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# Entombed Plant Communities Released by a Retreating Glacier at Central Ellesmere Island, Canada

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ABSTRACT. The release of a dead but well-preserved high arctic plant community, entombed for about 400 radiocarbon years (WAT-778 and 789) under glacial ice at Twin Glacier, central Ellesmere Island (78°53'N, 75°55'W) is reported. Remarkably intact plants have been emerging from under the ablating front of this polar glacier which has been retreating for several decades at an average rate of 4.1 $m \cdot yr^{-1}$ over the last 22 years. The vegetation can be readily recognized as a *Cassiope tetragona-Dryas integrifolia*-dominated community, similar in species composition and cover to an extant *Cassiope-Dryas* community 200 m below the ablation front. The excellent preservation of the plants supports the thesis that polar glaciers are frozen to their bases, and hence their movements are by internal deformation rather than by erosive basal sliding.

Key words: Ellesmere Island, Twin Glacier, polar (cold) glaciers, retreating glacier, Little Ice Age, ice-buried plants, paleobotany, radiocarbon dating

RÉSUMÉ. L'article rapporte l'émergence d'une communauté végétale du nord de l'Arctique, morte mais bien préservée, qui avait été ensevelie pendant quelque 400 ans au carbone 14 (WAT-778 et 789) sous la glace glaciaire du glacier Twin, dans la partie centrale de l'île d'Ellesmere (78°53'N; 75°55'O). Des plantes en état remarquablement intact sont à émerger d'en dessous du devant de ce glacier polaire en ablation depuis plusieurs décennies, reculant à un taux moyen de 4.1 $m \cdot an^{-1}$ au cours des 22 dernières années. La végétation peut être facilement reconnue comme celle d'une communauté dominée par les *Cassiope tetragona* et *Dryas integrifolia*, à composition d'espèces et à croissance semblables à une communauté de *Cassiope* et de *Dryas* en vie à 200 m à l'avant du front en ablation. L'excellente préservation des plantes appuie la théorie selon laquelle les glaciers polaires sont gelés à leur base et leurs mouvements résultent donc de déformations intérieures plutôt que de glissments érosifs à la base.

Mots clés: île d' Ellesmere, glacier Twin, glaciers polaires (froids), glacier reculant, le petit âge glaciaire, plantes ensevelies dans la glace, paléobotanie, datation radiométrique

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## INTRODUCTION

Temperate glaciers are well known as dynamic geologic agents by virtue of the tremendous erosion caused by basal sliding. On the other hand, Embleton and King (1968) suggested that most polar or cold glaciers are frozen to their beds, so that significant bedrock erosion does not occur. In fact, polar glaciers may preserve surficial features that preceded their advance. Goldthwait (1960) described 200-year-old dead moss between boulders on the bed of a tunnel in an ice cap near Thule, Greenland. Other authors have reported findings of intact lichens and dead but preserved plants in the vicinity of melting glaciers at Ellesmere Island (Beschel, 1961; Smith, 1961) and near Thule, Greenland (Swinzow, 1962). The most relevant work with respect to this report is that of Falconer (1966), who described the release of undisturbed, vegetated patterned ground features by the rapid recesson of a thin body of Tiger Ice Cap in northern Baffin Island. Exposed moss, *Polytrichum juniperinum*, was radiocarbon-dated at 330 ± 75 years. However, no released vascular plants were mentioned. At Ellesmere Island (Makinson Inlet, Alfred Newton Glacier, Jakeman Glacier, Sydcap Ice Cap, and Sverdrup Pass), Blake (1981) reported numerous finds of intact and partially preserved *Salix* spp., *Dryas integrifolia*, and moss specimens. These plants were found rooted near outlet glaciers and were radiocarbon-dated as fairly recent (up to 200 radiocarbon years). Blake unearthed further remnants of these species imbedded in the till or other substrate, which range from 1000 to 5500 years old.

This paper documents a significant finding of an identifiable pre-Little Ice Age (i.e. prior to ca. 1550 ± 140 A.D.) relatively undisturbed plant community that is being exposed by a retreating glacier in the Canadian High Arctic. It also supplies further evidence for the thesis of Blake (1981) that glaciers draining the ice caps in central and southeastern Ellesmere Island experienced an advance in the recent past, presumably as a response to the Little Ice Age cooling period. The glacial tongue we studied is the western lobe of Twin Glacier and terminates 250 m above sea level in the southern apex of a formerly glaciated lowland adjacent to Alexandra Fiord, Ellesmere Island (78°53'N; 75°55'W) (Fig. 1). This outlet glacier is fed from the higher reaches of a large upland ice cap in the mountainous interior of Johan Peninsula.

## METHODS

The recent rate of retreat of the Twin Glacier terminus was calculated using three independent methods. 1) The positions of the glacier front on 1959 and 1981 airphotos were compared. The photographs were adjusted by projection to the same scale (1:8500), and were aligned using distinctive topographic features. 2) Direct measurements of annual ice retreat were made. In 1980, nine reference stakes were established at approximately equidistant intervals along a 260-m-wide portion of the foot of the glacier, and the rate of ablation was measured throughout the summers of 1981 and 1982. 3) Five pioneer *Salix arctica* Pall. (arctic willow) plants collected from the recently deglaciated zone below the foot of the glacier were analyzed for their age. Fresh stems were hand-sectioned and stained with hydrochloric acid and phloro-

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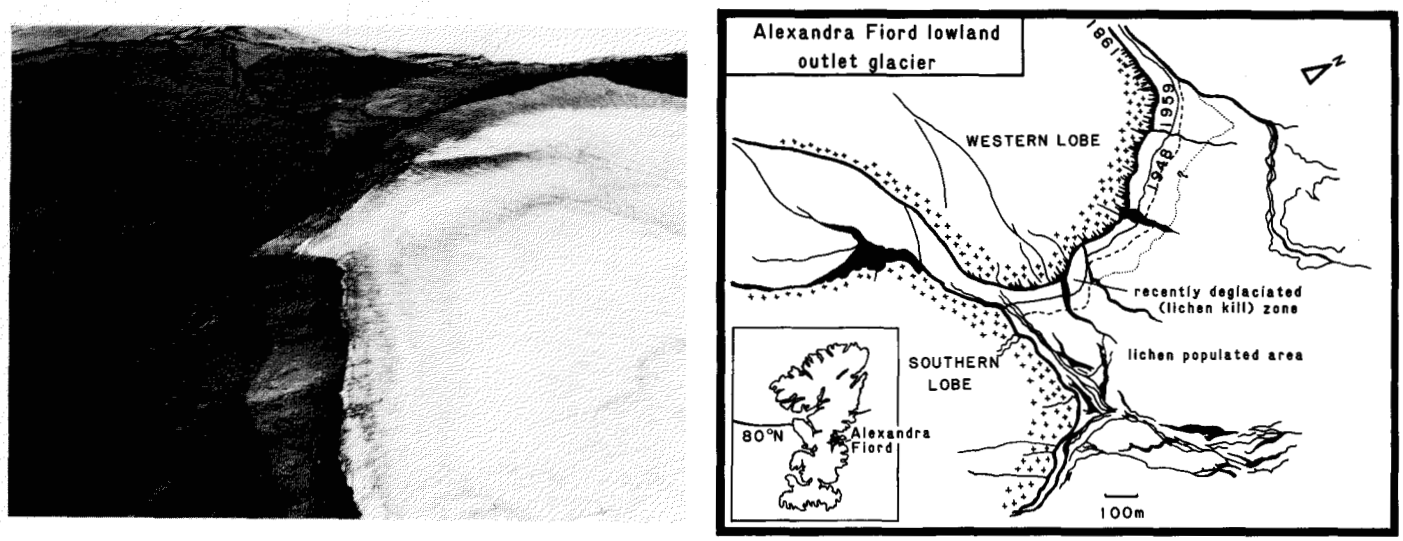


FIG. 1. (L) 1981 airphoto of the southern (upper right corner) and western lobes of the Twin Glacier outlets at Alexandra Fiord lowland. Lighter, recently deglaciated zone adjacent to the glacier terminus is clearly visible on the photograph. (R) Schematic representation of the positions of the southern and western lobes of the Twin Glacier outlets as reconstructed from 1959 and 1981 aerial photographs and ground reconnaissance of lichen kill zones.

glucinol, and the number of annual growth rings was counted. The distance of their occurrence from the glacier front was measured before the plants were extracted.

Cover and frequency of plants released from the basal ice ahead of the glacier were measured using 100 quadrats (50 × 50 cm; random number table applied in a grid within a 25-m-wide zone. Beyond this zone plant remains also occurred, but with increasing distance from the terminus they were progressively more weathered due to longer exposure, and were less suitable for study.) Plant species were easily identifiable. For purposes of comparison an extant plant community 200+ m from the glacier front (approximately 220 m a.s.l.) was also measured for cover and frequency (n = 40 quadrats). Plant materials acquired as specimens or for chemical analyses were collected at the edge of the glacier within hours of their release. During the warmest period in July the ablation of the terminus was several centimetres per day.

The length of time since the released plants were entombed in the ice was determined by radiocarbon dating of specimens of *Cassiope tetragona* (L.) D. Don (arctic white heather; 2-cm shoot tips) and *Salix arctica* (woody burl).

In order to quantify the presumed photosynthetic pigments, leaves of freshly released vascular plants (*C. tetragona, Dryas integrifolia* M. Vahl.) and a moss (*Racomitrium lanuginosum* (Hedw.) Brid.) were analyzed for chlorophyll. Comparative analyses on identical species were done using tissues of living specimens.

In addition, freshly released specimens of a crustose lichen (*Rhizocarpon geographicum* (L.) DC) and a fruticose lichen (*Thamnolia vermicularis* (Sw.) Schaer.) were collected. These were air-dried, and were later measured for $CO_2$ exchange using infrared gas analysis.

## RESULTS AND DISCUSSION

### *Field Observations*

The recent retreat of the Alexandra Fiord terminus of Twin Glacier is obvious from the light-coloured zone of dead and weathered lichens around its margin. This zone is in sharp contrast to the older deglaciated landscape, where all exposed rock surfaces are covered with dark saxicolous and terricolous lichens.

The average width of the light-coloured release zone, clearly visible on aerial photographs (Fig. 1), was ~45 m in 1959 and ~135 m in 1981, meaning that some 90 m were deglaciated over 22 years, a rate of ~4.0 m of retreat per year. Direct measurement of the retreat of the terminus showed a meltback of ($\overline{X}$ ± Standard Error) 5.6 ± 0.8 m·yr$^{-1}$ in 1981, 5.9 ± 1.9 m·yr$^{-1}$ in 1982, and 4.7 ± 0.9 m·yr$^{-1}$ in 1983. Based on the age of the living willow plants collected on the deglaciated terrain (15-90 years), the rate of glacial retreat was 3.7 ± 1.1 m·yr$^{-1}$. The latter value, however, is an underestimate of the true rate of retreat, since there is an unknown time gap between the year of deglaciation and the year of establishment of the willows.

Thus, the three estimates of the rate of retreat for the outlet glacier were ~4.0 (over 22 years), ~5.4 (over three years), and ~3.7 m·yr$^{-1}$ (over 15-90 years). The 5.4-m figure suggests that the glacier has been retreating faster in recent years. This should be attributed to thinning of the monitored section of the terminus rather than to a series of exceptionally warm years.

### *Release of Entombed Plants*

Many of the plants released at the edge of the retreating glacier were in remarkably good condition. For example, we found shrubs of the deciduous *Vaccinium uliginosum* L. (arctic blueberry) and *Salix arctica* with foliage still attached, and intact cushions of *Dryas integrifolia* (mountain avens) with flower heads and plumose seeds (Fig. 2). Apical tissues of *D. integrifolia* and *Cassiope tetragona* were reddish-brown, as they are in living plants following snowmelt. Seeds were found in fruiting bodies of several other species, but they

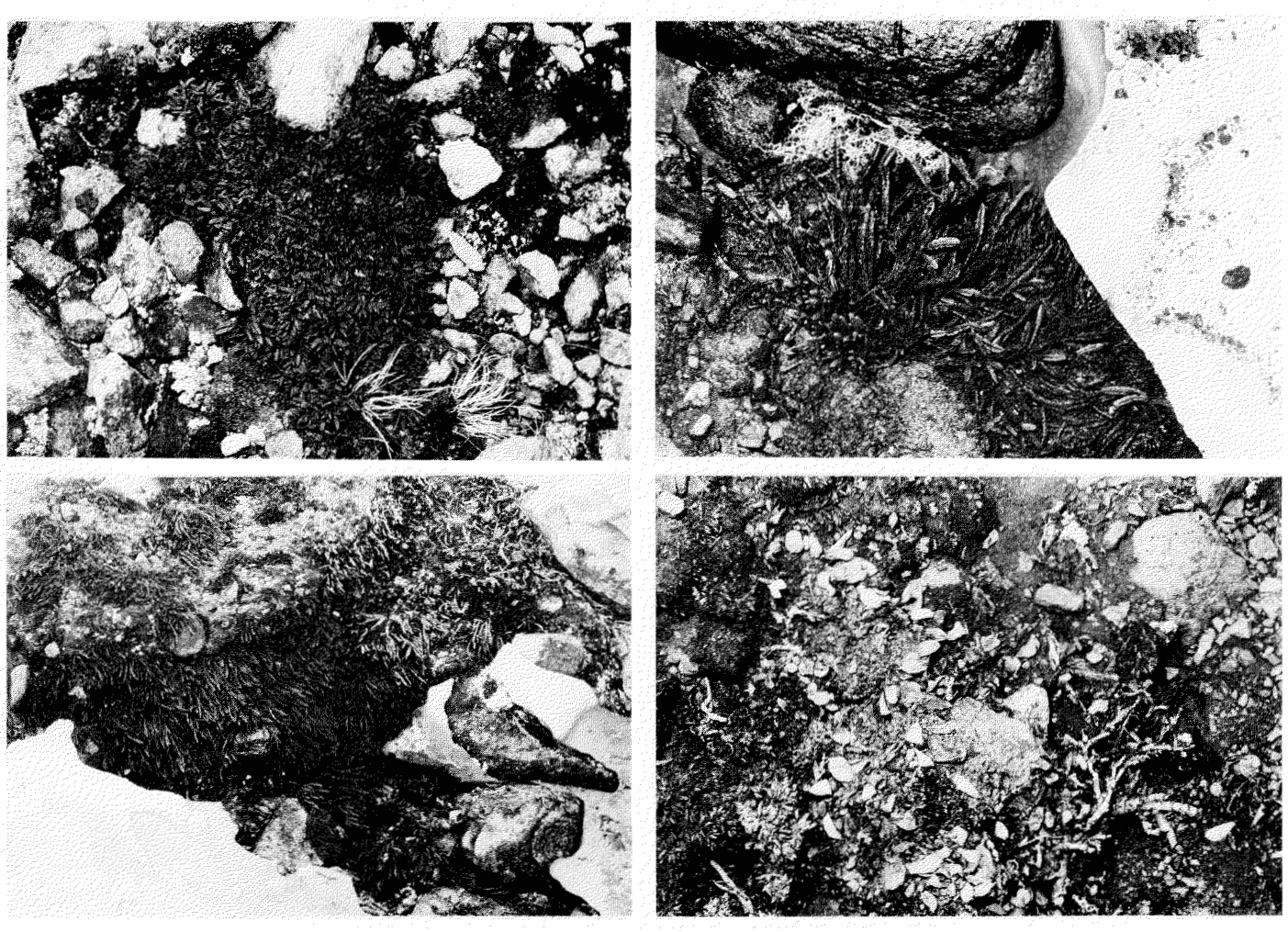

FIG. 2. Examples of extremely well-preserved clumps of plants released from under the retreating glacier at Alexandra Fiord, Ellesmere Island. (Upper left): *Dryas integrifolia* and *Carex nardina*; (upper right): *Cassiope tetragona* and lichen *Alectoria ochroleuca* at the edge of the glacial wall; (lower left): stands of *Cassiope tetragona* being released from ice; and (lower right): *Salix arctica* with leaves still attached, partially covered with fine debris deposited by melted ice.

proved to be nonviable in germination trials (incubated on filter paper at 20°C for three weeks).

In places the ice-free ground was so densely covered by released plants that it was possible to quantitatively describe the newly exposed plant community in terms of cover and species frequency. The floristic characteristics are summarized in Table 1. In terms of species composition this community was comparable to the existing *Cassiope-Dryas* community below the zone of retreat. However, there were striking differences in cover of the dominant elements. *Cassiope* and *Dryas* were found in a mutually exclusive cover pattern (Table 1), i.e., where *Cassiope* constituted the dominant cover, *Dryas* was low, and vice versa. The current *Cassiope* population shows a cover more than twice as high as the released *Cassiope*. This is not the case with *Dryas*, where the released population is twice as abundant as the current one. This may be indicative of somewhat drier conditions prior to and during the advance of Twin Glacier, as compared to the present, when there is an abundant supply of ablated water. (In terms of habitat requirements *Cassiope* is relatively mesophytic, while *Dryas* can tolerate more xeric conditions.)

The age of the released plant community was determined by radiocarbon dating of *Cassiope* and *Salix* collected from the

TABLE 1. Cover (%) and frequency (%) for released dwarf shrub-cushion plant community found within 0-25 m of the edge of the retreating glacier, and for a comparable living plant community found ~200 m from the edge

| | Released Community[a] | | Extant Community[b] | |
|---|---|---|---|---|
| Species | Cover | Frequency | Cover | Frequency |
| *Carex nardina* | 1.1 | 48 | 0.2 | 8 |
| *Cassiope tetragona* | 7.4 | 64 | 18.0 | 53 |
| *Dryas integrifolia* | 2.6 | 55 | 1.1 | 30 |
| *Luzula confusa* | 0.4 | 29 | 1.8 | 48 |
| *Papaver lapponicum* | <0.1 | 1 | 0.2 | 12 |
| *Salix arctica* | 0.6 | 21 | 1.3 | 23 |
| *Saxifraga oppositifolia* | 1.0 | 46 | 0.5 | 10 |
| *Stellaria monantha* | <0.1 | 2 | <0.1 | 5 |
| Other vascular species | 0.0 | 0 | 0.4 | 25 |
| TOTAL VASCULAR SPECIES | 13.1 | 266 | 23.5 | 214 |
| TOTAL BRYOPHYTES | 3.5 | 69 | 15.4 | 98 |
| TOTAL SAXICOLOUS LICHENS | 33.6 | 97 | 48.9 | 97 |
| TOTAL TERRICOLOUS LICHENS | 12.5 | 91 | 9.4 | 97 |

[a]n = 100 - 50 × 50 cm quadrats.
[b]n = 40 quadrats.

edge of the retreating terminus. The shoot tips of *Cassiope* were radiocarbon-dated at 400 ± 140 years (WAT-778), whereas the *Salix* burl was aged at 430 ± 90 years (WAT-789). In 1983 another willow burl was recovered and dated at 410 ± 45 years (SI-6033). Since the willow wood was at least 50 years old prior to its burial by ice, its radiocarbon date would tend to overestimate the time of burial.

Foliage on some of the released plants appeared to be green because of the presence of chlorophyll pigments (Table 2). For example, *Cassiope tetragona* foliage from specimens that were removed from the melting ice front had a total chlorophyll content that averaged 0.25 $mg \cdot g^{-1}$ dry weight, contrasted with 0.69 $mg \cdot g^{-1}$ d.w. for living plants collected from under a snowbank, and 0.98 $mg \cdot g^{-1}$ d.w. for plants collected at the peak of the growing season. The bryophyte *Racomitrium lanuginosum* preserved the highest chlorophyll content of the three species measured. However, the pigment colouration in the released plants degraded rapidly within days of exposure to atmosphere and light.

Some released lichens were also remarkably fresh in appearance. However, an assessment of $CO_2$ efflux by infrared gas analysis indicated no respiration in released specimens of *Rhizocarpon geographicum* or *Thamnolia vermicularis*, whereas lichens collected from a living community did show activity.

TABLE 2. Chlorophyll concentration in the foliage of plants released from the basal ice at the foot of the retreating glacier. For purposes of comparison, analysis for living plants are also indicated. $\bar{X} \pm SD$ n = 3 replicates per treatment

| Species | Total Chlorophyll ($mg \cdot g^{-1}$ dry weight) | | |
|---|---|---|---|
| | | Living Plants | |
| | Plants Released from ice | Released from snowbank | At peak season |
| *Cassiope tetragona* | 0.25 ± 0.05 | 0.69 ± 0.02 | 0.98 ± 0.05 |
| *Dryas integrifolia* | 0.03 ± 0.01 | 0.35 ± 0.06 | 1.02 ± 0.04 |
| *Racomitrium lanuginosum* | 0.17 ± 0.04 | — | 0.31 ± 0.07 |

## *Summary*

It appears that the plant community currently being released from beneath the Twin Glacier outlet at Alexandra Fiord was entombed in ice between 1410 and 1690 A.D. It follows that as the climate deteriorated at the onset of the Little Ice Age, and the upland ice mass thickened, advances of the outlet glaciers occurred. In front of the advancing terminus the vegetation was covered by a persistent snow bank. The snow gradually densified into glacial ice without destroying the plants, preserving much of their structure and chemistry. After a considerable time lag following the beginning of climatic amelioration in the mid-nineteenth century, the glacier began to retreat, releasing the entombed plant community in its "life position" in a remarkably intact state. This latter phenomenon is supporting evidence for the thesis that polar glaciers are frozen to bedrock, and hence that they advance by internal deformation rather than by basal sliding.

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