Géographie physique et Quaternaire

Little Ice Age history of Tzeetsaytsul Glacier, Tweedsmuir Provincial Park, British Columbia
Évolution du glacier de Tzeetsaytsul, au parc provincial de Tweedsmuir (Colombie-Britannique) au cours du Petit Âge glaciaire
Geschichte der kleinen Eiszeit des Tzeetsaytsul-Gletschers im Tweedsmuir Provincial Park, British Columbia

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Volume 54, numéro 2, 2000

URI : https://id.erudit.org/iderudit/004870ar
DOI : https://doi.org/10.7202/004870ar

Aller au sommaire du numéro

Éditeur(s)

Les Presses de l'Université de Montréal

ISSN

0705-7199 (imprimé)
1492-143X (numérique)

Découvrir la revue

Citer cet article

Smith, D. J. & Desloges, J. R. (2000). Little Ice Age history of Tzeetsaytsul Glacier, Tweedsmuir Provincial Park, British Columbia. *Géographie physique et Quaternaire*, *54*(2), 135–141. https://doi.org/10.7202/004870ar

Résumé de l'article

Des recherches en lichénométrie et en dendroglaciologie ont été menées sur les dépôts du Petit Âge glaciaire au glacier de Tzeetsaytsul, au parc provincial deTweedsmuir. Le glacier tire son origine d'un champ de glace situé sur le flanc nord-est du Tzeetsaytsul Peak et se termine dans un lac fermé par une moraine. Le cours d'eau qui draine le lac a incisé le barrage morainique et coule à travers des moraines emboîtées jusqu'à un deuxième lac. Deux moraines frontales près du lac inférieur témoignent de récurrences distinctes, avec de nombreuses crêtes morainiques observées entre les deux lacs. Une courbe de croissance de *Rhizocarpon geographicum* étalonnée localement a été établie et fournit l'âge relatif de toutes les moraines. Les datations absolues sur du bois recueillis à l'intérieur des débris morainiques ont été établies en faisant correspondre le modèle de croissance annuelle des cernes avec la chronologie de croissance d'un *Abies lasiocarpa* local. La moraine frontale la plus externe a été déposée pendant une récurrence survenue au XVII ^{e} siècle qui a culminé vers 1700. Après le recul qui a suivi, le glacier Tzeetsaytsul a réavancé et construit une seconde moraine vers la moitié du XVIII ^{e} siècle. Le recul du glacier s'est produit dans les 40 années qui ont suivies et, vers 1935, il commençait à vêler dans le lac le plus élevé. Les recherches montrent que la récurrence la plus récente du glacier Tzeetsaytsul au Petit Âge glaciaire n'a pas été la plus importante et que de multiples événements ont caractérisé le Petit Âge glaciaire supérieur. L'application de la courbe de croissance du *Rhizocarpon* fait ressortir une récurrence jamais rapportée pour d'autres glaciers de la région au XVII ^{e} siècle. Ces résultats renforcent le concept du synchronisme des fluctuations glaciaires survenues au Petit Âge glaciaire supérieur à l'intérieur de la Cordillère de la côte du nord-ouest de l'Amérique du Nord, reflétant ainsi un forçage climatique à l'échelle régionale.

Géographie physique et Quaternaire, 2000, vol. 54, n° 2, p. 135-141, 8 fig., 3 tabl.

LITTLE ICE AGE HISTORY OF TZEETSAYTSUL GLACIER, TWEEDSMUIR PROVINCIAL PARK, BRITISH COLUMBIA

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ABSTRACT This paper describes lichenometric and dendroglaciological investigations of Little Ice Age (LIA) deposits at Tzeetsaytsul Glacier, Tweedsmuir Provincial Park, British Columbia. The glacier originates from an icefield on the northeast flank of Tzeetsaytsul Peak and terminates in a moraine-dammed lake. A stream draining the lake has incised the moraine dam and flows through nested moraines into a second lake. Two end moraines near the lower lake record separate advances, with numerous morainic ridges found between the two lakes. A locally calibrated *Rhizocarpon geographicum* growth curve was constructed and provides relative ages for all the moraines. Absolute dates from wood fragments collected from within the morainic debris were determined by matching their annual growth ring patterns to a local *Abies lasiocarpa* tree-ring chronology. The outermost terminal moraine was deposited by a 17th century advance that culminated in *ca.* 1700. Following subsequent recession, Tzeetsaytsul Glacier readvanced to build a second terminal moraine by the mid-1800s. Recession of this glacier occurred within 40 years and by 1935 the glacier was beginning to calve into the uppermost lake. The research shows that the most recent LIA advance of Tzeetsaytsul Glacier was not the most extensive, and that multiple events characterized the late-LIA. Application of the *Rhizocarpon* growth curve indicates a previously unreported 17th century advance at other glaciers in the region. These findings serve to reinforce the synchroneity of late-LIA glacier fluctuations within the coastal cordillera of NW North America suggesting that they record regional climate forcing.

RÉSUMÉ *Évolution du glacier de Tzeetsaytsul, au parc provincial de Tweedsmuir (Colombie-Britannique) au cours du Petit Âge glaciaire.* Des recherches en lichénométrie et en dendroglaciologie ont été menées sur les dépôts du Petit Âge glaciaire au glacier de Tzeetsaytsul, au parc provincial de Tweedsmuir. Le glacier tire son origine d'un champ de glace situé sur le flanc nord-est du Tzeetsaytsul Peak et se termine dans un lac fermé par une moraine. Le cours d'eau qui draine le lac a incisé le barrage morainique et coule à travers des moraines emboîtées jusqu'à un deuxième lac. Deux moraines frontales près du lac inférieur témoignent de récurrences distinctes, avec de nombreuses crêtes morainiques observées entre les deux lacs. Une courbe de croissance de *Rhizocarpon geographicum* étalonnée localement a été établie et fournit l'âge relatif de toutes les moraines. Les datations absolues sur du bois recueillis à l'intérieur des débris morainiques ont été établies en faisant correspondre le modèle de croissance annuelle des cernes avec la chronologie de croissance d'un *Abies lasiocarpa* local. La moraine frontale la plus externe a été déposée pendant une récurrence survenue au XVII^e^ siècle qui a culminé vers 1700. Après le recul qui a suivi, le glacier Tzeetsaytsul a réavancé et construit une seconde moraine vers la moitié du XVIII^e^ siècle. Le recul du glacier s'est produit dans les 40 années qui ont suivies et, vers 1935, il commençait à vêler dans le lac le plus élevé. Les recherches montrent que la récurrence la plus récente du glacier Tzeetsaytsul au Petit Âge glaciaire n'a pas été la plus importante et que de multiples événements ont caractérisé le Petit Âge glaciaire supérieur. L'application de la courbe de croissance du *Rhizocarpon* fait ressortir une récurrence jamais rapportée pour d'autres glaciers de la région au XVII^e^ siècle. Ces résultats renforcent le concept du synchronisme des fluctuations glaciaires survenues au Petit Âge glaciaire supérieur à l'intérieur de la Cordillère de la côte du nord-ouest de l'Amérique du Nord, reflétant ainsi un forçage climatique à l'échelle régionale.

ZUSAMMENFASSUNG *Geschichte der kleinen Eiszeit des Tzeetsaytsul-Gletschers im Tweedsmuir Provincial Park, British Columbia.* Man hat mittels Flechtenmessungen und Dendroglaziologie die Ablagerungen der kleinen Eiszeit am Tzeetsaytsul-Gletscher im Tweedsmuir Provincial Park, British Columbia, erforscht. Der Gletscher entsteht aus einem Eisfeld an der Nordost-Flanke des Tzeetsaytsul Peak und endet in einem durch eine Moräne eingedämmten See. Eine den See dränierende Strömung hat sich in den Moränen-Damm eingeschnitten und fließt durch eingeschachtelte Moränen in einen zweiten See. Zwei Endmoränen nahe beim unteren See belegen getrennte Vorstöße und man findet zahlreiche Moränen-Kämme zwischen den zwei Seen. Eine vor Ort geeichte *Rhizocarpon geographicum* Wachstumskurve wurde erstellt und sie ergibt relative Alter für alle Moränen. Absolute Daten von innerhalb des Moränenschutts gesammelten Holzfragmenten wurden bestimmt, indem man das Muster des jährlichen Wachstums ihrer Ringe mit der lokalen Baumringchronologie von *Abies lasiocarpa* zusammenpasste. Die äußerste Endmoräne wurde durch einen Vorstoß im 17. Jahrhundert abgelagert, der früh kulminierte, etwa um 1700. Nach dem folgenden Rückzug machte der Tzeetsaytsul-Gletscher wieder einen Rückvorstoß und baute eine zweite Endmoräne gegen die Mitte des 18. Jahrhunderts. Das Zurückweichen dieses Gletschers geschah über 40 Jahre und um 1935 begann der Gletscher in den höchsten See zu kalben. Die Forschungen zeigen, dass der jüngste Vorstoß des Tzeetsaytsul-Gletschers in der kleinen Eiszeit nicht der extensivste war und dass vielerlei Ereignisse die späte kleine Eiszeit charakterisierten. Die Anwendung der *Rhizocarpon*-Wachstumskurve zeigt einen zwar nicht belegten Vorstoß an anderen Gletschern der Region im 17. Jahrhundert. Diese Ergebnisse bestärken den Synchronismus der glazialen Fluktuationen in der späten kleinen Eiszeit innerhalb der Küsten-Kordilleren von NW-Nordamerika und lassen annehmen, dass sie eine regionale Klima-Verstärkung belegen.

Manuscrit reçu le 17 mai 1999 ; manuscrit révisé accepté le 29 mars 2000

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INTRODUCTION

The mountains of coastal British Columbia record heightened glacial and geomorphic activity during the Little Ice Age (LIA) (Ryder and Thomson,1986). Inaugurated by cooler and wetter conditions in the 13th century (Mathewes, 1985; Clague and Mathewes, 1996), the LIA persisted until climatic warming in the 20th century resulted in glacier recession beginning *ca.* 1860 (Evans and Clague, 1994). Records from coastal British Columbia and nearby Alaska indicate that there were three main episodes of LIA glacial activity (Wiles *et al.,* 1999 ; Luckman and Villalba, *in press*). In the early-LIA, radiocarbon and dendrochronological evidence illustrates that glaciers advanced throughout the 13th and 14th centuries (Ryder and Thomson, 1986; Ryder, 1987; Desloges and Ryder, 1990; Wiles *et al.,* 1999). This episode was followed by a hiatus, until late-LIA glacial advances in the 17th and 19th centuries (Ryder and Thomson, 1986; Ryder, 1987; Desloges and Ryder, 1990; Clague and Mathewes, 1996; Calkin *et al*., 1998).

In this paper we present a late-Little Ice Age history of Tzeetsaytsul Glacier[1] located in southwest Tweedsmuir Provincial Park, British Columbia (52° 34' 30" N; 126° 22' W; Fig. 1). This history is based on lichenometic and dendroglaciological investigations undertaken during the summer of 1997. Previous work in this region showed that most LIA terminal moraines date from the period between 1860 and 1900 (Desloges, 1987; Desloges and Ryder, 1990). Our data supplements these observations, adding to our knowledge of the LIA in coastal British Columbia.

STUDY SITE

Tzeetsaytsul Glacier is located in the Kitimat Ranges of the British Columbia Coast Mountains. Peaks in the area are composed of Hazelton Group andesitic volcanic rocks (Tipper, 1963) and flank the edge of the Interior Plateau erosion surface (Baer, 1973). Tzeetsaytsul Peak (2682 m asl) likely persisted as a nunatak (above 1980 m asl) during Wisconsinan glaciation (Baer, 1973).

Tzeetsaytsul Glacier is one of two outlet glaciers that originate from a high-elevation icefield (*ca.* 1850 m above sea level [asl]) below the northeast face of Tzeetsaytusl Peak (Fig. 2). The southern glacier drains into Tzeetsaytsul Creek and its LIA limit is demarcated by a massive single-crested terminal moraine located 2 km downvalley from the present ice margin (Fig. 3). Tzeetsaytsul Glacier cascades down from the northeastern flank of the icefield (Fig. 2), to terminate at the proximal end of moraine-dammed upper Tzeetsaytsul Lake at 1265 m asl (Figs. 2 and 3).

Upper Tzeetsaytsul Lake drains through a moraine dam (Fig. 3) and an abandoned channel along its northern perimeter marks an earlier outlet (Fig. 4). The modern stream passes through a suite of moraines, before discharging into lower Tzeetsaytsul Lake and draining northwestward to the Dean River.

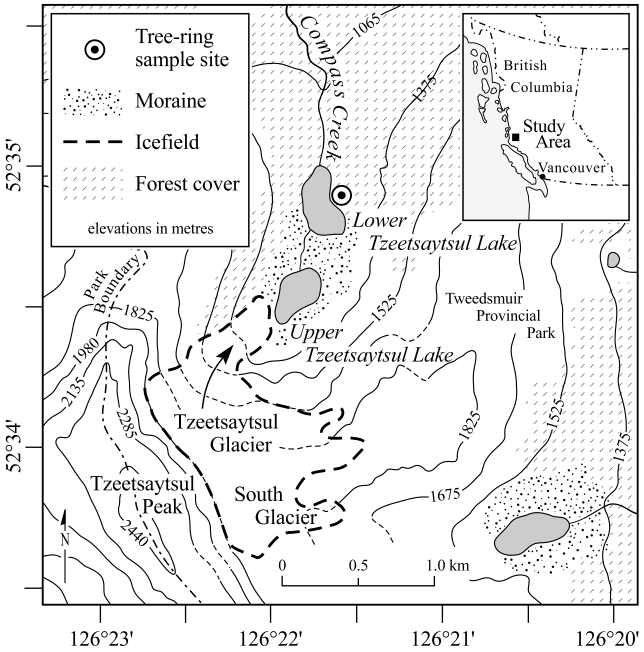

FIGURE 1. Map showing the study site in the central coast region of British Columbia.

Carte de localisation du site à l'étude dans la région côtière centrale de la Colombie-Britannique.

A single, subdued terminal moraine skirting the south shore of lower Tzeetsaytsul Lake marks the local limit of the LIA advance (Position 1, Fig. 4). The crest of the moraine is well-rounded and sits *ca.* 2 m above the lake surface. The moraine appears more weathered than those upvalley and has a patchy cover of trees, shrubs and soil, and is characterized by large *Rhizocarpon geographicum* thalli. Immediately upvalley, nested within 30 m of the terminal moraine is a concentric, 'fresh-appearing' moraine deposited by a later advance (Position 2, Fig. 4). The sharp-crested and unvegetated moraine crest sits *ca.* 6 m above the lake surface. Five prominent and numerous smaller moraines occur upvalley and record the subsequent retreat of Tzeetsaytsul Glacier (Fig. 4).

DATING OF MORAINES

LICHENOMETRY

The age of the moraines were determined from a locally-calibrated *Rhizocarpon geographicum* growth curve (Fig. 5). Traverses across the moraines were completed and the maximum thalli diameter of all lichen were measured (± 0.5 mm). The lichen with the largest mean diameter (average of a and b axis) on each moraine was used to provide a minimum substrate age from the curve.

The lichen curve used to establish the age of the moraines was developed from 12 control points found at four locations in the area (Table I). Nine of the points (1-7, 9 and 10) were derived from gravestones carved from local rock found in Hagensborg Cemetery, Bella Coola River valley, 23 km to the southwest (55 m asl; 52° 23' 30" N, 126° 32' W). Control

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[1] Tzeetsaytsul Glacier, upper Tzeetsaytsul Lake and lower Tzeetsaytsul Lake are all unofficial names.

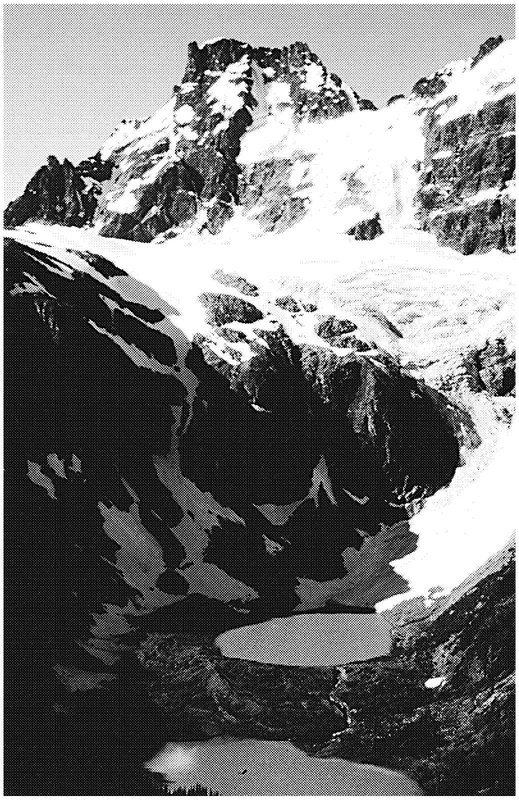

FIGURE 2. General view to the southwest showing Tzeetsaytsul Glacier in August, 1997. Upper Tzeetsaytsul Lake is dammed by a prominent suite of moraines.

Vue générale vers le sud-ouest montrant le glacier de Tzeetsaytsul, en août 1997. Le lac Tzeetsaytsul supérieur est fermé par une succession de moraines bien visibles.

FIGURE 3. Outlet of Upper Tzeetsaytsul Lake showing recent stream incision in moraine dam. Position of subfossil logs within till shown by person for scale.

La décharge du lac Tzeetsaytsul supérieur montrant l'incision récente du cours d'eau dans le barrage morainique. L'emplacement du bois subfossile à l'intérieur du till est indiqué par la personne.

points 8, 11 and 12 were derived from the diameter of the largest *Rhizocarpon geographicum* measured on three LIA moraines found around the Monarch Icefield 50 km to the south (Desloges and Ryder, 1990). The minimum age assigned to each of these lichens was determined from the age of the oldest tree found growing on the same moraine (Desloges, 1987). The calendar age assigned to each lichen also incorporates a correction factor for both tree ecesis (20-25 years, Desloges [1987: 356]) and sampling height error (*e.g.*, McCarthy and Luckman, 1993). All lichen ages greater than 165 years were interpolated using linear extrapolation from the final control point. This interpretation is reasonable given the similarity to the growth-curve presented by Calkin *et al.* (1998) for the first 150 years (Fig. 5). Because of this approach, all of our lichen-derived dates prior to 1800 are interpreted as minimum surface ages.

As differing *Rhizocarpon* subgenus were potentially included in the growth curve and in the lichen measurements at Tzeetsaytsul Glacier, the growth curve is designated as an aggregate *Rhizocarpon geographicum* sensu lato (s.l.) curve (*cf.* Dyke, 1990; Calkin *et al.*, 1998). While concerns might be raised about the variable effects of elevation and substrate variations on lichen growth rates in this setting, the consistent age-growth trend shown by control points 8 to 11 suggests any differences are inconsequential.

DENDROGLACIOLOGICAL DATING

Dendroglaciology is a research methodology that uses tree rings to study and date the movement of glaciers (Luckman, 1998). In recent applications, trees killed or displaced by advancing glaciers have been crossdated with reference to living tree-ring chronologies (Luckman, 1996; Smith and Laroque, 1996). For this approach to be successful, the living tree-ring chronology must have distinctive pointer years and encompass the age of the glacial advance being studied (Luckman, 1998).

At Tzeetsaytsul Glacier, recent stream incision through the centre of the moraine system found between upper and lower Tzeetsaytsul Lakes, had exposed a site with wood incorporated in till (Fig. 4). The site was located 2 m below the moraine, close to where the stream draining the upper lake has breached a recessional moraine (Fig. 3). Excavations in the adjacent stream bank yielded numerous detrital subfossil wood fragments, including intact boles (> 3 m length) and numerous smaller branch fragments (Fig. 6). While the subfossil boles appear to be the remains of living trees that were entrained during an advance of Tzeetsaytsul Glacier, some of the wood may have been deposited by contemporaneous snow avalanches from the adjacent forested valley sides. All the logs examined display some surface abrasion, however; cross-sections were successfully cut from the six largest.

In order to establish when the undated detrital samples were killed, cores were collected from a stand of subalpine fir (*Abies lasiocarpa* Nutt.) on the northeastern shore of lower Tzeetsaytsul Lake (Fig. 1). Subalpine fir dominate the local timberline and their ring-width sensitivity to climate offers considerable capacity for crossdating (*cf.* Ettl and

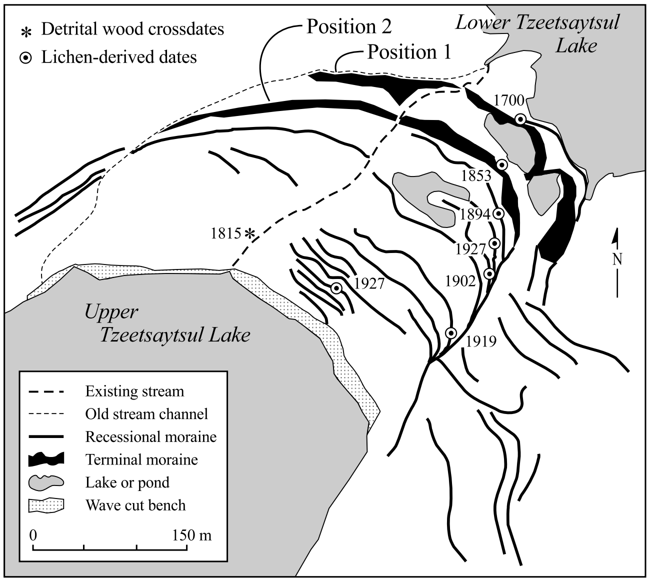

FIGURE 4. Schematic illustration of Tzeetsaytsul Glacier Little Ice Age moraine complex and position of crossdated subfossil wood sample sites. The relative age of each moraine was determined using a locally calibrated *Rhizocarpon geographicum* growth curve.

Illustration schématique du complexe morainique du glacier de Tzeetsaytsul datant du Petit Âge glaciaire et emplacement des sites d'échantillonage du bois subfossile interdaté. L'âge relatif de chacune des moraines a été déterminé grâce à une courbe de croissance de Rhizocarpon geographicum *étalonnée localement.*

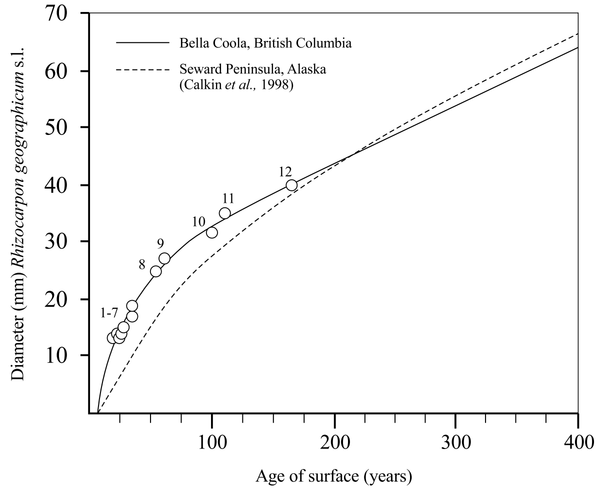

FIGURE 5. *Rhizocarpon geographicum* growth curve with control points developed for the Bella Coola area. Shown for comparison is a similar curve prepared by Calkin *et al.* (1998) for Seward Peninsula, Alaska.

La courbe de croissance de Rhizocarpon geographicum *avec les points de repères établis pour la région de Bella Coola. La courbe établie par Calkin* et al. *(1998) pour la région de Seward Peninsula, en Alaska, est présentée pour fins de comparaison.*

Peterson, 1995). After air drying, the cores were glued into slotted mounting boards, polished to a high finish and visually crossdated with reference to a set of local marker years (narrow rings in 1754, 1772, 1786, 1797, 1810, 1829, 1876, 1924 and 1976). The annual ring-widths were measured to the nearest hundredth of a millimetre using a computerized WinDENDRO^{TM} (Version 6.1D, 1998) image processing measurement system (Guay *et al.*, 1992). Where the ring boundaries were difficult to distinguish, a 40X microscope and Velmex-type stage measurement system were employed for ring boundary verification. The ring width data were checked for signal homogeneity using the COFECHA computer program (Holmes, 1983) and a standardized tree-ring series was constructed using a procedure within the ARSTAN computer program designed to remove any inherent age-growth trends (Holmes *et al.*, 1986).

The subalpine fir chronology spans the interval from 1717 to 1997 AD (Fig. 7). Table II presents the principle tree-ring statistics associated with the chronology. The mean series correlation value of 0.521 depicts the relative strength of the chronology and the mean sensitivity value of 0.196 provides a measure of between-ring variability (Fritts, 1976). Autocorrelation is a measure of the correspondence between successive increments and the value of 0.713 assigned to the chronology suggests that radial growth at the site is preconditioned by growth in the preceding year (Fritts, 1976).

The subfossil wood was identified as detrital subalpine fir on the basis of the anatomic characteristics of the annual rings (Schweingruber, 1993: 212-217). In order to facilitate ring-width measurement and crossdating (Stokes and Smiley, 1968), the disks were polished to a high finish using progressively finer sandpaper. The longest and most intact radii (pith to perimeter) were identified on each disk and the tree-ring widths were then measured using the WinDENDRO^{TM} system. These floating tree-ring series were initially visually crossdated with narrow marker rings derived from the adjacent subalpine fir chronology (notably years 1772, 1786, 1797 and 1810). These crossdates were subsequently verified against the living chronology using COFECHA (40-year dated segments lagged by 105 years, with the critical level of correlation for the 99 % confidence interval set at 0.328).

Figure 7 shows the chronological position of the detrital wood with respect to the living subalpine fir chronology. As the data in Table II suggest, the six cross-dated samples have variable outer ring dates. This variability is characteristic of glacially transported wood and a reflection of surface abrasion during transport (*e.g.*, Luckman, 1988). In spite of this loss of perimeter wood, all of the samples record similar kill dates, and therefore suggest a discrete glacial advance occurred toward the end of the 18th century.

INTERPRETATION

Tzeetsaytsul Glacier advanced to the south shore of lower Tzeetsaytsul Lake where it deposited a small terminal moraine. The subdued character of this moraine stands in sharp contrast to those created by later events. Based on measurements of the largest *Rhizocarpon geographicum* thalli present on the terminal moraine, the glacier began to

TABLE I

Lichenometric control points

No.	Surface	Location	Altitude (m)	Maximum diameter (mm)	Age (years)	Source
1	gravestone	Hagensborg	55	13	20	this study
2	gravestone	Hagensborg	55	13	25	this study
3	gravestone	Hagensborg	55	14	23	this study
4	gravestone	Hagensborg	55	14	27	this study
5	gravestone	Hagensborg	55	15	28	this study
6	gravestone	Hagensborg	55	17	36	this study
7	gravestone	Hagensborg	55	19	35	this study
8	moraine	East Smitley	1300	25	55	Desloges (1987)
9	gravestone	Hagensborg	55	27	62	this study
10	gravestone	Hagensborg	55	31.5	100	this study
11	moraine	Deer Lake	1435	35	111	Desloges (1987)
12	moraine	Talchako Lateral	1450	40	165	Desloges (1987)

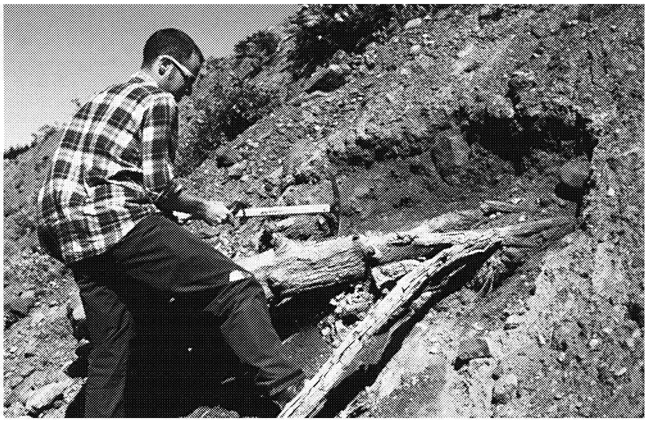

FIGURE 6. Excavation of subfossil wood from the moraine dam at Upper Tzeetsaytsul Lake. Crossdates on the samples indicate the subfossil boles and branches were entombed by Tzeetsaytsul in *ca.* 1815.

L'excavation du bois subfossile dans le barrage morainique du lac Tzeetsaytsul supérieur. L'interdatation des échantillons indique que les troncs et les branches subfossiles ont été ensevelis par le glacier de Tzeetsaytsul vers 1815.

recede from the moraine crest after *ca.* 1700 (Position 1, Fig. 4). Although the extent of this recession is unknown, the kill dates of trees buried by a subsequent readvance, indicate that the glacier had receded at least 500 m by 1815 when it was again advancing downvalley (Fig. 8). By *ca.* 1853, Tzeetsaytsul Glacier had advanced 225 m downvalley to build a conspicuous end moraine (Position 2, Fig. 4). According to the lichenometric data, Tzeetsaytsul Glacier remained in this position until *ca.* 1894 (Fig. 8), when it began to recede (4-5 m/yr), leaving behind a series of prominent moraines (Fig. 4). A suite of minor push moraines (less 1 m in height) suggest the glacier reached the shoreline of upper Tzeetsaytsul Lake by *ca.* 1935 and by 1997 had retreated a further 700 m upvalley (Fig. 2). For most of this interval the lake drained via a stream channel that followed the northern perimeter of the LIA limit (Fig. 4). Ring counts of trees and shrubs growing on a prominent strandline along the lake indicate that the present outlet was established in the early 1980s.

DISCUSSION

This research provides a regionally-controlled *Rhizocarpon geographicum* growth curve which is similar in form to that developed by Calkin *et al.* (1998) for the Kigluaik Mountains, Alaska (Fig. 5). This curve provided an opportunity to reconsider the findings of Desloges (1987) and Desloges and Ryder (1990).

Based on dendrochronological studies of sixteen LIA moraine systems surrounding the Monarch Icefield, Desloges and Ryder (1990) showed that most terminal moraines were deposited in the 19th century. During reconnaissance investigations, however; Desloges (1987) also noted three sites (Borealis, Deer Lake and Fyles Glaciers) where fresh-appearing moraines bordered a more weathered moraine. A lack of trees on the more weathered moraines made dating problematic and Desloges (1987) speculated that they formed sometime before 1869. Based on the lichen growth curve presented here, all three outer moraines date to an 18th century LIA maxima. Lichenometric evidence collected by Desloges (1987: 358-363) is interpreted to indicate moraine emplacement by approximately 1715 at Borealis Glacier, 1760 at Deer Lake Glacier and 1760 at Fyles Glacier (Table III).

CONCLUSIONS

Lichenometric and dendroglaciological studies completed at Tzeetsaytsul Glacier demonstrate two glacial advances during the late-LIA. The earliest advance, which attained the local LIA limit, is lichen-dated to the beginning of the 18th century. Application of our *Rhizocarpon* growth curve substantiates the widespread occurrence of a previously unreported 17th glacial advance (Desloges and Ryder, 1990). Cross-dating of glacially-overrun trees with a living *Abies* chronology at Tzeetsaytsul Glacier demonstrates that, after a period of recession, the glacier advanced downvalley

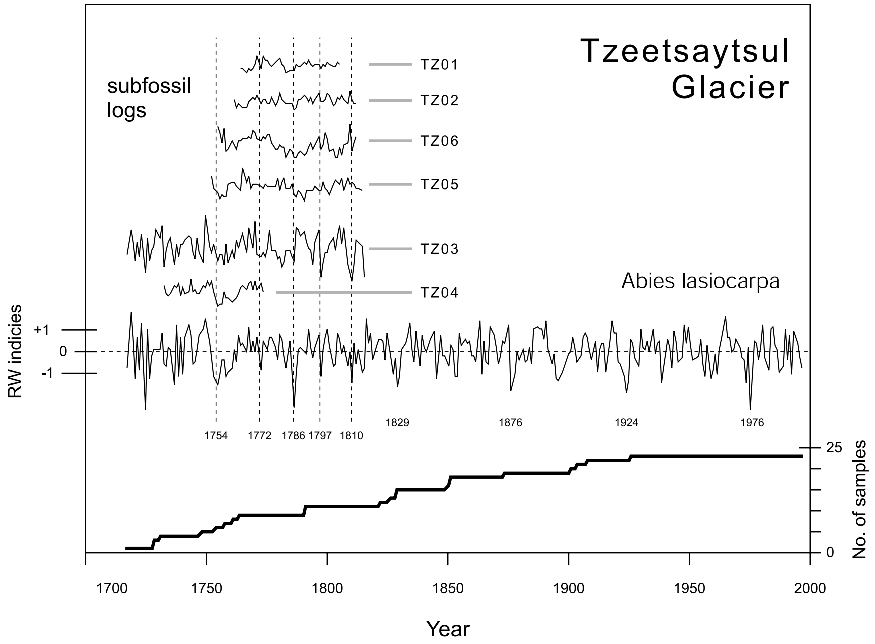

FIGURE 7. Summary of dendroglaciological studies at Tzeetsaytsul Glacier. The upper portion of the figure illustrates the duration of crossdated subfossil samples. While the youngest portion of each record indicates the pith date of the sample, the oldest portion does not necessarily represent the absolute age of the sampled wood due to surface abrasion. The middle graph illustrates the Tzeetsaytsul Glacier *Abies lasiocarpa* chronology derived from living trees found growing adjacent to Lower Tzeetsaytsul Lake. Dates refer to common pointer years in the chronology. The lower graph shows the sample depth of the living chronology.

*Résumé des études dendroglaciologiques menées au glacier de Tzeetsaytsul. La partie supérieure de la figure montre les périodes couvertes par les échantllons interdatés de bois subfossile. Si la partie la plus jeune de chacun des relevés donne la date du cœur de l'échantillon, la plus vieille partie ne représente pas nécessairement l'âge absolu, en raison de l'abrasion superficielle. Le graphique du centre illustre la chronologie d'*Abies lasiocarpa *du glacier de Tzeetsaytsul établie à partir des arbres vivants croissant près du lac Tzeetsaytsul inférieur. Les dates correspondent aux années de pointe courantes dans la chronologie. Le graphique inférieur montre le nombre d'échantillons vivants de la chronologie selon les années.*

TABLE II

Site characteristics and tree-ring statistics for Tzeetsaytsual Glacier Abies lasiocarpa tree-ring chronology

Site characteristics				
Location	Lat. 52° 35' W; Long. 126° 21' 30"W			
Elevation	1244 m asl			
Slope	20 %			
Living tree-ring statistics				
no. trees in chronology	18			
no. cores in chronology	31			
duration of chronology	1717-1997 A.D.			
Series correlation	0.521			
mean sensitivity	0.196			
Autocorrelation	0.713			
Detrital wood statistics				
no.	sample ID	no. of radii	crossdated interval (year AD)	correlation with master
1	TZ01	3	1764-1806	0.41
2	TZ02	3	1761-1813	0.43
3	TZ03	4	1717-1815	0.61
4	TZ04	4	1731-1771	0.68
5	TZ05	2	1748-1810	0.57
6	TZ06	2	1754-1812	0.33

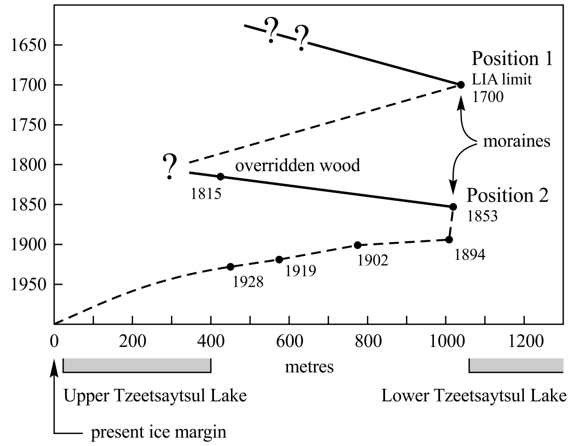

FIGURE 8. Time-distance graph showing the position of Tzeetsaytsul Glacier.

Graphique spatio-temporel montrant les différentes positions du glacier de Tzeetsaytsul.

TABLE III

Age of Little Ice Age terminal moraines in the Bella Coola area

Site	Inner moraine	Outer moraine
Tzeetsaytsual Glacier	1853(L)	1700(L)
Borealis Glacier	1869(T)	1715(L)+
Deer Lake Glacier	1874(T)	1760(L)+
Fyles Glacier	1900(T)	1760(L)+

L lichenometric dates.
\+ lichen measurements made in 1985 (Desloges, 1987).
T Tree-ring derived dates (Desloges, 1987: 356).

by 1815. A lichenometric date indicates moraine deposition by 1853, at a time when terminal moraines were being created throughout the region (Desloges and Ryder, 1990).

Although these findings add little to our understanding of glacier activity during the earliest part of the LIA (*cf.* Luckman, 1995), they do confirm the general synchroneity of LIA glacier fluctuations within the NW coastal Cordillera (Ryder and Thomson, 1986; Clague and Mathews, 1996; Calkin *et al.,* 1998; Wiles *et al*., 1999). Recognition of regional similarities in glacial activity suggests a common response, most likely attributable to climatic forcing. This behaviour is not apparent in recent mass balance histories of glaciers in this region (Hodge *et al*., 1998), suggesting stronger climate-forcing during the LIA buildup than has occurred this century. Because previous authors have suggested that the LIA maximum was later in the Coast Ranges than in the Canadian Rocky Mountains (*e.g.* Ryder, 1987; Osborn and Luckman, 1988; Luckman and Villalba, *in press*), the findings of this paper suggest that further LIA investigations are needed throughout the region.

ACKNOWLEDGMENTS

We thank John England and Brian Luckman for their comments which helped to improve this paper. Financial support for this study was provided by a grant from the Natural Sciences Engineering Research Council to D. Smith**.** Ze'ev Gedalof and Dave Lewis assisted in the 1997 fieldwork. We would like to thank Mike Church whose NSERC grant supported the early part of the study and to June Ryder who assisted with data collection in 1985. The maps which accompany the paper are a credit to the skills and patience of Ole Heggen, Cartographic Research Centre, Department of Geography, University of Victoria. Permission to work in Tweedsmuir Provincial Park was granted by BC Parks.

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