



ACADEMIC
PRESS

Available online at www.sciencedirect.com

SCIENCE @ DIRECT®

Quaternary Research 60 (2003) 233–241

QUATERNARY
RESEARCH

www.elsevier.com/locate/yqres

A *Rhizocarpon geographicum* growth curve for the Cascade Range of Washington and northern Oregon, USA

Michael A. O'Neal^{a,*} and Katherine R. Schoenenberger^b

^a Department of Earth and Space Sciences and Quaternary Research Center, Box 351310, University of Washington, Seattle, WA 98195, USA

^b Geology Department, 300 College Park, University of Dayton, Dayton, OH 45469, USA

Received 27 February 2003

Abstract

Lichen thallus measurements from 22 surfaces of known age on Mount Baker, Mount Hood, and Mount Rainier are used to construct a regional *Rhizocarpon geographicum* growth curve for the Cascade Range of Washington and northern Oregon. Growth rates determined by measuring the largest thallus diameters on the same surfaces at Mount Rainier in 1976 and 2002 are used for comparison with lichenometric data from Mount Baker and Mount Hood. Similar lichen thallus diameter vs age relationships identified in the data from the three mountains suggest the presence of uniform growth rates over the 400-km range. A regional growth curve developed during our study shows three growth phases of successively slower growth: a rapid phase from 8 to 20 yr, a linear phase from 20 to 145 yr, and a slow phase of unknown duration beyond ca. 145 yr. Uncertainty in lichen growth rates beyond 145 yr limits projection of the curve beyond that age; however, the age range of the constrained growth curve covers an important period of recent climate variability. When applied in appropriate settings, our growth curve can be used to determine numeric ages to ± 10 yr for surfaces between 20 and 145 years old in areas where other techniques are not applicable or do not provide unique or well-constrained ages.

© 2003 University of Washington. Published by Elsevier Inc. All rights reserved.

Keywords: Lichen; Lichenometry; Lichenometric dating; *Rhizocarpon*; Mount Baker; Mount Rainier; Mount Hood

Introduction

In the Cascade Range of Washington and northern Oregon, many glacier forelands have moraines that support substantial *Rhizocarpon geographicum* lichen populations. By applying lichenometric techniques on these landforms, previous studies in the North Cascades (Miller, 1969) and on Mount Hood (Lillquist, 1988) determined the relative age of Little Ice Age (LIA) and younger moraines. The only calibrated growth curve that can be used to derive numerical ages of lichens in the region was developed by Porter (1981) using *R. geographicum* lichens growing on Mount Rainier. Burbank (1981) applied Porter's curve to surfaces on Mount Rainier and indicated that lichenometric techniques provide more accurate landform ages than tree-ring dating techniques in that study; however, the applicability of the curve

beyond Mount Rainier was never tested. Because lichen growth can be affected by many environmental variables, including substrate lithology and roughness, moisture availability, aspect, and duration of snow cover, there is no reason to assume that a growth curve developed from data geographically restricted to Mount Rainier is applicable in adjacent alpine areas of the Cascades.

By using the data presented in Porter (1981) and replicating his methods, we determined the growth rate of *R. geographicum* on Mount Rainier by directly measuring the largest lichens on the same substrates that he used in 1976. The regional similarity of growth rates was assessed by comparing the Mount Rainier data with other well-constrained lichenometric data from Mount Baker and Mount Hood (Fig. 1). We find *R. geographicum* growth rates to be similar over the study area and present a growth curve that can be used to date surfaces accurately in a large number of glacier forelands between Mount Baker and Mount Hood.

* Corresponding author.

E-mail address: maoneal@u.washington.edu (M.A. O'Neal).

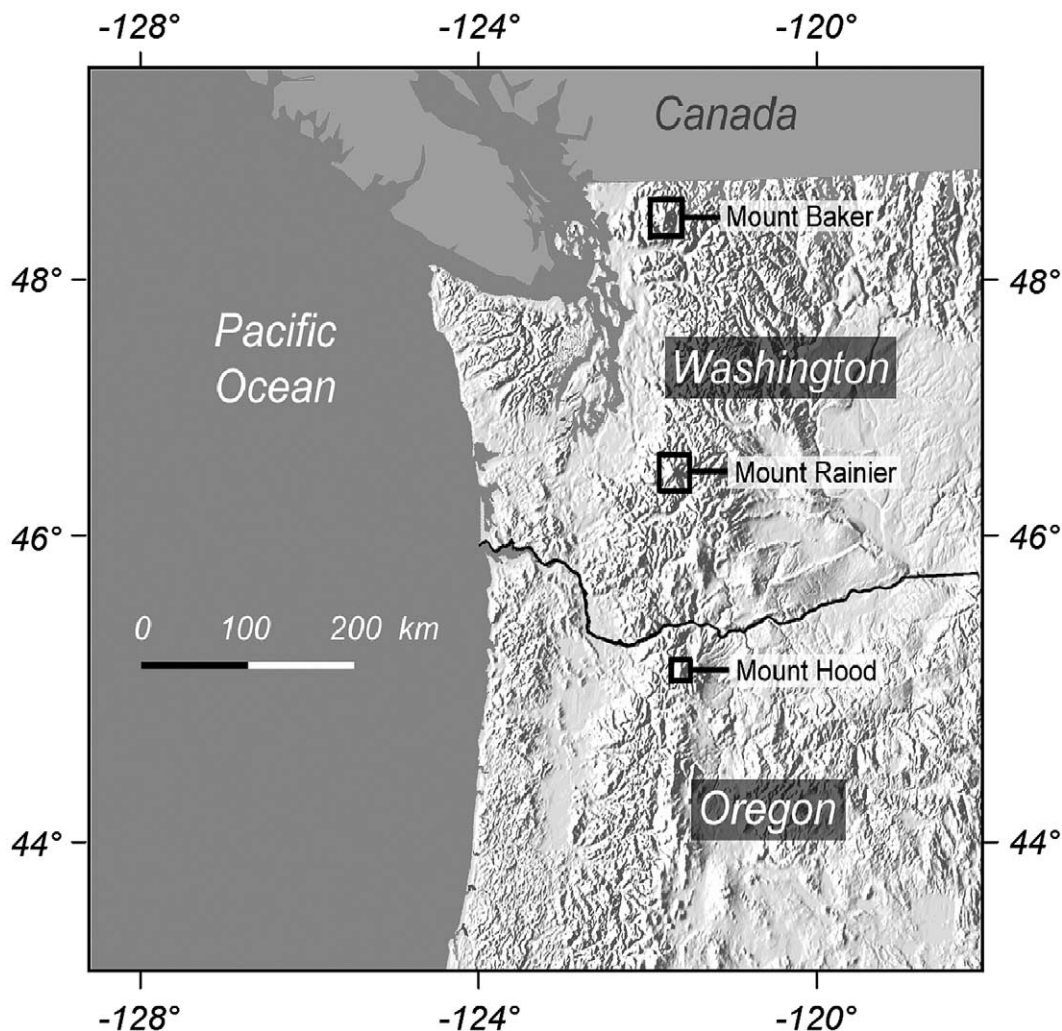


Fig. 1. Map of the study area showing the three source areas of lichen data.

Background

Lichenometry is based on the observation that lichens of many species grow at quasi-steady rates over spans of centuries to a few millennia. Since *R. geographicum* grows in a radial manner, the thallus diameter is used as a measure of growth. Once a substrate is colonized, the general growth of a lichen proceeds in three phases: (1) a rapid growth phase during which growth proceeds at a logarithmic rate, often called the “great growth period,” (2) a linear growth phase during which growth is nearly uniform, and (3) a slow growth phase where lichen growth generally declines until death (Armstrong, 1983; Beschel, 1959; Innes, 1985). Because the growth rate and the duration of the different growth phases are subject to environmental factors, lichenometric dating requires calibration in each region where the technique is applied (Innes, 1986).

By measuring lichen thallus diameters on surfaces of known age, growth rates can be determined and used to construct a growth curve that depicts the size vs age relationship. However, in order to develop a growth curve, a

statistic of a lichen population that best represents the time of substrate colonization must be determined. Because researchers differ in their choice of this statistical measure, a variety of methods are used to collect and interpret lichen data. This diversity in methodology has resulted in differing opinions on the overall precision and usefulness of lichenometric dating. In principle, the largest lichen growing on a surface should closely approximate the age of the substrate. However, erosional processes tend to degrade old growing surfaces and expose new areas for lichen colonization, so that lichen measurements can only provide an approximate minimum age of the substrate. Studies that use the largest lichen technique are often criticized because of (1) the uncertainty that the largest thallus may not belong to the same population as the majority of the surface population and (2) the possibility of measuring a coalescence of more than one lichen. Despite any limitations of the largest lichen technique, this method was chosen for our study because (1) it allows us to integrate data that Porter (1981) used to develop the original Mount Rainier growth curve, (2) Burbank (1981) measured the largest lichens on many land-

Table 1

Location, elevation, substrate type, measurement, and age data for *Rhizocarpon geographicum* thalli used in this study.

Area	Control point	Elevation (m)	Substrate and location	Substrate lithology	Largest lichen diameter (mm)	Substrate age when measured (yrs)	Limiting age of substrate (A.D.)
Mt. Baker	B1	1280	Bedrock along road between chalet and fee station	andesite	39.0	77	1925 ± 2
	B2	1275	Dam near overflow parking at Mount Baker Lodge.	andesite	35.5	75	1927 ± 3
	B3	1350	Bedrock adjacent to Austin Pass visitor's center	andesite	31.1	62	1940 ± 2
	B4	1345	Wall at the Austin Pass visitor's center	andesite	0.00	8	1994
	B5	1350	Austin Pass picnic area near visitor's center	andesite	29.2	62	1940 ± 4
	B6	1280	Moraine at Easton Glacier	andesite	49.9	97	1900 ± 10
	B7	1290	Rock wall at Easton Glacier	andesite	50.0	97	1900 ± 10
Mt. Hood	H1	1825	Coe Glacier (Lillquist-ECG-O)	andesite	70	189	1800 ± 15
	H2	1700	Coe Glacier (Lillquist-SEC-LT4)	andesite	55	122	1880 ± 15
	H3	1710	Coe Glacier (Lillquist-SEC-LT3)	andesite	27	62	1925 ± 15
	H4	1820	Moraine at Eliot Glacier	andesite	21	55	1946 ± 5
Mt. Rainier	R1	1265	Guardrail near Ricksecker Point (Porter #10)	granodiorite	35.9	84	1918 ± 2
	R2	1492	Guardrail at Inspiration Point (Porter #19)	granodiorite	16.7	33	1969
	R3	1655	Paradise Lodge (Porter #8)	andesite	40.4	86	1916
	R4	1615	Edith Creek Bridge (Porter #11)	granodiorite	36.0	82	1920
	R5	1308	Sunbeam Creek Bridge (Porter #18)	granodiorite	20.9	46	1956 ± 1
	R6	1195	Moraine at Nisqually Glacier (Porter #1)	andesite	63.0	145	1857 ± 3
	R7	1195	Moraine at Nisqually Glacier (Porter #3)	andesite	59.0	135	1867 ± 3
	R8	1285	Moraine at Nisqually Glacier (Porter #14)	andesite	31.9	59	1943 ± 2
	R9	1295	Moraine at Nisqually Glacier (Porter #15)	andesite	31.3	57	1945 ± 2
	R10	1370	Moraine at Nisqually Glacier (Porter #17)	andesite	27.2	51	1951 ± 2
	R11	1375	Moraine at Nisqually Glacier	andesite	11.8	26	1976 ± 2

Note. References to Porter indicate locations presented in Porter (1981) lichens were measured for this study. References to Lillquist indicate data from Lillquist (1988) used herein.

forms on Mount Rainier and showed that the Porter (1981) curve can be used to determine accurate landform ages, (3) our data can be compared with other largest-lichen data obtained throughout the region (Lillquist, 1988; Miller, 1969; Reynolds, 2001), and (4) the application of the technique has been supported in many different settings in the northern hemisphere (e.g., Andersen and Sollid, 1971; Bickerton and Matthews, 1992; Denton and Karlen, 1973; Karlen and Black, 2002).

Methods

The largest lichen was identified on each moraine and manmade structure at 22 sites on Mount Baker, Mount Rainier, and Mount Hood (Table 1). At each location, the maximum diameters of individual *R. geographicum* lichens with circular or nearly circular thalli were measured on boulders with surface area $>0.3 \text{ m}^2$ or on rock walls, where the largest lichen growing in each 1-m^2 area was recorded. For lichens growing on manmade structures, the largest lichens on individual building blocks were measured. To limit ecological factors that influence lichen growth, all measurements were made at altitudes between 1195 and 1825 m on exposed andesite and granodiorite rock surfaces away from trees and dense vegetation cover. Manmade structures chosen for data collection were found throughout the altitude range of moraines in glacier forelands to ensure that there was no bias between the setting and altitude.

Lichen measurements were tabulated at six sites on Mount Baker from five manmade structures in the Heather Meadows and Austin Pass areas (B1 to B5) and one moraine in the Easton Glacier foreland (B6 and B7) (Fig. 2). The 11 sites on Mount Rainier (Fig. 3) represent five manmade structures (R1 to R5) and six moraines in the Nisqually Glacier foreland (R6 to R11) (Fig. 4). Of the 11 sites where lichens were measured on Mount Rainier, 10 are the same moraines and structures used by Porter (1981) and 1 is from an ice-margin position that bore no lichens at the time of Porter's field study in 1976 (Table 1). However, not all lichens measured by Porter (1981) survived to the time of this study; lichens growing on the Kautz Creek lahar were subsequently overgrown by moss and other vegetation, and lichens growing on the rock foundations of the Sunrise Gas Station and the Narada Comfort Station were destroyed during maintenance. Lichen measurements at Mount Hood include data from three moraines in the Coe Glacier foreland (H1 to H3) reported by Lillquist (1988) and one moraine identified for this study in the Eliot Glacier foreland (H4) (Fig. 5).

Collection of lichen data was restricted to sites where the age of the substrate could be constrained using maps, photos, historical accounts, dendrochronology, and tephrochronology. The ages of landforms and structures on Mount Rainier were determined by Porter (1981) using mainly historical information that has accumulated since the designation of the mountain as a National Park in 1899. Mount Hood and Mount Baker also

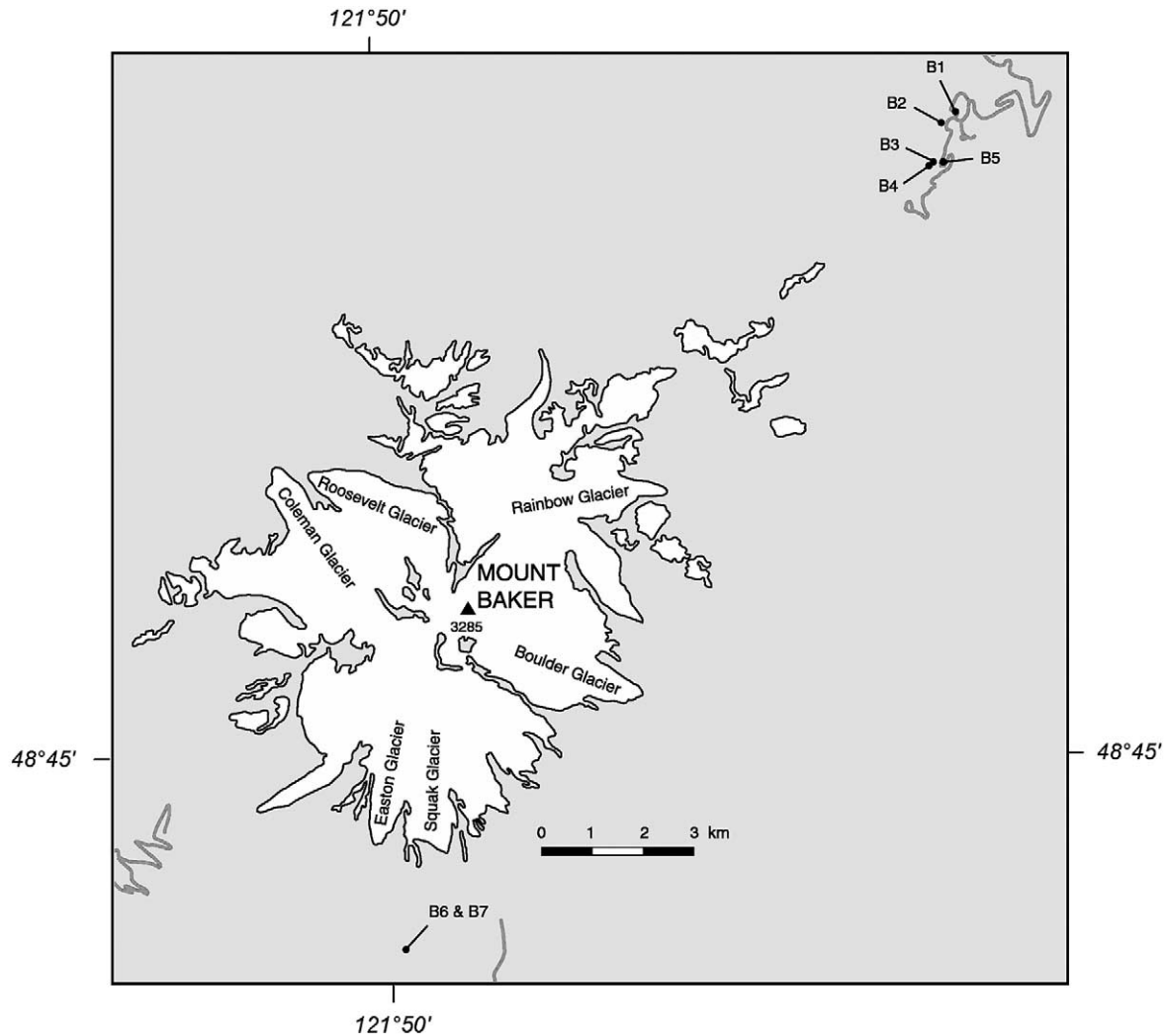


Fig. 2. Map of Mount Baker showing the location of lichen data collection points. Glaciers are shown in white.

have been the focus of recreation and natural resource extraction for more than 100 years, and abundant historical data are available to help constrain the ages of lichen-bearing surfaces on these mountains.

Because Porter (1981) used landforms and structures that were easily identified at the time of this study, we were able to determine *R. geographicum* growth rates on Mount Rainier based on the direct measurement of the largest lichens in 1976 and 2002. By calculating a regression of the thallus diameter vs the age of the control points from the Mount Rainier data and the 95% prediction interval of that data, we were able to compare Mount Baker and Mount Hood lichen thallus diameter vs age relationships to those of Mount Rainier statistically.

Results

Analysis of the thallus diameter vs age relationship of *R. geographicum* lichens measured on the same 10 surfaces at

Mount Rainier in 1976 and 2002 indicates a linear growth phase between 20 and 145 yr (Fig. 6). The average growth rate during this phase is 0.4 mm yr^{-1} . However, average individual rates range from 0.23 to 0.54 mm yr^{-1} , and residuals from the linear regression of the 2002 vs 1976 diameters (subplot of Fig. 6) indicate excursions of as much as 3 mm from linear growth. The lack of an age vs rate correlation associated with these variations suggests they are likely the result of natural phenomena affecting lichen growth, as well as inherent error in the identification and measurement of the largest lichen at each location. Regardless of these fluctuations in growth rates, a linear regression of the Mount Rainier data that range between 20 and 145 yr results in an R^2 value of 0.99. The thallus diameter vs age data from Mount Baker and Mount Hood for the same time interval, when fit to the linear regression of the Mount Rainier data, result in R^2 values of 0.90 and 0.95, respectively, and lie on or within the 95% prediction interval (Fig. 7).

Three control points were not included in the regression analysis: the zero-diameter measurements from the 7-year-old

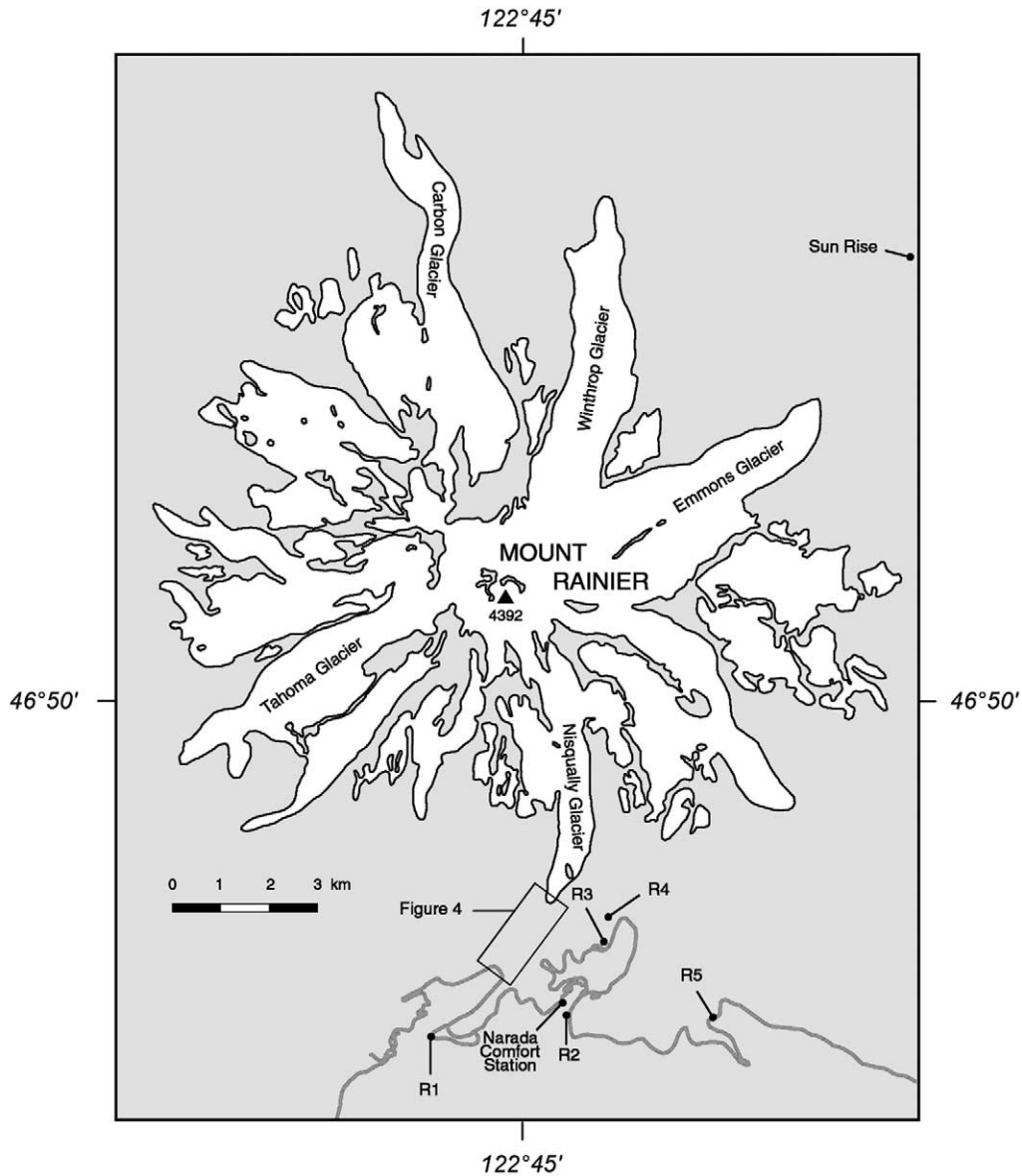


Fig. 3. Map of Mount Rainier showing the location of lichen data collection points. Glaciers are shown in white.

guardrail near Ricksecker Point on Mount Rainier (Porter, 1981) and the 8-year-old wall at the Austin Pass visitor's center on Mount Baker, as well as the largest measurement in the dataset from a late LIA moraine of the Coe Glacier on Mount Hood. A value of 0 mm is not used as a control point because it is not an indicator of actual size but rather a macroscopic presence/absence indicator that is used until lichens are visible sometime between 8 and 20 yr. The control point from Mount Hood, constrained at 189 ± 15 yr, is not used in the regression analysis because of the potential that it represents a change in the growth rate at that age.

Discussion

Based on the similarity of *R. geographicum* thallus diameter vs age relationships within the study area, we sug-

gest a single underlying growth curve for the Cascade Range of Washington and northern Oregon that can be divided into three phases: an initial rapid growth phase from 8 to 20 yr, a linear phase from 20 to 145 yr, and a slow growth phase of unknown duration after ca. 145 yr (Fig. 7). Although no lichen thalli were measured on surfaces younger than 20 yr, a period of initial rapid growth equivalent to the "great growth phase" suggested by Porter (1981) is inferred by the absence of lichens on 7- and 8-year-old surfaces and the apparent onset of a linear growth phase by 20 yr. For the portion of the growth curve between 20 and 145 yr, we have treated the data differently than Porter (1981) did in that (1) based on the similarity of lichen growth rates on andesite and granodiorite surfaces in Fig. 6, we reduce the data to one curve, and (2) the thallus diameter vs age data were not used as minimum values for position-

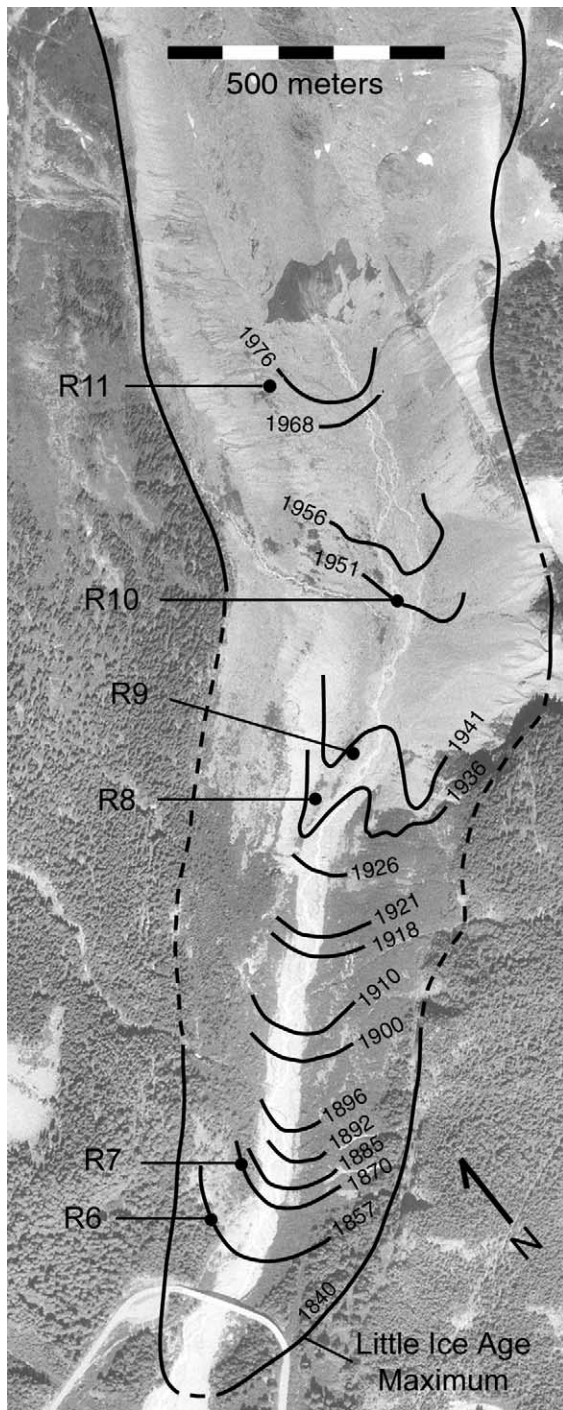


Fig. 4. Map of lichen data collection points R6–R11 in the Nisqually Glacier foreland (see Fig. 3) displayed on a 1992 U.S. Geological Survey digital ortho photo. Detailed ice-limit information is from Porter (1981).

ing the curve. We suggest that the regression of the Mount Rainier data provides the best growth curve between 20 and 145 yr and its use throughout the study area is justified by the fit of all other age-equivalent data within the 95% prediction interval (Fig. 7). The R^2 value of 0.99 for the regression of the Mount Rainier data underscores the suitability of a linear model for this period and is supported by

similar linear growth phases of greater than 100 yr depicted in other northern hemisphere growth curves (e.g., Benedict, 1967; Denton and Karlen, 1973).

The age vs diameter relationship of the 189-year-old lichen from Mount Hood deviates from the linear growth phase depicted for lichens between 20 and 145 yr and is used to suggest a transition to a slow growth phase of unknown duration after ca. 145 yr. This transition to slow growth is comparable to the pattern of reduced growth rates of ca. 0.1 mm yr^{-1} suggested by Miller (1969) for ca. 150- to 700-year-old *Rhizocarpon sp.* lichens growing in the North Cascades. However, due to the elimination of many early colonizers by factors such as vegetation competition and landform degradation apparent on old moraines at lower elevations throughout the study area, we believe the 189-year-old lichen is not representative of the early colonizers of the moraine on which it is growing. Thus, this lichen only provides a minimum estimate of the thallus diameter vs age relationship for its age range and does not provide enough information to estimate the position of the curve in the slow growth phase. At no point on the curve do we assume that the largest lichen was observed, and as more data become available, lichen thallus diameters in the linear and slow growth phases may shift in the direction of the upper limit of the 95% prediction interval shown in Fig. 7, thereby more closely approximating the curves of Miller (1969) or Porter (1981).

Due to a short ecesis period of *R. geographicum* compared with the range of 0 to 65 yr for trees on Mount Rainier (Burbank, 1981) and the abundance of deglaciated LIA glacier forelands in the Cascades where moraines lack trees (Crandell and Miller, 1964; Sigafos and Hendricks, 1972), we suggest that our growth curve provides a more precise and accurate method than tree-ring techniques over the same range. However, attempts to apply lichenometric techniques at elevations below the LIA glacier forelands (e.g., on the Kautz Creek lahar (Porter, 1981)) and/or where lichen populations are stressed from increased competition with other vegetation (e.g., on the Bonneville landslide (Reynolds, 2001)) resulted in lichen thallus vs age relationships that are not comparable with our growth curve. Despite elevation, our curve should not be used for dating surfaces between 0 and 20 years because this brief rapid-growth phase is only inferred from the data and not represented by any control points.

Photointerpretation of recent ice-marginal landforms using the abundance of modern satellite images and aerial photographs is likely to result in a more accurate estimate of recent surface ages than any lichenometric technique. However, when our curve is used to determine the age of surfaces between 20 and 145 years old, we suggest that the 95% prediction interval provides a reasonable error range of ± 10 yr based on the fit of all control points within that interval. The potential error associated with projecting our curve to date landforms beyond 145 yr increases to at least ± 20 yr due to uncertainties in the accuracy of the landform

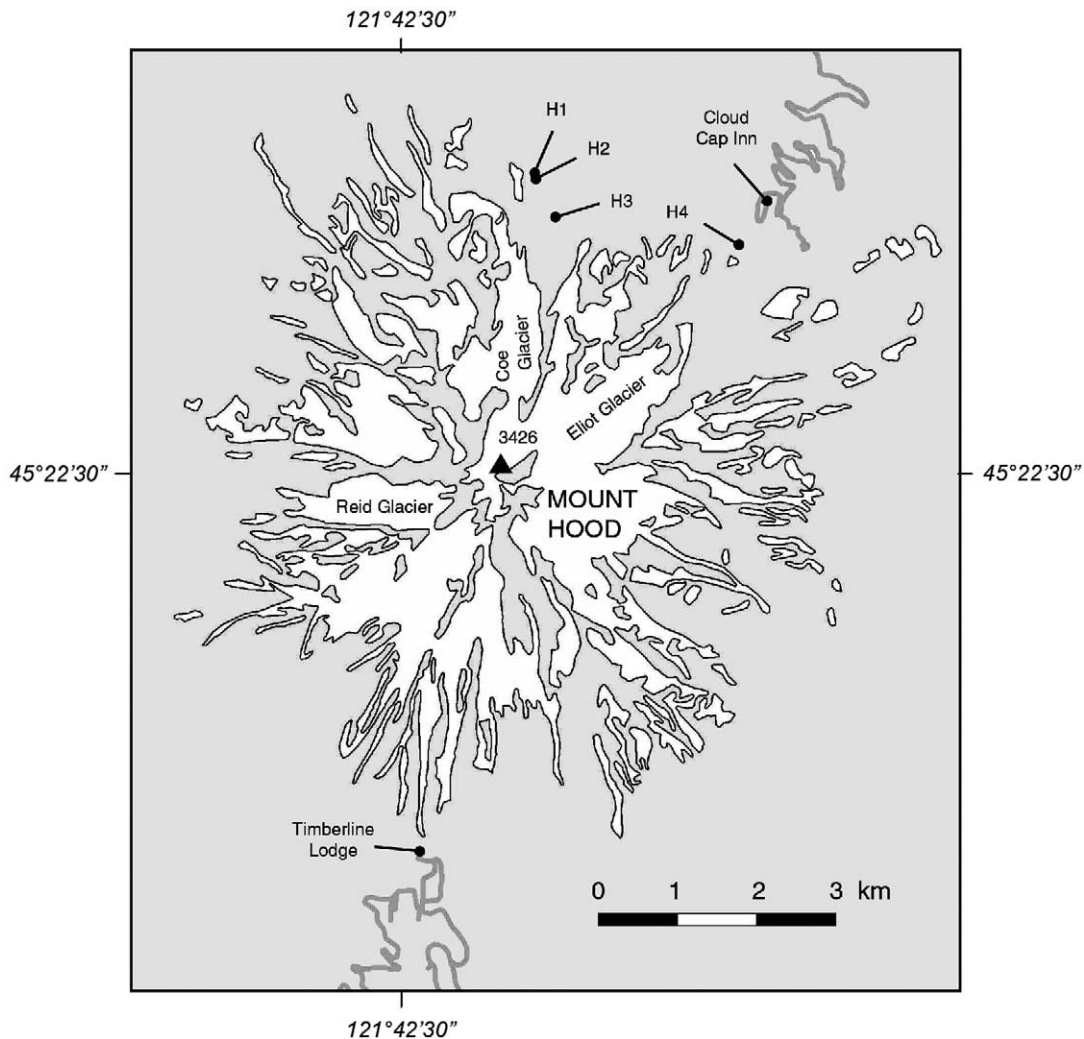


Fig. 5. Map of Mount Hood showing the location of lichen data collection points. Glaciers are shown in white.

and lichen ages, short-term growth-rate fluctuations, and possible measurement error of the single data point used to interpret the slow growth phase. Without more lichenometric data beyond 145 yr, the slow growth phase should only be used as a potential correlation technique or to estimate limiting ages.

Conclusion

The historical accounts, photos, and maps, combined with the availability of previous lichenometric data from well-dated manmade structures and moraines, permit the construction of a regional *R. geographicum* growth curve based on a larger number of control points than are available in most areas of the world. When applied in appropriate settings where (1) lichens are abundant, (2) the substrate is within an appropriate altitude range, (3) vegetation complexity and competition are minimal, and (4) andesite or granodiorite substrates are stable, our growth curve can be used to determine accurate numeric ages (± 10 yr) for sur-

faces that range in age from 20 to 145 yr. Although the growth curve resulting from this study is limited to a period of approximately 125 yr, it spans an important time interval for those interested in relating glacier-length fluctuations to recent climate variations. Because there are many deglaciated LIA forelands in the 400-km range between Mounts Baker and Mount Hood where tree-ring and cosmogenic techniques are not applicable, historical records are incomplete, and radiocarbon dates do not provide a unique numeric age, our growth curve constitutes an important alternative dating techniques for the study area.

Acknowledgments

We thank Stephen C. Porter, Claire J. O'Neal, Alan Gillespie, Bax Barton, and Bernard Hallet for their support, comments, and suggestions in all portions of this study, Ryan Murphy for his field assistance, and Karl Lillquist for providing the information necessary to incorporate his data into this manuscript.

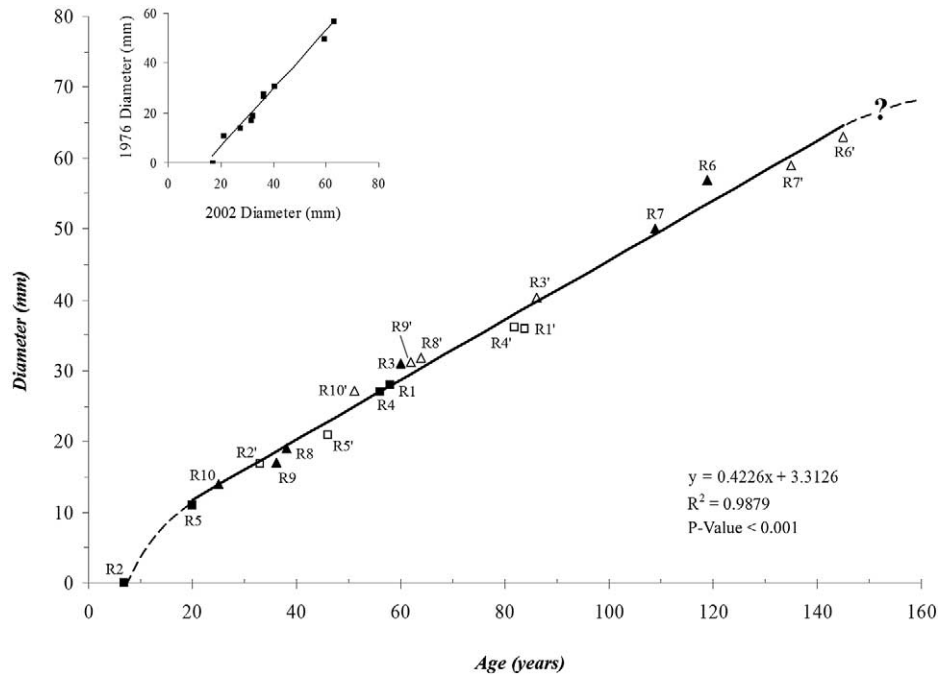


Fig. 6. The control points presented in Porter (1981) for lichens growing on granodiorite (solid triangles) and andesite substrates (solid squares) with measurements from this study at the same locations (hollow symbols). The subplot presents the largest diameters on surfaces measured in 1976 by Porter vs this study in 2002.

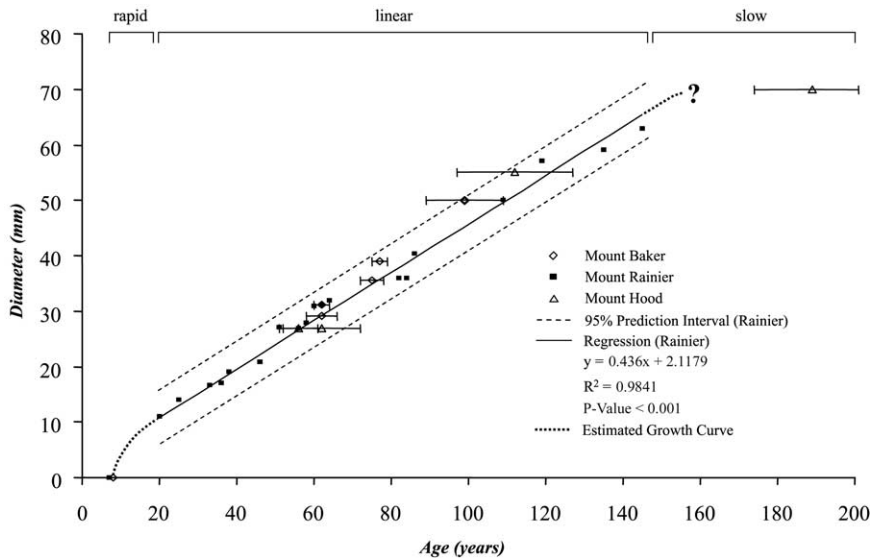


Fig. 7. Plot of all *Rhizocarpon geographicum* data used in this study, the linear regression and 95% prediction for the Mount Rainier data (from 20 to 145 yr) the interpreted growth curve for the rapid and slow growth phases. Error bars on the Mount Baker and Mount Hood data depict the uncertainty in the age of the substrate.

References

Andersen, J.L., Sollid, J.L., 1971. Glacial chronology and glacial geomorphology in the marginal zones of the glaciers, Midtdalsbreen and Nigardsbreen, south Norway. *Norsk Geografisk Tidsskrift* 25, 1–38.

Armstrong, R.A., 1983. Growth curve of the lichen *Rhizocarpon geographicum*. *New Phytologist* 94, 619–622.

Benedict, J.B., 1967. Recent glacial history of an alpine area in the Colorado Front Range, U.S.A. I. Establishing a lichen-growth curve. *Journal of Glaciology* 6, 817–832.

Beschel, R. E., 1959. Dating rock surfaces by lichen growth and its application to glaciology and physiography (lichenometry) [abstract] *Canadian Oil and Gas Industries*, v. 12, no. 12.

Bickerton, R.W., Matthews, J.A., 1992. On the accuracy of lichenometric dates: an assessment based on the “Little Ice Age” moraine sequence of Nigardsbreen, southern Norway. *Holocene* 2, 227–237.

- Burbank, D.W., 1981. A chronology of late Holocene glacier fluctuations of Mount Rainier, Washington. *Arctic and Alpine Research* 13, 369–386.
- Crandell, D. R., Miller, R. D., 1964. Post-hypsithermal glacier advances at Mount Rainier, Washington, in: *Geological Survey Research 1964*, U. S. Geological Survey, Reston, VA, pp. D110–D114.
- Denton, G. H., Karlen, W., 1973. Lichenometry: its application to holocene moraine studies in southern Alaska and Swedish Lapland, in: *Lichenometry*. Arctic and Alpine Research. University of Colorado, Institute of Arctic and Alpine Research, Boulder, CO, pp. 347–372.
- Innes, J.L., 1985. An examination of some factors affecting the largest lichens on a substrate. *Arctic and Alpine Research* 17, 99–106.
- Innes, J.L., 1986. Influence of sampling design on lichen size–frequency distributions and its effect on derived lichenometric indices. *Arctic and Alpine Research* 18, 201–208.
- Karlen, W., Black, J., 2002. Estimates of lichen growth-rate in northern Sweden. *Geografiska Annaler, Series A* 84, 225–232.
- Lillquist, K. D., 1988. Holocene fluctuations of the Coe Glacier, Mount Hood, Oregon. Unpublished M.S. thesis, Portland State University.
- Miller, C.D., 1969. Chronology of neoglacial moraines in the Dome Peak area, North Cascade Range, Washington. *Arctic and Alpine Research* 1, 49–65.
- Porter, S.C., 1981. Lichenometric studies in the Cascade Range of Washington: establishment of *Rhizocarpon geographicum* growth curves at Mount Rainier. *Arctic and Alpine Research* 13, 11–23.
- Reynolds, N.D., 2001. Dating the Bonneville Landslide with lichenometry. *Washington Geology* 29, 11–16.
- Sigafoos, R. S., Hendricks, E. L., 1972. Recent activity of glaciers of Mount Rainier, Washington, in: *U. S. Geological Survey Professional Paper*, U. S. Geological Survey, Reston, VA, pp. B1–B24.