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R. Paepe and A. Pissart

Liège

PERIGLACIAL STRUCTURES IN THE LATE-PLEISTOCENE STRATIGRAPHY OF BELGIUM

Résumé de l'auteurs

Les traces périglaciaires que sont les structures de fente de gel, les cryoturbations et les horizons caillouteux, ont au sein des dépôts du Pléistocène supérieur une uniformité d'aspect et une fréquence telles qu'elles constituent des repères stratigraphiques importants.

Dans le présent article, les traces périglaciaires utilisées comme repères sont décrites, leur genèse est brièvement discutée et leur position stratigraphique est précisée.

INTRODUCTION

General stratigraphical concepts are often found to be difficult when applied to Quaternary systems. The reason herefore lies in the fact that such concepts are based mainly on pre-Quaternary usually thick and widespread marine deposits showing also a great constancy as to its facies. This, already, facilitates long distance correlations, to which the overwhole presence of guide fossils must be added. Quaternary deposits, however, are mainly continental and therefore of an extreme complex morphology. It is mostly impossible to link two profiles, even when they occur in each other's vicinity, on basis of the geometrical projection of the various layers. Sometimes it may be hard to compare their stratigraphical sequences too. As long as traditional stratigraphy was applied to Quaternary deposits, subdivision was merely a matter of separating major lithologic units. The Quaternary legend of the geological map reflects in most cases this way of approach. This explains also why structures, due to frost, characteristic of the Quaternary deposits, were a long time looked at as occasional occurrings, worthwhile to be reported but without definite stratigraphical meaning. Whereas morphological structures are considered as interesting particularities of the older deposits, they do play a great part in determining the various layers of a Quaternary succession. Although the lithological constitution may vary profoundly from one place to another, the same type of periglacial phenomena, if they happen to occur, seems to be bound to deposits of the same age. At first, biostratigraphical and absolute dating may be necessary to assure the bio-chronological position of the periglacial features in a profile. But once this has been done, periglacial structures date independently the stratigraphic sequence within which they occur.

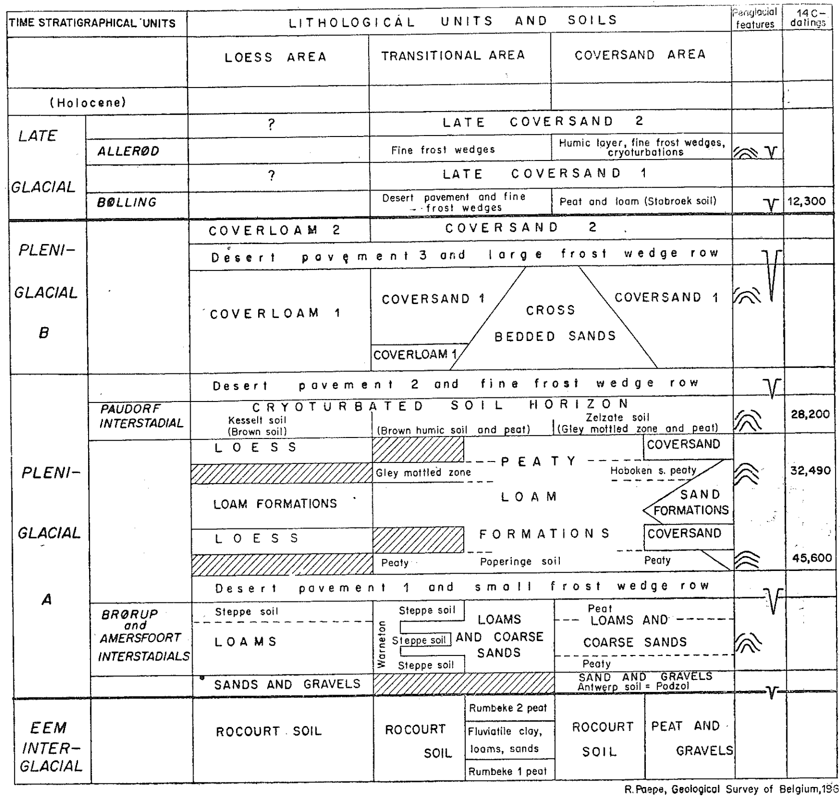
Actually, periglacial structures have been used for a long while or at least considered as complementary elements in the description of loess deposits in Belgium (C. Edelman and R. Tavernier, 1940; R. Tavernier and A. Hacquaert, 1940; R. Tavernier, 1945, 1948, 1954, 1957; F. Gullentops, 1952, 1954; P. de Bethune, 1951; R. Maréchal, 1955, 1956). In 1954, F. Gullentops tried to explain the climatic conditions controlling the loess sedimentation with the aid of pedological features and structures due to frost. Being aware of the insufficient knowledge about the genesis of a great number of the periglacial structures, especially the fossil ones, it does not seem necessary to understand these processes entirely in view of their application within the stratigraphic scope. Indeed, if some structures as e.g. ice wedge casts, are pretty well known at present, others remain doubtful. Even then, they remain a useful aid for stratigraphic investigations. This has been sufficiently demonstrated in recent publications by R. Paepe (1964) and R. Paepe and R. Vanhoorne (1967). While using the chronological significance of frost wedge levels and cryoturbatic horizons, distinction is made between those features which show an orderly subhorizontal arrangement and the solely occurring features. It is clear that the first ones are by and large the best disposed to indicate ubiquitous changes of the palaeoclimatic conditions. They also characterize the major breaks of the lithological sequences. Hence, they form the major subject of this paper.

STRATIGRAPHICAL POSITION OF THE PERIGLACIAL PHENOMENA

For the sake of clearness, we shall successively treat the structures of the wedges and fissures born by frost, the cryoturbatic plications and involutions and finally the stone line or so-called desert pavement horizons. Evidently, they are intermingled in a stratigraphical sequence as is shown in table I.

Tab. I

Litho-stratigraphical subdivision of the Late Pleistocene as proposed by R. Paepe in 1967



TIME STRATIGRAPHICAL UNITS		LITHOLOGICAL UNITS AND SOILS			Periglacial features	14C-datings
		LOESS AREA	TRANSITIONAL AREA	COVERSAND AREA		
(Holocene)						
LATE GLACIAL		?	LATE COVERSAND 2			
	ALLERØD		Fine frost wedges	Humic layer, fine frost wedges, cryoturbations	⌒ V	
		?	LATE COVERSAND 1			
	BØLLING		Desert pavement and fine frost wedges	Peat and loam (Stabroek soil)	V	12,300
PLENIGLACIAL B		COVERLOAM 2	COVERSAND 2			
		Desert pavement 3 and large frost wedge row			V	
		COVERLOAM 1	COVERSAND 1 COVERLOAM 1 CROSS BEDDED SANDS	COVERSAND 1	⌒ V	
PLENIGLACIAL A		Desert pavement 2 and fine frost wedge row			V	
	PAUDORF INTERSTADIAL	CRYOTURBATED SOIL HORIZON Kesselt soil (Brown soil)	(Brown humic soil and peat)	Zelzate soil (Gley mottled zone and peat)	⌒	28,200
		LOESS	▨ PEATY	COVERSAND		
		▨	Gley mottled zone	Hoboken s. peaty	⌒	32,490
		LOAM FORMATIONS	LOAM	SAND FORMATIONS		
		LOESS	▨ FORMATIONS	COVERSAND		
		▨	Peaty Poperinge soil	Peaty	⌒	45,600
		Desert pavement 1 and small frost wedge row			V	
	BRØRUP and AMERSFOORT INTERSTADIALS	Steppe soil LOAMS	Warneton Steppe soil Steppe soil Steppe soil LOAMS AND COARSE SANDS	Peat LOAMS AND COARSE SANDS Peaty	⌒	
		SANDS AND GRAVELS	▨	SAND AND GRAVELS Antwerp soil = Podzol	V	
EEM INTERGLACIAL		ROCOURT SOIL	ROCOURT SOIL Rumbeke 2 peat Fluviatile clay, loams, sands Rumbeke 1 peat	ROCOURT SOIL PEAT AND GRAVELS		

R. Paepe, Geological Survey of Belgium, 1966

WEDGES AND FISSURES DUE TO FROST

Three main levels of frost wedges and frost fissures are commonly found within the Vistulian periglacial deposits of Belgium. They are referred to as *small frost wedge row, fine frost wedge row* and *large frost wedge row*. These connotations have a purely stratigraphical meaning and were introduced by R. Paepe (1967) without a specific genetic precision. They are morpho-stratigraphical terms.

Large frost wedge row (ice wedge casts)

These ice wedge casts are the result of the melting of ice-wedge polygons and the infilling of the free space by clastic material.

The frost wedges were of the epigenetic type, extending to a great depth (5 m and more) and showing a large widening (1 m) at the top (fig. 1). They are filled with sand, loam or even gravelly material, and often more than one filling ("cone in cone") is observed. Their appearance goes along with the presence of pearlike or sacklike pockets in many cases.

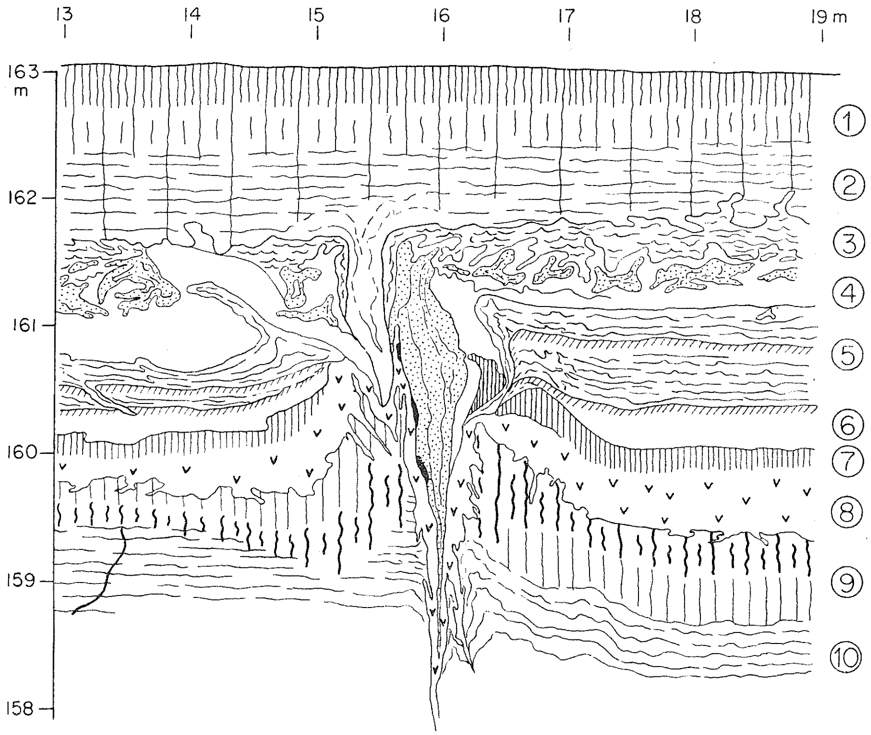


Fig. 1. Detail section of the profile recorded at Tongrinne (typical loess area) by R. Paepe (1965)

1. gray brown podzolic soil; 2. base of coverloam 2; 3. Kesselt soil or cryoturbated soil horizon pearced by large ice wedge cast; 4. loess; 5. stratified loam formations; 6. loess; 7. humic layer (Warneton soil); 8. grayish solifluction loam; 9. reddish B_2t-horizon of Rocourt soil (Eemian); 10. yellowish brown fine stratified clayey loam (Saale)

This large frost wedge row is the most important because of its steady appearance in the middle of the coversand, the sandloess and typical loess deposits. Sometimes, it lies directly upon the Kesselt-Zelzate soil when the lower part of the eolian deposits are lacking.

Best development is seen on high plateau positions and on typical eolian deposits, although frequency is rather low. On the contrary, as they occur in a valley position, frequency is increasing while the size is decreasing. In the latter case, syngenetic frost wedges do occur too. In the tunnelpit at Zelzate, this was the only form observed at this level.

From the foregoing, it may be concluded that very cold climatic conditions implying permafrost, were present during the formation of the ice wedges. Furthermore, it probably was a dry climate too for great changes of the ground temperature conjecture a thin or discontinuous snow-cover during a large part of the winter. In addition, their size points to a long period of development whereas the presence of superposed wedge fillings indicates several stages of activity (fig. 1). So they imply the existence of a severe cold and dry period of long duration at this level. Subsequently, the upper limit of the large frost wedge row represents an important hiatus in the sedimentation cycle of the eolian deposits which is thought to have last from 26.000 up to 14.000 years B. P. (W. H. Zagwijn and R. Paepe, 1968).

Small frost wedge row (associated with plications)

These structures are characterized by fine wedges filled with sediments from the overlying deposits. They attain maximum 1 m in depth and 5 cm in width. Between these wedges, which occur at a frequence of 0.40 m to 1.00 m distance, the stratification shows archlike deformations near the top (fig. 2).

The small frost wedge row is the lowermost well developed alignment of wedges overlying and pearcing into the loams and coarse sand series of the Early Vistulian. Sometimes, it rests directly on top of the Warneton soil, a steppic soil horizon which palynologically was dated Amersfoort in age (R. Paepe and R. Vanhoorne, 1967). This horizon is in turn overlain by the so-called peaty loam formations.

Flat horizontal topographies seem to have been preferential situations for its development. They show a high frequency of development on the subhorizontally displayed fluviatile deposits of large valley systems. The pattern is of the irregular type. The small frost wedge row also occurs on top of the more loesslike solifluction deposits of flat sloping plateau surfaces although a decrease in depth (maximum depth 30 cm) and frequency with an increase in width (maximum 15 cm) may be noticed. Such lateral changes also

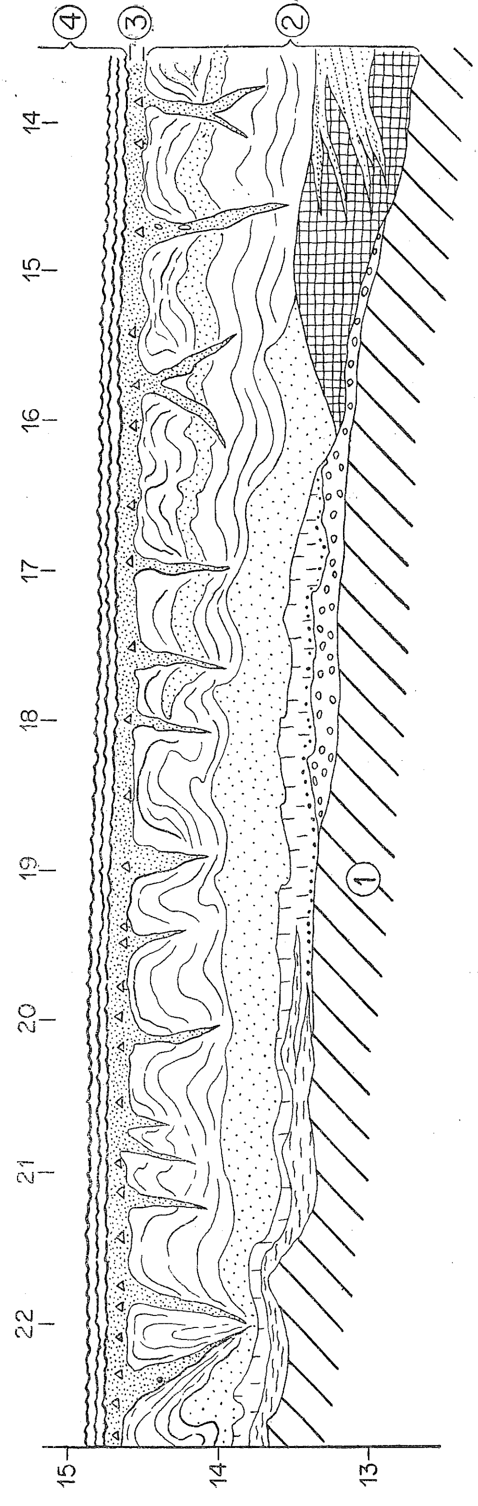


Fig. 2. Detail section of the profile recorded at Warneton in the Lys plain (sandloess area) by R. Paepe (1963-1966)

1. yellowish brown fine stratified clayey loam (Saale); 2. loams and coarse sands with Warneton soil at the base; 3. sandy layer with wind-faceted grains and stones, "small frost wedge row" and plications at the bottom; 4. gray brown fine stratified clay and loam layers (loam formations)

occur within short distance as a result of local topographic changes. Nevertheless, depth remains constant within each separate reach of development.

These wedges are not considered as frost contraction fissures because they are at too close a distance from one to another and not deep enough to be entirely within the permafrost zone. Neither are they desiccation fissuring only because the stratification is arched which deformation remains clear below the lower limit of the fissure. So these wedges are associated with cryoturbated structures. For this reason, we believe that the whole form is due to frost action and is the result of cryoturbation desiccation polygons combined under the impulse of the frost action. It is now well known that the apparition of segregation ice in silts is able to open desiccation cracks when frost is acting under very wet conditions (Pissart, 1964).

To this must be added that such structures as far as we know, have not been described in the literature concerned with present frost phenomena and for this reason, we do not know the climatic conditions of their apparition. This horizon completely lacks in the sediments of narrow V-shaped valleys and they were, hitherto, never observed on steep slopes.

Consequently, their occurrence seems to be bound to bad drainage conditions. It is noteworthy that even though only one row is generally observed, superposition of several (3 to 4) rows may occur.

Usually the lowest ones contain the smallest wedges. This is the case in extremely badly drained fossil floodplain flats. Does this mean that, climatically speaking, the onset of their development was a gradual one going along with a steady deterioration of the climate?

However that may be the climatic oscillation which is dealt with at this stage, looks much like a short and mild one, not capable to exert its influence on every single part of the landscape.

Fine frost wedge row (probably structures of hummocky soils)

A third type of frost wedge structure is shown in fig. 3. It consists of a succession of wedges attaining 50 cm (at the maximum) in depth and following at a distance of 15 to 50 cm. Between two neighbouring fissures the stratification is upturned, a distortion which seems to be due to frost.

This row of wedges occupies an intermediate position between the afore-mentioned ones. It follows on top of the peaty loam form-

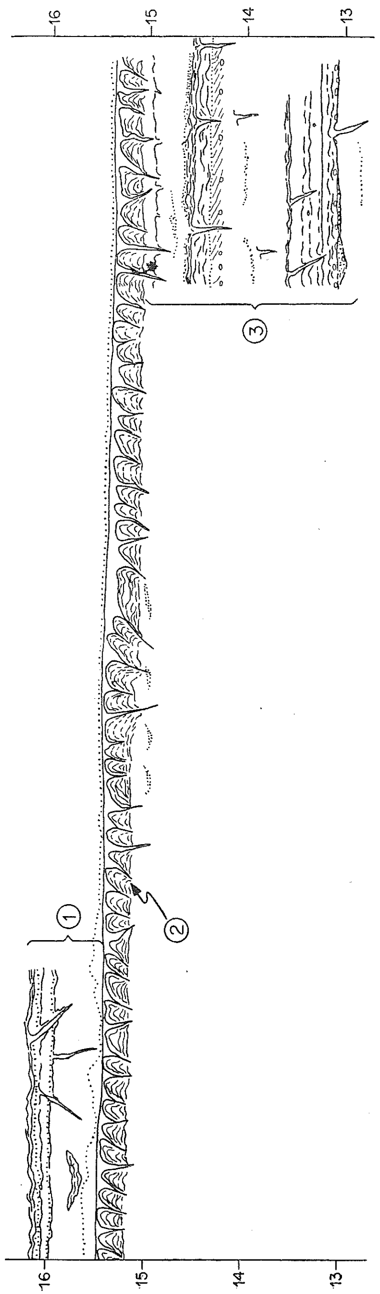


Fig. 3. Detail section of the profile recorded at Wevelgem in the Lys valley (sandloess area) by R. Paepe (1967)

1. coversand 1 with sporadical wedges; 2. "fine frost wedge row" (hummocky soil) with desert pavement 2; 3. peaty loam formations with sporadical wedges

ations characterized by the presence of three palaeosoils successively: Poperinge soil 45.600 yrs. B.P.), at the bottom, Hoboken soil (32.490 yrs. B.P.) in the middle and the Kesselt—Zelzate soil (28.200 yrs. B.P.) at the top. They correlate readily with the Dutch palaeosoil succession: Moershoofd, Hengelo and Denekamp (W. H. Zagwijn and R. Paepe, 1968). Usually the fine frost wedge row affects the uppermost palaeosoil. So this horizon becomes an important bench mark at this level of the stratigraphic succession.

We believe that these structures belong to a fossil hummocky soil (*sol à buttes*). Figure 3 shows indeed great similitude with fig. 4 representing a cross section through such a present day hummocky

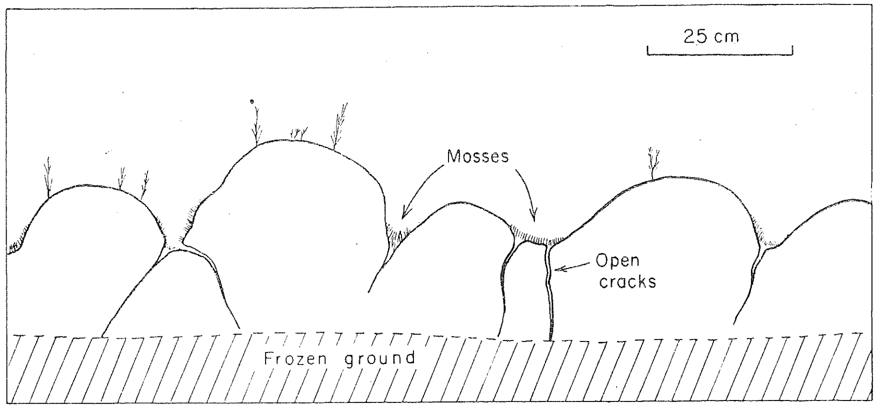


Fig. 4. Section in a hummocky soil of Prince Patrick Island (Canada — 76° lat. N)

soil of Prince Patrick Island. Hummocky soils occur frequently in the high Canadian Arctic and are widespread too. The genesis of these features under the prevailing severe climate of the Queen Elisabeth Islands, where they are a ubiquitous feature on silts, is not know very well. It is sure though that desiccation and plication (cryoturbation) are the principal agents. But even when it is certain that these structures appear under a very cold climate, yet their appearance under less severe climatic condition must be investigated.

The appearance of the fine frost wedge row however seems related to local conditions too. Again large thalwegs are to be reckoned among the most favourable sites. As to intensity of development, they rather are thin, and fairly undeep, in comparison with the small frost wedge row but of higher frequency (*sol à buttes*). As we shall see later, the cryoturbation horizon to which they are related has a more constant occurrence.

Sporadical wedges of different kinds

Sporadically wedges are found at the contact between the Vistulian and the Eemian deposits. So far, epigenetic fine frost wedges occurred as well pronounced features only at one place (Antwerp). But usually their form is diffuse and limited in size. As a result their origin is doubtfull. But they may contribute to the separation of stratigrafic horizons e.g. of the Warneton from the Rocourt soil.

Other sporadical wedges of the same kind as those observed with the small frost wedge row, occur within the bulk of the peaty loam formation. They form numerous, very thin and little wedges all inclined in the same direction. They add to the diagnostic characteristics of this formation.

Finally two rows of fine little frost wedges are occasionnally observed within the late coversands or late coverloams (Late Glacial). Thanks to their presence a subdivision is possible at this level, when other horizons (e.g. palaeosoils) are lacking.

CRYOTURBATIC AND SOLIFLUCTION STRUCTURES

A systematic record of the cryoturbatic and solifluction structures lead to the recognition of several levels where their occurrence is typical. As the frost wedges, they serve as marker horizons of the stratigraphical sequences.

Cryoturbated Soil Horizon

In the above, we mentioned the presence of a cryoturbation zone at the level of the Kesselt—Zelzate soil together with the fine frost wedge row of a much more constant occurrence than the latter. For this reason the morpho-stratigraphic connotation *cryoturbated soil horizon* was introduced to indicate this level (R. Paepe and R. Vanhoorne, 1967). The latter represents ont only a most striking morphological feature of this kind in the Late Pleistocene stratigraphy, but also it occurs at the transition of two widely differing climatic periods of the Vistula: the cold wet and the following cold dry phases. As one may know, observations in many parts of the European continent evidenced the general existence of fluvial structures and waterlaid sediments in the lowermost formation of the Last Glacial. The higher deposits are then usually composed of pure loess or coversands thus witnessing of dryer climatic conditions with the almost complete absence of vegetation.

Its strongest development occurs on solifluction deposits, while on fluviatile deposits it makes room for fine wedges (hummocky soil). It may be accompanied by a second less prominent cryoturbation level affecting the Hoboken soil. But the latter is less constant as to its occurrence and therefore not so reliable. However, its presence together with the cryoturbated soil horizon indicates a general trend of climatic instability in the evolution towards colder and dryer conditions at the end of the deposition of the paety loam formation. Actually, J. Büdel (1959) stated earlier that such phenomena only occur at the transition between such climatic phases.

Cryoturbatic undulations

Regular undulations occur within the coversand 1 and coverloam 1. They are attributed to a cryoturbatic activity. This interpretation seems more evident when they occur to appear within the bulk of these deposits. However, when they occur nearby the upper limit of the deposit, they sometimes are confounded with the distortions of the overlying large frost wedge row. M. Pécsi (1964) also described such bi-cyclic phenomena from sections along the Danube.

The bi-cyclicity of these features may be discussed. However, they help to distinguish the coversand 1 and coverloam 1 from the overlying coversand 2 and coverloam 2.

Solifluction deposits

Solifluction structures are the dominating features of the loams and coarse sands besides some occasional cryoturbations which may occur. They never attain, hereafter, such a well expression so that they are a characteristic inherent of the Early Vistulian.

Solifluction deposits were earlier recorded by R. Maréchal (1956), F. Gullentops (1952, 1954, and P. de Bethune (1951) although never a specific stratigraphic position was attributed to them.

PEBBLE BANDS

By pebble band is understood a more or less continuous row of pebbles of varying thickness. This depends on the amount of pebbles available in the sediments of the very proximity. But even when the pebbles are scarce, these horizons are well pronounced because of their lack in both over- and lowerlying deposits.

Three levels of pebble bands occur together with the higher mentioned frost wedge horizons. Earlier such horizons were described as *prêles* or *pediments deposits* (R. Tavernier, 1948). As they reveal the presence of eolised pebbles and sand grains, they are believed to be deflation zones (C. Edelman and R. Tavernier, 1940; R. Tavernier and A. Hacquaert, 1940). They are now reported in most of the European literature relative to the periglacial deposits. They can easily be correlated from one country to another (W. H. Zagwijn and R. Paepe, 1968; J. Fink, R. Paepe, J. Somme, W. Paas and O. S. Kuyl, 1968). Because of the cold climatic conditions under which they were formed — reminding polar desert conditions of the arctic and the subarctic — they were called *desert pavements* (R. Paepe and R. Vanhoorne, 1967). This idea finds its expression also in a recent Dutch paper (T. Van der Hammen, *et al.*, 1967) where so-called desert pavements and thicker pebble accumulations were commonly referred to as *Beuningen Gravel bed.*

In Belgium, it was found in many exposures that thin discontinuous pebble horizons laterally go over into thicker pebble accumulations. For this reason the name *desert pavement* is a somewhat unlucky choice in that it is biased by the picture of a typical kind of lag of the warm desert. Because in the desert different types of desert pavements also exist with regard to their composition and areal extend, R. Paepe earlier expressed the conviction that a genetic relationship between both phenomena is obvious. In the same line of thought the assimilation by R. V. Ruhe (1959) of widely occurring features in now different climatic belts as stone lines, pebble bands and pedisediments, is entirely approved.

Furthermore the desert pavement character of the thin pebble bands is shown by the following common characteristics which occur in many places:

— they are composed of a fine gravelly lag within a fine sandy matrix,

— they truncate along a flat, subhorizontally displayed line of unconformity, the underlying deposits,

— they are usually accompanied by a frost wedge row or/and underlain by a cryoturbatic horizon,

— they show a widespread occurrence and this large areal extent was evidenced by mapping in different parts of the sandloess area (R. Paepe and A. Louis, 1961). The pebble bands were followed over more than 5 km. Composition of the lag was coarser nearby the top of the outcropping Tertiary substratum, while in a downward direction, the lag becomes gradually more sandy terminating in lense-shaped accumulations when debouching into a watercourse. So to speak, one deals here with an original pedisediment.

If we want to group these real desert pavement features with the thicker accumulations, it is better to simply call them *pebble band.* This was already done by R. Paepe in a French paper on this matter where the name *cailloutis* was used (1968). As the term *desert pavement* is loaded with a stratigraphical meaning, we will use it here together with the new names e.g. pebble band 3. The detail descriptions follow hereunder in the same order of importance as the earlier mentioned frost wedge horizons. The numbers refer to their stratigraphical rank.

Desert pavement 3 (Pebble band 3)

This uppermost pebble band, as the large frost wedge row which it overlies, shows a great constancy as to its presence between the coversand/coverloam 1 and the coversand/coverloam 2. In many cases, parts of it, especially when of a greater thickness, show fluviatile structures, evidencing an original transport by water. This was also reported from its Dutch counterpart the Beuningen Gravel Bed (T. van der Hammen, *et al.*, 1967). Therefore its presence implies a long period which was needed first for its formation and then for its subsequent leveling off. Since it seems to occur as a world wide, steady phenomenon, regardless of topographic particularities, a long period of equal climatic evolution must be assumed for its establishment.

Desert Pavement 1 (Pebble band 1)

Contrary to the formation of the desert pavement 3, these pebble bands only occur on preferential, e.g. flat topographies of large valleys and plateaus. As the small frost wedge row which it under-lies, a short time can only be set forth for its formation and for the according cold climatic conditions.

Desert Pavement 2 (Pebble band 2)

An even shorter period of cold climatic high is thought to have controlled the establishment of the desert pavement 2. Its occurrence is rather sporadically and very often it was destroyed by subsequent cryoturbation activity or eroded before the deposit of the cross bedded sands deposits at the beginning of the cold dry part of the Vistulian.

From the above, it is a matter of course to conclude as to the reciprocity of the desert pavements and the frost wedge rows which they underlie. A continuous deterioration of the climatic conditions may then be set forth. Indeed the climate during which the fluvial gravel deposition took place was apparently milder than the one which caused deflation and eolisation of the gravel. In turn, the subsequent period of frost wedge development must have been colder than the previous one. So, it may be seen that a line of unconformity gives proof of a much longer and complex climatic evolution than its limited thickness lets presume.

CONCLUSIONS

A better understanding of the stratigraphical position of the above described phenomena makes it possible to assure the position of the various lithological units. Eventhough the latter show characteristics inherent to the formation to which they belong, lateral variations may sometimes completely change their facies. As of then their chrono-stratigraphical position may be cleared thanks to the morphology of the periglacial phenomena between which they occur.

The periglacial features also give an idea of the prevailing climatic conditions at certain levels of the stratigraphical sequence, during which sedimentation was little or non existing. They are additional facts for the illustration of the climatic fluctuations throughout the geologic record.

Finally, it was found, that they fill up to a large extent the apparant existing time gap in between the sedimentation layers. With this in mind, climatical and sedimentological evolutions are smoothened, and abrupt changes become completely imaginary.

This lead to the litho-stratigraphical classification of the Late-Pleistocene by R. Paepe (in R. Paepe and R. Vanhoorne, 1967) within which periglacial features rank as fully valuable stratigraphic elements.

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THAW LAKES, THAW SINKS AND SOILS IN NORTHERN ALASKA*

Abstract

Thaw lakes and thaw sinks are present in the aeolian silts just south of Umiat, Alaska. Through headward erosion, thawing of perennially frozen ground and filling, most lakes have undergone partial drainage exposing the lake floors. The lake floors are in step-like fashion, usually with 1 to 5 feet in elevation between the steps. The steps are a result of a complex of downcutting of drainage channels and collapse of underlying ground together with erosion and filling along the lake margins. Two C-14 dates from buried organic matter in the aeolian silts yielded ages of 9325 and 9130 yr. B. P. whereas one date from the 5-foot depth of the exposed lake floor yielded an age of 4590 yr. B. P.

Whereas the original aeolian silts were once virtually organic-free, the sediments of the lake floors have a considerable quantity of organic matter mixed throughout the substrate. This increased organic matter content in the lower positions is reflected in the soil morphology.

Thaw lakes and thaw sinks are recognized in numerous sectors of Alaska where the flat, poorly drained terrain is underlain by perennially frozen ground (Wallace, 1948; Hopkins, 1949; Hopkins and Karlstrom, 1955; Detterman, *et al.*, 1959; Tedrow, 1962 and others).

This report describes the occurrence of thaw lakes, thaw sinks and properties of attendant soils, in a sector centered about 10 miles south of Umiat (Fig. 1), The area under discussion is underlain by the Seabee formation (Colville group) of Late Cretaceous age and consists mainly of gray clay shales, siltstones, argillaceous sandstones and bentonite (Whittington, 1956). In the Umiat area (Fig. 1) the heavily braided Colville River flows generally eastward in a valley about 4 miles wide. The upland on the south side of the Colville River rises some 200 to 300 feet above the valley floor and

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