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Fossil polygonal periglacial structures in Flanders (Belgium)

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ABSTRACT: A systematic survey of aerial photographs in Flanders reveals an ephemeral visible polygonal pattern on the dissected plateau between the Coastal Plain and the Flemish Valley. The paper describes the characteristics of this pattern and discusses the origin and the age of these phenomena. The study is based on a comparative study of the literature, the analysis of aerial photographs, coupled with intensive fieldwork based on excavations. The spatial distribution of the sites, the visibility and the spatial structure of the patterns are described. Based on air photos the borders of the polygonal patterns were reconstructed and trenches were excavated in order to find underlying field evidence. The pattern corresponds with the infillings of frost wedges and excavated structures show characteristics of composite and ice-wedge pseudomorphs. The structures suggest formation in a continuous permafrost environment as a result of thermal contraction cracking. These features have been constrained to the period between the Elsterian and Weichelian, but are most probably of Late Pleistocene age.

1 INTRODUCTION

1.1 *Definition of the problem*

In Flanders (Belgium), various aerial photographs suggest the presence of polygonal networks (Fig. 2a), such as on the plateau between the Coastal Plain and the Flemish Valley (Figs. 1a, b). In this paper the origin and the age of these phenomena are discussed.

According to Washburn (1973), polygonal networks have a worldwide occurrence. The largest polygons however, are restricted to cold periglacial and warm semi-arid environments.

All the polygonal networks visible in the present-day temperate regions of the mid-latitudes are considered as imprints from differential crop ripening of an underlying network of fossil frost-wedges, developed under palaeo-periglacial conditions (Christensen 1974; Gozdzik 1994; Johnson 1990; Kozarski 1993, 1995; Morgan 1971, 1972; Romanovskij 1973; Svensson 1972, 1973, 1976, 1984, 1988, 1990; Vandenberghe 1992; Walters 1994; Washburn 1973).

Until now no evidence for these phenomena has been found in northern Belgium despite their presence in other European countries such as Poland and the U.K. This detailed study of networks is based on the aerial photograph archive of Prof. Dr. Bourgeois (RUG, Department of Archaeology and Old History of Europe) that was gradually set up with the assistance of J. Semey.

The term "frost-wedge" is used for all wedge structures that originate due to thermal contraction in a frozen soil (French 1996; Kolstrup & Mejdahl 1986). The distinction between a permanent frost-wedge, developed in permafrost and a seasonal frost-wedge ("soil-wedge"), developed in a seasonally frozen ground is critical (Romanovskij 1985).

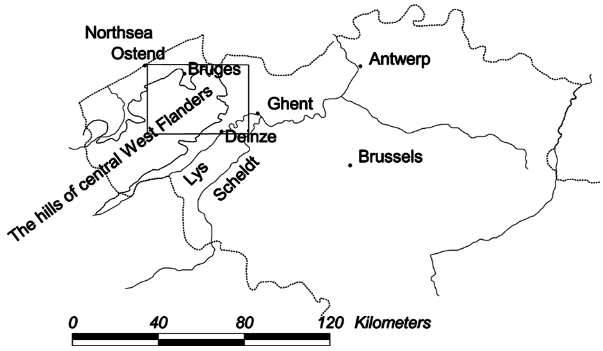


Figure 1a. General localisation of the study area.

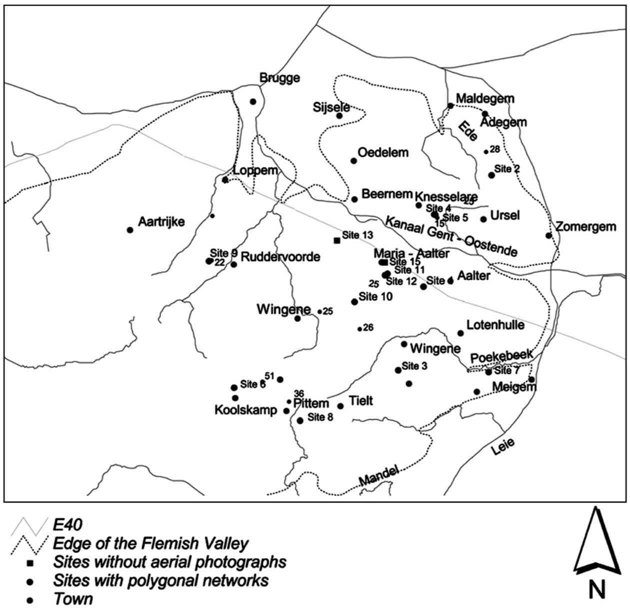


Figure 1b. Localisation of the sites where research was carried out.

According to the primary infilling, distinctions are made between ice-wedges, filled with ice, a mineral-wedge, filled with mineral material, and a composite-wedge, that consists of a mixture of both ice and mineral material. On the basis of the degree of deformation of fossil frost-wedges, a distinction is made between a "cast", that bears some resemblance to the original form and a "pseudomorph" that bears little resemblance to the original form (French 1996, p. 244).

1.2 *Methodology*

This paper presents an analysis of aerial photographs coupled with intensive fieldwork, based on excavations.

Firstly, all the oblique aerial photographs were georeferenced with the help of the software "ILWIS" (RUG, Department of Regional Geography, Prof. Dr. Antrop M.). Subsequently, the polygonal networks were mapped cartographically with the help of the software "Arc View" (Fig. 2b). The aim of the geometrical transformation was to obtain correctly orientated and full-sized polygonal networks. Polygonal patterns were reconstructed in the field and trenches were excavated in order to find underlying structures.

The observations of the polygonal networks in the field were impeded by soil formation, homogenisation and a high groundwater level during wintertime. Special attention is paid to visible macroscopic structures, because they are of prime importance to understand the mechanism of infilling.

A relative age for the features is obtained, based on the geomorphological position, the lithological contexts and the relation to other sedimentary structures of the polygonal patterns.

1.3 *Study area*

The study area is situated in the northern part of the plateau between the Coastal Plain and the Flemish Valley (Fig. 1). The rolling landscape slopes to the northeast, with mean heights of 20 m in the north and 50 m in the south.

A scarp and vale structure reflects successive denudation in the Tertiary clayley and sandy substratum, infilled and levelled to some degree by Quaternary deposits (Heyse 1998).

2 ANALYSIS OF THE AERIAL PHOTOGRAPHS

2.1 *Detection of polygonal networks*

The polygonal networks are periodically visible in cultivated land (Fig. 2a). The outline of the polygons is explained by variation in the ripening of crops and as a consequence the features are therefore known as "crop marks" (Svensson 1982).

The controlling factors influencing their visibility are the thickness of the surface Quaternary cover, the soil moisture differences, the contrast in lithology between host and fill materials, the type of growth, the period of the year and the meteorological conditions before and during the survey of the aerial photographs.

2.2 *The spatial distribution*

All the sites where polygonal networks occur are situated on the plateau between the Coastal Plain and the Flemish Valley (Fig. 1b). They are mainly located on low-angled (<1°), NW – NE orientated slopes, sometimes on the interfluves and the rims of valleys.

2.3 *The spatial structure*

Based on the size, the geometry and the spatial pattern of the polygonal structures 6 types have been

Figure 2a. Polygonal networks visible in arable land on an aerial photograph, site 1 (coordinates: X = 83.35 km; Y = 197.25 km; Lambert-72), Aalter, Oost-Vlaanderen, Belgium (Photo: Semey J., 07-08-1990, slidenumber 53 026, Department of Archaeology and Old History of Europe, RUG). Arrow: orientation (North).

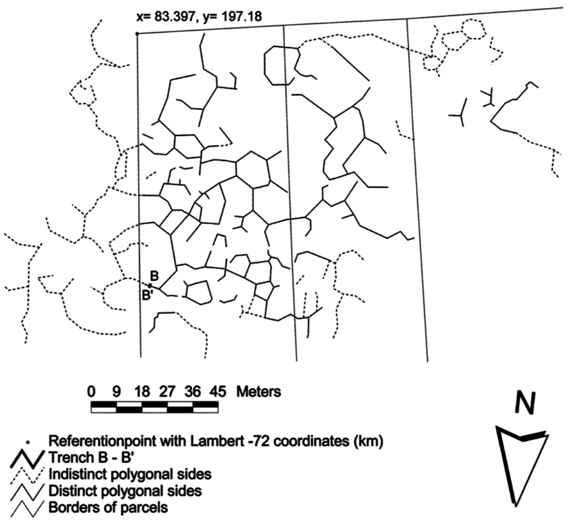
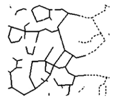
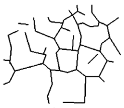
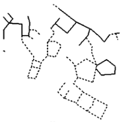
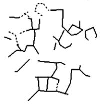
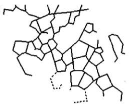


Figure 2b. Cartographic representation of the networks visible in Figure 2a.

Table 1. Typology of polygonal networks in Flanders, with characteristics and site properties.

Number	Cartographic representation Scale: 10 m	Site	Properties	Situation Soil texture - substratum
Type I		Site 4 Site 3 Site 5	Orthogonal Random Mean size: > 11 m	S - w L/P - w S - w
Type 2		Site 12 Site 11 Site 1	4-, 5-, 6-angled Random Size: > 11 m	Z - w Z - w Z - z
Type 3		Site 8	4-, 6-, 7-angled Random Size: 9,5 m	L/P - /
Type 4		Site 9	Orthogonal 4-, 5-angled Orientated Size: 8 m	S/Z - w (+Sst)
Type 5		Site 6	4-, 5-angled Orientated Size: < 6,5 m	P - u (+Sst)
Type 6		Site 7 Site 10 Site 2	4-, 5-, 6-angled Random Size: < 6,5 m	P - w S - w Z - u

Legend:
Lithological units:
Tertiary substratum: z: sand, w: clay-sand, u: clay, Sst: sandstone fragments. Soil texture: Z: sand, S: loamy sand, P: sandy loam, L: sandloam.

distinguished (Table 1). All 6 types belong to the "large type" (>1 m) following Washburn's (1973) classification.

According to various authors the networks could be developed by two manners:

- Owing to thermal contraction under cold periglacial conditions during the Pleistocene (Karte 1987; Pissart 1987; Vandenberghe & Pissart 1993).
- As a result of desiccation under warm semi-arid conditions during the Pre-Quaternary period, analogous to those described by Neal et al. (1968, in Murton et al. 2000) in current warm semi-arid regions.

3 FIELD EVIDENCES

The polygonal crop marks are associated with sand-wedge structures (Figs 3, 4 and 6) in the subsoil. In outcrops sand-wedge structures are visible with mean spacings of 3 to 10 m (Fig. 5). The term "sand-wedge" is used in a descriptive way, to indicate a sandy sedimentary structure. All the characteristics of the structures are summarised in Table 2. The tops of the structures are between 0.4 m and 0.75 m depth, the bases between 1.2 m and 1.8 m. The high width-height ratio, varying between 1.5 and 2.7 is particular. The shape is variable, ranging from wedge-shaped to strongly irregular, sack-shaped structures.

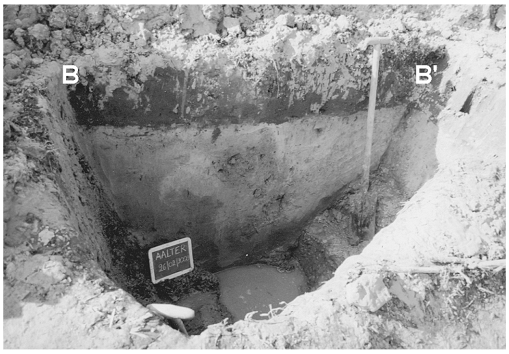


Figure 3. Wide sandy wedge structure developed in a tertiary clayley glauconiferous sandy substratum, Trench B-B′ (see Figure 2b and arrow in Figure 2a for localisation), site 1 (coordinates: X = 83.35 km; Y = 197.25 km; Lambert-72), Aalter, Oost-Vlaanderen, Belgium. Length of the spade: 1.2m. See Table 2, site 1 for characteristics.

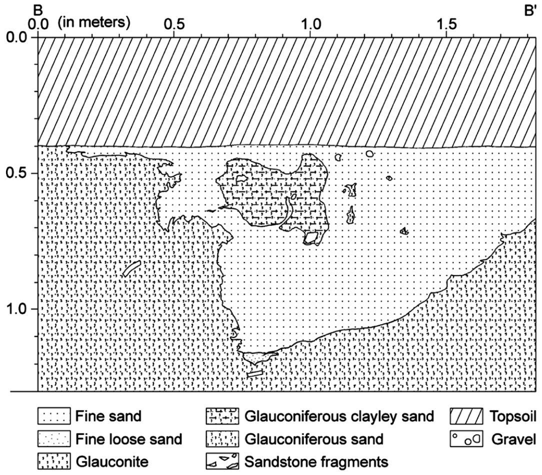


Figure 4. Drawing of the sand-wedge structure visible in Figure 3. Note the notch-like margins and large host inclusions in the fill.

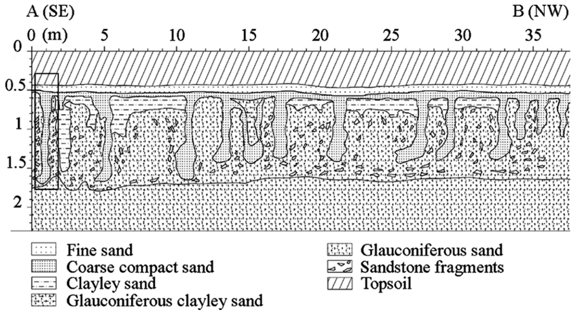


Figure 5. Excavation A-B, site 15 (coordinates: X = 80.00 km, Y = 199.00 km; Lambert-72), Maria-Aalter, Oost-Vlaanderen, Belgium. Sandy involutions developed in the tertiary green sandy glauconiferous substratum. Localisation of Figure 5 (rectangle). See site 15 on Figure 1b for localisation of the excavation site.

All the structures are filled with a complex of sandy material with scattered pebbles (Figs 3, 4 and 6).

Table 2. Characteristics of the sand-involutions.

Site	Type structure	Height (cm)	Width (cm)	W/H	Spatial	Litho	Chrono
1	Wedge	80	140	1.8	P	s/Gs	IV/III
4	Sack-shaped - C	60/90	240/115	2.7/1.92	P	s/Gw	IV/III
6	Deformed sack	115/75	100	2	P	s/u	IV/III
8	Sack-shaped	65	125<	1.9	P	s/l	IV/IV
15a	Deformed sack - C	120	100	1.7	P*	s/Gs Sst	IV/III
15b	Wide sack	100	90	0.9	P*	s/Gs	IV/III
15c	Long-waved sack - C	115	600	5.2	P*	s/Gs	IV/III

Legend: C: composite structure, W/H: width-height ratio, P: polygonal structure, *: sites with polygonal patterns in the neighbourhood, not observed at the site itself. Lithological units: s: sand, w: clayey sand, u: clay, l: loam, G: glauconite, Sst: sandstone fragments. Chrono: III: Tertiary, IV: Quaternary. Remark: structure 15c is an obliquely cut structure.

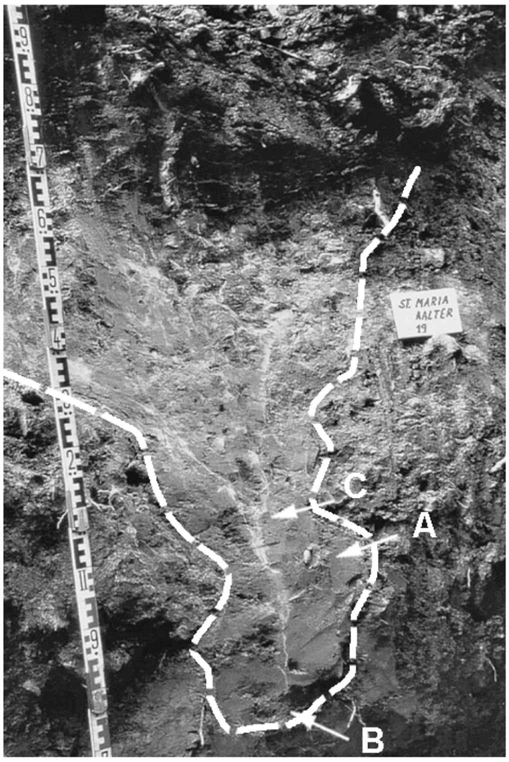


Figure 6. U-shaped, irregular sandy involution (dashed line) in the Tertiary green glauconiferous sandy substratum (see Figure 4 for localisation). At the bottom right a green convex curved sandtongue (B) is formed in the ochre sandy infill. Striking are the concave/downward curved green sandy inclusions (A), which point to slump-, subsidence- and flow related processes. In the central part a supplementary, wing-formed wedge structure (C), tapering down to a point is formed. Site 15 (coordinates: X = 80.00 km, Y = 199.00 km; Lambert-72), Maria-Aalter, Oost-Vlaanderen, Belgium). See Table 2, site 15a for characteristics.

They are formed in different kinds of sediments (sand, sandy clay, clayey sand, clay).

Common features are a downward curved lamination and micro-stratification of the host material, irregular margins (notch-like margins (Figs 3 and 4), tongue-like structures (Figs 3, 4 and 6), small-scale faulting and a fill with large host inclusions (Figs 3, 4 and 6), a concave downward curved lamination/inclusions (Fig. 6) and scattered pebbles (1–10 cm) (Figs. 3, 4 and 6).

Some of the structures are composite in nature, with supplementary wedge structures developed in the sand involutions (Fig. 6), sometimes piercing into the underlying host.

4 DISCUSSION

4.1 *Origin*

The polygonal sand-wedge patterns have been interpreted as a polygonal network of frost-wedge pseudomorphs. This is based on their geomorphological position, the denudation of the landscape during the Quaternary, the palaeoenvironmental and palaeolithological context, the spatial structure of the patterns and the characteristics of the associated sand-wedges.

Due to the intense denudation of the landscape in Flanders during the Quaternary it is most unlikely that these are Pre-Quaternary desiccation structures. Moreover, the structures are clearly filled with Quaternary sands, of which the exact stratigraphical age is not yet established. Frost-related features including cryoturbations, fossil ice-wedges have been described by Heyse (1979, 1983, 1998, 1999) in the surrounding area. The structures are indicative for cold periglacial conditions in the area during the Weichsel.

All the aforementioned features point to slump, flow, and subsidence related processes associated with the melt-out of an ice-body or ice-rich sediment (Harry & Gozdzik 1988, Kolstrup 1987). Although gravel elements might be present in frost-wedges with a primary infilling (Murton et al. 2000) or a secondary seasonal infilling (Romanovskij 1973), the presence of large host inclusions (Figs 3, 4 and 6) and a downward curved lamination of the fill (Fig. 6) may exclude such a seasonal origin.

The structures are analogous with those observed by Murton & French (1993c) in partly formed ice-wedge and composite-wedge pseudomorphs in actual periglacial areas. All the previously mentioned sedimentary structures seem to be characteristic of composite and ice-wedge pseudomorphs. Presumably, the sand-wedges observed in the field are composite- and ice-wedge pseudomorphs.

It's likely that considerable thaw consolidation has taken place giving wide, shallow wedge structures. High ice contents of host materials would explain such irregular forms (Murton & French 1993c). The strong deformation and irregular appearance of some structures is likely to be the result of thaw transformation (Murton & French 1993c), slope-related processes (Gozdzik 1994, Mackay 1990), frost-heave and loading processes (Van Vliet-Lanoë 1988).

For a more conclusive interpretation, texture analysis, the study of the grain morphology, microstructural analysis and the establishment of a regional framework are all necessary.

4.2 *Age*

In an eroded landscape it is very difficult to determine the age of the structures. An absolute age determination is almost impossible due to the absence of datable horizons, such as peat layers and other organic remnants (Svensson 1988, p. 65). The application of luminescence dating is potentially a very promising technique in obtaining an (in)direct age of the fossil wedge structures however. Nevertheless, based on the geomorphological and lithostratigraphical position and the relation to other sedimentary structures it is possible to obtain a minimum–maximum age.

All the sites are located in the northern part of the interfluve between the Coastal Plain and the Flemish Valley, of which the highest parts correspond with interfluvial terraces formed during the Elster Glacial (Oxygen Isotope Stage 12), resting upon the Tertiary substratum of Eocene age.

Consequently, the structures were developed during the Elster Glacial (Oxygen Isotope Stage 12), or afterwards, during one of the later glacial periods. In general one can assume that they were formed during a Late-Pleniglacial period (Oxygen Isotope Stage 2). According to Vandenberghe & Pissart (1993) a Late-Glacial age should not be ruled out. Permafrost conditions necessary for the formation of ice-wedges and composite-wedges existed during different parts of the Late Pleistocene (Vandenberghe J. et al. 1998, Vandenberghe & Pissart 1993).

Numerous structures are composite in nature and point to a polygenetic and polycyclic character. The composite structures were presumably developed due to reactivation during different glacial periods and/or stadials.

5 CONCLUSIONS

1. Polygonal structures are clearly present in Flanders (Belgium) on the plateau between the Coastal Plain and the Flemish Valley, irrespective of the lithology of the substratum and the geomorphological position.
2. All the polygonal networks were caused by thermal contraction of frozen ground associated with palaeo-periglacial conditions.
3. The polygonal crop marks are associated with sand wedges in the subsoil. They are interpreted as frost-wedge pseudomorphs (type composite wedge and ice-wedge), which may have been deformed by thaw-, slope- and frost-related processes.
4. The visibility on aerial photographs is periodical and is related to specific soil conditions. The late spring and summer were the most favourable periods for observation.
5. In a denudation relief it is difficult to date the structures, but in the context of established regional climate reconstructions, the structures are constrained to the Elster-Weichsel period, and are probably Late Pleistocene in age.
6. The high frequency of composite and ice-wedge pseudomorphs in northwest Flanders in various sediments and in different geomorphological positions points to the presence of continuous permafrost during the Late Pleistocene, as suggested by palaeoclimate reconstructions (Vandenberghe et al. 1998).

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