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PALEOCLIMATIC SIGNIFICANCE OF LATE PLEISTOCENE ICE-WEDGE CASTS IN SOUTHERN QUEBEC, CANADA

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ABSTRACT

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Ice-wedge casts in southern Quebec are exclusive to deposits pertaining to two ice front positions during the retreat of the Laurentides ice sheet: the Highland front morainic system located at the southern margin of the St. Lawrence lowlands, and the St. Narcisse front morainic system located at the southern margin of the Laurentides highlands. Wedge casts filled with sand and gravel are relic of true ice wedges and give evidence of former permafrost conditions in the ground during the retreat of the ice sheet in that area, between 13 000 and 11 000 years B.P. Mean annual air temperature was lower than −6°C, a difference of 8—12° with the present-day temperature. Humidity was high enough to allow the growth of ice wedges in the permafrost. These rigorous climatic conditions prevailed during a few centuries only. There is no positive evidence of tundra conditions in southern Quebec younger than 11 000 years ago.

INTRODUCTION

Ice-wedge casts are geological indicators that help to identify local or regional paleoclimates (Flint, 1961; Schwarzbach, 1963). Today active ice wedges are found throughout the Arctic and the Antarctic regions, which are characterized by severe winter conditions, relatively high moisture of the air, and continuous permafrost. Occurrence of ice-wedge casts in Quaternary deposits located in regions having today a temperate climate is thus significant and is evidence of former cooler conditions. According to Black (1969, p.229), "ice-wedge casts representing filling of former ice-wedges are the most widely recognized diagnostic periglacial indicators of paleoclimates". They are not only diagnostic of permafrost, but also of the range of temperature required for their formation.

In North America, only a few ice-wedge casts have been observed in the area south of the southern limit of the Laurentides ice sheet (Black, 1964a,b, 1965), and until the mid-sixties none were known to exist in southeastern

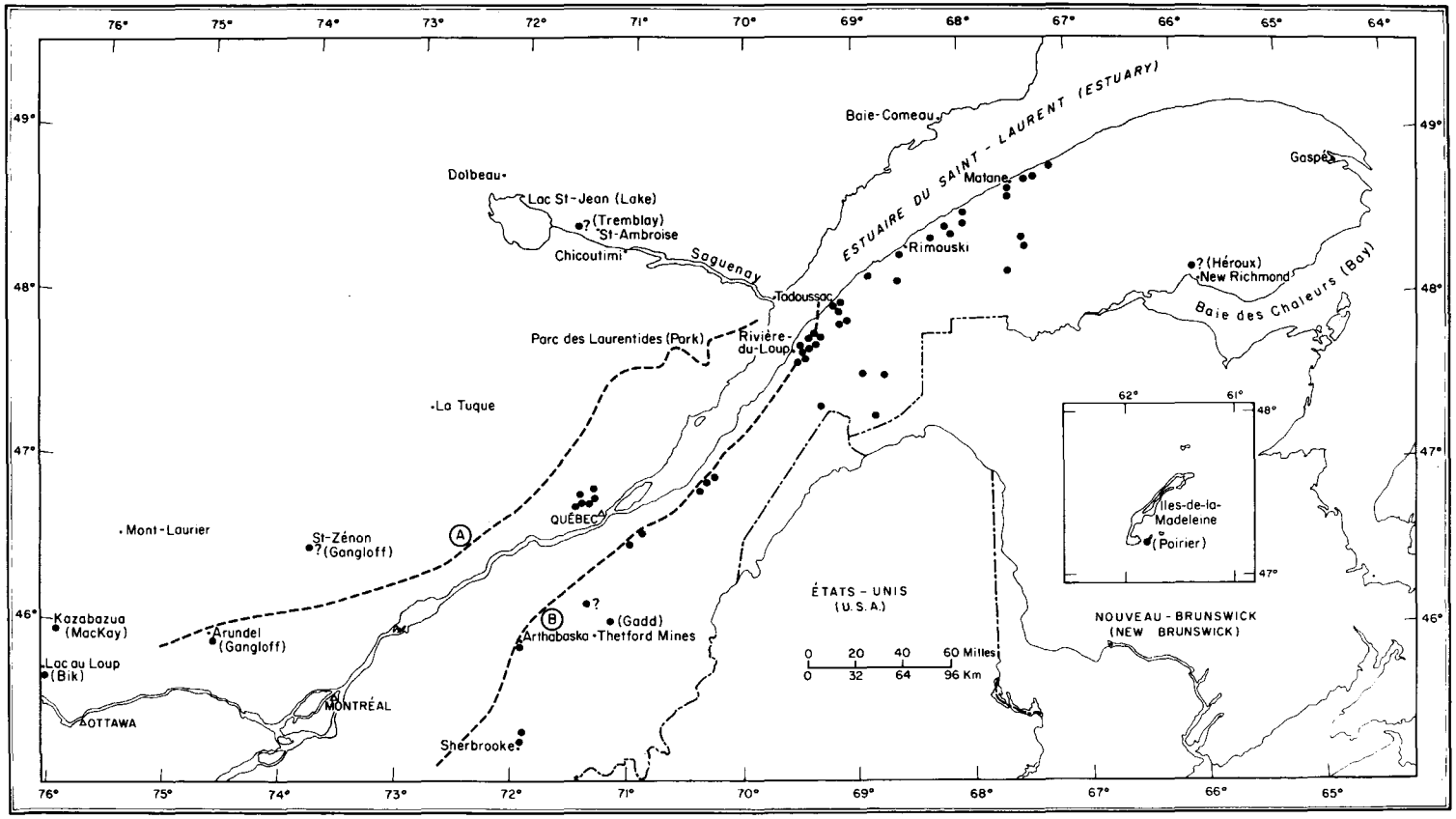

Fig.1. Ice-wedge casts occurrence in southern Quebec. *A*, Approximate position of the St. Narcisse front morainic system; *B*, Approximate position of the Highland front morainic system.

Canada within the area covered by the last Pleistocene ice sheet. Since the discovery ten years ago of the first ice-wedge casts in southern Quebec (Dionne, 1965, 1966), more than 300 have been observed in 60 sites in this area (Dionne, 1967, 1969, 1970, 1971a, 1972, 1973). Elsewhere in southern Canada a few late Pleistocene ice-wedge casts have been reported from Nova Scotia (Borns, 1965), Newfoundland (Brookes, 1971), and southern Ontario (Morgan, 1972).

The purpose of this paper is to discuss the paleoclimatic significance of ice-wedge casts occurring in Quaternary deposits in southern Quebec.

GEOGRAPHICAL DISTRIBUTION

Although the survey of frost-induced structures in southern Quebec is still in progress and large areas remain to be investigated, numerous ice-wedge casts have been discovered in six main regions of southern Quebec, located between lat. N 45° and 49°, and long. W 67° and 72°, an area with a present mean annual air temperature ranging from 2° to 5.5°C, with a mean air temperature for January ranging from −10° to −14°C. The author discovered relic frost structures within the coastal Appalachian region of the St. Lawrence Estuary in the area between Rivière-du-Loup and Matane (200 wedges), in the areas of Matapédia and Témiscouata valleys (15), L'Islet (20), Quebec City (47), Eastern Townships (4), and Arthabaska (7), at the southern margin of the St. Lawrence lowlands (Fig.1). In addition, a few other structures were observed elsewhere in southern Quebec by a few authors (Gangloff, 1970; Poirier, 1970; Laverdière and Guimont, 1973).

CHARACTERISTICS OF WEDGES AND DEPOSITS

Ice-wedge casts occur mainly in late glacial stratified drift deposits (fluvio-glacial and ice-contact sediments), but a few are found in deltaic and glacio-lacustrine deposits, and in raised beaches located near the highest limit reached by the Postglacial sea which submerged the St. Lawrence Valley. Most wedges occur in sand and small gravel deposits; some are in coarse to medium sand, and a few in fine to medium sand; but none was observed in till and bedrock. The wedges' filling is commonly made of medium to coarse sand, of small to medium gravel, or a mixture of sand and gravel; the infilling material is generally coarser than that of the enclosing layers (Figs.2, 3, 4). Contact between wedges and enclosing layers is usually sharp, contrasted, and evidenced by a few contorted or faulted layers near the cast (Fig.5). Inside the wedges, stratification usually is poor, but if present, layers are inclined downward toward the center with numerous elongated stones or pebbles in a nearly vertical position. The top of most wedges is found usually just under the soil layer, between 30 and 60 cm from the surface.

The depth of wedges rarely exceeds 250 cm, with an average depth range from 75 to 150 cm. The width of most casts ranges from 20 to 40 cm; only

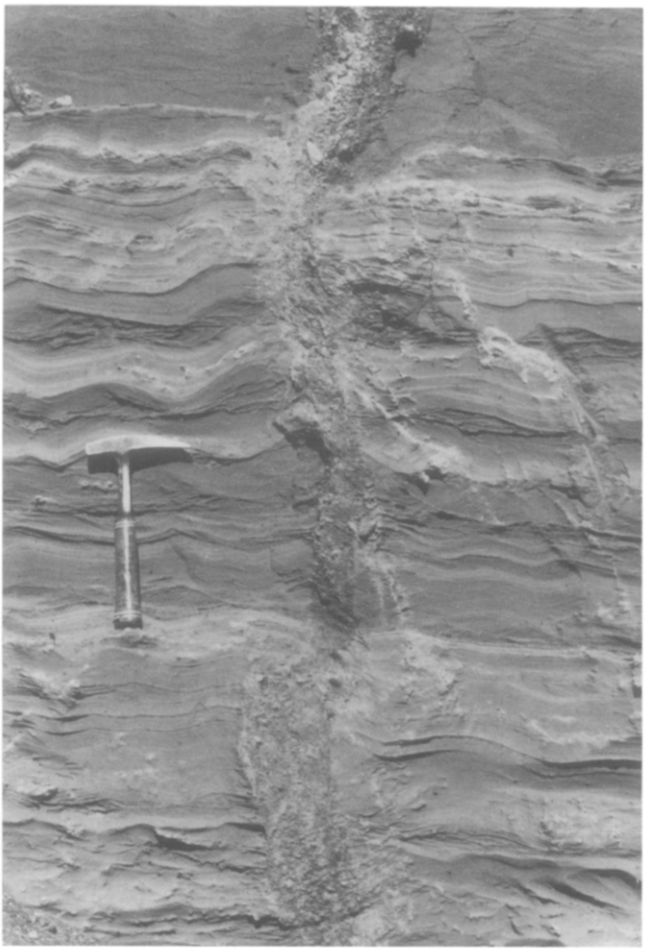

Fig. 2. A deep and relatively narrow ice-wedge cast cutting through subhorizontally stratified outwash sands, south of Rivière-du-Loup.

a few wedges exceed 60 cm in width at the top. Observations made at a few localities (Rivière-du-Loup, Saint-Modeste, Quebec City), indicate that wedges belong to former polygonal patterns having side lengths ranging from 2 to 15 m.

Considering their shape and their dimensions, three main types of wedges can be recognized: (1) wide and deep wedges; (2) wide and shallow wedges; and (3) thin or narrow wedges.

From their characteristics, the two first types of wedges are considered as true former ice wedges formed in permafrost. The third type of wedge may have formed in seasonally deep frozen ground. There is no evidence that any wedge casts are fossil sand wedges.

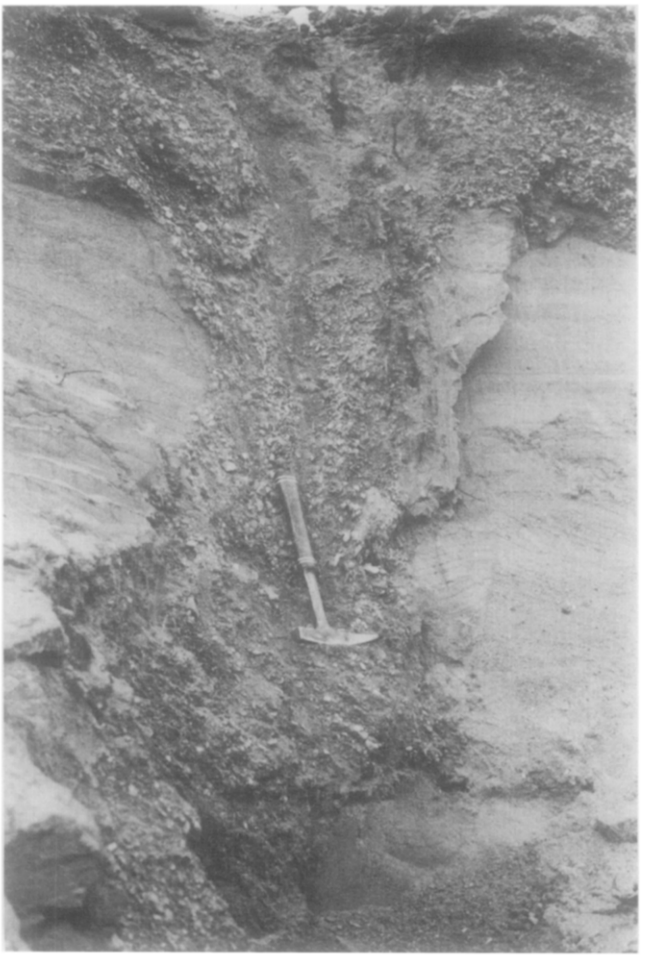

Fig.3. A deep and wide ice-wedge cast filled with sandy gravel cutting through sub-horizontally bedded sands, near Arthabaska.

PALEOCLIMATIC SIGNIFICANCE AND DATING

Ice-wedge climatic significance

According to Black (1952a, 1963, 1965, 1969), Péwé (1959, 1966a,b), Black and Berg (1963a, 1966), and Péwé et al. (1969), ice-wedge casts and sand wedges develop under severe climatic conditions. As demonstrated by Lachenbruch (1962) and several authors*, they originate by contraction of

* Contrary to the general belief of English-speaking authors, the theory of contraction cracks by frost was first proposed by A. von Bunge (1884), many years before Leffingwell (1915).

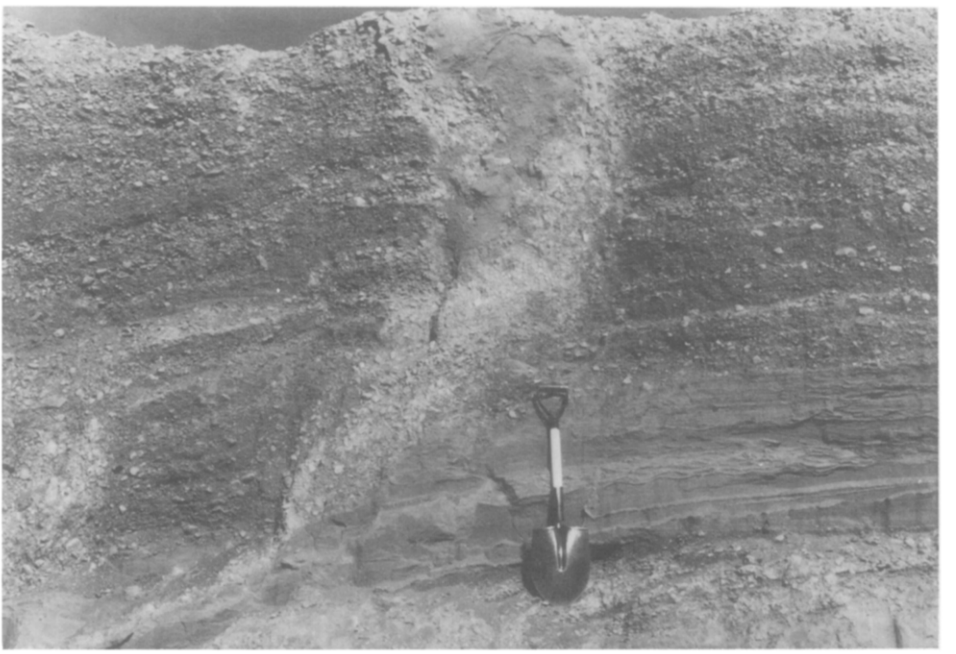

Fig. 4. Oblique view of an ice-wedge cast in fluvioglacial gravel, south of Rivière-du-Loup.

Fig. 5. Massive ice-wedge cast filled with coarse sand and small gravel cutting through sub-horizontally layered fine to medium sands, north of Quebec City. Note the deformational structure at upper right.

water-saturated sediments under low temperature ranging from —20° to —40°C, in areas where there is a thin or no snow cover.

From observations made in Alaska, Péwé (1966a, b) and Péwé et al. (1969) recognized that ice wedges are characteristic of regions with cold humid climate, having an annual air temperature from —8° to —12°C or lower. From observations made in Antarctica, Péwé (1959) and Black and Berg (1966) recognized that active sand wedges and active ice wedges develop respectively under cold and dry climate and cold and humid climate, when annual air temperature is −10° to −12°C or lower. Black (1969, p.228) recognized that "moderately high humidities are required during the spring to provide moisture for the development of hoar frost or melt water in the still open contraction cracks in permafrost. Where atmospheric humidity is low in the spring, or runoff water is not available, ice wedges do not grow; only sand wedges can form in such environments".

According to most authors (Dylik, 1966; Péwé, 1966a; Dylik and Maarleveld, 1967; Black, 1969), permafrost is a requisite condition for the development of true ice wedges. However, frost cracks form today in regions with no permafrost but which are characterized by deep seasonal frost with occasional low temperature (—20° to —30°C), and by a thin or no snow cover (Black, 1952b; Pataleiev, 1955; Lundqvist, 1962; Washburn et al., 1963; Bertouille, 1964; Svensson, 1967, 1969; and Aartolahti, 1972). There is a mean annual air temperature ranging from —1.5° to 6.5°C in regions where this type of frost cracks was observed.

Significance of ice-wedge casts in Quebec

From the above general remarks, it can be stated that ice-wedge casts in southern Quebec are relevant to a periglacial climate characterized by perennially frozen ground. Even though many wedges are sand-filled, none have the properties of true sand wedges. Ice is believed to have filled and grown in most frost cracks as it does today in polar regions. The melting of ice under warmer air temperature was followed by sediment filling, material falling into cracks from side walls and from top layers. Discontinuous permafrost rather than continuous permafrost is considered most probable in the area of ice-wedge formation. Geographical distribution of relic frost structures in southern Quebec indicates that permafrost occurred in the vicinity of two main ice fronts during the retreat of the Laurentides ice sheet, known as the Highland front morainic system and the St. Narcisse front morainic system (Gadd, 1964, 1971; Gadd et al., 1972).

The Highland front morainic system located at the northern margin of the Appalachian highlands predates the submergence of the St. Lawrence lowlands by the Champlain sea and was formed about 12 500 years B.P. or slightly earlier. The St. Narcisse front morainic system, located partly in the northern part of the St. Lawrence lowlands and partly at the southern margin of the Laurentides highlands, at a distance ranging from 50 to 100 km north

of the Highland front morainic system (Fig.1), is correlative of the Champlain sea and is dated about 11 000—11 500 years B.P. (Gadd et al., 1972).

The abundance of ice-wedge casts in deposits pertaining to the two ice fronts mentioned above, their rarity in highest beaches, their absence in deposits of the Champlain sea and other deposits that were submerged, and the absence of any ice-wedge cast in the Saguenay/Lac-Saint-Jean lowlands, 150 km north of Quebec City, suggest that the relic frost structures developed near the margin of the glacier. Thus there are two main possible periods of formation:

(1) Those in deposits of the Highland front morainic system may have formed when the ice front was at the northern margin of the Appalachian highlands, which means about 12 500 years B.P.

(2) Those pertaining to the St. Narcisse front morainic system may have formed when the ice front was at the southern margin of the Laurentides highlands, which means about 11 500 years B.P.

However, it is possible that ice-wedges of both systems developed during a single period, i.e. when the ice stood at the St. Narcisse moraine, but as yet there is no evidence this occurred. These ice wedges are considered to have formed in the period between 13 000 and 11 000 years B.P. The relic frost features reported by Lagarec (1972) from the terraces of the St. Lawrence River SW of Quebec City and dated about 2000—2400 years B.P. are not true ice-wedge casts but "soil wedges", a kind of structure that could develop in seasonal deep frozen grounds (Popov et al., 1966). Also, the contorted structures in Quaternary deposits of the St. Lawrence lowlands near Montreal reported by Gangloff et al. (1971) do not present evidence of periglacial conditions in this area, similar structures forming in various climatic conditions (Dionne, 1971b).

Ice-wedge casts from the Magdalen Islands (Laverdière and Guimont, 1973), located in the Gulf of the St. Lawrence, developed during the Wisconsin maximum when the Laurentides ice shelf expanded over the Gulf. Although the Laurentides ice sheet expanded about 300 km further south, these islands were not overridden by glacier ice, and a periglacial climate had existed over a long period, during which ice wedges and other periglacial features developed. Ice-wedge casts are relic features possibly older than 12 500 years B.P., and presumably older than 13 500—14 000 years B.P. This area should be considered separately in discussing the significance of ice-wedge casts in southern Quebec.

Considering the rate of growth of active ice wedges in Alaska and in Antarctica (Black, 1952a; Black and Berg, 1963a,b, 1966; Berg and Black, 1966, Péwé, 1966b; Péwé et al., 1969), and the width of wedge casts observed in southern Quebec, it is possible to estimate that most wedges developed during a period of about 300—400 years with a maximum of 500—600 years for larger wedges. This would mean that the periglacial (permafrost) conditions required for development of ice wedges existed for at least a few centuries during the retreat of the Laurentides ice sheet in southern

Quebec. The thickness of the surface layer, under which most wedge casts are found in southern Quebec, being 30 to 60 cm denotes the thickness of the active layer during the period of ice-wedge growth.

Pollen spectra available for southern Quebec (Auer, 1930; Potzger, 1953; LaSalle, 1966; Terasmae and LaSalle, 1968) do not indicate any tundra phase following the retreat of the ice sheet in that area, i.e. after 11 000 years B.P. (Bryson et al., 1969; Prest, 1969, 1970; McDonald, 1971), even though two or three cool periods did occur. This conclusion is in agreement with climatic interpretation of pollen diagrams given by Davis (1967) and Livingstone (1968). However, Richard (1971) had suggested that tundra conditions could have persisted as late as 7200 years ago in the Laurentides highlands, just north of the area considered in this paper*.

CONCLUSION

Ice-wedge casts in late Pleistocene deposits in southern Quebec provide evidence of a former periglacial climate shortly after or during deglaciation for at least some parts of this area. Discontinuous permafrost occurred near the margin of the retreating Laurentides ice sheet during two main periods both characterized by a frontal morainic system. The annual mean air temperature was less than -6°C and humidity was high enough to allow formation of ice wedges in frost cracks in the frozen ground. Current mean annual air temperature in the study area ranges from 2° to 5.5°C, that is at least 8 to 12°C warmer than during the period of ice-wedges formation that took place during the retreat of the Laurentides ice sheet in southern Quebec, between 13 000 and 11 000 years B.P.

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* It is noteworthy that the area of this highland region studied by Richard has a present mean annual air temperature ranging from 0° to 1°C.

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