NUMERICAL AGES OF GLACIER RETREAT AT EMMONS GLACIER, MOUNT RAINIER USING LICHENOMETRY

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Introduction

Lichenometric dating techniques have been shown to be effective for determining the age of glacial landforms on Mt. Rainier (Burbank, 1981); however, the technique has not yet been applied on landforms in the Emmons Glacier foreland. Sigafoos and Hendricks (1972) dated landforms in the Emmons Glacier foreland using dendrochronologic techniques, however these techniques may not yield accurate landform ages. It appears that the Pacific Decadal Oscillation has played a key role in climate change in the area, which occurs over a shorter period than the error of dendrochronologic techniques. Because of the relatively large time before tree growth establishment, ranging from 0 to 65 years (Burbank, 1981), and due to the abundance of Little Ice Age (LIA) landforms in the Emmons Glacier foreland that support substantial populations of *Rhizocarpon geographicum*, a study to refine ages of Little Ice Age moraine stabilization was undertaken using the growth curve of O'Neal and Schoenenberger (2003). The resulting lichenometric ages of landforms from the Emmons Glacier foreland were compared to ages of the same landforms determined by dendrochronology in the Emmons Glacier foreland (Sigafoos and Hendricks, 1972) to see if lichenometric techniques provide a more accurate calibrated age than dendrochronologic techniques provide.

Methods

Mount Rainier is located within Mount Rainier National Park in the central Cascades of Washington. Emmons Glacier lies on the northeastern flank of the mountain (Figures 1 and 2). Lichenometric techniques were used to date four landforms in the Emmons foreland. Measurements of diameter, quality and aspect of lichens were made during the month of September 2003. Landforms were chosen that had been previously dated by Sigafoos and Hendricks (1972) and Dreidger (1986) using dendrochronologic techniques and aerial photo interpretation (Figure 3). These are the 1900 lateral and end moraine, the post-1900 melt water terrace channel and the 1835-50 moraine (Sigafoos and Hendricks, 1972). The fourth area is a moraine-like feature dated 1928-1938, identified by Dreidger (1986) and dated using aerial photographs. This feature was chosen since it may provide ages of more recent glacier fluctuations.

Each landform was walked with traverses made approximately every 5 meters. The largest *R. geographicum* lichen on each boulder was measured and the quality, aspect, and diameter were recorded. The thallus diameter was measured in millimeters using digital calipers and the aspect of the lichen was also recorded. Individual lichens were given a quality rating of one to five based on its roundness (Figure 4). Where the lichen was not circular, the minimum diameter was measured to avoid the possibility of measuring compound thalli. Substrate lithology was not recorded, but was observed to be primarily andesite or granodiorite.

All landform ages were determined using the largest lichen technique, which assumes that the largest lichen on a surface should closely approximate the age of the substrate. However, new surfaces can be exposed due to erosional processes, which at the same time tend to degrade old growing surfaces. Thus lichen measurements can only provide a minimum age for a surface (Noller and Locke, 2000; O'Neal and Schoenenberger, 2003). Major drawbacks of this technique are the possibility of measuring coalesced lichen thalli, measuring a thalli that predates surface stabilization and the dependence on finding the largest lichen in the field area (Noller and Locke, 2000). Even with these drawbacks the largest lichen technique was chosen for this study because this is the method employed to construct a recent *R. geographicum* curve for the Washington and Oregon Cascade Mountains (O'Neal and Schoenenberger, 2003) (Figure 5). This allows comparison of the resulting lichenometric ages to the growth curve of O'Neal and Schoenenberger (2003) for other areas of the Cascades. Burbank (1981) employed the largest lichen technique and showed that it could be applied on Mount Rainier using Porter's (1981) *R. geographicum* curve.

Ages of the largest lichens for each landform were calculated using the regression curve of O'Neal and Schoenenberger (2003)

$$y=0.436x+2.1179;$$

where y is the lichen diameter in mm and x is the age of the lichen in years B.P. O'Neal and Schoenenberger (2003) indicate that lichenometric-dating techniques applied to glacial landforms in the Cascades of Washington and northern Oregon can yield numeric ages for landforms between 20 and 145 years with an accuracy of +/- 10 years.
Moraine ages in the Emmons Glacier foreland determined from lichenometric data and dendrochronologic data were compared to Mount Rainier ice margin positions studied by Burbank (1981) using lichenometric techniques. This was done in order to determine if ice margin position ages for Emmons Glacier are synchronous with ice margin positions for other glaciers on Mount Rainier.

Results

The measurements, converted into chronological ages, are compared with tree-ring dates obtained by Sigafoos and Hendricks (1972) (Table 1). The left lateral LIA maximum moraine yielded a lichenometric age of 1838 A.D, compared to an 1835-50 dendrochronologic age. Previously dated as post-1900, the melt-water terrace yielded a lichenometric age of 1852 A.D. The left lateral moraine previously dated as 1900 yielded a lichenometric age of 1929 A.D. An age of 1891 A.D was determined using lichenometric techniques for the terminal position of the 1900 moraine. The moraine like feature in the kame and kettle terrain yielded a lichenometric age of 1950 A.D, compared to 1928-1938 using dendrochronologic techniques. Each lichenometric date was calculated from the regression curve of O'Neal and Schoenenberger (2003), and has an error of +/- 10 years. The lichenometric data indicates that the Emmons Glacier features previously dated using dendrochronology can be constrained and assigned a more accurate age.

Discussion

Applying lichenometric-dating techniques to glacial landforms within the Emmons Glacier foreland allows direct comparison of the accuracy of lichenometric and dendrochronologic dating techniques. Lichenometric ages for the 1835-50 and 1900 A.D. moraines appear to be more accurate than the original ages assigned using dendrochronology by Sigafoos and Hendricks (1972) based on the size of trees present. The above moraines yielded lichenometric ages of 1838 and 1891 A.D. Trees growing on the moraines were not large enough to be either the dendrochronologic or lichenometric age. The post-1900 melt-water terrace channel was determined to have a lichenometric age of 1852 A.D. Again trees were not large enough in size to be approximately 150 years old. This indicates that the trees began growing many years after the feature was deposited and stabilized enough to allow lichen growth. The uncertainty of dendrochronologic methods, which is based on the time to begin tree growth, has been shown be as great as 65 years for the Washington Cascades (Burbank, 1981; O'Neal and Schoenenberger, 2003), compared to 10 years for lichenometric methods (O'Neal and Schoenenberger, 2003). Because of the longer period of time required for establishment of tree growth, a lichenometric age is more accurate than a dendrochronologic age for the same landform. Thus, within the Emmons Glacier foreland, lichenometric techniques prove more useful when dating Little Ice Age landforms.

The lichenometric ages of the 1835-50 and 1900 moraines, as well as the post-1900 melt-water channel are more accurate than dendrochronologic ages. However, some ages obtained by this study appear younger than expected because of factors hindering ideal lichen growth. The 1900 lateral moraine yielded a lichenometric age of 1929, compared to 1891 for the same moraine at its terminal position. Field mapping and aerial photograph interpretation show that the two moraines represent the same system and therefore the terminal and lateral moraines have and age of 1891 A.D. The lichenometric age for the lateral moraine is younger than the terminal moraine age due to the following factors. (1) The lateral moraine crest coincides with the Emmons Moraine trail leading out of the White River Campground; and construction of the trail required the removal of many of the lichen-sustaining boulders. (2) The proximal slope of the lateral moraine sustains no lichen population due to heavy rock fall. Heavy lichen kill is experienced and new growing surfaces are continually being created. Thus, old lichens are not found on the 1900-left lateral moraine. For this reason, lichenometric ages from the terminal moraine appear to be more reliable where less slope movement is observed and there is less anthropogenic influence.

Lichenometric data shows the 1928-38 moraine-like feature dated by Dreidger (1986) to date 1949. This age difference can be explained by the locality of the feature. It is located in a kame and kettle type terrain characterized by ice-cored soils that are actively collapsing. This leads to the exposure of new growing surfaces, while killing existing lichens and allowing new lichens to begin growing. The majority of the growing lichens are therefore younger than the age of the landform.

Applying lichenometric-dating techniques allows for the determination of past ice margin position ages in the Emmons Glacier foreland. Comparison to ice margin position ages for other glaciers on Mount Rainier will indicate whether glacier fluctuations on Mount Rainier were synchronous or asynchronous. Initial comparison indicates that lichenometric ages of ice margin positions for Emmons Glacier are synchronous with past ice margin positions with five other glaciers on Mount Rainier (Burbank, 1981). Moraine stabilization in the Emmons Glacier foreland was nearly synchronous with moraine stabilization for the five forelands studied by Burbank (1981) (Table 2). Periods of moraine stabilization appear to have occurred in the mid 19^{th} century and the late 19^{th} to early 20^{th} centuries. The first period of stabilization occurs approximately at the LIA maximum, while the second period occurs during the late LIA. For many of the glaciers, including Emmons Glacier, it has been concluded that the associated ice margin position during the mid 1800s represents the maximum extent of Mount Rainier glaciers during the LIA (Burbank, 1981). Stabilization ages for the six glacier forelands indicate that during periods of climate change, the glaciers on Mount Rainier adjust their length nearly synchronously regardless of aspect.

Conclusion

This study has shown that lichenometric dating techniques allow the researcher to assign ages for ice margin positions based on moraine stabilization ages. Lichenometry proves more successful than dendrochronology because the time for lichen growth establishment is short compared to tree growth establishment. Glaciers on Mount Rainier respond to climate changes nearly synchronously. Because of the increased accuracy of ice margin position ages provided by lichenometric techniques, future researchers can employ lichenometry as a means to date ice margin positions in forelands where historical data is unavailable, or where other methods of surface age dating are inadequate. This could aid in the understanding of past and future impacts of the Pacific Decadal Oscillation and other short-period climate fluctuations.

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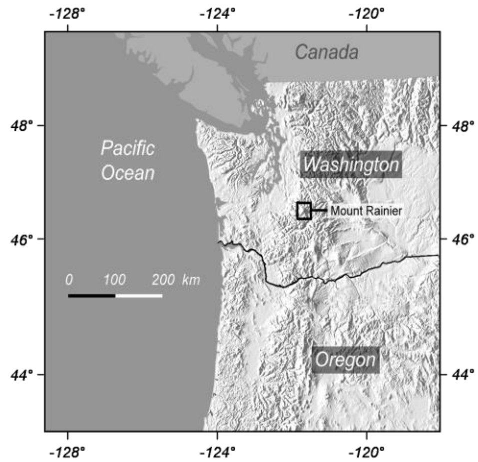

Figure 1: Map of Cascade Range in Washington showing Mount Rainier. Modified from O'Neal and Schoenenberger, 2003.

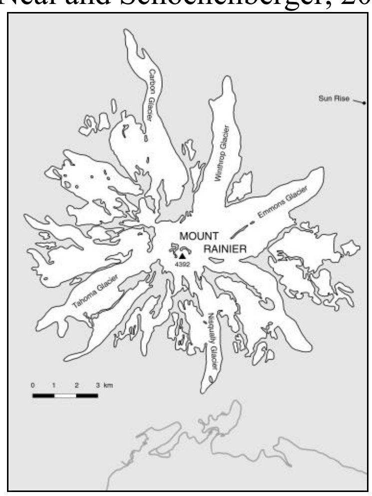

Figure 2: Map of Mount Rainier (Emmons Glacier foreland boxed in). Glaciers are shown in white. Modified from O'Neal and Schoenenberger, 2003.

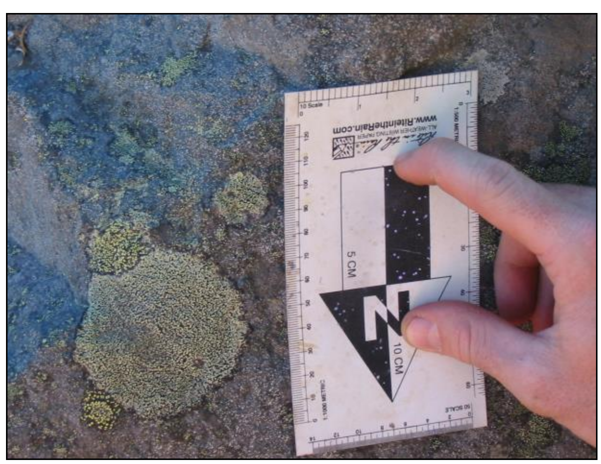

Figure 3: *Rhizocarpon geographicum* lichen.

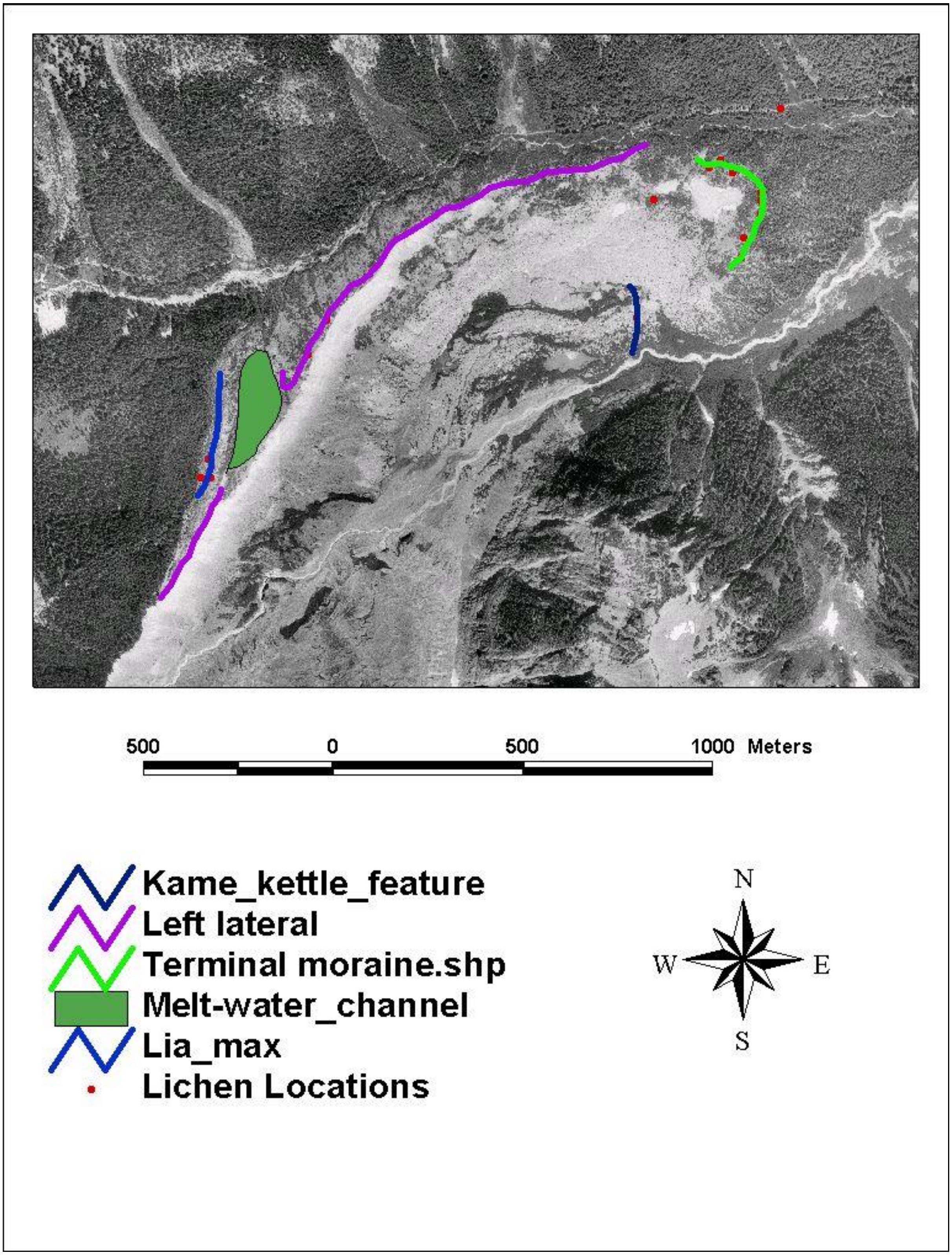

Figure 4: Aerial photo showing location of studied features and lichen measurements.

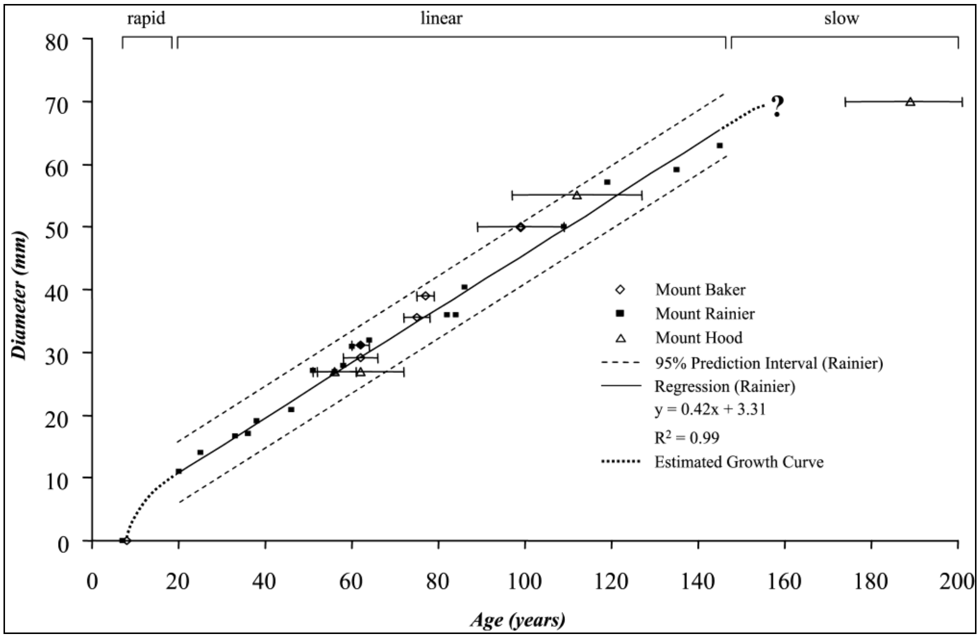

Figure 5: O'Neal and Schoenenberger (2003) *R. geographicum* growth curve for the Washington and northern Oregon Cascade Mountains.

Feature Description	Tree Ring Age (A.D.) (Sigafoos and Hendricks, 1972)	Lichen diameter (mm) (O'Neal, unpublished data)	Lichen age (yrs/A.D.)
Terminal Moraine	1900	51	112 ± 10 / 1891
Left Lateral	1900	34.42	74 ± 10/1929
Melt-water channel	Post 1900	68.13	151 ± 10/ 1852
Left lateral, LIA Max	1835-50	73.92	167 ± 10/ 1838
Kame/kettle plain feature	1928-1938	25.66	54 ± 10/ 1950

Table 1: Location, tree-ring age, lichen diameter and age for *R. geographicum* used in this study.

N. Mowich,[a]	Carbon,[a]	Winthrop,[a]	Cowlitz,[a]	Ohanapecosh,[a]	Emmons,[b]
1902	1902	1912	1903	1915	-
1881 1860	1880 1863	1885 -	1882 -	1882 -	1891 -
-	-	-	1857	1830	1838

Table 2: Dates of moraine stabilization on Mount Rainier for six glacier forelands. All ages from *R. geographicum* measurements.

a: Burbank, 1981 b: This study - : No correlating age data