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Some Periglacial Phenomena and their Stratigraphical Position in Weichselian Deposits in the Netherlands

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Summary: The most characteristic periglacial features in the Weichselian deposits of the Netherlands are ice wedge casts and large involutions. The ice wedge casts consist of a central part with vertical lamination and an external part which has been lowered blockwise in a graben-like structure. They are mostly arranged in a subparallel pattern, which represents the initial stage in the development of a polygonal network. Those involutions with amplitude of ± 1.5 m are often flatbottomed and symmetrical. They are due to periglacial loadcasting and require a reversed density gradient and a state of liquefaction. These conditions probably were present when permafrost degraded at places of poor drainage and oversaturation of soil. Ice wedge casts are always closely associated with involutions. Sand wedge casts are rarely found. The lithostratigraphy reflects an evolution from a fluvial and wet environment at the beginning of the Weichselian to conditions with more aeolian (but reworked) supply and to pure aeolian deposition in the Pleniglacial. Two levels of ice wedge casts connected with cryoturbation structures point to permafrost conditions in the beginning of the Pleniglacial, about 20 to 25,000 years BP. In between these two periods conditions were relatively milder. The end of the Pleniglacial was characterized by a severe, dry climate.

Zusammenfassung: Eiskeilpseudomorphosen und große Involutionen sind die charakteristischen fossilen Periglaziärerscheinungen in den weichselzeitlichen Ablagerungen in den Niederlanden. Die sekundär gefüllten Eiskeile bestehen aus einem zentralen, vertikal laminierten Teil und einem in Blöcke zerfallenen, nach unten hinabgesunkenen Teil. Im allgemeinen sind sie subparallel angeordnet. Dieses Muster repräsentiert das Initialstadium in der Entwicklung von Eiskeilpolygonen. Die großen Involutionen (Mächtigkeit bis 1,5 m) haben vielfach eine flache Untergrenze und sind symmetrisch entwickelt. Sie sind vom periglaziären „load cast"-Typ. Zu ihrer Bildung ist ein umgekehrter Dichtegradient sowie Wasserübersättigung mit Verflüssigung notwendig. Diese Bedingungen waren zur Zeit der Permafrostdegradation gegeben. Die Eiskeilpseudomorphosen treten fast immer mit den überlagernden Involutionen zusammen auf. Sekundär gefüllte Sandkeile sind selten. In der lithostratigraphischen Abfolge ist eine Entwicklung von fluvialen und feuchten Bedingungen am Anfang des Weichselglazials bis zu zunehmender äolischer Akkumulation im Hochglazial zu erkennen. Zwei Niveaus von Eiskeilpseudomorphosen in Verbindung mit überlagernden Involutionen weisen auf zwei Perioden mit Dauerfrostboden am Anfang des Pleniglazials hin (ca. 20—25 000 Jahre B.P.). Dazwischen war das Klima relativ mild. Das Ende des Hochglazials war wieder durch strenge und trockene Klimabedingungen charakterisiert.

INTRODUCTION

For many years the coversand areas of northern Belgium, The Netherlands and northern Germany have been studied for their significance as to the nature of Pleistocene periglacial processes. Reference can be made to EDELMAN et al. (1936), MARECHAL & MAARLEVELD (1955), GRIPP (1963), GULLENTOPS & PAULISSEN (1978), MAARLEVELD (1956, 1981), DE MOOR (1983), VANDENBERGHE & VAN DEN BROEK (1982). The early papers usually give a descriptive analysis accompanied by some general, speculative interpretations. Later, parallels with actual periglacial phenomena and conditions were made and genetic explanations and the dynamics of periglacial phenomena were stressed. In some cases a cautious start has been made to a (semi)-quantitative approach.

In the coversand areas a variety of periglacial features have been observed. In this paper only wedge structures and involutions which are found in the Weichselian deposits of the southern Netherlands and northern Belgium will be dealt with (Fig. 1). All are formed in loose, fine aeolian or fluvial sands and loams.

Many periglacial structures have environmental significance. Therefore, it is important to place them in a stratigraphic framework. A lithostratigraphic column for the areas under study has been developed (VANDENBERGHE, 1981; VANDENBERGHE & KROOK, 1981) and supplemented with chronostratigraphic data (VANDENBERGHE, 1982).

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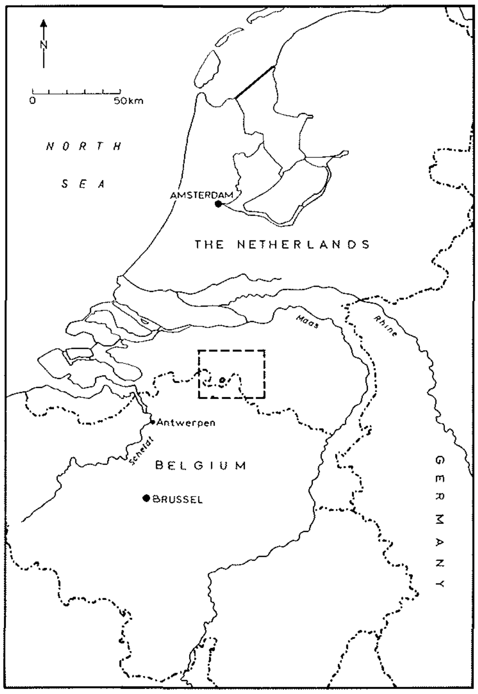

Fig. 1: Location map of the study area.

Abb. 1: Lage des Untersuchungsgebietes.

PERIGLACIAL PHENOMENA

Ice-wedge casts

Ice-wedge casts found in the study region consist of an internal and an external part. Each part is genetically different. The internal part shows a wedge form with more or less distinct vertical lamination (Fig. 2). The infilling sediment is clearly derived from the adjacent layers and is not brought in from the surface at the time of ice wedge growth (e. g., by eolian acitivity). Additional proof comes from sediment-petrological analyses which show the same heavy mineral composition for both the sediments infilling the wedge and those surrounding the wedge. The sediments deposited at the time of ice-wedge formation have a different composition. As degradation of the frozen ground and melt of the ice wedges progresses, the surrounding sediments would have become wet and muddy. The space left by the melt of the ice is filled with liquefied adjacent sediment. This process gives rise to the vertical lamination of the central part of the ice-wedge cast.

The external part does not show any flow structures, but consists of blocks which have been displaced downward along extension faults (Fig. 2). The zone adjacent to the former ice wedge has clearly been lowered in a graben-like structure at the time of melt of the ice. Apparently, this blockwise movement is only possible when the ground is still frozen, although the wedge is already melting at its edges. This implies that this process occurs before or simultaneously with the development of the internal vertical laminated zone. Movements in the zone adjacent to the degrading ice wedge result in a disturbed zone which is several times wider than the original ice core.

As to the dimensions, the width of an ice-wedge cast should best be measured only at its inner part. This generally amounts to 15 to 25 cm at the top of the cast in the coversand region. The depths of the casts are generally about 1.5 m and do not exceed 2 m. However, in most cases, the top of the cast cannot be defined. Thus, the dimensions of the ice wedge casts are relatively small.

Modern periglacial environments report that ice wedges tend to form a polygonal network. Starting from a vertical exposure the horizontal picture of the ice-wedge casts was reconstructed at a few localities. Such a polygonal pattern could not be demonstrated in our case where an almost parallel arrangement of ice wedge casts seems to prevail (Fig. 3). It is assumed that the linear pattern represents the start of the development of a polygonal pattern. In fact, solitary ice-wedge casts of this linear pattern are found more frequently than the real polygonal networks of ice-wedge casts, as described for example by GULLENTOPS & VANDENBERGHE (1981) at Ramsel in northern Belgium. This means that the development of the polygonal pattern of Weichselian ice-wedge casts in the Belgian and Dutch coversand areas was only in its initial stage (analogous to the ''incomplete mud cracks'' of SHROCK, 1948).

Involutions

a) Mechanism

Involutions of amplitude of ± 1.5 m are also very characteristic in the Weichselian deposits. They show a

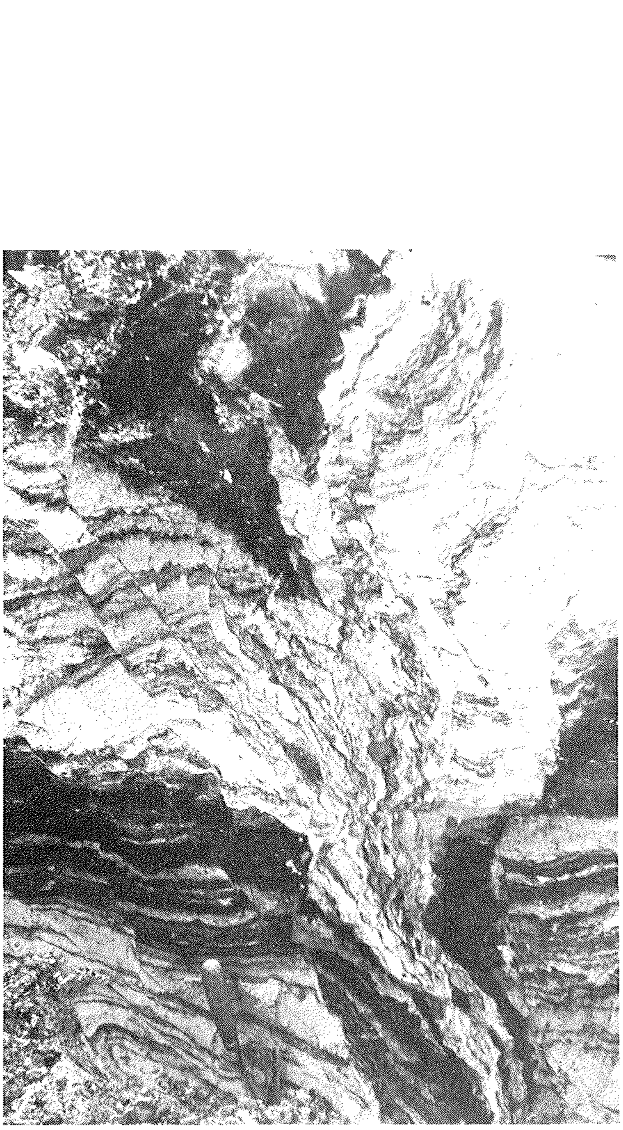

Fig. 2: Ice-wedge cast with vertical lamination in the central part and block-faulted structure in the external part (Tilburg Blaak, southern Netherlands).

Abb. 2: Sekundär gefüllter Eiskeil mit vertikaler Bänderung im Zentrum und schollenartigen Verwerfungen am Rande (Tilburg Blaak, südliche Niederlande).

clear symmetrical pattern. This suggests that they have been produced by alternating upward and downward movements (Fig. 4). This regularity cannot be the result of purely local events. However, the original homogeneous horizontal layering precludes explanations where lateral heterogeneity is a necessary condition (e. g., in PISSART's (1970) experiments). Although soils are never perfectly homogeneous occasional irregularities will cause local rather than regularly spaced deformations. It follows that there is no reason to suppose differential cryostatic pressures or differential volume changes during freezing to produce the involutions. Furthermore, the deformations show distinct flow characteristics, which are difficult to explain if the intrusions penetrate frozen material (FRENCH, 1976).

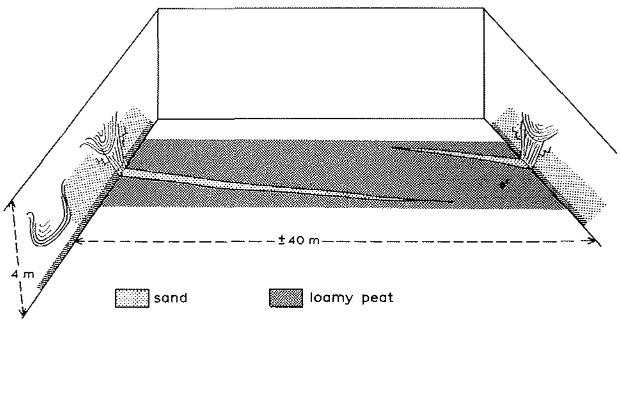

Fig. 3: Diagrammatic representation of subparallel arranged pattern of ice-wedge casts (Tilburg Blaak).

Abb. 3: Diagramm subparalleler angeordneter Eiskeilmuster (Tilburg Blaak).

Fig. 4: Upper peat layer sunk down within older sands (Alphen, southern Netherlands).

Abb. 4: Ältere Sande mit eingesunkener überlagernder Torfschicht (Alphen, südliche Niederlande).

For a loadcasting origin two conditions have to be fulfilled. Apart from a reversed density gradient, it is necessary that the carrying capacity of the lower beds is such that the overlying deposits can sink into them. Density measurements did not reveal reversed density gradients, even when the sediments were water-saturated (VANDENBERGHE & VAN DEN BROEK, 1982). Also, the high shear strengths of the sediments oppose any movement. Consequently, loadcasting could only occur in a setting which differs from the present one. In this respect, the flattened bottom of many involutions (Fig. 5) and the constant depth to which they have sunk (± 1.6 m) points to the existence of an impervious layer. However, there is no lithological contrast at this level. Since the top of the ice wedge casts coincides with the base of the involutions, the impervious layer is explained as former permafrost. The top of permafrost is a favourable situation for ice in various forms (e. g., see POLLARD & FRENCH, 1980). When such ice-rich permafrost degrades, large amounts of water are liberated. In a flat landscape of fine sediments a poorly drained oversaturated condition may result. There are two consequences. First, the water volume exceeds porosity and thus makes the underlying sediment less dense. Second, the excess pore water pressures cause the loss of intergranular contacts leading to liquefaction. It means that during melt of the permafrost a reversed density gradient exists and cohesion has disappeared. In this way it can be argued that the involutions are caused by periglacial loadcasting (VANDENBERGHE & VAN DEN BROEK, 1982).

The three dimensional structure of involutions which has been observed in the field shows remarkable similarity with theories developed and laboratory experiments conducted by DZULINSKI (1966), ANKE-

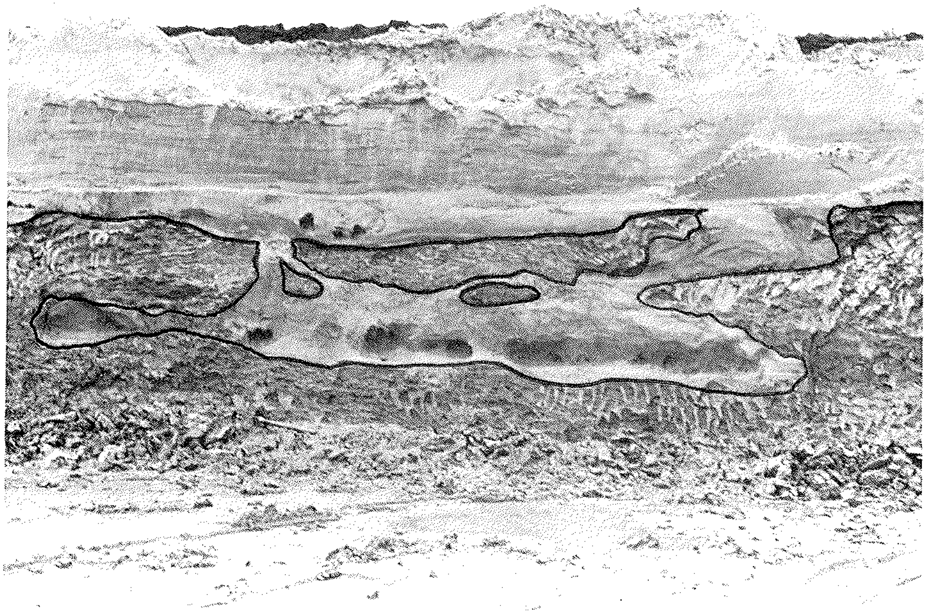

Fig. 5: Flat-bottomed sand involutions in clay (Meerle, northern Belgium).

Abb. 5: Sandiger Tropfenboden in Ton mit flacher Untergrenze (Meerle, Nord-Belgien).

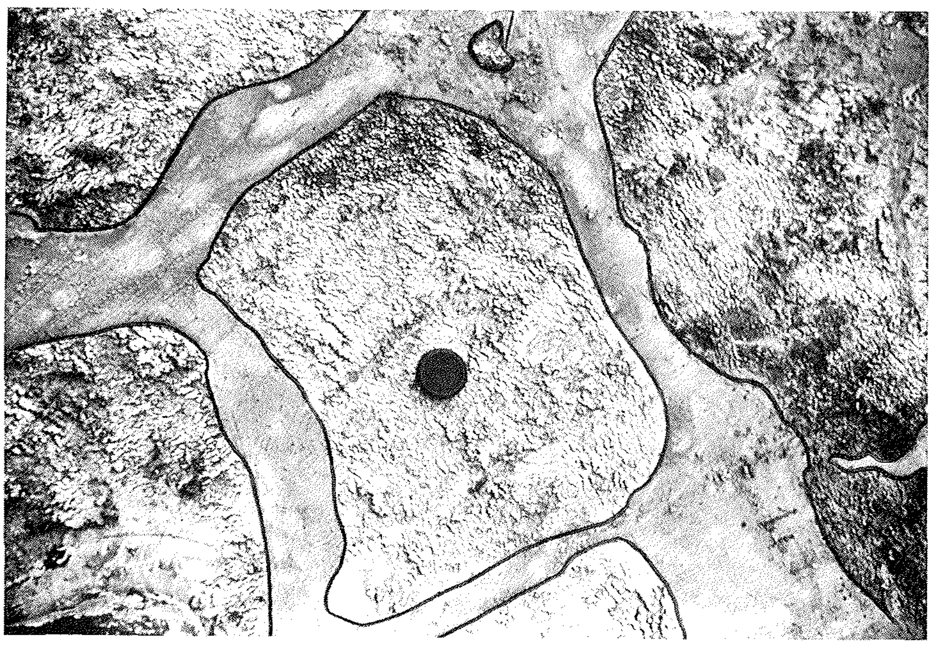

Fig. 6: Horizontal plan of the involutions of Fig. 5.

Abb. 6: Horizontale Ansicht der Involutionen von Abb. 5.

TELL et al. (1970) and others. These structures, too, were the result of gravitational movements due to reversed density gradients. However, in contrast to Dzulinski's idea of a hexagonal horizontal pattern, in reality a more or less quadrangular pattern has been found at the top of the involutions (Fig. 6).

b) Implications

Several implications of the proposed mechanism need to be mentioned. First, involutions do not develop during the climatic minimum of the cold period, but at the transition from cold to warm, i. e., when permafrost is melting. This may explain why cryoturbations are seldom observed in permafrost regions today. It also implies that cryotubations are younger than the ice wedges and contemporaneous with their sedimentary infill.

The close connection between ice-wedge casts and involutions may be observed in many localities. Ice-wedge casts always occur below the soil which has moved downward (Fig. 7). The fact that individual uprising and downsinking structures are more numerous than ice-wedge casts is not surprising. Indeed, the number of up- and downward-moving cells for a given area is only dependent on the thickness and character of the thawed material. Moreover, the presence of ice-wedges is not necessary for the initiation of involutions, provided enough water was present at the top of the degrading permafrost by the melt of ice lenses. On the other hand, downward movement of overlying soil will be initiated preferentially at the top of a melting ice-wedge. This mechanism also explains why ice-wedge casts are frequently deformed, especially near their top.

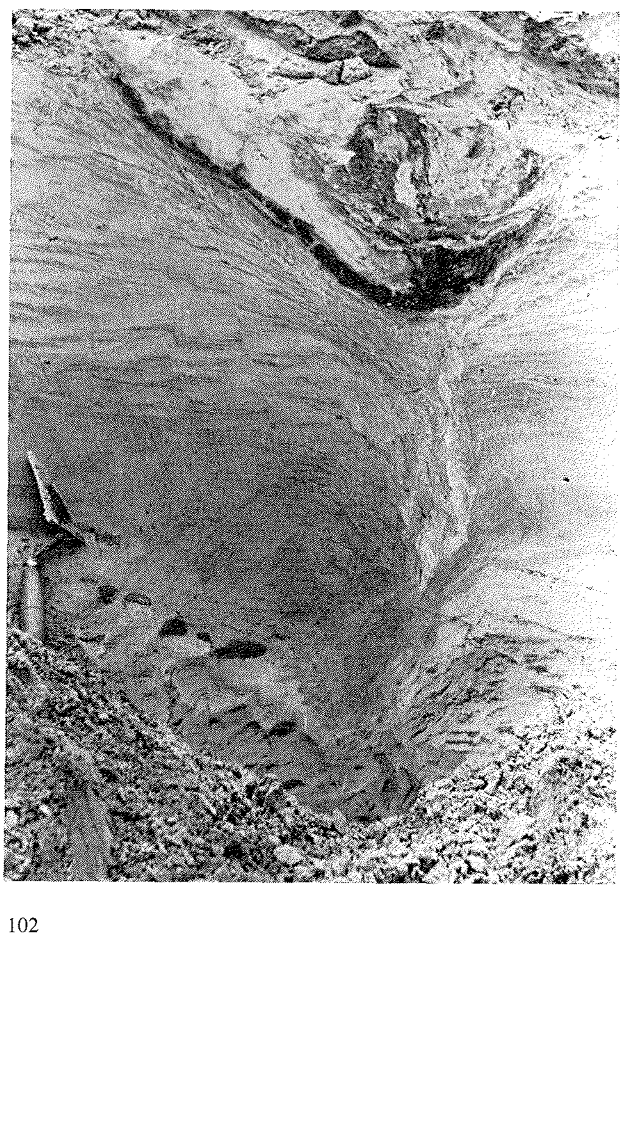

Fig. 7: Photograph showing the relationship between involution and ice-wedge cast (Alphen).

Abb. 7: Stratigraphische Beziehung zwischen Involutionen und sekundär gefülltem fossilem Eiskeil (Alphen).

The amplitude of the involutions probably did not equal the thickness of the acitve layer during the cold period but corresponded to the depth of the degraded permafrost table. Therefore, the amplitude of cryoturbation structures can be considerably greater than the thickness of the acitve layer in actual permafrost regions (see also (MAARLEVELD, 1981).

Finally, this mechanism explains the frequency of involutions in loamy sediments which possess reduced permeabilities and impeded drainage. In such sediments, oversaturation and liquefaction may be retained for a certain time. This contrasts with well-drained coarser sediments which show fewer deformations.

It should be borne in mind that one is dealing with involutions of amplitude ± 1.6 m which are often flat-bottomed. Although their dependence on permafrost has been suggested, small scale involutions, which are not treated here, may develop in seasonally frozen ground.

c) Further evolution

Due to the mechanism described above, the original lateral homogeneity may be replaced by laterally changing lithologies. This means that physical properties such as water content and freezing rate may alternate in the horizontal section. Thus, cryostatic pressures may develop due to different freezing rates and volumetric changes. In turn, these may initiate differential movement of the sediments.

Fig. 8 may be interpreted to show that involution processes give rise to the development of sand pockets within a loam layer. Then, in a second phase, the saturated sediments are frozen again and the differential volumetric increase of the sand pockets leads to an upward motion involving slight undulations of the sand-loam complex. This process requires only local and temporary water saturation and not necessarily permafrost.

Sand wedge casts

In the Netherlands and Belgium sand wedge casts are scarce. They are characterized by a clear vertical lamination and by upturning of the surrounding sediment (Fig. 9). In contrast to ice wedge casts, there is little or no disturbance, either at the top or at the sides. It follows that the top of the sand wedge cast represents the former surface. This does not hold for ice-wedge casts.

In some cases transition forms between ice and sand wedge casts have been found, characterized by minor involution structures at the top and without lateral disturbances (Fig. 9).

According to many authors, sand wedges indicate perennial frozen ground and a dry climate. According to KARTE (1981), Weichselian sand wedge casts are not found with certainty in Western Europe.

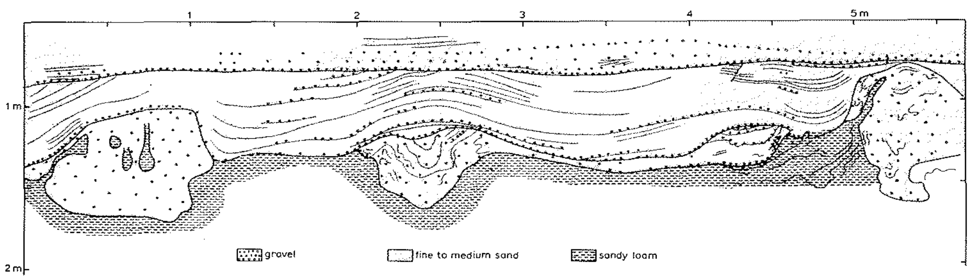

Fig. 8: Section from Weelde, northern Belgium, showing the uplift of older involuted sand bodies due to differential cryostatic pressures.

Abb. 8: Aufgepreßte ältere verwürgte Sande im Aufschluß bei Weelde, Nord-Belgien.

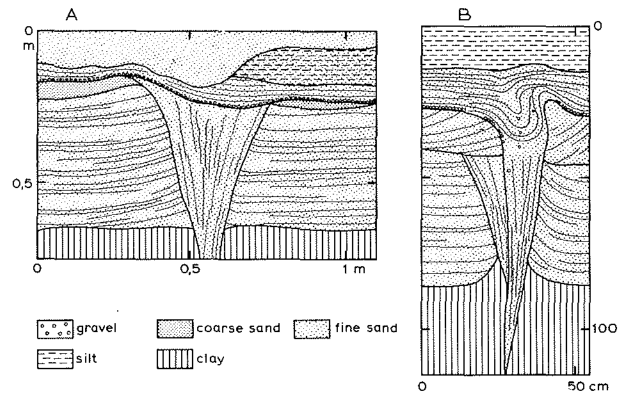

Fig. 9: Typical sand wedge cast (A); tansitional form of sand wegde cast (B) (Ravels, northern Belgium).

Abb. 9: Typischer fossiler Sandkeil (A); Übergangsform zu fossilem Sandkeil (B) (Ravels, Nord-Belgien).

STRATIGRAPHIC POSITION

Involutions and ice and sand wedges did not form throughout the whole Weichselian stage. Because these periglacial features are excellent paleoclimatic indicators, it is important to place them in a stratigraphical sequence. Many observations and analyses have resulted in a detailed stratigraphical diagram for the southern Netherlands and northern Belgium (Fig. 10). It will be discussed in a general way only with emphasis on the periglacial structures. Besides, an estimate is given for the climatic environment of the Weichselian Pleniglacial. Unfortunately, it is incomplete because of several gaps in sedimentation. This qualitative approach is based mainly on criteria derived from periglacial phenomena as proposed by MAARLEVELD (1976) and on vegetation characteristics as revealed in pollen diagrams.

At the base the sediments are thought to have been deposited in a fluvial or wet environment at the close of the Eemian or during the Early Weichselian. During the Weichselian Pleniglacial, aeolian sediments dominate. At first, loams and fine sands were reworked, but later they were preserved in situ as coversands and dune sands. In this diagram the importance of humidity for the sedimentary facies can be observed. This has implications for periglacial features.

As to the occurrence of periglacial structures, the most striking fact is the occurrence of two stratigraphic levels of ice wedge casts which are associated with overlying cryoturbations. They probably represent two cold periods with permafrost conditions. On top of each level of cryoturbations is a desert pavement. These are important lithostratigraphic marker horizons. The upper one represents the Beuningen gravel bed (VAN DER HAMMEN et al., 1967). The age of the older cold phase is situated at the very beginning of the Pleniglacial. According to data obtained by DE MOOR et al. (1978) and VANDENBERGHE & VAN DEN BROEK (1982), this period of permafrost conditions is older than ca. 50,000 years BP. On the other hand, the data obtained from Amersfoort (ZAGWIJN, 1961; GROOTES, 1977) allows one to date the ice wedge casts with associated convolutions as being younger than the Brørup-interstadial ($\pm$63,500 BP according to GROOTES, 1977). In the region of Brugge (exposure Vijve-Kapelle) some data are available concerning the age of the upper cold phase (VANDENBERGHE et al., 1974; VANDENBERGHE & GULLENTOPS, 1977). It is younger than the age of a peat layer, dated at 26,220 years BP, disturbed by younger ice wedges. Degradation of this permafrost occurred later than 24,760 years BP which is the age of a peat layer deformed by involutions. On the other hand, these ice wedge casts and involutions are older than the Upper Pleniglaical coversands and desert pavements (= Beuningen gravel bed). The age of the younger period of permafrost is thus somewhat less than 25,000 years BP. Probably, it formed during the maximum extent of the last glaciation about 18 to 22,000 BP (see COOPE & SAND, 1966; DREIMANIS, 1973; MOJSKI, 1980).

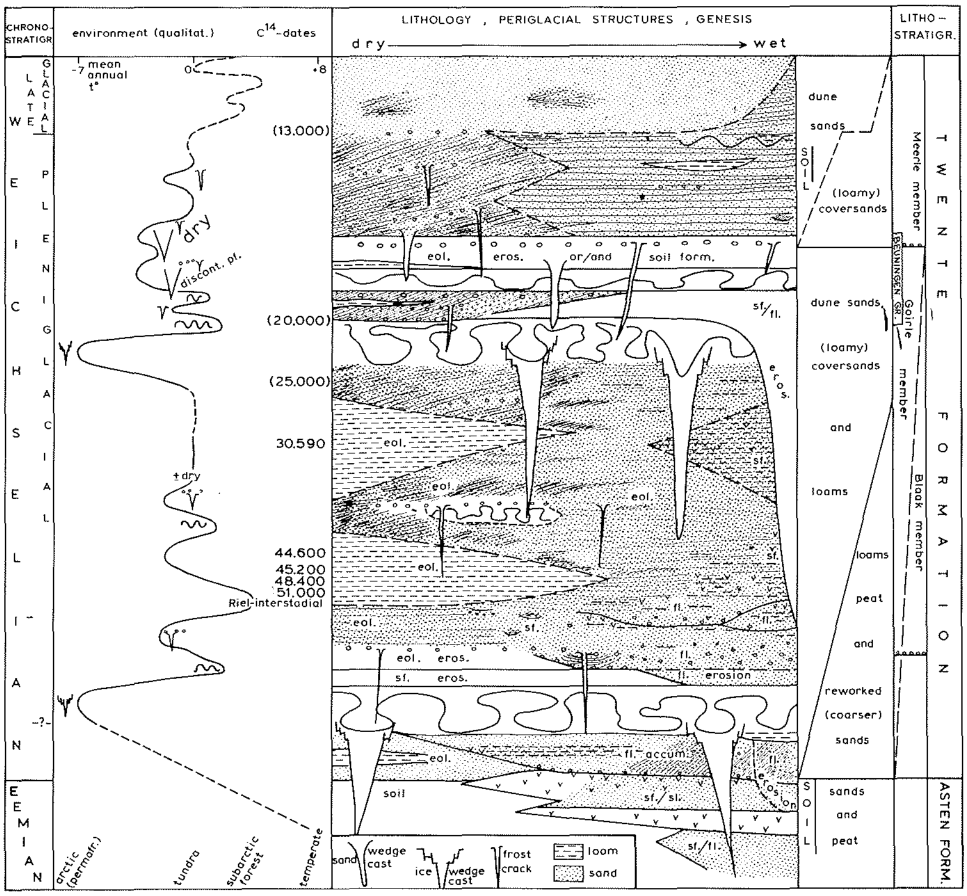

Fig. 10: Stratigraphic succession of Weichselian deposits and environmental conditions in the southern Netherlands and northern Belgium.

Abb. 10: Stratigraphische Abfolge weichselzeitlicher Ablagerungen und Milieubedingungen in den südlichen Niederlanden und in Nord-Belgien.

Between the two levels of ice wedge casts small involutions and narrow frost cracks are found. The long interval between the two cold periods was thus relatively mild. This was also the case in North-America (e. g., SANCETTA, et al. 1973; DREIMANIS & RAUKAS, 1973; DREIMANIS, 1981). There, the beginning of the Middle Wisconsin interstadial complex is dated at 65,000 years BP. The period between ±20,000 years BP and the end of the Pleniglacial was also very severe as proven by the occurrence of aeolian desert pavements and rare sand wedge casts. However, further indications of permafrost are missing. In any case, it was a dry period, characterized by the relative absence of fluvial activity and the presence of aeolian deposits.

CONCLUSIONS

Ice-wedge casts consist of an external blocky part and an internal part with vertical laminations. The sediments of both parts come from the layers adjacent to the original wedge and thus may be older than the formation of the wedge. In many cases, the ice wedge casts are arranged in a subparallel pattern. This is interpreted as an initial stage of a polygonal network.

Large scale involutions originated at the top of degrading permafrost at the end of the last cold phase. In these circumstances, reversed density gradients and states of liquefaction were locally created. It follows that involutions with large amplitude (up to 1.8 m) are indicators for the existence of former permafrost.

Two stratigraphic levels of large involutions associated with ice-wedge casts have been found in the Upper Quaternary deposits of the Netherlands. They represent two periods of permafrost conditions in the Weichselian Pleniglacial: the older one occurred between the Brørup-interstadial and 50,000 years BP, the younger one at about 20 to 25,000 years BP.

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References

Anketell, J. M., Cegla, J. & S. Dzulinski (1970): On the deformational structures in systems with reversed density gradients. — Ann. de la Soc. Géol. de Pologne 40: 3—30.

Coope, G. R. & C. H. S. Sands (1966): Insect faunas of the last glaciation from the Thames valley, Warwickshire. — Proc. R. Soc. B 165: 389—412.

De Moor, G. (1983): Cryogenic structures in the Weichselian of Northern Belgium and their significance. — Polarforschung 53 (2).

De Moor, G., Heyse, I. & V. De Groote (1978): An outcrop of Eemian and Early Weichselian deposits at Beernem (N. W. Belgium). — Bull. v. d. Belgische Vereniging voor Geologie 87: 27—36.

Dreimanis, A. (1973): Mid-Wisconsin of the Eastern Great Lakes and St. Lawrence Region, North America. — Eiszeitalter u. Gegenwart 23/24: 377—379.

Dreimanis, A. (1981): Middle Wisconsin Substage in its type region, the Eastern Great Lakes, Ohio River Basin, North America. — Quat. Studies in Poland 3: 21—28.

Dreimanis, A. & A. Raukas (1973): Did Middle Wisconsin, Middle Weichselian, and their equivalents represent an interglacial or an interstadial complex in the northern hemisphere? — 9th INQUA Congress, Abstracts, 84—85.

Dzulinski, S. (1966): Sedimentary structures resulting from convection-like pattern of motion. — Ann. de la Soc. Géol. de Pologne 36: 3—21.

Edelman, C. H., Florschutz, F. & J. Jeswiet (1936): Über spätpleistozäne und frühholozäne kryoturbate Ablagerungen in den östlichen Niederlanden. — Verh. Geol.-Mijnbouwk. Gen., Geol. Serie XI: 301—336.

French, H. M. (1976): The periglacial environment. — 309 pp., London.

Gripp, K. (1963): Zur Entstehung von Tropfenböden. — Neues Jb. f. Geol. u. Paläont., Monatshefte 9: 490—492.

Grootes, P. M. (1977): Thermal diffusion isotopic enrichment and radiocarbon dating beyond 50.000 years BP. — 221 pp., Groningen.

Gullentops, F. & E. Paulissen (1978): The drop soil of the Eisden type. — Biul. Peryglac. 27: 105—115.

Gullentops, F. & J. Vandenberghe (1981): Ramsel claypits. — In: F. Gullentops, E. Paulissen & J. Vandenberghe, Fossil periglacial phenomena in NE-Belgium, Biul. Peryglac. 28: 350—352.

Karte, J. (1981): Zur Rekonstruktion des weichselhochglazialen Dauerfrostbodens im westlichen Mitteleuropa. — Bochumer Geogr. Arb. 40: 59—71, Paderborn.

Marechal, R. & G. C. Maarleveld (1955): L'extension des phénomènes périglaciaires en Belgique et aux Pays-Bas. — Meded. Geol. Stichting N. S. 8: 77—86.

Maarleveld, G. C. (1956): Sur les sédiments périglaciaires en Hollande: formes et phénomènes. Notre connaissance et nos activités sur ce terrain. — Biul. Peryglac. 4: 73—82.

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

Maarleveld, G. C. (1981): Summer thaw depth in cold regions and fossil cryoturbation. — Geologie & Mijnbouw 60: 347—352.

Mojski, J. (1980): Vistulian stratigraphy in the glaciated area of the Polish Lowlands. — Quat. Studies in Poland 2: 77—98.

Pissart, A. (1970): Les phénomènes physiques essentiels liés au gel, les structures périglaciaires qui en résultent et leur signification climatique. — Ann. de la Soc. Géol. de Belgique 93: 7—49.

Pollard, W. H. & H. M. French (1980): A first approximation of the volume of ground ice, Richards Island, Pleistocene Mackenzie delta, NWT, Canada. — Canad. Geotechn. J. 17: 509—516.

Sancetta, C., Imbrie, J. & N. G. Kipp (1973): Climatic record of the past 130.000 years in North Atlantic deep-sea core V23-82, correlation with the terrestrial record. — Quat. Res. 3: 110—116.

Shrock, R. (1948): Sequence in layered rocks. — 507 pp., Toronto.

Vandenberghe, J. (1981): Weichselian stratigraphy in the southern Netherlands and northern Belgium. — Quat. Studies in Poland 3: 111—118.

Vandenberghe, J. (1982): Upper Pleistocene stratigraphy and paleo-environment of the coversand region in the southern Netherlands and northern Belgium. — 11th INQUA Congress, Abstracts 1: 326.

Vandenberghe, J., Vandenberghe, N. & F. Gullentops (1974): Late Pleistocene and Holocene in the neighbourhood of Brugge. — Meded. Kon. Acad. Wetenschappen, Letteren en Schone Kunsten v. België, Kl. Wetenschappen 36: 1—77.

Vandenberghe, J. & F. Gullentops (1977): Contribution to the stratigraphy of the Weichsel Pleniglacial in the Belgian Coversand Area. — Geologie & Mijnbouw 56: 123—128.

Vandenberghe, J. & L. Krook (1981): Stratigraphy and genesis of Pleistocene deposits at Alphen (southern Netherlands). — Geologie & Mijnbouw 60: 417—426.

Vandenberghe, J. & P. Van den Broek (1982): Weichselian convolution phenomena and processes in fine sediments. — Boreas 11: 299—315.

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

Zagwijn, W. H. (1961): Vegetation, climate and radiocarbon datings in the Late Pleistocene of the Netherlands I: Eemian and Early Weichselian. — Meded. Geol. Stichting N. S. 14: 15—45.