6 · Weichselian periglacial structures and their environmental significance: Belgium, the Netherlands, and northern France

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Abstract

The paleo-climatic significance of periglacial structures known in Belgium, the Netherlands and northern France is reviewed. Their position in the stratigraphic sequence of the last glaciation is presented as well as a short summary of the main climatic variations of this cold period.

Resumé

La signification paléoclimatique des principales structures périglaciaires connues en Belgique, aux Pays-Bas et dans le nord de la France est examinée. La position de ces phénomènes dans la séquence stratigraphique de la dernière glaciation est donnée ainsi qu' un bref résumé des variations climatiques principales actuellement connues pendant cette période.

Introduction

The reconstruction of the climatic environment of Pleistocene periglacial times remains a difficult and hazardous task partly because our knowledge of the climatic significance of fossil periglacial features is incomplete. Moreover, the stratigraphy is still much in doubt and as a result, often we may be mixing features from different times. However, it is useful to review our present knowledge of this subject not only to make a contribution to the paleo-climatic reconstruction of Europe, but also to illustrate where further research on present-day periglacial phenomena is needed. In this paper, we briefly present what is known about the periglacial conditions of the last glaciation in Belgium, northern France and the Netherlands.

The difficulties encountered in the reconstruction of paleo-environments from fossil periglacial features are numerous. Karte (1979) has shown clearly that reliance on a single feature is not satisfactory and that we must consider several together and exclude atypical sites that were exceptionally favourable for the development of the features. Such a procedure is not easy in the study of fossil features. Complications arise because of the effect of other factors such as variations in vegètation, differences in geomorphological situations (e.g. Vandenberghe, 1985), and the nature of the soil (e.g. Romanovsky, 1985). There is also the problem of determining the temperature under which periglacial features are formed. For areas with less than 50 cm of snow in winter, Harris (1982) has shown the existence of relationships between the formation of periglacial features, mean annual temperature and freezing and thawing indices. At present, it is not possible to apply his results in paleo-climatic research, but if we find a relationship between the distribution of zones of vegetation and the thawing index, it will be possible to deduce freezing indices and this will provide important paleo-climatic information.

Paleo-climatic indicators

Poser (1947 a and b; 1948 a and b) was probably the first to use the distribution of fossil periglacial phenomena to map past climates. Since his important contributions, more information has been gained about the significance of these phenomena.

Ice wedges

It is well known that the formation of modern ice wedges is partly dependent on temperature (e.g. Black, 1976). For instance, the highest mean annual air temperature which allows ice wedges to form in Alaska is between −6 and −8 °C by (Péwé, 1966). Similar values are reported by Brown and Péwé

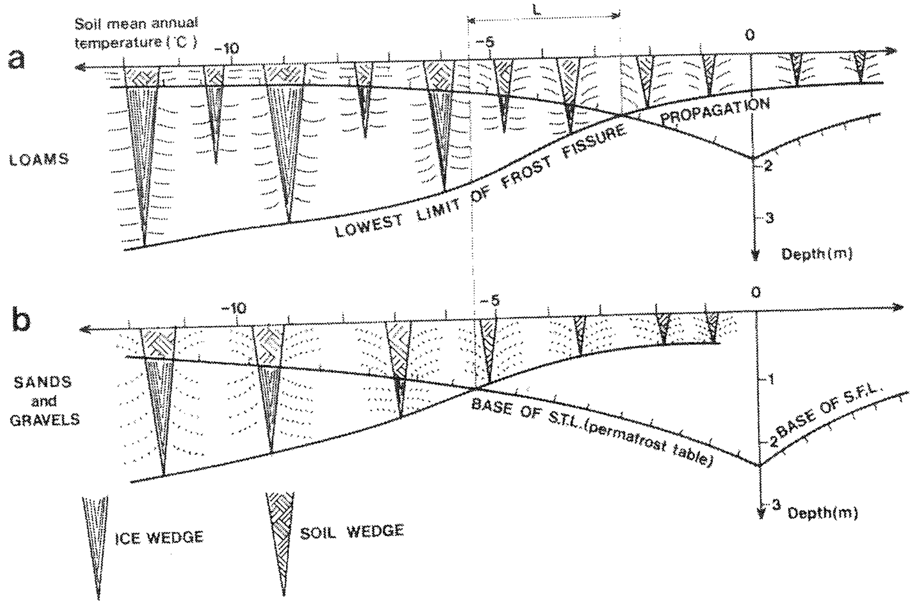


Figure 6.1. Correlation between ice and soil wedges with mean annual soil temperature in, a) loams and b) sands and gravels. S.T.L. = seasonally thawed layer; S.F.L. = seasonally frozen layer (from Romanovsky, 1985, p. 159 with small modifications).

(1973), and by Washburn (1980). A relationship also exists between the material in which ice wedges develop and mean annual temperature. Harris (1982) found that ice wedges formed in peat under a mean annual air temperature of −3.5 °C, while in mineral soil the mean annual temperature had to be much lower (−7.5 °C). Romanovsky (1985) specifies that the soil mean annual temperature favourable to the development of ice wedges is −5.5 °C in sands, −2.5 °C in loams (Figure 6.1) and −2 °C in peat. His paper confirms the idea presented by Goździk (1973) and Kolstrup (1980) that ice wedges grow at a higher temperature in loess than in sands. But the conversion from soil mean annual temperature to mean annual air temperature is hazardous. Gold and Lachenburch (1973) give a difference of 1 to 6 °C between the two values, the difference being greater as the winter snow cover increases.

Although permafrost is necessary for the formation of ice wedges, it is not the only condition. Brutal drops in temperature (Lachenbruch, 1966) are needed to open frost cracks in the frozen ground. To be efficient, such temperature variations must occur when there is no thick snow cover insulating the ground surface. This is the main reason why ice wedges are better developed in continental than in maritime climates.

Soil wedges

Soil wedges, mainly described by Soviet authors, are formed by repeated frost cracking and infilling with mineral sediments. Because they grow in seasonally thawed layers, the ice melts in summer and these remain wedges of mineral soil (mainly sands) with a vertical lamination. The conditions necessary for the formation of these structures are not well known. The evidence reported by Romanovsky (1985) (Figure 6.1) shows that soil wedges, like ice wedges, have a more southerly limit in loams than in sands. The soil mean annual temperature for the formation of soil wedges in sands must be below −0.5 °C. In loams, a temperature limit does not exist.

Frost mounds

As in the case of ice wedges, perennial mounds formed by accumulation of ice in the ground are proof of permafrost. For the closed system pingo, the maximum mean annual air temperature is −5 °C (Mackay, 1978) or −6 °C (Washburn, 1980). Open system pingos are found in locations where the mean annual air temperature is below −2 °C (Washburn, 1980).

Mineral palsas giving scars similar to pingo remnants were described in Canada by Pissart and

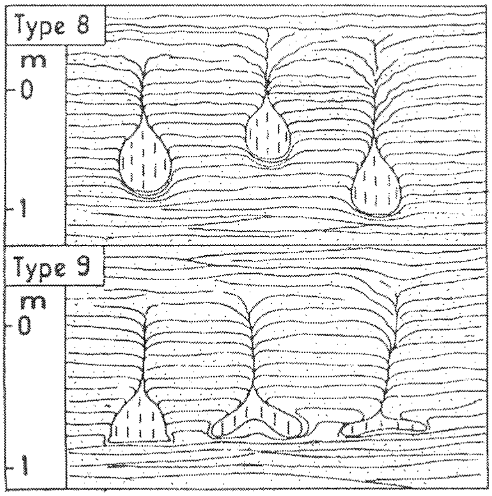


Figure 6.2. Cryoturbation of type 8 and 9 following the classification of Heyse (1983). Type 8 = drop-structures and spherical structures with no relation to permafrost; type 9 = clock-structures and boomerang structures with a flat base formed in association with a permafrost table.

Gangloff (1984). At present, they occur where the mean annual air temperature is below −3 °C. On the other hand, for the formation of organic palsas, the mean annual air temperature must be below 0 °C (Washburn, 1980; Pissart, 1985; Dionne, 1984). Remnants of such features are unknown in Holland, Belgium and France, and these features are therefore no help in paleo-climatic reconstruction.

Involutions

It is generally agreed that fossil involutions are not necessarily related to the former occurrence of permafrost. Maarleveld (1981) found no relationship between the depth of modern involutions, the thickness of the active layer and the air temperature in July in present-day cold areas. For involutions which are remnants of large non-sorted polygons, Williams (1961) suggests that the mean annual air temperature, during the time of their formation, is below −3 °C. On the other hand, Goldthwait (1976) said it was −4 to −6 °C, while Washburn (1980) suggests 0 °C for polygons with diameters of more than 2 m. These figures are not compatible.

Today in Belgium, the Netherlands and France, authors identify as proof of permafrost, involutions with a flat base (Figure 6.2) that probably corresponds to the permafrost table (Gullentops and Paulissen, 1978; de Moor, 1981, Vandenberghe and Vandenbroeck, 1982; Vandenberghe, 1983, 1985; Lautridou et al. 1985, Van Vliet-Lanoë, 1985). Such involutions allow one to measure the thickness of the active layer if the level of the ground surface is known at the time of formation.

Stratigraphic position of periglacial structures

The determination of the significance of periglacial structures is not the only problem of paleo-climatic reconstruction. To be useful, the structures must be located unambiguously in the stratigraphic sequence which is based upon lithologic units, palynological studies and ^{14}C dates. The stratigraphic sequence in W. Europe is still uncertain because (a) ^{14}C dates are limited to the last 50,000 years (b) organic material for ^{14}C dating is uncommon when dealing with cold environments (c) the stratigraphy of the last glaciation is based mainly on loess deposits, and we now know that aeolian sedimentation did not occur throughout the glaciation but only for short periods; important gaps exist, (d) all the organic horizons from the last cold period were first regarded as proof of interstadials; it seems probable now that some organic layers are due to local thermokarst phenomena and are not related to climatic events.

To illustrate these uncertainties, the differences between the sequence of Paepe and Vanhoorne (1967) and that of Haesaerts (1984) (Figure 6.3) for the beginning of the last glaciation, are great. Also the age of the important lithostratigraphic horizon, the 'Kesselt soil', is now thought to be about 23,000 years B.P. (Haesaerts & Van Vliet, 1981) and it is not now regarded as being equivalent to the Denekamp soil of 29,000 years B.P.

In *The Netherlands*, ice-wedge casts in sands are found from two periods in the last glaciation (Maarleveld, 1976; Vandenberghe, 1985). The more recent are dated at about 20,000 years B.P. (Kolstrup, 1980) and were formed at, or a little before, the time of the maximum of the last glaciation. The oldest ice wedges are older than 55,000 B.P.: Vandenberghe (1985) believes they probably formed between 62,000 and 70,000 B.P. by comparison with the Grande Pile diagram in the Vosges (Mook and Woillard, 1982). On the basis of the presence of ice-wedge casts in sands, it is likely that the mean annual air temperature was below −6.5 °C.

Pingos which were described for the first time in the Netherlands by Maarleveld & Van der Toorn (1955) were also formed before 19,000 years B.P. (Paris *et al.*, 1979; De Gans, 1981; De Gans *et al.*, 1984). Because they were closed system pingos, they support the conclusion that the mean annual air temperature was below −6 °C at this time.

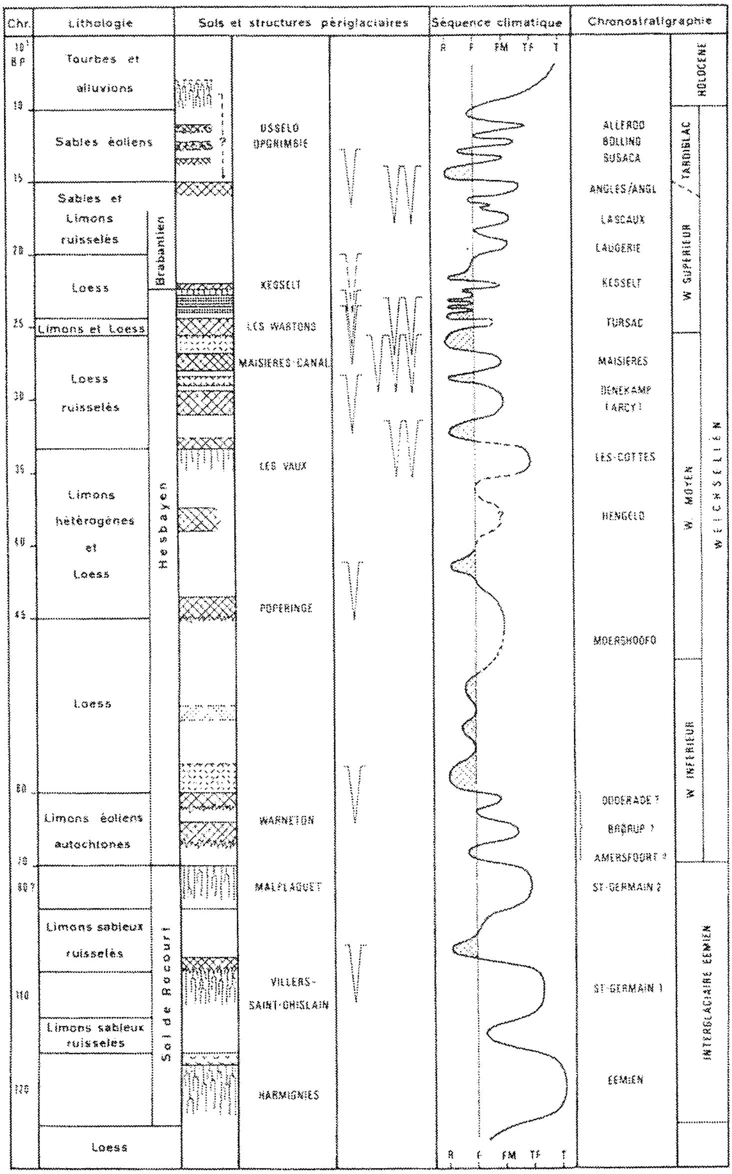
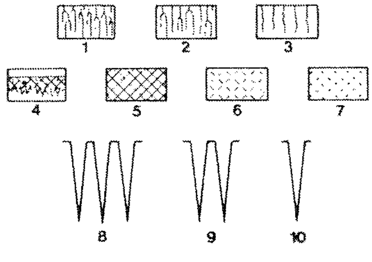


Figure 6.3. Paleo-climatic reconstruction of the last glaciation for the loess part of Belgium by Haesaerts (1984). R = rigorous with continuous permafrost; F = cold with discontinuous permafrost; FM = medium cold; TF = temperate cold; T = temperate; 1: leached soil (B + horizon); 2: leached soil to brown leached soil (sol brun lessivé); 3: Decalcified brown soil (B horizon); 4: eluvial horizon; 5: humic soil with bleached patches; 6: soil or humic deposits; 7: highly iron depleted horizon (tundra gley); 8: frequent ice wedges; 9: occasional ice wedges; 10: isolated ice wedges.



In the loess cover of *Belgium*, several levels of ice-wedge casts have been described. They are shown on the stratigraphic diagram of Haesaerts (1948) (Figure 6.3). The ice-wedge casts are well developed in the upper pleniglacial as was the case in the Netherlands. Typical ice-wedge casts were also discovered at other levels in the stratigraphic sequence where they are not known in the sands of the Netherlands. This distribution is completely in agreement with Romanovsky's diagram (1985) (Figure 6.1) which shows that the mean temperature may be higher for ice wedges in loams than in sands. The description of three levels of ice wedges in the very complex filling of the Flemish valley before 50,000 B.P. by De Moor (1983), proves that it is an oversimplification to speak of only two periods of permafrost during the last glacial period.

In the north of *France*, two levels of ice wedges have been described (Paepe and Sommé, 1970; Lautridou and Sommé, 1981). For all these countries, the evidence collected from periglacial phenomena is consistent but general. Precise stratigraphic correlations remain difficult and often impossible.

The short period of the Younger Dryas, between 11,000 and 10,000 years B.P., is easier to identify. Maarleveld (1976) has shown that during this period, soil wedges were formed in the Netherlands and because they were in sands they cannot be dessication cracks. Maarleveld (1976) believes that they indicate a mean annual temperature between 0 and −6 °C.

Evidence of discontinuous permafrost in Belgium during Younger Dryas time is presented by De Moor (1981) and Heyse (1983). They describe involutions with an horizontal base in sandy ridges north of the Flemish valley. The thickness of the active layer as shown by these structures is about 1.5 m.

Features now interpreted as remnants of mineral palsas (and previously described as pingo remnants) (Figure 6.4) on the Hautes Fagnes plateau were formed during the Younger Dryas (Pissart and Juvigné, 1981; Pissart, 1983; Mullenders and Gullentops, 1969). These features probably formed outside the limit of continuous permafrost and indicate a mean annual temperature of −3 °C or lower. This value agrees with the observations

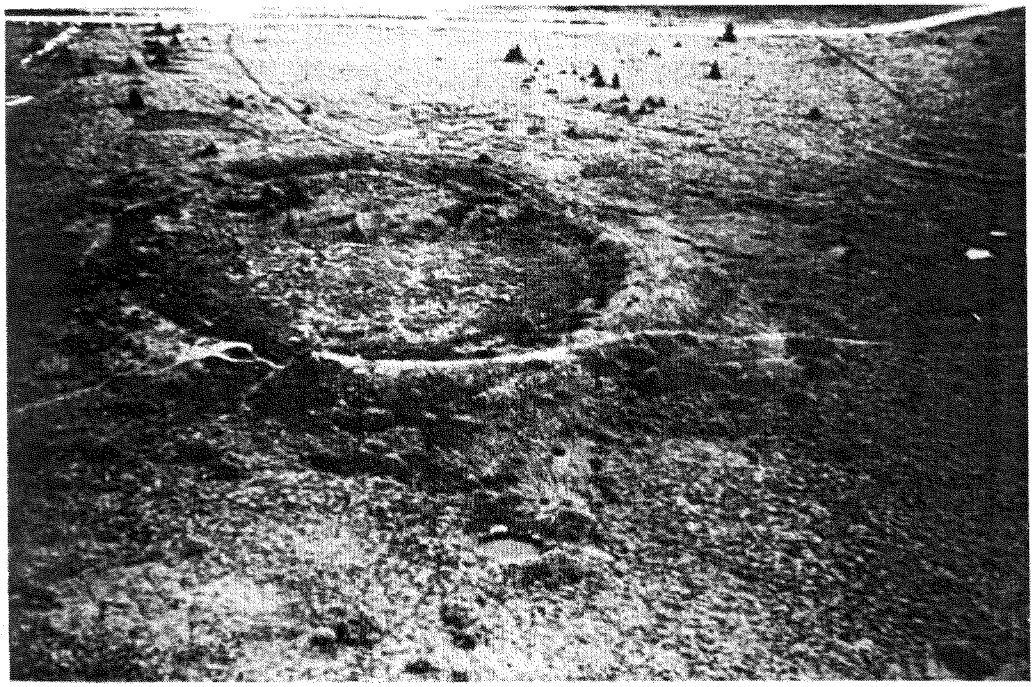


Figure 6.4. Remnant of a periglacial mound in the Hautes Fagnes (Belgium). Formerly interpreted as pingo scars, these features are now regarded as remnants of mineral palses (Pissart and Gangloff, 1984).

previously reported from the north of Belgium and the Netherlands, because the altitude of the Hautes Fagnes, about 600 m above sea level, gives a difference at present of 3 °C in mean annual temperature.

We have no information about the temperature of northern France during the Younger Dryas.

The stratigraphic sequence of the last glaciation in Belgium, The Netherlands and Northern France

Stratigraphic difficulties, especially those due to discontinuous sedimentation, make it virtually impossible to present a paleo-climatic reconstruction of the last glaciation based solely upon periglacial arguments. It is necessary to look for other observations and to combine profiles to try to obtain a more complete record of the glaciation.

As Haesaerts (1984) has shown, different records give similar views of the paleo-climatic succession. The palynological profile from Grande Pile in the Vosges (Figure 6.5) (Mook and Woillard, 1982) which was confirmed by the profile from Les Echets near Lyon (de Beaulieu and Reille, 1984), is now probably the best evidence that one could use in positioning our paleo-climatic phenomena. This curve is very similar to the curve obtained by Dansgaard *et al.* (1971) from isotopic studies of ice

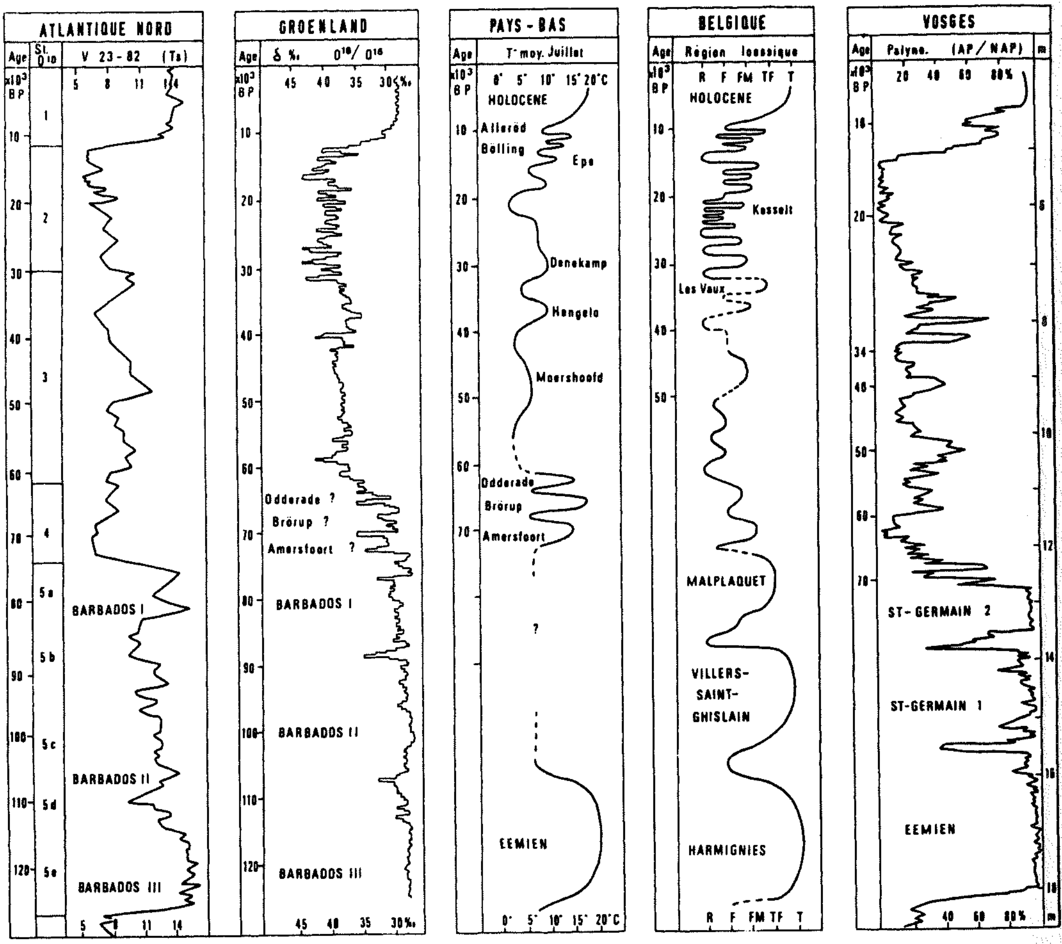


Figure 6.5. Comparison of some palaeo-climatic curves by Haesaerts (1984) 1. North Atlantic, foraminifera (Sancetta *et al.*, 1973); 2. Greenland, 0¹⁸/0¹⁶, Camp Century (Dansgaard *et al.*, 1971); 3. The Netherlands – palynology – July Temperature (Zagwijn, 1975; Kolstrrup, 1980); 4. Loess part of Belgium (Haesaerts, 1984); 5. Vosges, La Grande Pile (France) palynology (Mook and Woillard, 1982).

at Camp Century in Greenland. The curve from Haesaerts (1984) is not only the most recent but also the best one as it is confirmed by all the observations made in loessic deposits of Belgium. The curve for the Netherlands given by Haesaerts is based upon the work of Zagwijn (1975) and Kolstrup (1980). Placed with the other curves, it identifies the gaps which probably exist in the stratigraphic sequence of the Netherlands (Figure 6.5).

After the Eemian (*sensu stricto*, Mook and Woillard, 1982), evidence of St Germain I and II interstadials is seen in the remnants of soils (Villers St Ghislain and Malplaquet) formed under forest (Haesaerts and Van Vliet, 1974, Haesaerts and Van Vliet-Lanoë, 1981). Between these soils, the first indication of permafrost is found (Figure 6.3). The stratigraphic position of these features is derived from a comparison with the Grande Pile curve and may therefore be questionable.

The next periglacial period begins between 70,000 and 60,000 years B.P. and develops a cold continental climate. Periods of better conditions (Amersfoort, Brørup, Odderade) produced humiferous soils (Warneton soil, Paepe 1964). The palynology shows that during these interstadials trees returned (Bastin, 1974; Paepe and Vanhoorne, 1967). The first cover of loess came around 50,000 years B.P. probably during a dry period.

The middle pleniglacial, from 50,000 to 25,000 B.P. corresponds to a wetter climate. During this period, permafrost occurred several times. Three climatic ameliorations, deduced by palynology, were called Moershoofd (50 to 45,000 B.P.), Hengelo (39 to 37,000 B.P.) and Denekamp (32 to 29,000 B.P.) (Zagwijn, 1975). Trees were not numerous. The herbaceous plants indicate that during the Denekamp in the Netherlands, the mean July temperature was below 10 °C (Kolstrup, 1980); large ice-wedge casts indicate continuous permafrost immediately after Denekamp time.

From 25,000 to 15,000 years B.P., during the upper pleniglacial, the climate was first dry and cold, allowing sedimentation of aeolian silt and coversands, but later from 20,000 to 15,000, it was cold and wet. Three climatic improvements are shown by palynology: the interstadials of Laugerie, Lascaux and Angle-sur-Langlin (Haesaerts and Bastin, 1977).

The late glacial, from 15,000 to 10,000 B.P., is the best known period with two climatic improvements: Bolling (12,300 B.P.) and Allerod (between 11,800 and 11,000 B.P.). Permafrost developed at the beginning of this period as demonstrated by ice-wedge casts. Discontinuous permafrost returned during Younger Dryas time (11,000 to 10,000 B.P.). The evidence of herbaceous plants suggests that the mean July temperature was + 11.5 °C during the Younger Dryas, and + 13 °C during the Allerod (Kolstrup, 1979). Van der Hammen *et al.* (1967), report + 10 °C and + 14 °C. As conditions became cold, pine disappeared and was replaced in northern Belgium by herbaceous cover with some lichens (Munaut and Paulissen, 1973; Damblon, 1974). A microfauna collected from a cave at Bomal-sur-Ourthe illustrates the complexity of the landscape (Cordy, 1974): coexisting were animals from cold steppes, wet grassland, swamps and also woodland, showing the existence of different types of vegetation in favourable places.

Conclusion

Some advances have occurred during the last few years which help us to attempt paleo-climatic reconstructions:

1. A better knowledge of the significance of periglacial features (a) the relation between the soil character and the mean annual temperature for ice and soil wedges (Romanovsky, 1985); (b) the distinction between remnants of palsas and pingos (Pissart, 1985); (c) flat-based involutions as an indication of permafrost (Gullentops and Paulissen, 1978).
2. A better understanding of the influence of local site factors on the different geomorphological processes, as Vandenberghe (1985) has demonstrated in Kempen.
3. The stratigraphic sequence is improved, and we now understand how important are the breaks in Weichselian aeolian sedimentation.

It is clear, however that we still need to improve our knowledge to obtain a better understanding of the paleo-climatic evolution of the last glaciation. Periglacial phenomena have proved to be valuable tools for this work.

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References

Bastin, B. (1974). Recherches sur l'évolution du peuplement végétal en Belgique durant la glaciation du Würm. *Acta geographica Lovaniensia*, **9**, 136 p.

Black, R.F. (1976). Features indicative of permafrost. *Annual review of Earth and Planetary Science*, **4**, 75–94.

Brown, R.J.E. and Péwé, T.L. (1973). Distribution of permafrost in North America and its relationship to the environment: a review, 1963–1973. In, *Permafrost. North America Contribution to the second Intern. Conf.*, Natl. Acad. Sci., Washington.

Cordy, J.M. (1974). Etude préliminaire de deux faunes à rongeurs du Tardiglaciaire belge. *Ann. Soc. Géol. Belg.*, **97**, 5–9.

Damblon, F. (1974). Observations palynologiques dans la grotte de Remouchamps. *Bull. Soc. Roy. belge Anthrop. et Préhist.*, **85**, 131–5.

Dansgaard, W., Johnson, S.J., Clausen, H.B. and Langway, C.C., (1971). Climatic record revealed by the Camp Century ice core. In, *Late Cenozoïc Glacial Ages.* (Ed. K.K. Turekian), pp. 37–56, New Haven, Connecticut.

De Beaulieu, J.L. & Reille M. (1984). A long Upper Pleistocene pollen record from Les Echets, near Lyon, France. *Boreas*, **13** (2), 111–132.

De Gans, W. (1981). *The Drentsche Aa Valley System.* Doctor's thesis. Free University. Amsterdam. 132 p.

De Gans, W., Cleveringa, P. and Gongrijp, G. (1984). Een ontsluiting in de Wal van een pingoruine naby Papenvoort (Drente). *Report Rijksinstituut voor Natuurbeheer*, 84/6, Leersum, 53 p.

De Moor, G. (1981). Periglacial deposits and sedimentary structures in the Upper Pleistocene infilling of the Flemish Valley (NW Belgium). *Biul. Perygl.*, **18**, 277–90.

De Moor, G. (1983). Cryogenic structures in the Weichselian deposits of Northern Belgium and their significance. *Polarforschung*, **53** (2), 79–86.

Dionne, J.-Cl. (1984). Palses et limite méridionale du pergélisol dans l'hémisphère Nord: le cas de Blanc-Sablon, Québec. *Géogr. phys. et Quaternaire*, **38** (2), 165–84.

Gold, L.W. and Lachenbruch, A.H. (1973). Thermal conditions in permafrost. A review of North American literature. In, *Permafrost. North American Contribution to the Second Intern. Conf.*, pp. 3–23, Natl. Acad. Sci., Washington.

Goldthwait, R.P. (1976). Frost sorted patterned ground: a review. *Quaternary Research*, **6**, 27–35.

Goździk, J. (1973). Geneza i pozycja stratygraficzna struktur peryglacjalnych w Srodkowej Polsce. (summary: The genesis and stratigraphical position of periglacial structures in Central Poland). *Acta Geogr. Lodziensia*, **31**.

Gullentops, F. and Paulissen, E. (1978). The drop soil of the Eisden type. *Biul. Perygl.*, **27**, 105–15.

Haesaerts, P. (1984). Aspects de l'évolution du paysage et de l'environnement en Belgique au Quaternaire. Chapitre III: 'Peuples chasseurs de la Belgique préhistorique dans leur cadre naturel'. *Publication Inst. Roy. Sc. Nat. de Belg.*, 27–40.

Haesaerts, P. & Bastin, B. (1977). Chronostratigraphie de la fin de la dernière glaciation à la lumière des résultats de l'étude lithostratigraphique et palynologique du site de Maisières-Canal (Belgique). *Géobios*, **10**, 123–7.

Haesaerts, P. & Van Vliet, B. (1974). Compte rendu de l'excursion du 25 mai 1974 consacrée à la stratigraphie des limons aux environs de Mons. *Ann. Soc. Géol. Belg.*, **97**, 291–324.

Haesaerts, P. & Van Vliet, B. (1981). Phénomènes périglaciaires et sols fossiles observés à Maisières-Canal, à Harmignies et à Rocourt. *Biul. Perygl.*, **28**, 291–325.

Harris, S.A. (1982). Distribution of zonal permafrost landforms with freezing and thawing indices. *Biul. Perygl.*, **29**, 163–82.

Heyse, I. (1983). Fossil cryoturbation types in eolian Würm late glacial sediments in Flanders (Belgium). *Polarforschung*, **53** (2), 87–95.

Karte, J. (1979). Raumliche Abgrennzung und regionale Differenzierung des Periglaziärs. *Bochumer Geographisches Arbeiten*, Heft **35**, 211 p.

Kolstrup, E. (1979). Herbs as July temperature indicators for parts of the pleniglacial and Late Glacial in the Netherlands. *Geol. en Mijnbouw*, **58** (3), 377–80.

Kolstrup, E. (1980). Climate and stratigraphy in Northwestern Europe between 30.000 B.P. and 13.000 B.P. with special reference to the Netherlands. *Meded. Rijks Geol. Dienst*, 32–15, 181–253.

Lachenbruch, A.H. (1966). Contraction theory of ice wedge polygons: a qualitative discussion. *Permafrost International Conference* (*Lafayette, Ind., 11–15 Nov. 1963*). *Proceedings.* pp. 63–71, Natl. Acad. Sci. National Research Council Publication 1287.

Lautridou, J.P. & Sommé, J. (1981). L'extension des niveaux repères périglaciaires à grandes fentes de gel de la stratigraphie du Pléistocène récent dans la France du Nord-Ouest. *Biul. Perygl.*, **28**, 179–85.

Maarleveld, G.C. (1976). Periglacial phenomena and the mean annual temperature during the last glacial time in the Netherlands. *Biul. Perygl.*, **26**, 57–78.

Maarleveld, G.C. (1981). Summer thaw depths in cold regions and fossil cryoturbation. *Geologie en Mijnbouw*, **60**, 347–52.

Maarleveld, G.C. & Van der Toorn, J.V. (1955). Pseudo-sölle in Noord-Nederland. *Tijdschr. Kon. Nederl. Aardrijk. Genootschap*, **72**.

Mackay, J.R. (1978). Contemporary pingos: a discussion. *Biul. Perygl.*, **27**, 133–4.

Mook, W. and Woillard, G. (1982). Carbon-14 dates at Grande-Pile. Correlation of land and sea chronologies. *Science* (Washington, D.C.), **215**, 159–61.

Mullenders, W. and Gullentops, F. (1969). The age of the pingos of Belgium. *The periglacial environment; Past and Present.* (Ed. Troy L. Péwé), pp. 321–35, McGill Queen's University Press. Montreal.

Munaut, A.V. & Paulissen, E. (1973). Evolution et paléo-écologie de la vallée de la petite Nèthe au cours du post-Würm (Belgique). *Ann. Soc. Géol. Belg.*, **96**, 301–48.

Paepe, R. (1964). Les dépôts quaternaires de la plaine de la Lys. *Bull. Soc. belge Géol., Paléont. et Hydrol.*, **73**, 327–65.

Paepe, R. & Somme, J. (1970). Les loess et la stratigraphie du Pleistocène récent dans le N de la France et en Belgique. *Ann. Soc. Géol. du N.*, **90**, fasc. 4, 191–201.

Paepe, R. & Vanhoorne, R. (1967). *The stratigraphy and paleobotany of the Late Pleistocene in Belgium.* Mém. pour servir à l'explication des cartes géologiques et minières de la Belgique. **8**, Bruxelles, 96 p.

Paris, F.P., Cleveringa, P. and De Gans, W. (1979). The Stockersdobbe: geology and palynology of a deep pingo remnant in Friesland (The Netherlands). *Geologie en Mijnbouw*, **58** (1), 33–8.

Péwé, T.L. (1966). Paleoclimatic significance of fossil ice wedges. *Biul. Perygl.*, **15**, 65–73.

Pissart, A. (1983). Remnants of periglacial mounds in the Hautes Fagnes (Belgium): structure and age of the ramparts. *Geol. en Mijnbouw*, **62**, 551–5.

Pissart, A. (1985). Pingos et palses: un essai de synthèse des connaissances actuelles. *Inter-Nord.*, **17**, 21–32.

Pissart, A. & Gangloff, P. (1984). Les palses minérales et organiques de la vallée de l'Aveneau, près de Kuujjuaq, Québec subarctique. *Géogr. physique et Quaternaire*, **38** (3), 217–28.

Pissart, A. & Juvigne, E. (1981). Genèse et âge d'une trace de butte périglaciaire (pingo ou palse) de la Konnerzvenn, Hautes Fagnes, Belgique. *Ann. Soc. Géol. Belg.*, **103**, 73–86.

Poser, H. (1947a). Dauerfrostboden und Temperaturverhaltnijsse während der Würmeiszeit im nicht vereisten Mittel - und West Europa. *Naturwissenschaften*, **34**, 10–18.

Poser, H. (1947b). Auftautiefe und Frostzerrung im Bodem Mitteleuropas Während der Würm-Eiszeit. *Naturwissenschaften*, **34**, p. 323–8 & 262–7.

Poser, H. (1948a). Boden- und Klimaverhältnisse in Mittel- und Westeuropa während der Würmeiszeit. *Erdkunde*, **2**, 53–68.

Poser, H. (1948b). Äolische Ablagerungen und Klima des Spätglazials in Mittel und West Europa. *Naturwissenschaften*, **9**, 269–75, 302–12.

Romanovsky, N.H. (1985). Distribution of recently active ice and soil wedges in the U.S.S.R. *Field and Theory: Lectures in geocryology* (Eds. M. Church and S. Slaymaker), pp. 154–65, University of British Columbia.

Sancetta, C., Imbrie, J. and Kipp, N.G. (1973). Climatic record of the past 130,000 years in the North Atlantic deep-sea core V 28–32: correlations with terrestrial record. *Quaternary Research*, **3**, 110–16.

Vandenberghe, J. (1983). Ice-wedge casts and involutions as permafrost indicators and their stratigraphic position in the Weichselian. In, *Permafrost – Fourth Int. Conference*, pp. 1298–1302, Nat Acad. Sci., Washington.

Vandenberghe, J. (1985). Paleoenvironment and stratigraphy during the last glacial in the Belgian-Dutch Border Region. *Quaternary Research*, **24** (1), 23–38.

Vandenberghe, J. & Vandenbroeck, P. (1982). Weichselian convolution phenomena and processes in fine sediments. *Boreas*, **11**, 299–315.

Van der Hammen, T., Maarleveld, G.C., Vogel, J.C. & Zagwijn, W.H. (1967). Stratigraphy, climatic succession and radiocarbon dating of the last glacial in the Netherlands. *Geol. en Mijnbouw*, **46**, 79–95.

Van Vliet-Lanoe, B. (1985). Frost effects in soils. In, *Soils and Quaternary Landscape Evolution* (Ed. J. Boardman), pp. 117–58, Wiley and Sons, Chichester.

Washburn, A.L. (1980). Permafrost features as evidence of climatic change. *Earth-Sci. Rev.*, **15**, 327–402.

Williams, P.J. (1961). Climatic factors controlling the distribution of certain frozen ground phenomena. *Geogr. Annlr.*, **43**, 339–47.

Zagwijn, W.H. (1975). Chronostratigraphie en biostratigrafie, indeling van het Kwartaire op grond van veronderingen in vegetatie in Klimaat. In, *Toelichting by geologische overzichts-Kaarten van Nederland. Haarlem. Ryks geologische Dienst.* (Eds. W.H. Zagwijn and C.J. Van Staalduinen), pp. 109–14.