LICHEN DATING METHODS AND APPLICATIONS IN NORTHERN CALIFORNIA

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ABSTRACT

Certain genera of crustose lichen can be used as indicators of the minimum theoretical age of exposure for recent archaeological rock features. The purpose of this study is to calculate the growth rate of a crustose lichen "indicator species" and establish a usable chronology for dating recent human phenomena. This controlled study was undertaken in Sonoma and Lake Counties using the Genus *Lecidea*. The dating range for the principal study specie was tested on lithics with known dates up to 150 years old. The oldest individual found of this specie in the study area is estimated at 450 years b.p. with numerous individuals over 300 years old. Studies indicate that lichenometry is an effective tool in dating historic period features such as walls, quarries, foundations and late prehistoric lithics.

THE THEORY OF LICHEN DATING

Is it possible that the diameter of a lichen can be used to determine the exposure age of an undated archeological surface? By measuring the diameter of a round lichen plant body or "thallus" on a known dated surface, an annual growth rate can be established. This growth rate can then be extrapolated to lichen found as macro-striations on lithic features to establish their age and the approximate exposure date of the underlying lithic surface.

The theory of lichen dating techniques or lichenometry is based on the physiology and growth of lichen. Analogous to annual growth in trees, lichen will radiate from a central point unless disrupted by terrain, competition or other environmental factors such as smog (Hale 1967). Their growth rate and longevity varies to specie, macro climate and substrate. To account for these variables the development of a reliable lichenchronology should be limited to slow growing species typical of Crustose lichen within a geographic area where annual temperatures and rain fall are similar.

Regardless of these variables, lichen within a similar macro-climate, will grow at a consistent and measurable rate. Once that annual growth rate is known, it can then be extrapolated to lichen on other rocks yielding an exposure date for the underlying surface. This age estimate indicates a "minimum theoretical age" for the underlying surface since lichen in this area will begin growth soon after the surface is exposed. It can be applied to both human and natural exposures in either a relative or chronometric manner.

BACKGROUND

First described as an archeological tool in the 1930s by Renaud (1939), principle formulation of the procedure was undertaken by Beschel, a glacial geologist dating recent moraines in Europe and Canada in the 1950s and 60s (Renaud 1939; Beschel 1961). Studies in the Swiss Alps showed lichen life spans for crustaceous species of the genera *Rhizocarpon* to range between 600 to 1300 years, and in western Greenland ages were found at over 2000 years old. Applications were found in studying the exposure times of glacial moraines, changes in lake levels, rock falls and alluvial fans. Beschel estimated one lichen-covered Eskimo site to be at least 500 years old, and Gerhard Folmann, using the same method estimated the age of statues on Easter Island to be about 430 years old (Beschel 1961). Application to glacial and archeological studies, since that time, have been conducted by

Benedict (1967), Curry (1969) and Innes (1985) in the United States. Using the methodology developed in these studies an intriguing archeological application was made by Bettinger and Oglesby in their 1985 study of Alpine villages of the White Mountains of California. Using growth rates from these previous studies for *Rhizocarpon* ssp. estimates were made on numerous prehistoric dwelling sites dating from over 500 years old (Bettinger and Oglesby 1985).

This current study differs from past inquiries in three ways. First, dating was confined within a confirmed range of 150 years based on lithics of known exposure dates as a control group. Second, his study also centers on a moist low altitude marine environment where colonization periods are short and growth rates are rapid compared to tundra, alpine and desert climates. This enables variables such as colonization period and growth rate changes during lichen maturing to be incorporated and averaged directly into the growth rate calculation. Third, the introduction of a new technique to establish accurate annual growth rates by cross sectioning lichen and counting areoles in appropriate species. Areoles rates were compared to growth rates calculated on dated lithics.

LICHEN BIOLOGY AND ANNUAL AREOLATE FORMATION

Lichen are in reality composed of two or more organisms living in a symbiotic relationship of mutual benefit. They are made up of a fungus specie (either the Classes *Ascomycetes* or *Hymenomycetes*) and one or two algae species of the green or blue-green types.

Classification is based on the morphology and fruiting bodies of the fungus since they have differentiated tissues. The general appearance of a lichen can be used to group members according to the differentiation of the cortical, algal and medullary tissues. This simple approach leads to three general groups along with many intermediary types. Crustose lichen are the least differentiated, generally slow growing and in close contact with the substrate. This group especially members of the genus *Rhizocarpon, Rinodena* and *Lecidea* are ideal for dating purposes because of their longevity. *Rhizocarpon geographicum* has been used to date glacial moraines as far back as 1,000 years (Beschel, 1961). Foliose lichens have a leafy thallus with differentiated cortex and distinct rhizinal attachment to the substrate. The third group is the Fructicose lichen which are branch like with a differentiated thallus and cortex layer. Members of the foliose and fruticose groups were not studied for this report since they are generally faster growing, asymmetric in growth, and have a shorter life span. It is of interest to note that faster growing species have higher concentrations of algae and thus a higher photosynthetic rate (Hale 1967).

The crustose lichen used for this study is a member of the *Lecidea* genus and has been tentatively identified as *Lecidea lapicida* var. *lithophila*. *Lecidea* ssp. is composed of a fungus from the group *Ascomycetes* and one specie of symbiotic green algae from the trebouxioid group. A quick taxonomic classification for this genus is as follows: thallus and proper exciple is well developed, compact and circular, spores are small, unicellular with 8 per ascus (spore sac) and the thallus is crustose in growth form (Hasse 1913).

The growth of a lichen begins with the germination of lichen spores on a suitable substrate with suitable moisture. A newly exposed rock surface comes in contact with wind and water-born spores which will adhere or become entrapped in small fissures and holes. When proper growth conditions are met colonization of the new surface begins. This period of colonization varies to specie and its particular growth rate and possibly the development of available nutrients through weathering and chelation by micro-organisms (Hale 1961).

Lichen growth begins very slowly and a period of years can pass before the thallus is visible, and then proceeds in classic sigmoidal curve generally fast growing in youth and then slowing to a consistent linear growth rate. Eventually the oldest portion dies out or specializes in the formation of reproductive bodies while the outer diameter continues to expand (Hale, 1967). Seasonal variation in growth has been determined to be greatest during the rainy season and slowing during dry periods.

Certain species of crustose lichen are areolate, meaning that small areas of the lichen thallus separate from other similar areas by minute segments. These individual areoles occur by the segmentation of the epithecium and hymenium layer. They include vegetative tissues along with algae or specialized reproductive tissues such as ascocarps. Areole are formed shortly after or during the annual growth cycle. Based on tombstone growth rate analysis in Sonoma County a diametric growth rate of 1.0 mm per year was determined. Areole counts of the same lichen gave an average diameter of 0.5mm per areole. It was thus determined that one areole is created each year around the circumference of lichen. This was confirmed in the Lake County survey where average areole diameters were smaller reflecting the slower growth rates in this drier environment.

PROCEDURE AND METHODOLOGY FOR ESTABLISHING LICHEN CHRONOLOGY

Identification of an indicator specie

To begin a chronology, the investigator must identify the most common crustose lichen specie present on the lithic feature which is to be dated. This is the most likely indicator specie. In making this determination it is important to consider the following: lichen which are useful indicators are disk shaped and slow growing species of the Crustose group. This specie is assumed to be at its optimum growth conditions within the macro climate thus minimizing variables in growth rates. Because of varying germination times, older thalli will be found scattered in low populations over the lithic surface at about one individual per 1-2 square meters usually surrounded by numerous younger individuals. In the study area of Sonoma County, species within the genus *Lecidea* were found to meet chronology requirements.

Establishing growth rate of the indicator specie can be accomplished by two procedures: by using dated lithic surfaces such as tombstones or dated stone features, or by counting areole in appropriate areolate lichen genera such as *Lecidea* and *Rhizocarpon*.

Procedure 1: Tombstone Chronology

To develop an accurate chronology based on tombstone dates, one must survey each stone for large, disk-shaped, free growing lichen thalli. Not all stones have usable lichen due to limited surface. The greatest most consistent diameter of the largest thalli should be measured and recorded. This should be done on at least 10-20 stones of varying ages. Increments of about 10 years should be used in order to establish when the growth rate has stabilized to a constant. In *Lecidea lapicida*, growth rate stabilized to 1mm/year in 20-30 year old individuals and remained constant after that age (see Table 1). Once the chronology is complete, the annual growth rate can be calculated by dividing the tombstone age into the lichen diameter measured in millimeters. This can also be plotted and graphed as a function of date vs diameter. For *Lecidea lapicida*, a growth rate of 1mm/ year was consistent after the juvenile phase has ended in the principal study area of region 1 in Sonoma County. Regions 2 and 3 in Lake County exhibited slower growth rates as expected due to lower annual rainfall.

Problems in Tombstone Analysis

Several cemeteries within the study area were discounted due to cleaning tombstones. Secondly, the date on a tombstone is not necessarily the date the stone was placed or perhaps replaced. Another tombstone problem encountered was family members sharing the same grave stone. Another variable is the rock used; substrates such as marble are toxic to most lichen species. The final variable is the time needed to colonize a surface, which can be determined from analyzing newer tombstones. In *Lecidea* ssp. in Sonoma County, analysis of tombstones under ten years old showed that colonization was not visible to the unaided eye at five years, but was clearly established at nine years with measurable thalli of 4 to 5 mm (see table 1). As the lichen ages, this establishment period becomes less of a factor as its growth rate accelerates and then levels off for a prolonged period of over 150 years. Measurements used in this study incorporate the colonial period and juvenile growth phase into the annual growth rate calculation. In areas of low rainfall the colonization period can be prolonged up to 20-50 years (Benedict 1967). In extreme environments such as desert, tundra and high elevations, the colonization period should be calculated from tombstone analysis and added to calculations of age.

Procedure 2: Crustose Lichen Areole Chronology

Can growth rate be determined in crustose areolate lichen by counting the areoles? Making the assumption that growth rate can be accounted for by the formation of one areole layer around the outer circumference of the lichen thallus per annual growth season, age and growth rate can be determined. The following procedure was undertaken to compare the growth rate determined in procedure one to the rate calculated by areoles chronology:

Radial cross section cuts were made of lichen thalli including the underlying substrate using a gem saw. Measured under 10-20x magnification and counted, areoles were divided into the number of millimeters and multiplied by 2 to calculate annual growth rate. Since growth rates are standardized to lichen diameter, multiplying by 2 converts from the radial measurement. Growth rates calculated in this way fell consistently within the range of growth taken from the tombstone and dated lithic chronology studies in Sonoma County and Lake County.

Procedure for the Dating of Archeological Features

The establishment of a minimum theoretical age for an undated archeological feature is the goal of lichen dating. Once the growth rate for one or more species is established using the above procedures, a complete lichen survey of the archeological feature should be undertaken in the following way. From practice in the field, the best approach is to measure all the large lichen individuals directly on the feature, being careful to take the greatest diameter reading across the thallus. By calculating their age, a minimum theoretical age range of the lithic exposure can quickly be determined. The measurement of the largest diameter will pinpoint the most accurate estimate of the theoretical minimum age. An important consideration at this stage is the square meter area of the lithic surface and the number of individuals present. It is apparent that a small sampling from a limited lithic surface of less than a meter could lead to a false reading. The older a lithic surface (in the study region of Sonoma County beyond 200 yrs. b.p.), the larger the sampling area needed since lichen colonies could be affected by competition and crowding. This is not the case in more arid climates where competition may not be a factor for several hundred years. The growth rate will eventually be affected by this competition for space when individuals collide. As reported by Beschel, using lichen dating methods on glacial moraines older than 1000 years b.p., areas of 100 square meters were needed to get accurate results (Beschel 1961). This study conducted surveys on two types of features, rock quarries and stone walls which contained over 100 meters of surface area making them good test features as well as smaller exposures under 10 meters square.

Age can be determined by multiplying the lichen diameter by the known growth rate. Each lithic dated should be recorded on a standardized survey form showing site location, minimum age estimate and all pertinent data. It should be noted that the averaging of the diameters of all the individuals on a lithic does not work since it is only the older thalli that approximate the age of the underlying surface. Following the above procedures this study successfully estimated dates on several features of known date to verify results (see Table 2).

Smaller thalli can only be used in specific situations such as in the comparison of an exposed exterior foundation (oldest and largest) to the interior facings (smaller and younger) which were exposed after the above building was removed.

Surveys should be run off-site on nearby rock outcrops. By comparison these diameters should generally be older, representing a geologic exposure date. If these diameters are similar, the general area could be environmentally affected giving dates pertaining to a fire or other factors. For example, in dating the rock walls of Tilden Park the question of fire affected rock was quickly answered by surveying rocks in close proximity with lichen over 100 years older than the wall which dates to the early 1850s.

Table 1. Comparison of growth rates determined by areole versus tombstone chronologies.

	Areoles growth rate range / average mm	Tombstone chronology growth rate range / average mm per year
Region 1 Sonoma Co.	.95-1.16 / 1.03	.98-1.02 / 1.0
Region 2 Lower Lake	.44-.47 / .46	.40-.60 / .53
Region 3 Middletown	.59-.63 / .62	.58-.87 / .71

Table 2. Lichen age estimates on rock surfaces with known exposure dates.

LOCATION	FEATURE	LICHEN DIAMETER	LICHEN AGE /DATE	LITHIC DATE
Chanslor Ranch	Stone foundation	140mm	140 yrs./1856	Prior to 1861 photo
Fort Ross	School Foundation	70mm	70yrs./1926	Moved 1923-25
Fort Ross	Call Ranch stairs	118-120mm	118-120yrs./1878-76	Constructed 1887
Fort Ross	Mill Stones	50-55mm	55yrs./1941-46	Re-exposure 1940s
Jack London	Wolf House	82mm	82yrs./1914	Fire affected 1913
Salt Point	Rock Quarry	135mm	135yrs./1861	Quarried 1855-61
Salt Point	SON-1668H	110mm	110+5-10yrs.fire/1881-1878	1860-1880
Salt Point	SON-250/H	120-125mm	120-125 +3 fire/1873-1868	1860-1880
Olompali	Rock walls	125-130mm	1872-1867	1870-1880

DATA ANALYSIS

Within the study regions, lichenometry provided accurate estimates of age when tested against dated lithics (Table 2). The principal study area of Sonoma County (Region 1), a moist marine environment of 30+ inches of annual rain and summer fog, creates an optimum environment for consistent lichen growth. Growth rates attained by areoles chronology were within the range of growth rates established by extensive cross referencing to tombstone analysis and tests on dated lithics. Individual areole diameters vary and it is currently suspected to reflect annual climatic changes such as rainfall. The areole diameters for the years 1994-1989, a period of prolonged drought, are noticeably reduced in size as compared to areole formed in the 1980's, during periods of consistent rain.

This test was duplicated in Lake County in two distinct micro-climates. Region 2 in Lower Lake based on open sun graves at the town's cemetery and the Gamer Island prehistoric site CA-LAK-28. The areoles chronology established from lichen collected in proximity to the cemetery have a rate of .44 to .47 mm/yr. which confirmed the reduced growth rate found in the tombstone survey of .40-.60 mm/yr. When applied to the Gamer Island survey where the largest lichen diameter directly on lithic features was 55 mm, an abandonment range of prior to 1871-1879 was calculated (Table 3).

Table 3. Lichen age estimates on undated lithics.

Location	Feature	Lichen Diameter	Lichen age/date	Rainfall
Tilden Park	Stone Wall	145mm	1880-1851	22
Fort Ross	CA Son-1879	153 on cupule	1843	46
Fort Ross	Plow Scrapes	80mm	1916	46
Fort Ross	Fire Pits	80mm	1916	46
Garner Island	Cupules	55mm	1870-79	22

CONCLUSIONS

Findings in this study confirm that lichenometry can be incorporated into archeological survey as a useful tool in dating. Test results were consistently confirmed on known dated surfaces. Preliminary results indicate that determination of growth rate can be accomplished by areoles chronology as well as basing rates on dated lithics. Dated lithic chronology could serve as a confirmation test and to establish the colonization period in desert and high elevation surveys. Areoles rates are quick to determine, accurate and not subject to limitation of tombstone analysis. Lichen should be taken in proximity to an archeological feature, sampling individuals of similar age, substrate and exposure. This procedure eliminates variables of age-related growth rate changes, substrate variation and lack of dated lithics in proximity to establish growth rate. Also, because of the taxonomic uncertainties in the identification of species within the suitable genera, tests can be done without extensive field identification. Areoles chronology is possible in several genera of crustose lichen including *Rhizocarpon* and *Lecidea*. This new procedure enables accurate dating beyond the time scale of known dated lithics since no extrapolation of growth rate takes place as in the tombstone analysis. Areole chronology gives an exact age, accurate growth rates and possible climatic history.

NOTES

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