horizons with cryothermal and lithogenic weathering characteristics enriched with carbonates of arctic desert soils in the active frost zone. One of their indications is the

Table 1. Continuation

Age 14C ka BP	Stratigraphic distribution of events		Geomorphic processes		Climates	Soils
14	Permafrost partly degradation and surviving		Deep erosion		Cold, dry	Rusty soils
	Soil frost cracking		Glacial and fluvioglacial accumulation			
	KAMION					
	Ice sheet recession			Arctic		
15	**14.50 GARDNO PHASE**		Deflation and loess accumulation (patches)	desert ↑	Cold, dry	Cryosols
	Ice-sheet recession					
16		North Poland deglaciation	Deep erosion			Cryosols
	16.20 POMERANIAN PHASE		Vertical cutting		MAAT ~ -1(-2) °C	
	Permafrost aggradation		Glacial and fluvioglacial accumulation		Air/soil therm. gradient	
17	Soil frost cracking		Lateral erosion and fluvial accumulation		Cold, dry	Cryosols
	Icing development		Deflation and eologliptolites			
	Ice-sheet recession					
	17.70 CHODZIEŻ READVANCE		Sheet-wash		Cold, dry	Cryosols
	Permafrost aggradation		Deep erosion			
18	Icing development		Glacial and fluvioglacial accumulation		MAAT ~ -12 → -20 °C	Cryosols
	Ice-sheet recession		Deflation and eologliptolites		Air/soil therm. grad. very high	
	18.80 POZNAN PHASE					
	Permafrost aggradation		Glacial and fluvoglacial accumulation			
19	Soil frost cracking					
	Icing development		Intensive deflation and eologliptolites		Mean soil temp. ~≤-2 °C	
	Ice-sheet recession					
20	**20.00 LESZNO PHASE**		Glacial and fluvioglacial accumulation		MAP ≤ 100 mm	Salic cryosols
	Permafrost aggradation				Very dry, cold	

T a b l e 1. Evolution of the environment in North Poland after 20 ka BP in the Vistulian and on the turn to holocene (after Kozarski [52], partly changed)

Age 14C ka BP	Stratigraphic distribution of events		Geomorphic processes	Plant formations	Climates	Soils
9	**9.30 BOREAL**	Scandinavian deglaciation	**Carbonate sedimentation**	Mixed forest with	Temperate warm	Rusty soils
	Dead ice thawing?		**Intense carbonate leaching**	coryllus	Temperate warm	
	Dead ice thawing			Pinus forest		
	Permafrost degradation		**Dunes accumulation**	Birch-pinus forest		Parabrown soils
10	**10.25 PREBOREAL**		**Frost segregation**			Podsolic soils
	Soil frost cracking		**Eolic cold cover sand and loesses**	Cold steppe	Temperate warmer	Gleyic soils
	Permafrost degradation		**Dunes accumulation**	(patches)	July ~10 °C	Rusty soils
11	**10.90 YOUNGER DRYAS**		**Carbonates leaching**	Park tundra	Semi cold dry	Finowboden
	Partly degradation and		**Rinsing and gelifluction**			
	surviving of permafrost		**Frost segregation**			
	Permafrost degradation		**Deep erosion**	Pinus-birch forest	Semi cold wet	Parabrown
			Carbonate leaching	Birch-pinus forest		Finowboden
			Weak eolic activity			Podsolic soil
12	**11.80 ALLEROED**		**Frost segregation**	Park tundra	July ~17 °C	Rusty soils
	Soil frost cracking		**Eolic cold cover sands and loesses**	Park tundra	Semi cold, wet	
	12 20 OLDER DRYAS		**Deflation and eologliptolites**	Shrub-tundra	Cold, semidry	Cryosols
	Soil frost cracking		**Frost segregation**	Birch forest	MAAT ~ -1 °C	
	Permafrost degradation		Lateral erosion and fluvial accumulation	(patches)	Cold, dry	Podsolic
13				Park tundra		Gleyic soils
	13.00 BÖLLING		Carbonate leaching			
	Partly degradation and		Weak eolic activity	Park tundra	July ~15 °C	Rusty soils
	surviving of permafrost		Frost segregation			
			Eolic cold cover sands and loesses	Shrub tundra	MAAT ~ -1 °C	
			Deflation and cologliptolites		Cold, dry	Cryosols
	13.80 OLDEST DRYAS		Rinsing and gelifluction			
			Transformation of river-bed system			
			Lateral erosion and fluvial accumulation			

deflation gravel-stone pavement with eologliptoliths. In the rock shallow accumulation cavings the salty and saline soils as well as desert tacyrs with permafrost might have appeared in their substrate, the horizons of which were subject to cryogenic homogenization in the active layer during the humid periods [53].

In the morpho-pedogenic active areas of the glacial and periglacial environment, four basic types of soil chronosequences [43,46] might have occurred as follows: succeeding, simultaneous, time complete and time-transgressive with or without partial covering. Those soils may differ by means of the initiation time or the final moments of their development. The moments of their initiation may be divergent on the time scale - if they are soils with isochronic initation, or nondivergent - then they are soils with time-transgressive initiation. The current complicated time initiation dynamics and sporadic soil development has been taking place since 14.5 ka BP in the European Lowland areas at the surface stabilisation moments of cryogenic desert soils through the rhythmically appearing clusters of tundra and taiga flora from the younger Dryas, through Bölling, Older Dryas, Alleröd and Younger Dryas to the break of the Holocene. Periodically intensifying processes of decalcification, sedimentation and homogenisation of the loess ledges, dune walls and sand covers [52,89] in the climate close to that of the Holocene in the extraglacial regions, covered the old surface of the previous desert soils having relic wedges systems, and cryodeflation pavement with younger sediments, thus evolving younger generations noncarbonate tundra and forest, rusty and parabrown soils or the chronosequences of soil horizons in them and the post permafrost substrate (Fig. 3).

GENESIS ELEMENTS OF DIAGNOSTIC RUSTY AND PARABROWN SOIL HORIZONS

The periglacial perstruction profiles and the related soil horizons profiles, occurring in recent soils in the regions within the Vistulian Glaciation and its periglacial sphere (Fig. 1), create the solid scaffolding being the holocene environment of soil processes. The less Holocene pedomorphogenesis is marked in the morphology profile of litho- and authogenic soils inherited from the Pleistocene, the more visible the continental climate conditions are.

Contemporary dry and very dry arctic regions of North and East Syberia, Alaska and Canada are characterised by the occurrence of cryosoils with their homogenised profile [6,62,63,72,78]. The characteristic feature is non-diversified profile of chemical composition, silt and floatable parts, organic carbon and colour,

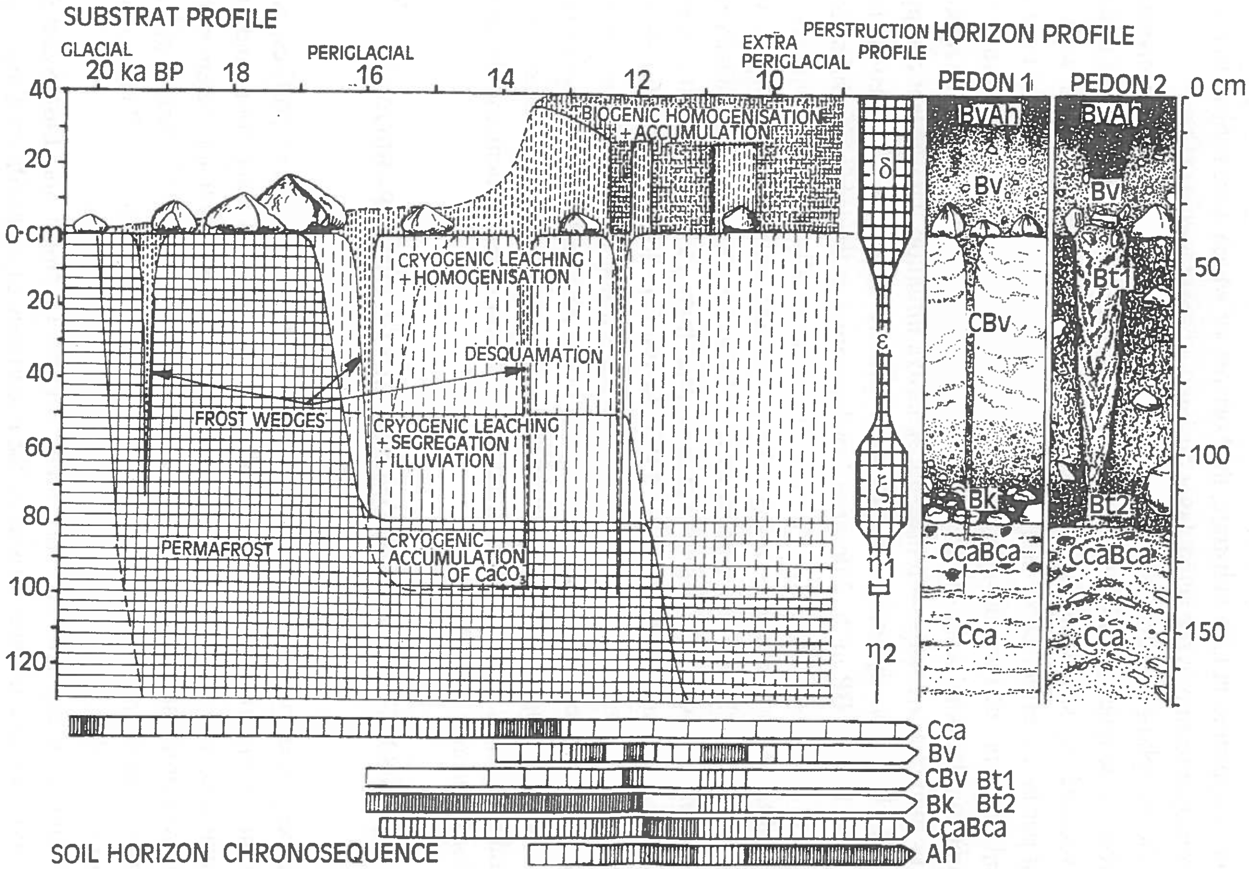

Fig. 3. Conception scheme of cryogenic perstruction and horizon profiles of rusty soil (pedon 1) and parabrown soil (pedon 2) in the time period from Vistulian maximum to the beginning of Holocene with soil horizons chronosequence.

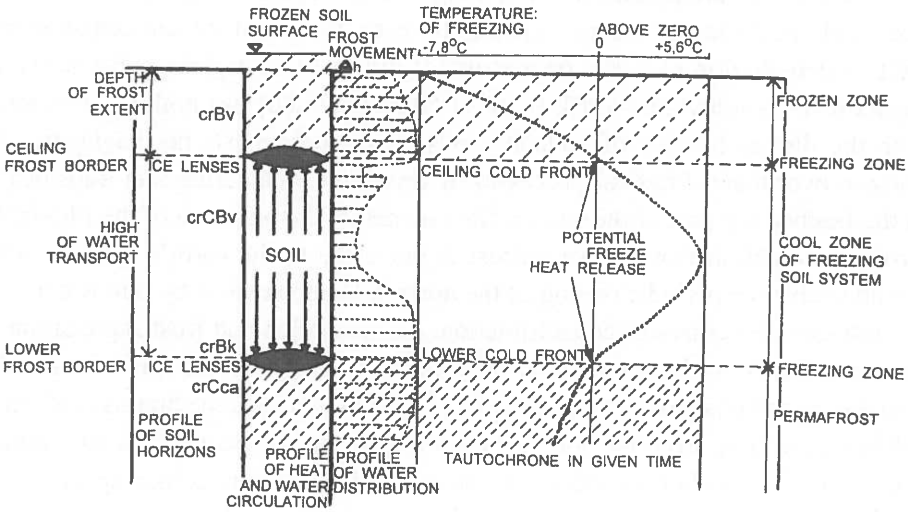

Fig. 4. Scheme of the thermic-water conditions in freezing soil systems in abundance of two cold fronts.

corresponding to the Vistulian crBv horizon [34,36,42]. In the Siberian continental regions, on the surface of cryosoils parts there was a settlement of unique steppe-like flora so-called "steppeoid" [62]. Similarily in the floor of meadow steppe in the Changai Mountains, rusty frost polygonal soils developed with the homogenised yellow-brown coloured [39] Bv horizon. Dry cryosoils are marked by less energy of frost perstruction from the desert soil of the moderate zone with the same number of freezing and melting cycles. The arctic desert soils are, however, subject to strong deflation with the transportation of silt and loam fractions, forming the deflation pavement and alkalization with encrustings and salt efflorescences on the surface [79,80].

In contemporary cold climate zones, according to Iwanowa [22], Karawajewa *et al.* [29], and Naumowa *et al.* [63] independently from the ice content in permafrost, in active frost layer there are cryoturbation processes and frost displacement of soil material linked with the migration of soil solutions to the cold front in the bottom part of the cryogenic perstruction profile. Their effect may be both homogenisation or differentiation of mineral - nutritional components displacement in the soil profile. Those processes perform an essential profile-forming role in the development of cryogenic tundra and taiga soils. In negative temperature conditions, there are both frost perstruction and soil material segregation processes and the permafrost interaction as the layer supporting the soil solutions.

The temperature gradients functioning in that situation (Fig. 4) cause the convectional circulation of warmer soil solutions to the cold front and coagulation as well as dehydration over the permafrost of mineral and organic substances. The permafrost cryoilluvium - crBk [6,40,41,53,54,66,78,80] has nothing in common with the illuvial horizon of podzolic soils, since there exists no diagnostic albic horizon over them. Physical processes of cryogenic weathering and translocation in the leached top part of the soil profile counteract the originate of the illuvial horizon on condition that the permafrost is not close to the earth's surface, which would enable the periodic rinsing of the horizon located over it by rain water.

Intensive processes of congelifraction, desquamation and frost segregation occur periodically in the cryoilluvial crBk horizon enriched with basic ions, called also the cryoilluvial contact horizon [42,43,46-48], whereas the humus acids in the solutions reaching from the soil surface are grieving for the permafrost "retinisation" [53,54]. This horizon contains humus of black or grey colour up to 4%, depending on the lack or presence of carbonates. In the post-permafrost areas this horizon is interpreted as fossil soil, or groundless as illuvial horizon of podzolic soils in case of their shallow occurrence [6,40,53,63].

In the Alaska cryogenic tundra soils, according to Nakano *et al.* [61], there are close relationships between thermal conditions and the localisation depth in their profile of the cryoilluvial humus horizon, the content of organic matter in them and the intensity of warmth diffusion through the organic and mineral horizons. With its extension, the cryoilluvial horizon forms the increasing thermal barrier for mineral and organic compounds circulating in solutions thus delaying the permafrost degradation [68]. The lowest thermal conductivity indexes however, exist in the enriched cryogenic with carbonates Bca horizon directly located over the permafrost roof.

Fe enrichment of cryogenic surface horizons, giving them the uniform yellow-brown to brown colour - 7,5YR 4/3 to 10YR 4/3 is connected with cold soil solutions capillary rising in the direction of cold top front - surface freezing zone (Fig. 4). Under the influence of low temperatures, there is irreversible coagulation of organic compounds with Fe coming from the soil mineral weathering *in situ* in the cold freezing zone of the soil system [24,29,30,34,37,38,43,46,66,78,79]. Low temperatures up to -25 - -35 ^{o}C contribute to Fe precipitation on the surface of mineral grains in the frozen zone, in which soils gain high aeration ability due to their ice and frost structures. Under the influence of daily temperature fluctuations, the air circulating in their structures contributes to the oxidation of Fe^{2+} to Fe^{3+} and its coating on the surface of fine soil particles [68,78]. Contrary to the podzolic soils, the cryogenic rusty and brown soils are developed in cold climate

[78], in which the start up of Fe^{2+} appears in the frozen soil environment, thus reaching the highest concentration directly after melting [85].

Targuljan [78] calls "orthopodbur" the rusty soils with the yellow-brown crBv horizon formed in the non-uniform parent material (Fig. 3) in the most severe climate of humid areas, plain and mountainous tundras and sharp continental forest-tundra regions and north taiga. In less cold humid regions of south taiga forest-tundra and north taiga of lowlands and highlands, according to the above mentioned author, there is "parapodbur" in the complex of podzolic soils and "lithopodbur" formed from the parent rocks making podzolization difficult. In crBv of ortho- and parapodbur horizons the floatable and silt parts consist mainly of sharp edged particles of ground of fine grained weathering of primary minerals, partially hydromicas and amorphic red-brown material. The lack of gleying in the rusty soil profile, according to Targuljan [78], and Tedrow [79,80] is connected with good water permeability of those soils, conditioned by the occurrence of so-called dry "permafrost".

Depending on the type and way of solution circulation in cryogenic soils there are diversified processes of mineral components leaching - in permafrost gley-podzols - Al>Ca>Fe>Si, in cryozems - Al>Ca>Fe>Si>Mg, and cryogenic rusty and brown soils with dry permafrost - Fe>Ca>Al>Si [62,63]. Al, Fe and Ca therefore are washed out from all cryogenic soils. The leached Ca is either accumulated in the lower part of the profile in crBca horizon and/or Cca horizon within the top part of the permafrost or washed out from the frozen soil in the side directions e.g. with the use of frost wedges.

The intensification and ranges of temperature influence on the release and circulation of mineral elements depend on the physical properties of the mineral materials and on the resulting cryogenic processes:

- the solutions of mineral compounds, surface absorption volumes, velocity of ions change, mutual interactions are different in the soil micro-volume;
- different water potential gradients, solution, soil solution concentrations, chemical potentials, steam and solutions dislocation appear in different points of the same soil volume. As a result, there is a change in chemical composition of soil in particular points or in physical and physico-chemical properties. The temperature gradients are important factors of soil diversification on the genetic horizons;
- active frost layer and permafrost changed the soil properties in a considerable way on the different organisational levels from the molecular to the structure of soil cover.

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