Dating the East Asulkan Glacier Spill-over Zone in Glacier National Park, British Columbia

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Abstract

Lichenometry and dendroglaciology were two methods used to date the Asulkan Glacier spill-over zone in Glacier National Park, B.C. Thalli measurements of *Rhizocarpon geographicum* were taken at three different moraines for detailed analysis using statistics and growth curves. Dendroglaciology measurements were taken at similar sites to the lichen measurements. These consisted of tree core samples, whorl counts and basal disks where applicable. Field measurements were taken in September 2008. Results showed the terminal moraine to date to approximately 1738. The lower recessional moraine dated to 1855, and the upper recessional moraine dated to 1906. A detailed comparison to nearby study areas includes similarities and differences between site results.

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1.0 Introduction

The Illecillewaet Icefield in Glacier National Park has long been the subject of keen ground observations and record keeping. The East Asulkan spill-over zone has not had the same attention or been subject to as many studies. The Illecillewaet Glacier is currently retreating (Sidjak, R. W., *et al.*, 1999); therefore, this study intends to determine the greatest extents of past ice-margins of the East Asulkan spill-over zone. Three methods were used in this study to assist with the process of glacial mapping.

A mutual relationship exists between algal and fungal communities in the form of lichens. Lichenometry is the process of measuring the diameter of the radial growth of lichen to determine the amount of time a particular surface has been exposed (Webber and Andrews, 2003). The limit on this technique is 10,000 years, as that is the amount of time lichen can be preserved on a surface. This study used a growth curve developed by D.P. McCarthy in lichenometric work performed in the neighbouring Illecillewaet Glacier valley in order to date the age of deposition of the substrate on which lichen communities were flourishing.

Dendroglaciology is a technique that uses tree ring analysis to date past glacial events and was implemented in our study of the East Asulkan spill-over zone (Smith and Lewis, 2007a). Tree ages were determined by analyzing annual growth rings in tree core samples taken along the moraines within the study site. These ages help create an estimate of when the ground ice cover receded allowing these trees to germinate. Ecesis rates were derived from analyzing multiple publications that allowed the age of maximum glacial extent to be inferred.

A comparative site analysis coupled with lichenometry and dendroglaciology allowed a multi-faceted approach to dating the past glacial maximums of the East Asulkan spill-over zone. Each technique staged as a basis for comparison and justification for the ecesis rates and absolute dates of the other techniques.

2.0 Study Site

The East Asulkan spill-over zone is located approximately 75km from Golden, British Columbia, within the Columbia Mountain range in Glacier National Park (Figure 2.1). The study site is accessible via the Asulkan Valley Trail, and would account for the good record of ground observations based at the neighbouring Illecillewaet Glacier. The area, centered at N 51°13.238', W 117°28.023’, with an elevation of 1783m ASL, is the location of the terminal moraine chosen for this study.

Lichen and tree core samples (where possible) were taken at three locations: the terminal moraine, lower recessional moraine, and the upper recessional moraine. The terminal moraine consists of a marshy area fed by the Asulkan Creek, with a distribution of large boulders, Subalpine Fir (*abies lasiocarpa*) as well as Mountain Hemlock (*Tsuga mertensiana*). The upper and lower recessional moraines consists of smaller distributions of boulders, as well as subalpine Fir trees that were much younger than ones found at the terminal moraine.

The forefield consists of two lateral moraines that are well over 20m in height, with moss, shrubs, along with boulders being key features of the moraine suite. Shrubs, and trees flanked the terminal moraine with some areas appearing to be reworked by nearby streams, or snow avalanches. Meanwhile, the recessional moraines had few saplings, and lines of boulders that appeared to be relatively undisturbed, and ideal for the purposes of lichenometry.

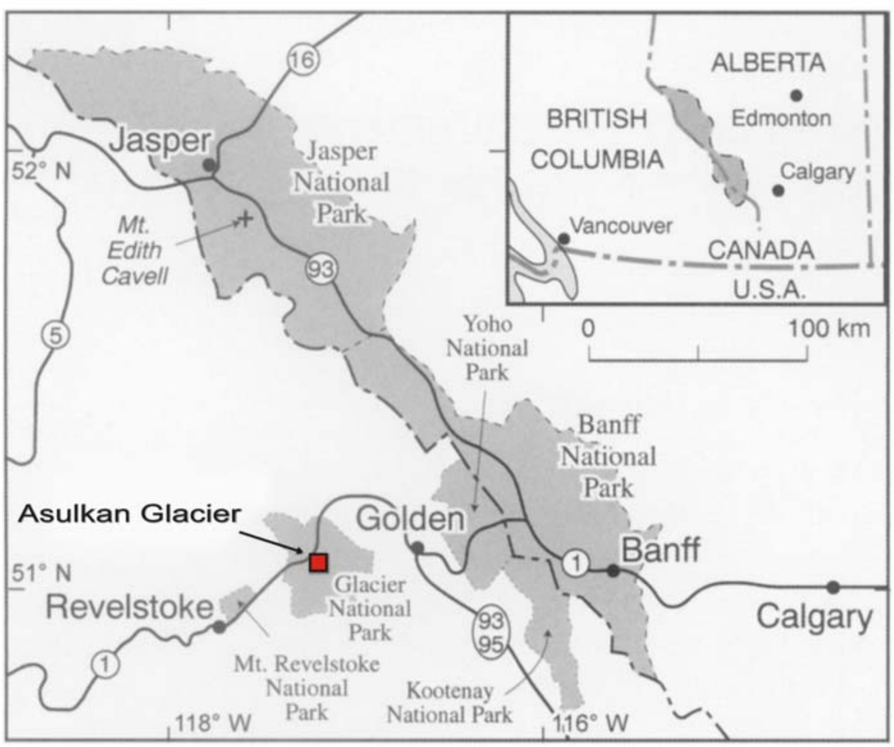

Figure 2.1: Asulkan Glacier Study Site

3.0 Lichenometry

3.1 Introduction

Spatial analyses of moraine ridges formed by glacial movement are commonly studied to determine past ice-margin positions. However, when considering past ice margins and post-depositional moraine surface disturbances, such geomorphic records tend to become increasingly complicated (Dugmore, *et al.*, 2008). As such, determining the relationship between current ice margins and past known locations are not indicative of the actual rate of recession. Such disturbances can also discompose the size distribution of lichen populations that provide a historic record or distinct signature for surfaces with similar histories.

As a result of frequent phases of glacial advance and retreat, detailed analyses of glacial moraines are often difficult to achieve. In such instances, any historic records that have accumulated on moraine features are compromised as glacial advances overrun or breach moraine suites, thus, complicating any morphological interpretations (Dugmore, *et al.*, 2008). To further confound results, variable ice-margin activities result in moraines exhibiting bifurcate tendencies, as well as crosscutting patterns (Dugmore, *et al.*, 2008). The denouement of such modifications to a glacial environment only serves to create an esoteric spatial association between moraines deposited at the same time.

Moraines created during a depositional phase are subject to similar post-glacial conditions, and will be of similar age. The identification of surfaces with similar histories would prove to be very useful as they can be used to identify antecedent ice margins. Disparities in the size of lichen populations should reflect post-depositional environmental and biological perturbations of moraine surfaces (Dugmore, *et al.*, 2008). Geomorphic history of moraine fragments can be determined by studying the distinctive signatures left by lichen thalli sizes.

It is possible to identify distinct ice margins by statistically comparing the size of lichen thalli from different moraine fragments (Dugmore, *et al.*, 2008). This approach is made possible based on the assumption that surfaces have common geomorphic and depositional histories, exposure rates, growth environment, as well as statistically and scientifically similar lichen populations. The *Rhizocarpon* genus will be used in this study because they are long lived and have a global distribution (McCarthy and Smith, 1995).

Through the use of lichen size data and descriptive statistics, it is possible to date moraines with a technique called lichenometry. This technique has been developed in Canada by the late Roland Beschel and can determine lichen substrate ages for soil, wood and most particularly rock (Webber and Andrews, 1973). With these techniques, we attempted to date the ages of ice-margins within the East Asulkan spill-over zone.

3.2 Methodology

Lichenometry involves measuring the diameter of lichen on a substrate, and using statistics programs to process the acquired data. Acquisition of data at the East Asulkan spill-over zone took place in three locations on three different moraines. Approximately 30 samples were taken at each moraine. The moraine furthest from the glacier was deemed the terminal moraine while the one just inside this study location was considered the lower recessional moraine. The study location at the bottom of the lateral moraine and in between the lower recessional moraine and the current glacier was considered our upper recessional moraine.

For each moraine, approximately 30 lichen samples were taken of healthy yellowish green *Rhizocarpon geographicum*. Samples were taken based on the largest thalli while attempting to span the entire moraine as well. Each thallus was measured on its x and y axis with a digital caliper with accuracy of +/- 1mm. Beschel's fundamental assumption was only the lichen thalli with maximum diameter are indicators of substrate age (Webber and Andrews, 1973). These measurements were booked and stored for future calculations.

Only ellipsoidal or circular lichen thalli were studied. No lichen readings were taken on the top (zenith) of the substrate so as to minimize the chance of biological factors playing a role in increased fertilization and growth of the thalli (e.g. Marmot fecal matter). No lichen measurements were taken in well shaded or covered areas (minimal solar radiation) and no lichen measurements were taken where one lichen patch had overtaken another in spatial competition (Haines-Young, 1988).

Calculations consisted of taking the mean of the x and y axis for each separate measurement. Each site combined its samples for a mean length. The mean thallus data was plotted on McCarthy's Illecillewaet Glacier growth curve (McCarthy, 2003). Based on this curve, approximate dating of the recessional moraines and terminal moraine could be accomplished.

Measurements were also taken along the span of the lateral moraine, from the upper recessional moraine to the East Asulkan tongue. However, calculations were not applied, as the lateral moraine did not prove to be significantly different from the recessional moraines.

3.3 Results

Data at each moraine proved to be significantly different from the other moraines and could be plotted on the Illecillewaet growth curve as a result. This growth curve was chosen due to spatial proximity and substrate similarity (quartzite) to the East Asulkan spill-over zone. The terminal moraine was dated to be 270 years old (1738), based on the lichen growth curve. The lower recessional moraine was 153 years old (1855) and the upper recessional moraine was dated at 102 years old (1906).

Creating an extension on McCarthy's curve will give an approximate lichen ecesis of 30 years. The first 50 years of this curve (Figure 3.1) have an increased slope compared to the subsequent years. This section of the curve is named the 'Great Period' by the late Roland Beschel and is prominent in many lichen curves (Porter, 1981; Luckman 1977). Other authors, such as Armstrong (1983) claim there is an early lag period leading up to the *Great Period,* and then finishing with a decelerating growth rate for the rest of the lichen's life. This would change the ecesis noted above, as it was interpreted using a straight-line extension off McCarthy's curve (McCarthy, 2003).

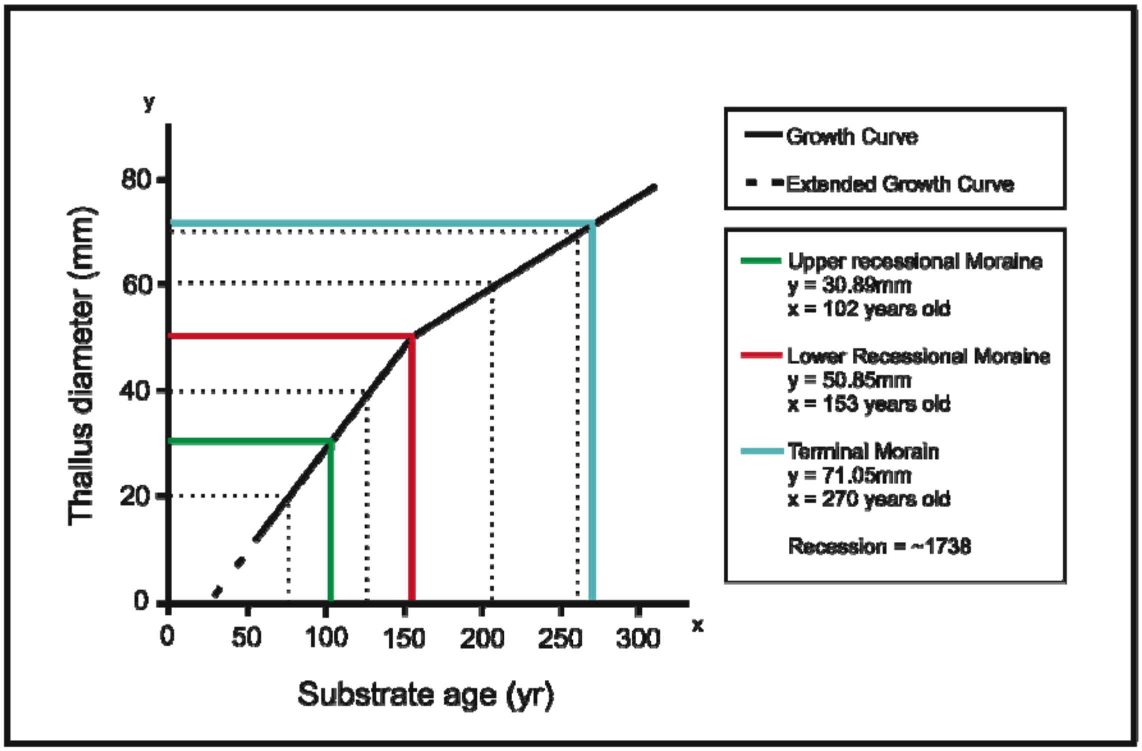

Figure 3.1 Illecillewaet growth curve with upper recessional, lower recessional and terminal moraines in place.

4.0 Dendroglaciology

4.1 Introduction

Dendrochronology refers to the science of using annual tree growth rings to infer relative dates of established vegetation in a specific area (Smith and Lewis, 2007a). Tree ring analysis has been noted in the literature as early as 1737; Leonardo da Vinci recognized its potential use as early as the 15th century (Smith and Lewis, 2007a). A branch of dendrochronology, dendroglaciology uses the dates extrapolated from tree ring analysis to aid in reconstructing past glacial activities (Smith and Lewis, 2007b). Using basic assumptions that morainal features remain relatively undisturbed after deglaciation, subsequent vegetal growth can be used to infer the year of maximum glacial extent. This date must also incorporate an ecesis rate, which describes the minimum delay of germination after the ground is exposed and free of perennial ice. In addition, dendroglaciology can be used to determine a subsequent glacial recessional rate once an ecesis value is added to the oldest tree. Typically, ecesis estimations are not standardized, and can be subject to error and bias (McCarthy and Luckman, 1993). Tree ring formation is subject to seasonal climate variability, which produces distinct small dark cell growth in the winter (latewood) and large lighter cells in the spring (springwood or earlywood) (Smith and Lewis, 2007a). A warming century and a retreating trend in glaciers has created more sites where dendroglaciology could be put into practice.

4.2 Methodology

The predominant tree species in the Asulkan Glacier study area was Subalpine Fir (*abies lasiocarpa*) as well as Mountain Hemlock (*Tsuga mertensiana*). The terminal moraine study area produced 17 subalpine fir cores and 3 mountain hemlock cores, while the upper recessional moraine produced 8 subalpine fir samples. A 5mm incremental borer was originally implemented at a consistent height to minimize germination date errors (McCarthy and Luckman, 1993). Initially, a slight downward angle was used (Smith and Lewis, 2007b), in order to core into the root crown interface to minimize age errors. In response to several rotten pith cores at this lower level, consistent corer handle height and standard breast height were used to extract suitable cores, which were subsequently stored in protective plastic tubes for transportation. In an attempt to minimally damage the tree specimens in this slow growing region, secondary tree cores at 90° to the original core angle were only taken when the initial core was broken or determined to be unusable. In this study, a second core was thought to be unnecessary, as cores would not be used for dendroclimatological analysis. Each core taken was labeled appropriately on a drawn map of the study area indicating relevant metadata including tree species and location. Trees in the upper recessional moraine and lateral moraine were determined to be too small for coring. Consequently, tree whorls were counted to determine the age of trees in these locations. To determine the validity of tree whorl counting, one of the trees was cut to extract a basal tree ring disk. The growth rings of this disk were counted to determine the accuracy of whorl counting.

The cores were brought to the University of Victoria Tree Ring Laboratory and glued into grooves in wooden boards. A five stage sanding process was used to sand cores to a smooth 600-grit finish, sufficient to determine distinct annual growth rings. Growth rings were then counted under a Velmex-type measuring stage mounted with a Wild M3B stereomicroscope using *WinDendro* to record the age. This data was then sorted into respective study regions in a spreadsheet program where the maximum tree ages for each moraine was extrapolated. To ensure legitimacy of our oldest tree age, the core sample from this tree was re-counted with the understanding that the oldest sample is key in determining the minimum age of a moraine (McCarthy and Luckman, 1993). Our initial intentions were to manually determine an ecesis value from aerial photo interpretation; however, suitable photos could not be acquired. Ecesis rates are notoriously difficult to determine. A previous study from the Canadian Cordillera assumes germination occurs 5-60 years after glacial retreat for coniferous species (McCarthy and Luckman, 1993). Subsequent studies at the Illecillewaet Glacier identified ecesis rates for subalpine fir of 26 and 32 years; however, a common rate of 35 +/- 5 years has been widely used (McCarthy, 2003). Moreover, ecesis rates of 40 and 42 years have been documented for mountain hemlock on the Illecillewaet Glacier, while an ecesis rate of 45 years has been determined in one study for subalpine fir on the Asulkan Glacier (McCarthy and Luckman, 1993). By selecting the closest and most relevant data to our study area we were able to extrapolate ecesis rates for our two species of trees. An ecesis rate of 45 years was assigned to the subalpine fir, whilst a 41year ecesis rate was chosen for the mountain hemlock. This ecesis age for the upper recessional moraine is justified by the 1897 photo of the Asulkan glacier showing it to be glaciated (Figure 4.1).

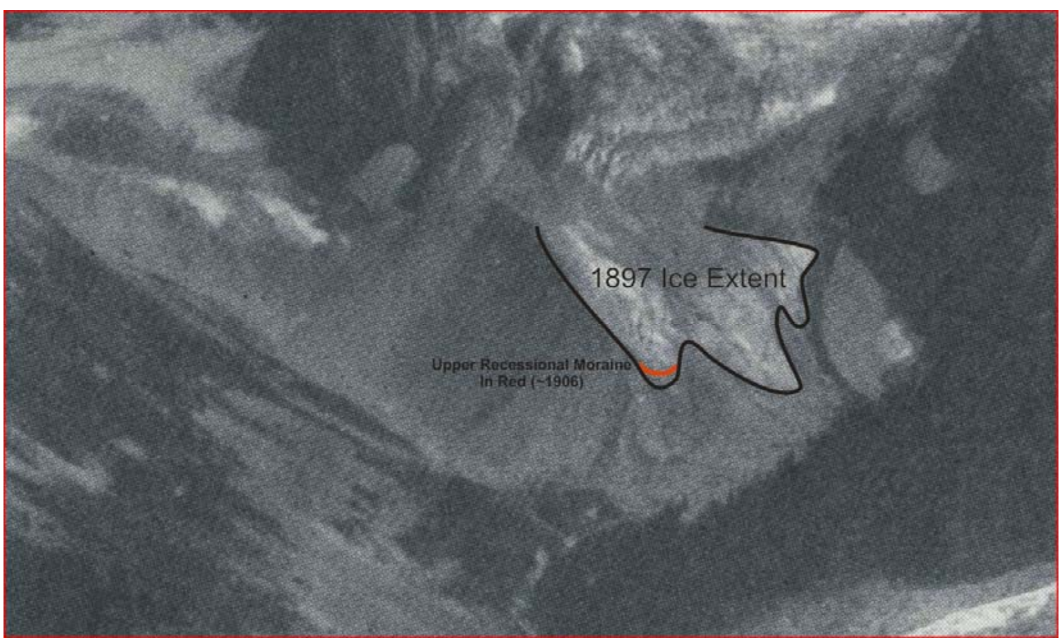

Figure 4.1: 1897 Asulkan Glacier oblique photo.

4.3 Results

The tree core data indicated a maximum tree age of 149 years for the terminal moraine. The terminal moraine was deglaciated 194 years ago (1813), once the assumed ecesis rate is applied (Table 4.1). The lower recessional moraine did not have trees present and therefore no tree ring data was produced. The upper recessional moraine data indicated a maximum tree age of 59 years. Results indicate that the upper recessional moraine was deglaciated 104 years ago (1903), including ecesis rate adjustments (Table 4.2). The lateral moraine indicated to have been deglaciated 97 years ago (1910), after ecesis adjustments. The ages of trees along the lateral moraine were progressively younger as they neared the current tongue of the glacier (Table 4.3).

Table 4.1

Terminal Moraine Study Area				
Ice Free Date: 1813				
Minimum Ecesis: 45 Subalpine Fir; 41 Mountain Hemlock				
Tree #	*Germination Date*	*Age*	*Age with Ecesis*	*Species*
M1F1	1934	73	118	Subalpine Fir
M1F2	1920	87	132	Subalpine Fir
M1F3	1916	91	136	Subalpine Fir
M1F4	1921	86	131	Subalpine Fir
M1F4B	1906	101	146	Subalpine Fir
M1F5	1873	134	179	Subalpine Fir
M1F6	**1858**	**149**	**194**	Subalpine Fir
M1F7	1885	122	167	Subalpine Fir
M1F8	1901	106	151	Subalpine Fir
M1F9	1869	138	183	Subalpine Fir
M1F10A	1877	130	175	Subalpine Fir
M1F10B	1885	122	167	Subalpine Fir
M1F10C	1897	110	155	Subalpine Fir
M1F11	1933	74	119	Subalpine Fir
M1F12	1935	72	117	Subalpine Fir
M1F13A	**1951**	**56**	**101**	Subalpine Fir
M1F14	1903	104	149	Subalpine Fir
M1H1	1906	101	142	Mountain Hemlock
M1H2	1890	117	158	Mountain Hemlock
M1H3	1927	80	121	Mountain Hemlock
Min:	1858	56	101	Subalpine Fir
Max:	1951	149	194	Subalpine Fir

Table 4.2

Upper Recessional Moraine Study Area				
Ice Free Date: 1903				
Minimum Ecesis: 45 Subalpine Fir				
Tree #	*Germination Date*	*Age*	*Age with Ecesis*	*Species*
SAFM2TOP	**1988**	**19**	**64**	Subalpine Fir
SAFM2BOT	**1948**	**59**	**104**	Subalpine Fir

Table 4.3

Lateral Moraine Study Area				
Minimum Ecesis: 45 Subalpine Fir				
Tree #	*Germination Date*	*Whirl Count*	*Age with Ecesis*	*Species*
T1	**1987**	**20**	**65**	Subalpine Fir
T2	1964	43	88	Subalpine Fir
T3	1978	29	74	Subalpine Fir
T4	1984	23	68	Subalpine Fir
T5	**1955**	**52**	**97**	Subalpine Fir
T6	1966	41	86	Subalpine Fir

5.0 Discussion

Often when methodologies are combined, they do not agree with one another. Using lichenometry and dendroglaciology on three different moraines yielded different results for each site. It is important to note that both methodologies provide approximations and neither technique produces absolute results. It appears as though dendroglaciology provides significant underestimates for age compared to lichenometry. When approximations and potential errors are taken into account the lichenometric and dendroglacial dates fit within the threshold of the most recent advances during the Little Ice Age.

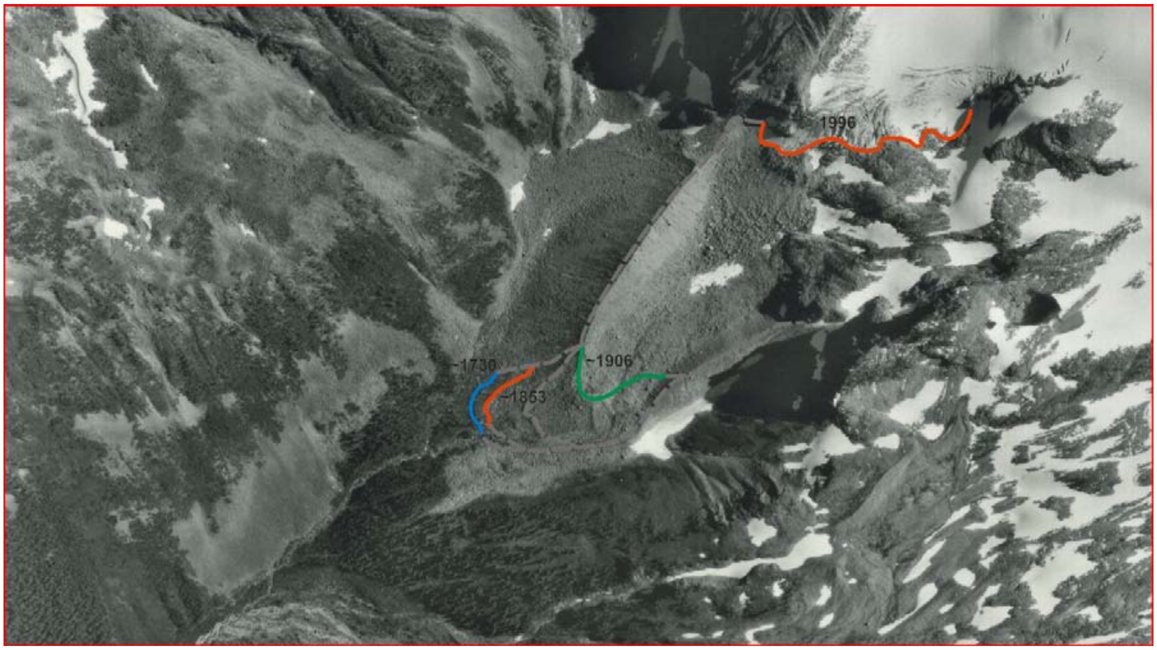

Table 5.1: East Asulkan spill-over zone map. Moraine dates based on lichenometric results.

5.1 Lichenometry Discussion

The validity of lichenometry is often questioned since it is a relatively new technique. For *Rhizocarpon geographicum*, lichen that is ubiquitous worldwide, experts claim that if properly recorded, growth curves can be useful. The most common use for lichenometry is dating glaciers, though other practical applications do exist such as estimating earthquake recurrence intervals, and estimating the timing and extent of rockfall hazards in alpine areas (McCarthy, 1999).

There are still arguments over biological factors that affect growth rates. These factors can overestimate or underestimate lichenometric dating. Prolonged snow cover can influence lichen growth creating an underestimate when dating. From a biological perspective, streams provide increased moisture and could create an ideal environment for lichen growth. Some studies have indicated that streams do not have an adverse effect on thallus size (Innes, 1985). However, if streams are only adjacent to certain study sites (such as the terminal moraine that was studied), the growth rate at the moraine next to the stream may be more rapid than the moraines (Innes, 1985). McCarthy (2003) also states that no lichens in his study were near streams. This was difficult to accomplish for the study site, as a stream was adjacent to the terminal moraine.

The technique of lichenometry could potentially be improved for greater acceptance within the scientific community. Standardization should occur, as McCarthy (1999) suggests with his safe site model. It combines the traditional approach and statistical approach. There is potential to use digital analysis to efficiently gather data while in the field (McCarthy and Zaniewski, 2001).

It is debatable whether or not to utilize multiple thalli readings at each site or to use the largest reading at each site to infer the age of the substrate. Also, it is important to take only ellipsoid or circular thalli because this is what the growth curve is based upon. Note that measuring an ellipsoidal thallus over a radial thallus could contribute to potential errors given that the mean length for an ellipsoidal thallus will have varying x-y axes readings as opposed to radial thalli (Jochimsem, 1973).

Rhizocarpon geographicum is often confused with *rhizocarpon alpicola* since they are both yellow-green in colour (Jochimsem, 1973). They have similar growth rates and can be represented on the same growth curve (Solomina and Calkin, 2003). Lichenometrists are rarely taxonomists and therefore must know what lichen subspecies they are looking for before heading into the field. Proper chemical identification of lichen is expensive and time consuming, so proper observation of *Rh. geographicum* is crucial (Benedict, 1988).

Having a terminal moraine date of 1738 correlates well with climate data of the area. Luckman and Wilson (2005) have stated that 1738 was one of the coldest years in the last millennium and indicate that years since have been warmer. This would trigger a moraine deposit at that time and strengthen the data calculated from the McCarthy growth curve (McCarthy, 2003). The upper recessional moraine, which was dated to 1906, could be due to a glacial advancement that occurred in 1899, another year with cool year-round temperatures (Luckman and Wilson, 2005). Using basic climatic and temperature correlations for the area reveal that our lichenometric dates have relevance in comparison to temperature.

5.2 Dendroglaciology Discussion

Dendroglaciology has proven to be a useful tool in the reconstruction of past glacial activity in the Asulkan region. However, it has been noted that conifer mortality rates tend to be more common in high-elevation forests where stress from weather, insects, and disease are major factors (Filip *et al.*, 2007). Subalpine firs are susceptible to wood-rotting fungi, especially Indian paint fungus *(Echinodontium tinctorium)* and bleeding conk fungus *(Haematostereum sanguinolentum)*, which often infects many trees. Mortality, as a result, occurs between 120 and 140 years of age (Ministry of Forests, 2001). The methodology utilized in the process of determining the age of the upper recessional moraine was executed with precision and accuracy, thus providing confident results. However, it is recognized that potential errors could exist within the methodology. The dating accuracy, particularly for the terminal moraine, could be underestimated by as much as 75 years due to missing the oldest tree, age-height error, pith error, broken core error and/or ecesis errors.

Missing the oldest tree within a study area can occur due to multiple factors. It is possible that the trees sampled were not first generational and could have been subject to avalanches or other major natural disturbances following a glacial recession. Although precautions were taken to carefully examine the study area to determine the oldest trees for coring, it is possible that the oldest tree was not cored as a direct result of human error.

The height at which the core is taken can have severe affects on the resulting core age. Initially, it was intended to core trees at their root crown interface, a position that would have provided the most accurate age. However, due to small diameter borers and rotten tree piths, samples were taken at higher points on the trees. Boring at higher points excludes the oldest tree rings, consequently omitting valuable age data. During the study, it was observed that trees at chest height were well over 65 years. Therefore, if a large tree is cored at chest height, the subsequent loss of rings will amount to a significant error.

Tree rings are counted concentrically towards the center where it is desirable to reach the absolute center known as the pith. It is quite common that the pith is not always reached, especially on larger trees, which makes it difficult to determine the exact date of germination. On the terminal moraine, it is estimated that the pith was missed by approximately 3-5 years on the oldest sample.

The cores were processed and counted with the assumption that they had been collected and stored without any lost tree rings. Due to breakages in the cores during extraction and transport, there is a potential that multiple years of data could be unaccounted for.

As previously mentioned, the ecesis value is difficult to determine. Ecesis rates were consequently quite subjective. Applying the most suitable values from past studies may not be the most correct rates for this specific site as ecesis rates are affected by numerous climatological variables. Local topography influences microclimates that exist within a specific study site, and can affect these variables making them very site specific. At the time of data collection, the study site was subject to ground water saturation from glacial run-off at the terminal moraine; however, the upper recessional moraine had better drainage and was considerably drier.

Combined, these factors could contribute to a bias of as much as 75 years for dendroglacialogical dating, despite measuring the oldest original tree at the study site. This would mean that the ice-free date for the terminal moraine could have theoretically been 1738, which is same year that was estimated using lichenometric techniques. 1738 was reconstructed as one of the coldest summer temperatures in the Canadian Rockies during the last millennium (Luckman and Wilson 2005). The upper recessional moraine date of 1903 is similarly justified because the reconstruction of the third coldest summer temperature in the Canadian Rockies occurred in 1899 (Luckman and Wilson 2005). Glacial advancements during these times are likely to occur because they are strongly correlated with reduced summer temperatures (Luckman, 2000).

6.0 Comparative Analysis of Local Moraine Dating

The techniques used in lichenometric and dendrochronological analyses are not absolute but rather are approximations that compliment each other recreating a geomorphic story. When dating glacial landscape features such as moraines, focusing on a single study area can introduce bias during analysis. For this reason, it is important to supplement our finding with a comparison to similar studies adjacent to our site: the neighboring Asulkan glacier tongue studied by Anastasiades *et al.* (2007), and the Illecillewaet glacier studied by McCarthy (2003).

6.1 Results

Anastasiades *et al.* (2007) dated the terminal moraine at the west Asulkan spill-over zone to be 151 years old (1856), while the work conducted for this project found the terminal moraine to be 270 years old (1738). According to McCarthy (2003), the terminal moraine of the Illecillewaet glacier dates back to 1860, with the last definitive advance occurring in 1887.

There were similarities found between study sites. There is a correlation between our upper recessional moraine (1906) and the Anastasiades *et al,* (2007) mid-recessional moraine (1905). Another similar finding was our lower recessional moraine (1855) and Anastasiades *et al.* (2007) terminal moraine (1856). These similar results possibly indicate concurrent glacial advances on both Asulkan spill-over zones.

6.2 Technique

All three studies in this comparison make use of similar dendrochronological and lichenometric techniques to derive the approximate moraine dates. The lichen data collection was done measuring the maximum diameter of the largest lichens on the particular morainal ridge. To collect tree rings, cores were taken from the largest trees. McCarthy (2003) used the same methods, but had a more precise method to collecting data. The data collection went to greater detail by taking into account the lichen and the aspect of trees as well as their vertical distance from the ground. It was noted that “the largest thalli were found on the shaded western side of the forefield, while many of the landform ages were developed using trees on the sunnier eastern moraine complex” (McCarthy, 2003). This variation in growth, particularly with lichen, could partially explain the difference between the results from this study and those of Anastasiades *et al.* (2007).

The dissimilarity in ecesis is another explanation for the differences. Although certain moraines were dated the same year, they were done so on different lichen curves. According to Anastasiades *et al.* (2007), the mean lichen diameter found at the moraine dated to 1905 is 40.1 mm and the mean lichen diameter on our 1906 corresponding moraine is 10mm smaller (30.89mm). Anastasiades *et al.* (2007) used Luckmann’s (1977) growth curve to derive their lichen dates. This growth curve is based on Mount

Edith Cavell in Jasper National Park. The curve, based at Mount Edith Cavell and has similar substrate lithology as the Illecillewaet glacier, shows similar growth rates for the first century. Despite substrate similarities, climate factors contributed to a faster growth over the following 200 years at the Illecillewaet (McCarthy, 2003). It can be presumed that this same difference in growth occurs at the Asulkan glacier. The difference in growth can be attributed to climatic factors, more particularly, moisture regimes. The Illecillewaet site receives about 950 mm of annual precipitation, while the Mount Edith Cavell site in Jasper receives about 394 mm each year (McCarthy, 2003).

6.3 Environmental Factors

There are a myriad of other environmental factors that must be taken into account when comparing the two Asulkan glacier studies. Two reasonable explanations for the difference in terminal moraine age are: (1) the terminal moraine's proximity to a stream and; (2) potential disturbances to the terminal moraine studied by Anastasiades *et al.* (2007). McCarthy (2003) notes that streams adjacent lichen populations are capable of accelerating their growth. The terminal moraine dated by Anastasiades *et al.* (2007) could possibly be a recessional moraine and the actual terminal moraine that corresponds with ours may have been reworked or destroyed by slides, snow avalanches, or streams.

Topography is another environmental condition to help explain differences in moraine dates. In a steeper section of either spill-over, the glacier would tend to advance at a faster rate. Conversely, if there is a sudden shift to a lesser degree of slope, the ice will have a tendency to pile up. Thus, the plateau on our site could have caused the terminal moraine to be deposited much earlier than that of Anastasiades *et al.* (2007).

Rock type was considered as a potential source of variation in lichen growth, but Quartzite is the dominant rock type on both Asulkan study sites and the McCarthy study site (Anastasiades *et al.* 2007; McCarthy, 2003).

7.0 Concluding Statements

The research done for this paper was conducted over a short time period. With more substantial field time, a lichen growth curve could have been developed for the East Asulkan spill-over zone, limiting error and creating a more representative dating sequence. The methodologies (lichenometry and dendroglaciology) were useful for calculations to recreate past glacial events in the study area, but are recognized to have potential errors. Comparing our methodologies and results to similar papers allows for a justification and confirmation of the data generated in our study. Future research at the East Asulkan spill-over zone could incorporate dendroclimatological evaluation of the tree cores taken to help generate a paleoclimatic database to supplement regional records.

8.0 Acknowledgements

This project could not have been put together without the expertise and sharing of knowledge of some individuals. Thanks to Dan Smith, Sarah Hart, Bethany Coulthard, Kate Johnson and Lynn Koehler for their ideas and cooperation throughout. Thanks to Jim Gardner for his excellent stories and all knowing persona.

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