

Deeply Dissected Tundra Polygons on a Glacio-Fluvial Outwash Plain, Northern Ungava Peninsula, Québec

Polygones de toundra profondément disséqués sur plaine d'épandage fluvio-glaciaire, au nord de la péninsule d'Ungava, Québec

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Résumé de l'article

On décrit ici les polygones de toundra profondément disséqués de la zone de pergélisol continu de l'extrémité nord de l'Ungava. Ils se sont développés sur une plaine d'épandage fluvio-glaciaire qui s'est formée à la suite de la déglaciation vers 7500 BP. Une végétation rare occupe la surface exposée des polygones et la déflation a emporté la matrice sablonneuse. La profondeur des sillons entre les polygones atteint de 0,5 à 2 m. À la base d'un d'entre eux, on observe une fente large de 0,25 m à remplissage composé de lentilles de tourbe et de sable, jusqu'à au moins 0,7 m de profondeur (front de dégel). Deux datations au 14C de 1650 ± 60 BP et de 740 ± 80 BP montrent que le remplissage progressif de la fissure s'est fait au fur et à mesure de la désintégration d'une fente de gel préexistante. La basse température moyenne annuelle de - 7°C indique que la fonte des fentes de gel dépend davantage de facteurs dynamiques locaux, comme la déflation et un meilleur drainage, qu'à une amélioration du climat. On croit que des fentes de gel occupent encore la partie inférieure des sillons de polygone.

Note

DEEPLY DISSECTED TUNDRA POLYGONS ON A GLACIO-FLUVIAL OUTWASH PLAIN, NORTHERN UNGAVA PENINSULA, QUÉBEC

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ABSTRACT Deeply dissected tundra polygons are described from the continuous permafrost environment of northernmost Ungava. They are developed on a glacial outwash plain, formed subsequent to deglaciation of the site about 7,500 BP. The exposed surfaces of the polygons are sparsely vegetated and aeolian deflation has removed their sandy matrix material. The furrows between the polygons attain depths of 0.5-2 m. From the base of one, a 0.25 m wide wedge of peat and sandy material penetrates to a minimum depth of 0.7 m (the frost table depth). Radiocarbon dates of 1650 ± 60 BP and 740 ± 80 BP indicate that progressive filling of this fissure accompanied decay of a pre-existing ice-wedge. The present low mean annual air temperature at the site (-7°C) suggests that thawing of the ice-wedges may be related more to local dynamic factors, such as deflation and improved local drainage associated with fluvial dissection, than to regional climatic amelioration. Wedge ice is believed to still underlie the polygon furrows.

RÉSUMÉ Polygones de toundra profondément disséqués sur plaine d'épandage fluvio-glaciaire, au nord de la péninsule d'Ungava, Québec. On décrit ici les polygones de toundra profondément disséqués de la zone de pergélisol continu de l'extrémité nord de l'Ungava. Ils se sont développés sur une plaine d'épandage fluvio-glaciaire qui s'est formée à la suite de la déglaciation vers 7500 BP. Une végétation rare occupe la surface exposée des polygones et la déflation a emporté la matrice sablonneuse. La profondeur des sillons entre les polygones atteint de 0,5 à 2 m. À la base d'un d'entre eux, on observe une fente large de 0,25 m à remplissage composé de lentilles de tourbe et de sable, jusqu'à au moins 0,7 m de profondeur (front de dégel). Deux datations au ^{14}C de 1650 ± 60 BP et de 740 ± 80 BP montrent que le remplissage progressif de la fissure s'est fait au fur et à mesure de la désintégration d'une fente de gel préexistante. La basse température moyenne annuelle de -7°C indique que la fonte des fentes de gel dépend davantage de facteurs dynamiques locaux, comme la déflation et un meilleur drainage, qu'à une amélioration du climat. On croit que des fentes de gel occupent encore la partie inférieure des sillons de polygone.

INTRODUCTION

Their widespread occurrence and distinctive surface manifestation make ice-wedge networks one of the most striking features of the periglacial landscape. They have been called in the literature: tundra polygons, fissure polygons or ice-wedge polygons (Hamelin and Cook, 1967, p. 31-35, 144-147). The most favourable conditions for the current development of ice-wedges are to be found in relatively poorly drained tundra lowlands within the continuous permafrost zone (e.g. French, 1983, p. 84-85). Fine-grained moisture rich soils are probably highly susceptible to frost cracking, although not as favourable as gravel for preservation of ice wedge casts (Washburn, 1979, p. 104; Harry and Gozdzik, 1988, p. 53)

Most large, non-sorted tundra polygons on coarse gravel surfaces possess only shallow furrows, up to a few decimetres in depth, as indicated for Varanger Peninsula in northernmost Norway (Svensson, 1963), from Mesters Vig in northeastern Greenland (Washburn, 1969, fig. 92; 1979, fig. 5.17), central Iceland (Friedman *et al.*, 1971, figs. 3, 12, 16; Schunke, 1974) or West Spitsbergen (Åkerman, 1980, figs. 2.11 and 2.29).

They also occur frequently in northern Ungava (Seppälä *et al.*, 1988) and are identified on aerial photographs because of a denser vegetation cover in the furrows.

The aim of the present note is to describe recent observations on a somewhat different type of tundra polygon network, formed on a well-drained glaciofluvial outwash plain, composed of sands and gravels. The most distinctive feature of these polygons is the great depth of the furrows on their margins. Such deep furrows have not been noted elsewhere in Ungava.

LOCATION

The polygon network is located on a large glaciofluvial outwash plain in the middle section of the Rivière Déception valley ($62^{\circ}04' \text{N}$, $74^{\circ}01' \text{W}$; topographic map sheet 35J/1) in northernmost Ungava Peninsula, Québec, Canada (Figs. 1 and 2).

The outwash plain is situated above marine limit, at about 165 m above sea-level. Its surface has therefore not been modified by wave action, and still displays shallow, sinuous, melt-water channels. However, since its formation, it has been dissected by Rivière Déception, and by a western tributary, to a depth of 20-25 m. Several levels were noted on the outwash plain (Fig. 2). Tundra polygons were only observed on the high-

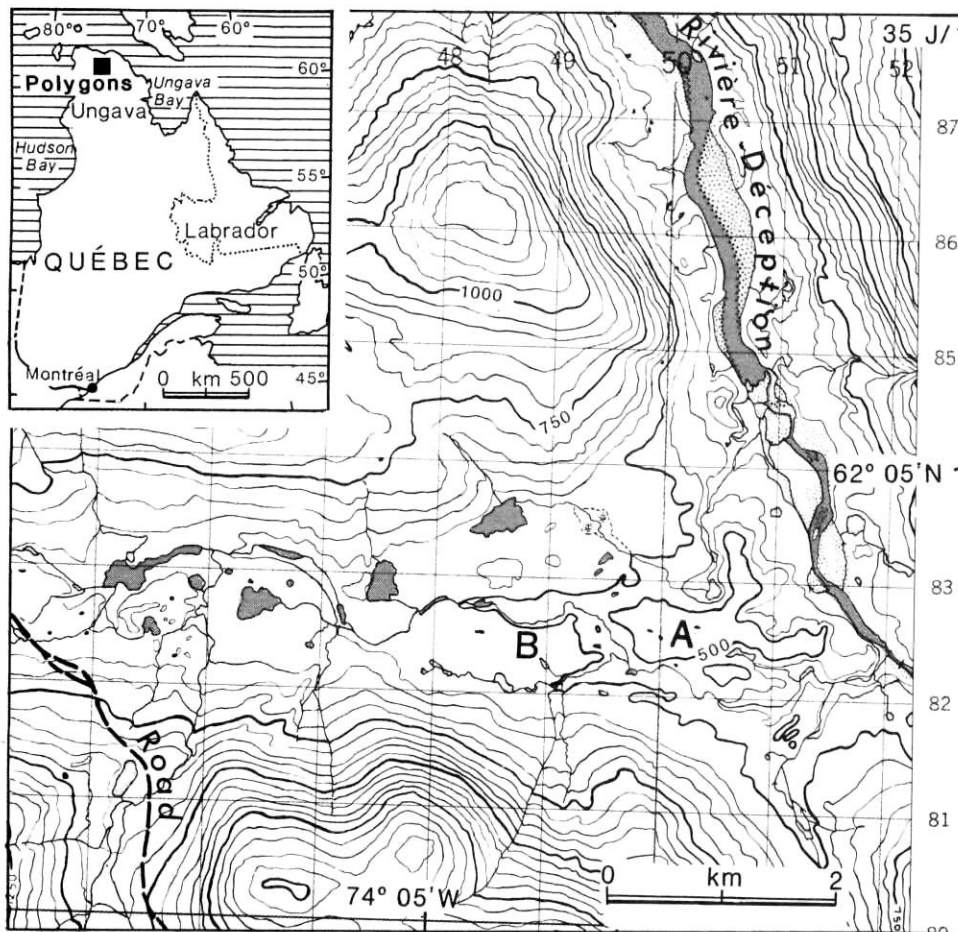


FIGURE 1. General location of the field site. Part of topographic map sheet 35J/1, with contour interval of 50 feet. A) outwash plain with tundra polygons; B) surface without polygons.

Carte de localisation du site à l'étude (section de la carte topographique 35J/1 avec courbes de niveaux aux 50 pieds). A) Plaine d'épandage avec polygones; B) surface dépourvue de polygones.

est level however (point A, in Fig. 2). The meltwater channels are clearly visible, not only on this highest level, but also on a lower level, a short distance to the west (point B in Fig. 2). The probable age of this outwash plain can be estimated from radiocarbon dates obtained from shells in glaciomarine sediments of an ice-front delta, situated 15 km to the WNW (Gray *et al.*, 1985; Gray and Lauriol, 1985; Lauriol and Gray, 1987; Gray *et al.*, 1987). The area of the ice-front delta must have remained ice covered until about 7500 BP when the foreset beds near its summit were formed. Deglaciation of the site probably occurred shortly thereafter, although the ice sheet may have remained much later on the high plateau to the south, as suggested by Lauriol and Gray (1987).

CLIMATE AND VEGETATION COVER

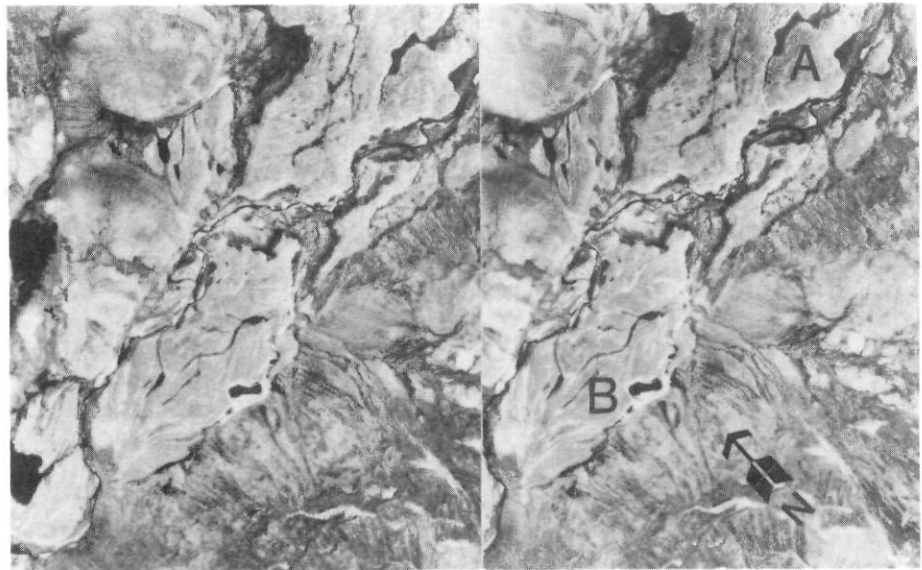
Two meteorological recording stations operated in a discontinuous manner in the region during the 1960's (Fig. 3). Mean annual air temperatures were computed for the two stations — Colline de l'Amiante (Asbestos Hill) and Baie Déception — by comparison of the fragmentary data with records from the regularly recording station at Cape Hope's Advance, 250 km to the south-east (Gray, 1983). At Colline de l'Amiante, at an elevation of 525 m, the mean annual air temperature is approximately -11°C , whereas at Baie Déception, at sea-

level, the mean annual air temperature is -6°C . For the study site, at an altitude of 165 m, an intermediate value of about -7°C is suggested as reasonable.

Precipitation data are not available locally, but abrasion marks on large erratic blocks, and on old wooden stakes used as road markers, suggest a mean annual snow depth of 20 to 40 cm. An isolated snow survey, conducted by one of the authors on Colline de l'Amiante plateau, prior to the spring thaw in May 1984, revealed an average snow depth of 50 cm. Snow depths at the study site, situated at a very exposed, wind-blown location were undoubtedly much less. Local variations in snow cover, related to difference in exposure may be significant in ice-wedge polygon formation (Mackay, 1974). In this context, the most favourable locations for large ice-wedges in the Rivière Déception valley would be the exposed outwash terrace surfaces, such as the one discussed in the present paper.

Situated about 500 km north of the treeline, the region is characterised by a herbaceous tundra cover, dominated by mosses, lichens and several species of tundra grasses. It belongs to the zone of continuous permafrost (Taylor and Judge, 1979). At Colline de l'Amiante, 35 km to the south, the permafrost body exceeds 540 m in thickness, and may attain a total thickness of 600 m (Seguin, 1978; Taylor and Judge, 1979).

FIGURE 2. Aerial photo stereopair showing local morphology. Enlargements obtained from N.A.P.L. air photos A 19665, Nos. 53 and 54. Scale: 1: 43,000.
Couple stéréoscopique montrant la morphologie locale. Agrandissements à partir des photos A 19665, n^{os} 53 et 54. Échelle: 1/43 000.



Mean daily maximum, mean and minimum temperatures

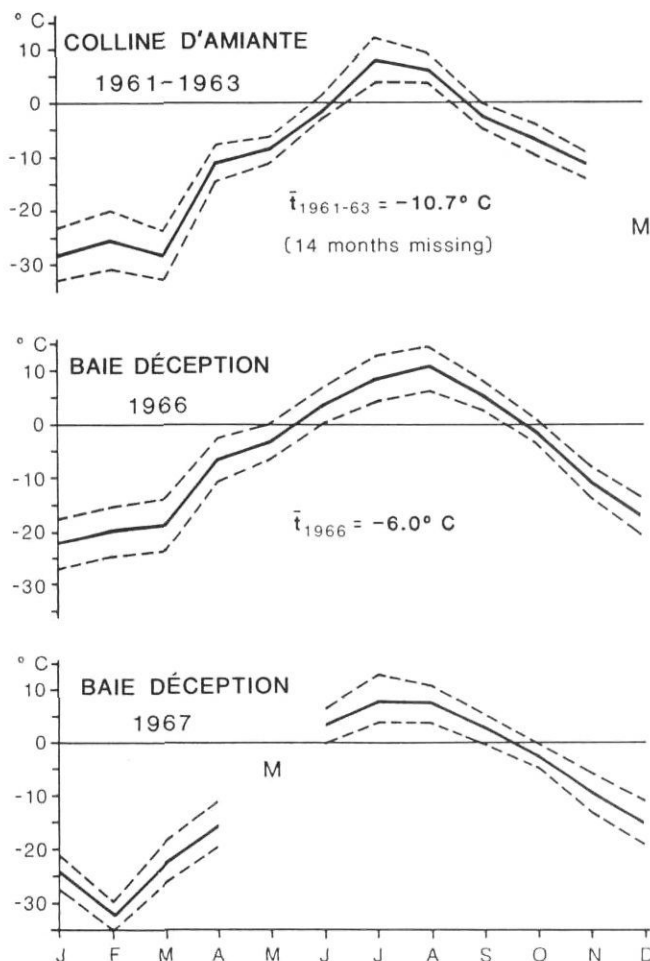


FIGURE 3. Air temperature data from Colline de l'Amiante and Baie Déception.
Données sur les températures de la colline de l'Amiante et la baie Déception.



FIGURE 4. Low level aerial view of tundra polygons at field site. Looking west (photo by D. Bruneau).
Vue aérienne oblique vers l'ouest du champ de polygones (photo D. Bruneau).

DESCRIPTION OF POLYGONS

The polygons observed at the study site are relatively orthogonal in pattern (Fig. 4). Their diameters range from 30 to 120 m. Several furrows are over 2 m deep (Fig. 5). The deepest parts of the furrows are found at fissure junctions. On the terraced edge of the outwash plain some gully formation is evident, as observed also in Scandinavia by Svensson (1982). Surface water from heavy rains, prior to the visit, was found in some furrows (Fig. 6). In the middle of several furrows, open fissures, up to a few centimetres wide and 10-20 cm deep, were observed. In some cases these were double fissures about 10 cm wide (Fig. 7).

Such fissures may be interpreted as residual frost cracks, and may represent the surface manifestation of continued ice-wedge activity at depth in the gravels. Their width and depth are similar to examples noted by Seppälä (1982) in Finnish

Lapland, by Svensson (1963) in northern Norway, and by Mackay (1974, 1975) from Garry Island in the Mackenzie Delta region of the Canadian Arctic.

A preferential orientation was noted for the furrows. They tend to be developed, either parallel or perpendicular to existing meltwater channels, and also to the downcut edges of the outwash plain.

The surface of the polygon field is very even, and paved mainly by lichen covered stones of 3-10 cm in diameter. The surfaces of the stones are well-polished by strong wind action. Most of the fine sediment particles are deflated away and deposited beyond the limits of the outwash plain, or in the polygon furrows. Only a few residual masses of sandy sediment, anchored by vegetation, remain on the surface (Fig. 8). The growth of scattered clumps of vascular plants, such as *Dryas*, *Salix*, *Silene*, *Diapensia*, and *Saxifraga*, was noted on the polygon surfaces. Denser vegetation growth was found in the furrows. This includes several mosses, lichens and grasses. *Cladonia* spp., and *Epilobium latifolia* were noted. This more

luxuriant vegetation cover is made possible by the more sheltered environment of the furrows. They are protected directly from the strong winter winds, and indirectly, by being filled with an insulating snow cover. Increased moisture content during the summer season is also undoubtedly an important factor, leading to mesic conditions, as compared to the rather xeric conditions in the polygon centres.

A considerable thickness of peat has been developed as a result of the decay of this vegetation cover in the furrows. In one furrow, about 20 cm deep, an excavation revealed 40 cm of peat (Figs. 9 and 10). Two samples were collected for radiocarbon dating. The first, from the bottom of the peat layer, gave an age of 740 ± 80 BP (Hel 2217). The second, from the underlying sand with thin organic layers, gave an age of 1650 ± 60 BP (Beta 11124). The frost table in this pit had reached a depth of 70 cm on August 4th, 1984. The material in the pit walls was observed to be composed of coarse textured sand, without stratification, in striking contrast to the stony surfaces of the polygons themselves.



FIGURE 5. Deep furrow formed along the fissure between two tundra polygons. This and succeeding ground level photographs taken on August 4, 1984.

Profond sillon qui s'est formé le long de la fissure entre deux polygones. Cette photo et les suivantes ont été prises le 4 août 1984.

FIGURE 7. Double fissures on the surface.
Fissures doubles en surface.



FIGURE 6. Furrow junction with water at the base.

Raccordement de deux sillons dont le fond est en partie recouvert d'eau.

FIGURE 8. Erosion remnant on the surface of the outwash plain.
Lambeau d'érosion à la surface de la plaine d'épandage fluvio-glaciaire.



FIGURE 9. Photograph of ice-wedge cast, shown schematically in Figure 10.

Moulage de la fente de gel dont le schéma apparaît à la figure 10.

ORIGIN OF THE POLYGONS

In any discussion of the origin of the polygon network, one of the key elements to establish is whether the fissures are or were underlain by ice-wedges, by ice-wedge pseudomorphs (Harry and Gozdzik, 1988), by permafrost sand wedges (Péwé, 1959), by active layer ground wedges (Harry and Gozdzik, 1988), or by seasonal frost wedges (Dionne, 1978).

The possibility that the polygonal network of furrows were formed either as active layer or seasonal frost wedges can be ruled out. The features described by Dionne (1978, p. 196-197) from the James Bay region of sub-Arctic Québec, occur in the zone of sporadic permafrost occurrence on terraces characterised by rapid penetration of seasonal frost. They are only 15 to 30 cm wide, and are underlain by infilled material from the surface to a depth of only 20 to 50 cm. By contrast the Deception Valley polygon fissures occur in the continuous permafrost zone, with an active layer which only attains a depth of about 70 cm. The surface furrows attain depths of up to 2 m and widths of several metres, clearly extending well into the permafrost layer on the terrace surface.

A purely sand-wedge origin for the Deception Valley polygon fissures can also be rejected. Thermal conditions favourable for permafrost sand-wedge development certainly could have prevailed on such an exposed terrace at the margin of a large ice sheet during deglaciation, as is the case for the classic present day sand-wedge environment in Antarctica (Péwé, 1959). However, the considerable depth and width of the furrows clearly indicates the loss of infilling material from the site. If infilling sediments have been transported away from the site,

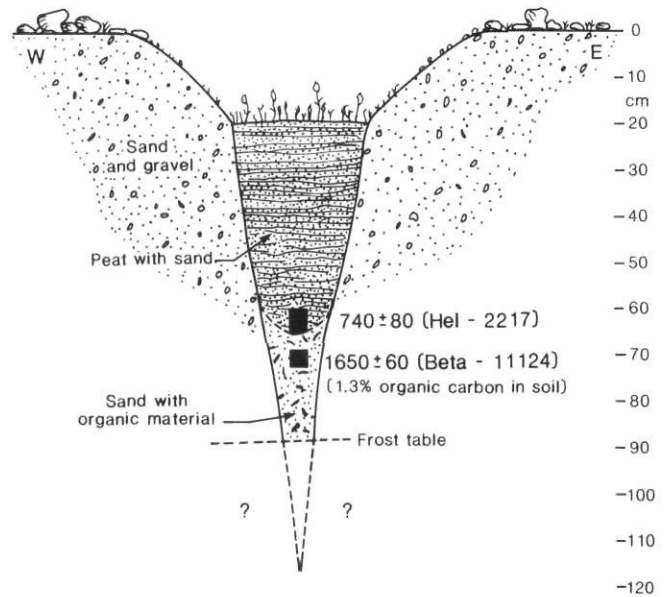


FIGURE 10. Cross-section of the exposure dug at the base of a furrow.

Coupe de la partie dégagée à la base d'un sillon.

then one would expect some sort of coherent gully network with a continuous gradient leading off the terrace edge, and also some alluvial cone deposition at the base of the latter. In fact the deepest and widest parts of the furrows occur at fissure intersections with no topographic gradient towards the terrace edge. There is no evidence of important dissection of the terrace margin by gully systems, nor of alluvial cones, to indicate such sediment transport. The conclusion is inescapable. The lost material must have been ice, in the form of large ice-wedges, > 1 m in width.

The creation of the network of ice-wedges must post-date the formation of the outwash plain at the Laurentide Ice Sheet margin, at *circa* 7500 BP. The exposed nature of the surface, coupled with an initial absence of a vegetation cover, would have resulted in a thin snow cover. This would have permitted deep and rapid penetration of the cold wave into the ground in winter. Such conditions are necessary for thermal contraction cracking in surficial sediments.

However, extremely cold winter temperatures near the surface are probably not sufficient in themselves to account for the strong and repeated contraction cracking necessary to produce ice-wedges in such coarse grained sediments. A second critical factor may be the degree of water saturation of the surface sediments by ground-water. If the ground-water table was at a much higher level, several thousand years ago, prior to dissection of the outwash plain, both thermal and hydrological conditions would have been favourable for ice-wedge formation. A high water table would have created saturated conditions near the ground surface, leading to a high ice content. This in turn, would have increased the potential for thermal expansion and contraction leading to ice-wedge formation, which may have been initiated at that time. How long the ice-wedges continued to grow is unknown. It is significant, how-



FIGURE 11. Active ice-wedge at edge of 30 m marine terrace at the head of Salluit Inlet, 50 km W of Rivière Déception field-site. This ice-wedge attains a depth of >5 m, and a width of >1 m.

Fente de gel active au bord d'une terrasse marine de 30 m, au fond de la baie de Salluit, à 50 km à l'ouest du site de la rivière Déception. La fente de gel a une profondeur de >5 m et une largeur de >1 m.

ever, that such features are absent from lower terrace levels in the vicinity (surface B, in Fig. 2). This indicates that, during the phase of fluvial dissection of the outwash plain, conditions ceased to be favourable for ice-wedge polygon development in the immediate vicinity. The radiocarbon age of the lowest thin organic horizon, which could be excavated at a depth of 70 cm below the terrace surface in one furrow (Fig. 10), suggests that at least one of the ice-wedges had ceased to grow actively, prior to 1650 BP.

The active phase of ice-wedge development for the excavated furrow shown in figure 10, was followed by a recent phase of infilling from the surface, as indicated by a small wedge structure. The following interpretation can be made from the presumed ice-wedge cast. The lower sand-filling, with isolated organic layers, might have been formed when the ice-wedge was still rather wide and close to the surface. Then, more recently than 1000 years ago, the ice-wedge was continuing to thaw steadily, giving an increasingly large and more sheltered habitat for peat forming plants, which then filled the wedge. Because there is only one dated site, it is hard to tell if the wedges all have the same history of development, or if they are metachronous in their evolution. Some are wider and deeper than the one studied in detail.

Because penetration beyond the frost table was impossible with the field equipment available, and a subsequent visit with drilling equipment had to be aborted because of difficult aircraft landing conditions, it was not possible to prove conclusively the presence of ice-wedges beneath the furrows. Circumstantial evidence suggests that this is the case, however. The presence of open fissures in a number of the furrows are a good indication that the latter may be underlain by ice-wedges, which are still subject to contraction cracking on occasion. Also, large ice-wedges from 0.3 to 1.0 m wide and > 5 m deep, have been observed by J. T. Gray and B. Lauriol in a river-bank exposure of sands and gravels in the Salluit area, 50 km to the west of the Rivière Déception Valley (Fig. 11). Finally, drilling by Seppälä *et al.* (1988), in a depressed centre polygon field on a flood-plain at the confluence of a small tributary with Rivière Déception, 15 km downstream from the field-site being discussed in this paper, has revealed the continued existence of ice-wedges beneath surface peat, albeit in a rather different topographic situation.

Indeed, apart from this circumstantial evidence, it would be very surprising if residual ice-wedges did not occur, given the low mean annual air temperature (about -7° C) and the exposed nature of the site. Under these conditions, one must wonder whether the considerable thawing, evidenced by the peat layers, was not favoured more by local dynamic factors than by regional climatic amelioration. One such dynamic factor could be the strong deflation, evidenced by the gravel lag on the outwash surface. The upper layers of sediments covering the wedges could have been removed by wind, thus exposing the latter to increased heat penetration in the summer, and hence, to increased thawing. Another such dynamic factor could be locally improved drainage, associated with a drop in the local ground-water table due to fluvial down-cutting. This would also favour the development of a thicker active layer, and some degradation of the ice-wedges.

CONCLUSIONS

This study demonstrates that northernmost Ungava, situated well within the continuous permafrost zone, has been characterised by sufficiently severe winters, to permit extensive thermal contraction cracking and ice-wedge polygon formation on exposed terrace surfaces. The unusually deep and wide furrows, and the presence of infilling sands, with organic horizons, indicate considerable ice-wedge thawing during at least the last two millennia.

The existence of such well developed fissure polygons on such coarse textured sandy gravels, and their very localised occurrence on the highest, oldest level of a glaciofluvial outwash terrace, suggest that conditions for development of the ice-wedge polygons, may have been particularly suitable, during early deglaciation, when an ice cap still existed on the plateau, and prior to fluvial dissection of the outwash plain. Their growth, through thermal contraction cracking in such coarse textured sandy gravels may be due to a combination of thermal and hydrological factors. The continued presence of the plateau ice-cap, would have been associated with strong katabatic winds, leading to very cold winter conditions in the peripheral valleys. In addition, a relatively high ice content, may have

contributed to an increase in the thermal contraction potential of the sediments. An elevated water table, during permafrost formation on the aggrading sediments of the outwash plain, would have permitted ground ice to fill all pore spaces and voids.

Although the deep and wide surface furrows indicate some surficial thawing of the ice-wedges, permafrost conditions remain favourable for ice-wedge preservation at depth. Local terrain conditions, as well as the discovery of wedge ice at two other localities in northernmost Ungava, suggest the likelihood of finding similar massive ground ice bodies, beneath the furrows described in this paper.

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