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PROPERTIES AND DISTRIBUTION OF VISTULIAN PERMAFROST TRACES IN TODAY SURFACE SOILS OF BELGIUM, WITH SPECIAL REFERENCE TO THE DATA PROVIDED BY THE SOIL SURVEY

Résumé

La carte des sols de la Belgique (échelle 1:20.000) et les textes explicatifs qui l'accompagnent sont étudiés en vue d'y trouver des renseignements concernant des traces de permafrost. Des données sur des pingos, traces de coins de glace, coins de sol, gley de toundra, involutions, sols polygonaux triés, solifluction et fragipan sont recherchées. C'est sur le fragipan qu'on trouve le plus de renseignements valables. Une carte indiquant la distribution minimale de cet horizon dans les sols belges est produite.

1. INTRODUCTION

Soil maps are among the most detailed information on the distribution of certain properties of the earth surface sediments. Consequently it is worthwhile to check what information they provide on a feature like permafrost traces. The purpose of the present paper is to investigate this subject for Belgium.

A systematic soil survey of Belgium started in 1947 (R. TAVERNIER and R. MARECHAL, 1962) and is still going on today. For a prospection covering the whole country (30,500 km^2) the scale is very detailed; every 75 m an auger observation is made up to a depth of 1.25 m and profile pits are made at an average density of one per 4—5 km^2. The field maps are at a scale 1:5,000. About 3/4 of the country are now covered by 300 sheets at a scale of 1:20,000. Each of these sheets is accompanied by an explicative legend giving, besides the characteristics of the soil mapping units, some general information on the area.

The legend of the Belgian soil maps is based on a limited number of soil characteristics. These are principally (1) the soil texture and its eventual variation with depth, (2) the soil drainage class, (3) the kind of profile development (or horizon sequence) and (4) the nature of an eventual stoniness and/or substratum occurring within a depth of 1.25 m.

It is important to note that in this investigation the depth limit of observation will be situated at 1.25 m which is the depth of the routine auger observations in the Belgian Soil Survey.

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2. MAIN SOIL-GEOMORPHOLOGICAL AREAS OF BELGIUM

To facilitate the description of the distribution of permafrost traces in the surface soils of Belgium the country is subdivided in eight soil-geomorphological areas. These are represented in fig. 1; table I indicates for each of the areas those characteristics which are important for the further discussion.

3. EXISTING INFORMATION ON PERMAFROST TRACES IN SURFACE SOILS

3.1. PINGOS

Pingo scars, or pingo-like scars, are observed in the Ardennes or High Belgium (fig. 1, area VII) and more particularly on some of the poorly drained plateaus covered by bogs. The depressions and the associated rims are clearly observable at the surface; their genesis has mainly been discussed by A. PISSART (1974) and his collaborators (e.g. B. BASTIN, *et al.*, 1974). Unfortunately these features are not so evident on the published soil maps and this for several reasons:

(1) landscape morphology is not included in the soil survey legend (§ 1),

(2) from the point of view of soil type, often it is only the mineral soil of the pingo rim which is distinguishable as the pingo depression and the whole surrounding landscape is covered by peat,

(3) many pingos have a diameter of less than 100 m, this is to small to be represented as a single feature on a map at scale 1:20,000.

Finally there are only a few large pingos situated outside of the bog areas which are represented on the maps. Indeed, here the peaty and/or poorly drained depressions clearly contrast with the rest of surrounding mineral soils. Nevertheless in the explicative legend accompanying these particular soil maps the reference to pingos is rare (P. PAHAUT, 1969, p. 16 and 69).

3.2. WEDGE CASTS

Ice wedge casts and large soil wedges are among the most important evidences of past permafrost and are frequently mentioned in studies on Quaternary geology of Belgium. In some places it has been observed that wedge casts start within a depth of 1 m from the actual soil surface (e.g. R. PAEPE, 1969, fig. 1; R. PAEPE and J. SOMMÉ, 1970, fig. 3). In the Condroz area (fig. 1, area V), in a 3 m deep soil composed of residual weathering clay from limestone, R. LANGOHR has observed a 2.4 m deep silt wedge filled with Vistulian loess and starting from the actual soil surface. Yet no information can be gained on these features from the Belgian Soil Survey, neither from the maps, nor from the explicative legends.

3.3. TOUNDRA GLEY

Toundra gley is described as a paleosoil in deep loess deposits of Belgium. The most important one is the *Kesselt soil* proposed by F. GULLENTOPS (1954, p. 164). In fact this author (p. 139), after K. BRYAN, calls it a *mollisol*; R. DUDAL (1955, p. 216) considers these bleached horizons more as an *arctic structure formation* than as a soil development and refers to H. FREISING (1951) who calls them *Nassböden*. In a detailed study P. HAESAERTS and B. VAN VLIET (1978) use the term *toundra gley*. The development of this soil type is supposed to be the consequence of periodic water-saturation on a permafrost table or on a temporary frozen subsoil. This process probably did occur in some of the soils which are still at the surface today. Nevertheless it has never been mentioned at this level.

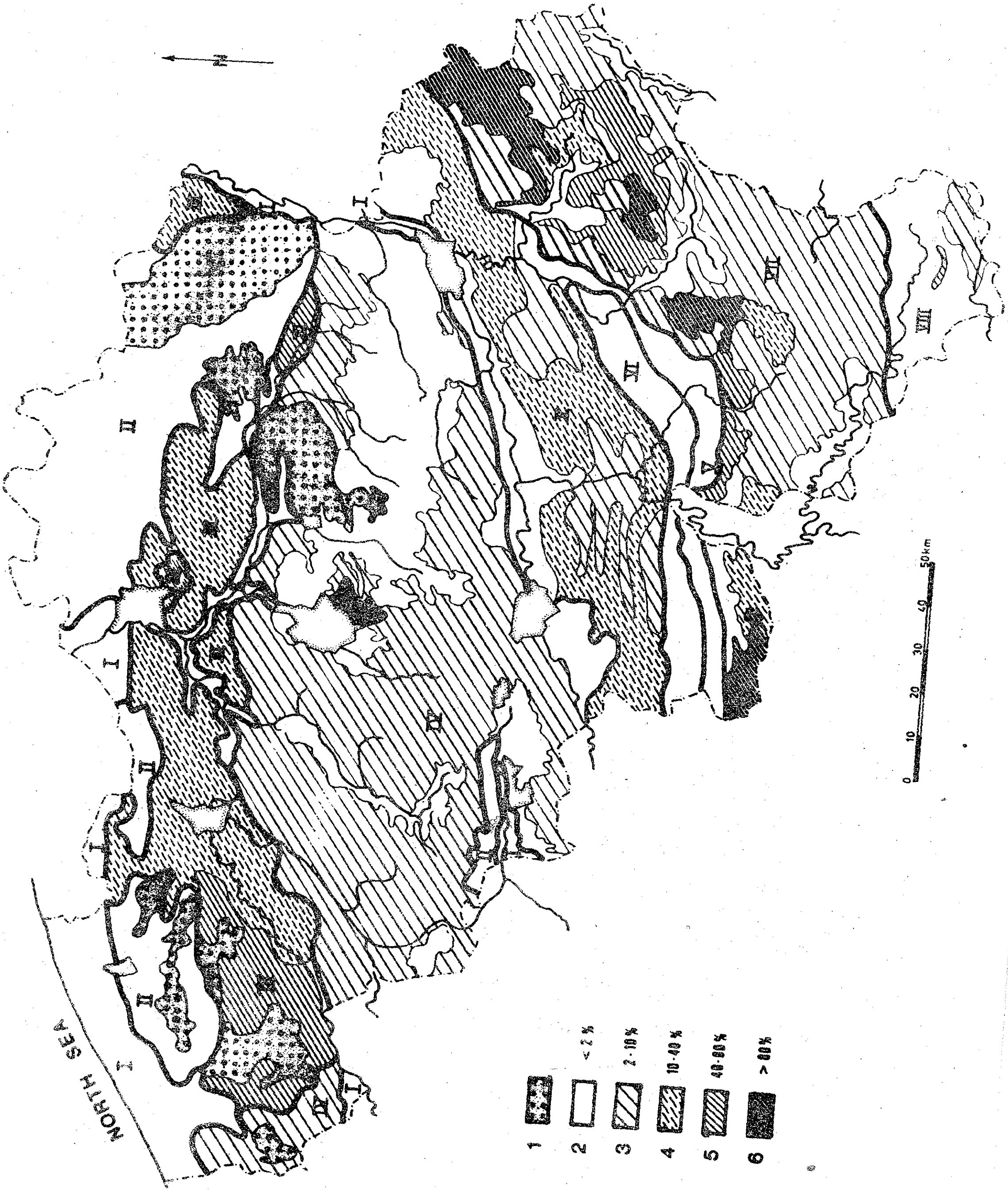
To the authors' opinion it is rather well possible that traces of toundra gley subsist in some soils of Belgium, but special investigations will be needed in order to distinguish the fossil properties from those associated to the still active processes of pedogenesis.

3.4. INVOLUTIONS, SORTED PATTERNED GROUND, SOLIFLUCTION

Involutions, sorted patterned grounds and solifluction are not necessarily linked to the presence of permafrost, yet they are often associated to a periglacial climate. In today surface soils, after some 10,000 years of pedogenesis, traces of these features will only be explicit in strongly heterometric sediments or in places where strongly contrasting sediments occurred one above the other. Latter condition is met in those areas of Belgium where loess or cover sands cover at shallow depth a gravelly substratum. The largest of these areas are indicated on fig. 1 (symbol 1). Among these, it is mainly on the Mid-Pleistocene Maas terraces (eastern part of area II) that features associated to cryoturbation, such as several meters deep involutions, have been described (e.g. E. PAULISSEN, 1973; E. PAULISSEN and F. GULLENTOPS, 1978). In the other areas indicated on fig. 1 (symbol 1) involutions and sorted patterned grounds are less obvious but have sporadically been observed by the authors. Involutions or *Taschenböden* are furthermore described by F. GULLENTOPS (1954, p. 194) in some of the gravelly heterometric soil sediments covering the Ardennes (fig. 1, area VII). This feature has also been observed regularly by the authors when digging profile pits in soils of the Ardennes (R. LANGOHR and B. VAN VLIET, 1979; fig. 1).

Yet involutions and sorted patterned grounds are not indicated on the Belgian soil maps and are not mentioned in the explicative legends.

Solifluction, on the contrary, is frequently reported by the soil scientists. Nearly all soil parent material which is gravelly or mixed (for example loess mixed with Tertiary sands), would have been transported and deposited by solifluction. This has been described for the whole country by R. MARECHAL and G. C. MAARLEVELD (1955, map 1) and at a broad regional level by R. MARECHAL (1957, p. 57) for the Condroz (fig. 1, area V), by R. VERMEIRE (1962, p. 211) for the Famenne (fig. 1, area VI), by J. DECKERS (1966, p. 40) and P. PAHAUT (1963, p. 61) for the Ardennes (fig. 1, area VII) and by R. STEFFENS (1971, p. 26) for the Belgian Lorraine (fig. 1, area VIII). Of these authors, only J. DECKERS distinctly links the solifluction deposits to permafrost. Solifluction is furthermore stated in nearly all explicative legends accompanying those sheets of the Soil Map of Belgium on which "mixed" or "heterogeneous" sediments occur, and this from the sandy area in the north (fig. 1, area II) up to Belgian Lorraine (fig. 1, area VIII) in the south.


NORTH SEA
1
2 < 2 %
3 2-10 %
4 10-40 %
5 40-80 %
6 > 80 %
0 10 20 30 40 50km

3.5. FRAGIPAN

Fragipan is a soil subsurface horizon which is particularly compact — but non--cemented — and which is difficult to be penetrated by plant roots and sometimes even by water. E. A. FITZPATRICK (1974) calls such horizon isons and links their genesis to permafrost. To the opinion of the authors fragipans in Belgium are developed by the pressure engendered by growing ice lenses in the upper part of permafrost aggradating in moist or wet grounds (VAN VLIET and LANGOHR, 1979). The top of the fragipan is rather abrupt, more or less parallel to the soil surface and situated at a depth of about 35—80 cm. As the pan is distinctly more compact than the overlying ground it certainly is one of the permafrost traces which is easiest to be identified with an auger. Yet, although this subsurface horizon is recognized by several soil classification systems (e.g. FAO-UNESCO 1974; Soil Survey Staff 1975), it has not been included in the legend of the published soil maps of Belgium. However some surveyors did indicate the feature on the field maps and several authors of the explicative legends and of regional soil studies do report the presence of the fragipan. In table II these references are given for each of the soil-geomorphological areas of fig. 1. On basis of these data and on field investigations made by the authors it has been possible to draw on fig. 1 a minimal extension of this horizon in the Belgian soils. This distribution will be further commented in § 4.3.

4. DISCUSSION

4.1. PRELIMINAR REQUIREMENTS

The presence of permafrost traces in today surface soils depends on some preliminar requirements which should be all fulfilled. They are commented first.

(1) *Traces of permafrost can only be present in those soils which are developed in parent material deposited, or formed in situ, before or at the moment of the latest permafrost period.*

On basis of this requirement no permafrost traces are expected in the soils of area I of fig. 1 (polders and Holocene alluvial plains). In all other seven areas permafrost traces may be present as pedogenesis started before or during the Tardiglacial (tab. I) which, in Belgium, seems to be the latest period with permafrost (e.g. P. HAESAERTS and B. BASTIN, 1977).

(2) *Traces of permafrost will only occur in those grounds where the internal and external environmental conditions were such that, at the moment of permafrost aggradation, features did develop which leave specific traces after thawing.*

Fig. 1. Main soil-geomorphological areas of Belgium (tab. I) and distribution of fragipans

Soil-geomorphological areas (see tab. I): I — polders and recent alluvial plains; II — sandy area of Flanders and Kempen; III — transition area between II and IV; IV — loess belt; V — Condroz; VI — Famenne; VII — Ardenne; VIII — Lorraine

Distribution of fragipans in surface soils: 1. areas with shallow coversands or loess over Tertiary marine sediments or Mid-Pleistocene river terrace deposits; very variable distribution of fragipans (0—40 %), not differentiated on the map; 2, 3, 4, 5 and 6: areas with rather uniform proportion of soil containing a fragipan (percentages indicated on the map)

From this point of view, and for ground conditions, following correlations can be mentioned:

— pingos are associated to very specific groundwater conditions,

— all other factors being equal, ice wedges are largest in fine textured or in peaty sediments (P. A. Shumskii, 1964, p. 198; cited in A. L. Washburn, 1973, p. 92),

— toundra gley is expected to develop best in non-calcareous ground with a vegetation cover (better conditions for reduction of iron and manganese),

— involutions and sorted patterned grounds are best expressed in sediments which were originally or strongly heterometric, or composed of successive layers of contrasting texture; solifluction is only active in those grounds which are not flat and which are in at least some period of the year saturated with water,

— fragipans will only develop in ground with water supply from the subsoil; all other factors being equal, this supply will be maximal in medium textured sediments (such as loess) as these have a high suction potential and a good permeability.

(3) *The subsistence of permafrost traces in surface soils depends on the nature of the pedogenetic processes active since the thawing of the latest permafrost.*

Indeed, no physical and/or chemical and/or biological process should have been strong enough to destroy completely the eventual existing traces. For Belgium two important elements can be reported here.

(1) In the surface soils developed in loess the pedogenetic processes of decalcification, brownification and clay migration have changed much of the initial properties of the sediments.

(2) Large regions of the country, particularly in areas III, IV and V of fig. 1 are since many centuries under agriculture. In these regions many upland soils are actually partly eroded and all pre-existing depression soils are burried. It is furthermore observed that when soils of these areas are deforested and brought under agriculture, the soil biological activity drastically increases (particularly by earthworms). In loess profiles for example, we have observed that under old agriculture the original soil horizons have been homogenized up to a depth of 60—80 cm. If traces of permafrost existed within this depth, they have disappeared completely at present-day.

4.2. COMMENTS ON THE EXISTING INFORMATION

From § 3 it can be concluded that, although the Belgian Soil Survey is made on a small scale (field maps at scale 1:5,000), few data on permafrost can be obtained through it. This situation can be attributed to various factors.

(1) Permafrost traces can be absent over large areas because one or more of the previously commented preliminar requirements (§ 4.1) are not fulfilled.

(2) Several kinds of permafrost traces are difficult to observe in a soil survey based on auger observations. This aspect is valid for large areas of Belgium. Indeed, wedge casts, involutions and solifluction deposits are very difficult to detect in deep homogeneous sediments like loess or coversands. Table I indicates that such material covers large part of areas II and V, and nearly completely areas III and IV (fig. 1).

Table I

Important characteristics of the soil-geomorphological areas of Belgium (fig. 1)

Soil-geomorphological area No.	Name	Properties of the today surface soils (depth limit: 1.25 m) Age of parent rock[1]	Nature of sediment	Texture of sediment	Period when pedogenesis started[1]	Altitude above sea level (m)	Topography
I	Polders + recent alluvial plains	Holocene	marine + alluvial	variable, often clayey	Holocene	0—20	flat
II	Sandy area of Flanders and Kempen	(Holocene)[2] Tardiglacial Pleniglacial B Mid-Pleistocene Tertiary	(dunes)[2] coversands river terraces marine	sandy gravelly sands sandy to clayey	(Holocene)[2] Tardiglacial Pleniglacial B Vistulian or older	5—100	flat
III	Transition between areas II and IV	(Tardiglacial) Pleniglacial B Tertiary	coversands and loess marine	loamy sand to sandy loam sandy to clayey	(Tardiglacial) Pleniglacial B Vistulian or older	5—50	flat + very smoothly undulating
IV	Loess belt	Pleniglacial B (Tertiary)	loess (marine)	silty (sandy)	Pleniglacial B (Vistulian or older)	20—200	smoothly undulating
V	Condroz	Pleniglacial B Pleniglacial A or B + Primary or Tertiary	loess cryoturbated loess + stone fragments	silty gravelly silt	Pleniglacial B Vistulian or older	200—350	moderately undulating
VI	Famenne	Pleniglacial A or B + Primary Primary	cryoturbated loess + shale fragments shale	gravelly silt gravelly clay	Pleniglacial A or B	140—250	flat up to smoothly undulating
VII	Ardenne	Pleniglacial A or B + Primary or Tertiary	cryoturbated loess (?) + stone fragments	gravelly silt	Vistulian or older	250—690	flat up to smoothly undulating plateaus + deep valleys
VIII	Lorraine	Pleniglacial A or B Secondary or Tertiary	loess cryoturbated sedimentary rock	silty sandy up to clayey (gravelly)	Vistulian or older	100—400	flat up to slightly undulating plateaus + cuesta scarps

[1] Upper Pleistocene chronostratigraphy following P. Haesaerts (1974)

[2] (   ) — minor inclusions.

In Belgium the difficulty of observation, particularly with an auger of 1.25 m length, does also exist for sorted patterned grounds and involutions as these features mostly are covered by at least 60—80 cm of homogenized sediments.

(3) Permafrost traces and associated features have not been included in the soil survey legend. This can be justified when the feature has no influence on soil management practices. This is the case of most wedge casts, involutions and even sorted patterned grounds observed up to nowadays in Belgium. It is less defendable for pingo scars but can be understood as these cover only a very small area of the country. The absence of fragipans in the soil survey legend is open to large criticism. This horizon is easily observable with an auger and has important soil management implications as it limits the effective soil depth for roots and as it may cause the presence of a temporary water table at relatively shallow depth. The absence of information on fragipans on the published maps is partly balanced by the reference to it in articles and in some of the explicative legends (tab. II). Latter information however is erratic as not all surveyors looked with the same care to this horizon. Solifluction is very frequently mentioned in the explicative legends. Yet this is far from being an undoubtful permafrost trace and particularly in the way it has been cited in the soil survey. Indeed, nearly all soil parent material which is a mixture of sediments (for example loess with some Tertiary sands, loess with gravels from a stony substratum) undifferentiately have been called solifluction deposits, regardless to other environmental factors such as landscape position.

4.3. COMMENTS ON THE DISTRIBUTION OF FRAGIPANS FOR TRACING FORMER PERMAFROST AT THE LEVEL OF THE PRESENT-DAY SURFACE SOILS

From § 3 and 4.2. it can be concluded that in the surface soils of Belgium, fragipan is the permafrost trace which is easiest to survey. Fig. 1 gives for this horizon a minimal extension which is based on literature data (tab. II) and on the authors' field

Table II

Authors who mention the presence of fragipans in soils of Belgium

Soil geomorphological area (fig. 1)	References
II	J. Ameryckx, e.g. 1977, p. 30; J. Deckers and L. Baeyens, 1963.
III	J. Ameryckx, e.g. 1958, p. 22; R. Leys and A. Louis, 1963, p. 30.
IV	L. Baeyens, e.g. 1968, p. 40; L. Baeyens and G. Scheys, 1958, p. 19; R. Dudal, 1955, p. 73 and 206; A. Louis, e.g. 1959, p. 40.
V	J. M. Lozet and A. J. Herbillon, 1971; R. Marechal, 1957, p. 123; F. B. Oldehove de Guertechin, 1973, p. 32; R. Tavernier and R. Marechal, 1957.
VII	P. Avril, e.g. 1961, p. 28; J. Deckers, e.g. 1966, p. 115; P. Pahaut, e.g. 1969, p. 52; A. Platteborse, 1970, p. 37; R. Tavernier and G. Smith, 1957, p. 246.
VIII	R. Steffens, e.g. 1971, p. 43.

observations. Except for areas I, II and VI fragipans are not uncommon throughout Belgium.

The absence of fragipans in area I (polders and Holocene alluvial plains) can be explained by the non-fulfilment of the time requirement (§ 4.1 — 1), the sediments of this area being deposited after the latest permafrost period (later than Tardiglacial). In area II fragipans have only been reported on the Mid-Pleistocene Maas terraces (J. DECKERS and L. BAEYENS, 1963). The scarceness of fragipans in this region can be attributed to the fact that soil parent material is mainly composed of sands. It is known that ice segregation difficulty develops in coarse-textured sediments (e.g. A. L. WASHBURN, 1973, p. 55). Another possible explanation is that the present-day definition of fragipans — compaction associated to a prismatic structure (Soil Survey Staff, 1975, p. 42) — is mainly based on a morphology commonly met in medium textured soils. Consequently it could be that in the future the extension of fragipans has to be increased in the sandy area of Belgium. Reconnaissance observations of the authors support this hypothesis. The complete absence of the pan in the Famenne (area VI) is probably due to the shallowness of the soils — most soils have a stony substratum at less than 80 cm depth — combined with a high porosity of the subsoil (shales). In such an environment there is little possibility for ice segregation in an aggradating permafrost. The absence of fragipans in parts of areas III up to VIII can be largely linked to the non-fulfilment of one or more of the three preliminar requirements (§ 4.1.). For example, the absence of fragipan in the eastern part of the loess belt (area IV) can be associated to the presence in that region of a very permeable substratum of chalk under the loess cover. The lack of sufficient groundwater supply for ice segregation and for consequent ground compaction can also be invoked for the central and southern part of the Ardennes (area VII) where the soil substratum is composed of very permeable slates; this in contrast with a less permeable substratum of weathered shales and siltstones in the north part of the Ardennes (where fragipans are common).

5. CONCLUSIONS

(1) Although the soil map of Belgium is made on a very detailed scale (auger observations every 75 m), little direct information on permafrost traces can be obtained through it.

— Reference on doubtfull traces of permafrost like pingo scars, ice wedge casts and soil wedges are very rare. Yet pingo scars exist in some small areas and wedge casts and soil wedges are not so unfrequent, but are difficulty detected in the surface soils.

— Toundra gley is not reported; it could exist but special investigations are needed in order to separate the fossil features from those associated to the more recent pedogenesis.

— Involutions and sorted patterned grounds are not mentioned, yet they occur in some areas.

— Solifluction deposits are very frequently described, but in the way this term has been applied in the Belgian Soil Survey it is not necessarily linked to presence of permafrost. In many cases it is even not sure whether the so described material has been deposited by any kind of solifluction.

— Fragipans are not indicated on the published maps but are mentioned rather frequently in the explicative legends. Literature data and the authors' prospections have permitted to draw a minimal extension of this soil subsurface horizon (fig. 1).

(2) Among the permafrost traces discussed, fragipan is the most suitable feature to prospect for in a soil survey.

(3) For discussing the presence and the distribution of permafrost traces in present-day surface soils, three preliminar requirements should be checked for. These are:

(a) a time requirement: pedogenesis should have started before or during the latest permafrost period;

(b) an environment requirement: at the moment of permafrost aggradation, the environmental conditions should have been such that features could develop which leave traces of the permafrost;

(c) a conservation requirement: during further pedogenesis, no processes should be strong enough to destroy the existing traces.

(4) Considering,

(a) that the pedogenesis of most surface soils of Belgium started in the Pleniglacial B or in the Tardiglacial (tab. I),

(b) the three preliminar requirements previously commented under (2),

(c) the actual known distribution of fragipan (fig. 1),

it can be concluded that in Belgium permafrost was very widespread during probably both Pleniglacial B and Tardiglacial. Whether the permafrost was continuous or not, is not sure and the answer to this question would need more detailed investigation in order to check if traces of permafrost subsist in all places where the three preliminar requirements are fulfilled.

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