Wave-transported boulders imbricated near Marquette, Michigan, as indicators of past Lake Superior storm activity

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Introduction

Lake Superior has the largest surface area of any freshwater lake in the world (Swain, 1980). This large surface area helps to produce powerful storms on Lake Superior. According to Eichenlaub (1979), storms that form over the lake tend to be the strongest during the “unstable season” in November and December when the greatest temperature differences exist between the lake surface and the overlying air.

Lake Superior produces large storms that have the power to sink and drive ships ashore. On November 10, 1975, the *Edmund Fitzgerald,* after loading 26,000 tons of taconite at Superior, Wisconsin, sank suddenly to the depths of Lake Superior in the teeth of 60 mile per hour winds and large waves (Marshall, 1997). Ships have been tossed about the lake since navigation of Lake Superior began during the times of the fur traders. Wolff (1990) tells of a ship, the *Western Star,* that was pushed ashore by strong winds during a storm known as the “Big Blow” on November 28, 1905. What becomes evident is the strength of Lake Superior storms in moving massive materials. In a like fashion, materials such as cobbles and boulders are moved by the most violent Lake Superior storms. As lake freighters have been tossed about the lake, it is assumed that the cobbles and boulders within the lake were also moved. The shoreward transport of large boulders, if their age were to be identified, could reveal possibilities for reconstruction of a storm timeline for Lake Superior. The purpose of this study is to extend further the chronology and lake record of extreme storms over Lake Superior through a lichenometric dating analysis of shoreline boulders near Marquette, Michigan.

Literature Review

Severe storms over Lake Superior are rare, but there is evidence that they do occur. Angel (1995) charted a possible severe storm timeline by noting storm damage such as flooding and erosion for all five of the Great Lakes. This study gives a good storm sequencing for those storms that caused severe erosional damage; although, the data was not collected exclusively for Lake Superior. In addition to the study by Angel, Phillips (1982) investigated cobble ridges for wave-induced formation. He proposed that a former large magnitude storm potentially could account for some of the variations he observed in the cobble ridges. Phillip's paper is unique because it introduced the idea of massive storm waves transporting cobbles and boulders (Philips, 1982).

The biggest waves occur during infrequent storms that ravage the lake and drive the water surface into steep waves. Maximum wave height occurs when extensive fetch combines with high velocity winds of a sustained duration. For example, when northerly winds blow over Lake Superior, these wind currents of 30-50 knots can produce waves that range in height from 4.9 to 9.1 meters (Kotsch, 1983).

The work by Dott (1974) provides the quantitative assessment for wave height needed to move boulders based on paleogeographic studies near Baraboo, Wisconsin. Dott studied an ancient tropical sea that inundated the area that is now Wisconsin. Through this study he discovered that waves of 6.1 to 7.9 meters are necessary to move boulders 1.5 meters in diameter (Dott, 1974).

Erosive Lake Superior storms with northeasterly storm winds affect and erode the southern Lake Superior shores (Johnson and Johnston, 1995). Shoreline erosion and subsequent boulder transport occurs most often when Lake Superior winds blow from the north, northwest or northeast, the directions of greatest fetch. As storm waves move across the lake, the downwind shore is affected by various erosive events including the transportation and removal of shoreline materials. A similar situation occurs on the southern shore of Lake Michigan. This southern shore is buffeted by large waves when northerly winds blow the length of the lake from north to south. Storms over Lake Michigan from the north have the most concentrated energy during the time period from November through April, (LaMoe and Winters, 1989).

Lichenometry is a surface dating technique that can be used in estimating the age of certain geologic features such as moraines and boulders. Beschel (1973) studied moraines associated with Vernagtferner, a well-known glacier in the Eastern Alps. He found that ice retreated towards the west, thereby indicating older morainic deposits on the eastern side. Lichen dating is typically used for dating moraines, but it is also used for dating boulders. McCarroll (1994) indicates averaging the largest sample from a number of boulders as a good way to determine a lichen growth curve.

Surface exposure dating is possible if the length of lichen growth including colonization time is known. Dorn and Phillips (1991) stated, "if numerical age control can be obtained in an area, it may be possible to calibrate the growth rate of lichens." For this study, the growth rate was established at the two cemeteries. Newton and Newton (1989) support the use of local cemeteries to teach the basic concepts of lichenometry and how to establish a growth curve.

The two lichen genus groups measured for this research both are crustaceous life forms. Crustaceous means that the lichens have a stiff upper thallus, or upper layer. Also, the lichen is firmly attached to the rock across the entire bottom side (Newton and Newton, 1989).

First hand ship accounts provide valuable information that supports the stormy nature of Lake Superior. Many ships over the years have experienced storm-related problems on Lake Superior. One particular account by Holden (1985) chronicles ten shipwrecks near Isle Royale. The wind was blowing out of the northeast as one ship, the *Kamloops*, heading north from Whitefish Bay to Canada, was blown off course and sank on the north coast of Isle

Royale (Holden, 1985). Wind strength and wave height, while not scientifically measured in these historic ship records, are evident from the vivid descriptions of the storms.

Methodology

The dating of shoreline boulders involved one main technique and one auxiliary technique. The main technique involved using lichenometry to identify a possible timeline for storms that helped create the present shoreline. The second technique involved using mariners' accounts of extreme Lake Superior storms.

Field data was collected for individual boulders at the two shoreline sites. Each boulder was measured according to these six parameters: latitude and longitude, rock type, imbrication, relative size, main exposure direction, and lichen size. Latitude and longitude were not used extensively except to confirm in the field the close proximity of many boulder samples. Each shoreline had a different predominant rock type. Rock coloration was also noted. The accurate collection of shoreline data also involved the identification of imbricated boulders.

Imbricated boulders were described as large stones lying on smaller rocks with a definite tilt toward lake level. Signs of imbrication were always checked for and recorded but sometimes were not apparent. Boulders near lake level that did not show signs of imbrication were also measured. It was assumed that the boulders near lake level were transported by waves to the shoreline, while rock areas obviously impacted by mass wasting were avoided.

The boulders next to the shore varied in size according to qualitative criteria. Visual classification of boulder size was done at each of the study sites. The classes were grouped according to rock size with small boulders (< 1 meter), medium boulders (1-2 meters), and large boulders (> 2 meters).

Both shoreline sites in the study area are exposed to the physical and climatological elements of Lake Superior. This characteristic of the study sites was highlighted through the documentation of the main exposure direction. The exposure direction was assumed to be the angle with the most rock frontage flanking the open waters of Lake Superior. This exposure measurement was collected using a Brunton compass and was expressed in azimuthal degrees (0-360).

Much of this study focused around the concentrated use of lichenometry as a research tool. The first step of the dating procedure was to measure lichens on shoreline boulders. The age of the shoreline lichens was determined using regression analysis where the lichen radius was the independent variable and the boulder age was the dependent variable. The establishment of the regression equation was accomplished by ascertaining lichen growth rates. Lichens of a known age were measured at Park and Holy Cross Cemeteries in Marquette to establish a growth rate. Lichen radius measurements gathered at the two shorelines were subsequently inserted into their respective growth rate equations according to lichen type. From this operation, dates for shoreline boulder placement were gleaned.

Fifty-six boulders were studied at the two shorelines. Of these boulders, 11 (20 percent) were located at Presque Isle. The other 45 (80 percent) were studied at Freeman's Landing. At these two sites, the lichens with the most clearly defined edges were measured. Sometimes the largest lichens were not measured due to overlapping edges and their generally poor condition (part of the lichen was rubbed off a particular boulder). The actual shoreline measurements were carried out using a 150-millimeter ruler. Radius measurements were recorded for two lichen genus types: *Caloplaca* and *Parmelia*.

A complete analysis regarding boulder placement on the two shorelines required obtaining data that would provide information regarding the individual lichen growth rates. Using the date from the cemetery markers enabled the specific growth rate of each lichen type *Caloplaca* and *Parmelia* to be determined. This information was gleaned at two local cemeteries, Park Cemetery and Holy Cross Cemetery in Marquette, Michigan. The lichen radii were recorded according to type and cemetery. This grouping of lichens according to type and cemetery allowed any anomalies to become evident.

The actual growth rate calculation for *Caloplaca* and *Parmelia* per the two cemeteries required a simple mathematical calculation where lichen radius was divided by growth period in years. The end result of this was its growth rate in millimeters per year. The lichen growth rates provided required data that was necessary to perform regression analysis on the shoreline boulders. The lichens measured on shoreline boulders acted as the independent variable (x value) in the regression routine. By analysis of the boulder lichens (*Caloplaca* and *Parmelia*) according to the regression equation, an approximate date (the dependent variable) of shoreline boulder placement becomes available, and Lake Superior's storm history can be studied.

Regression analysis provided data indicating historic periods of strong storms on Lake Superior. This data was cross-referenced with shipwreck records that provided qualitative information from sailors and traders actually on the lake during some of these vast storm events. Their testimony was used as supporting evidence regarding timing and actual occurrence of some of the storms. Assuming that boulder placement coincides with large storms over Lake Superior, the records of mariners as experienced by survivors help to confirm the Lake Superior storm timeline as indicated by regression analysis.

Study Area

Presque Isle and Freeman's Landing are two regions of Lake Superior shoreline located near Marquette, Michigan. Presque Isle is a city park within Marquette proper, while Freeman's Landing is a section of shoreline about five miles northwest of the city. Figure 1 shows the locations of these two study sites. These two locations vary according to rock type, number of imbricated boulders, relative sizes of boulders, and main exposure direction.

Presque Isle:

Presque Isle is a rocky headland that juts out into Lake Superior on the north end of Marquette, Michigan. The tip of this headland, especially on the north and northeastern sides, is very rugged. The main exposure directions on Presque Isle were direct. The peninsula was entirely exposed to water, waves, and the full brunt of Lake Superior storms due to its orientation to the lake and the lake's energy. With the peninsula thrusting out into the lake, the pounding

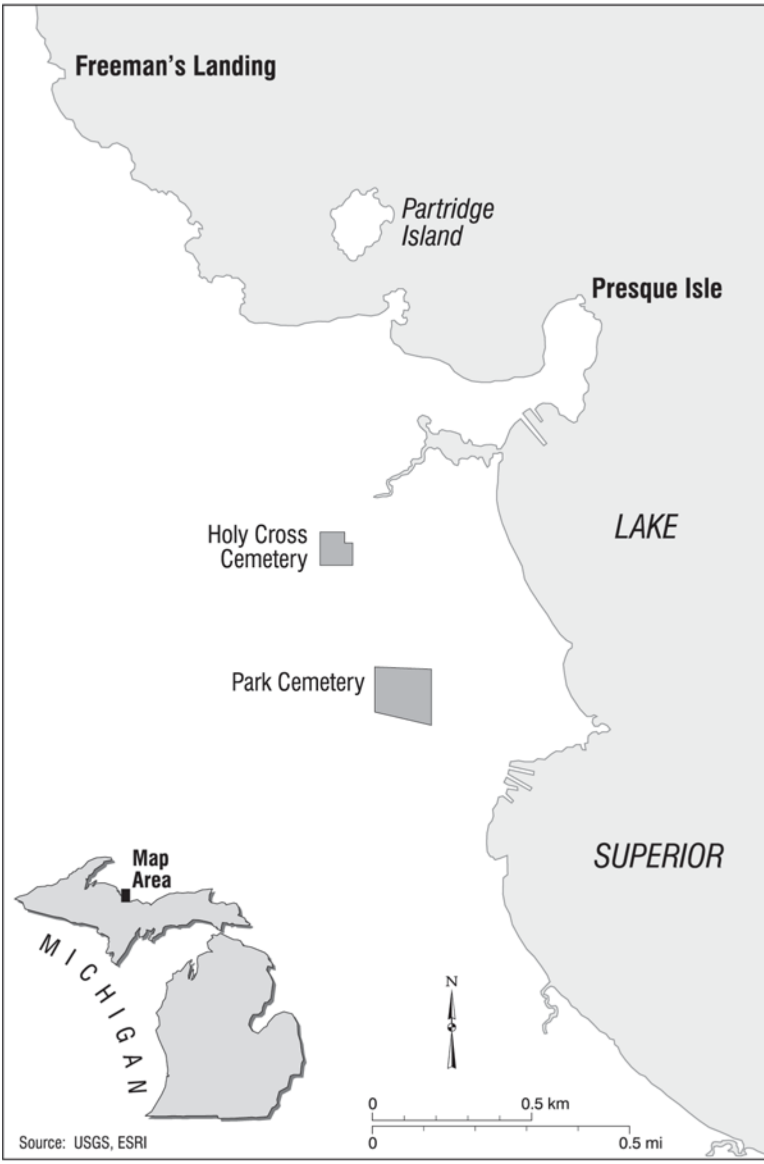

Figure 1: *Location of study area.*

water and wave energy would be most pronounced at the tip of the headland (Pethick, 1984).

Periodite, a form of metamorphosed sandstone, composes the bedrock in these areas and was laid down in the Upper Precambrian (Bennison, 1978). Most (82 percent) of the boulders on this peninsula are imbricated. Many are perched as stark monoliths of past storm events although most of the boulders there were classed as small or medium sized. Twenty percent of the total number of boulders examined for lichens were found at Presque Isle.

Freeman's Landing:

The second shoreline data collection site was Freeman's Landing, a remote shoreline site about five miles northwest of Marquette, Michigan. This study site forms a series of small headlands and bays composed of extremely rugged cobbles and boulders. The shoreline is not as wide as the Presque Isle site, and in a number places cobbles thrust into nearby undergrowth are evidence of past storms. This series of rocky headlands is composed of granitic gneiss, an ancient rock of extreme solidity from the Lower Precambrian (Bennison, 1978).

The Freeman's Landing site had more boulders than the Presque Isle site. At this site, 45 boulders were measured. This is 80 percent of the total number of boulders studied. These boulders were carefully checked for signs of imbrication because there was evidence of mass wasting due to gravity and frost wedging in the vicinity. No boulders near the upper beach slope were measured. Many of the boulders measured were located on smaller stones with a downward tilt that is characteristic of imbrication. Of all the boulders at Freeman's Landing, 40 (89 percent) were considered imbricated with 13 (29 percent) small, 13 (29 percent) medium, and 19 (42 percent) large. Freeman's Landing contained the largest imbricated boulders in the study, and these large stones were located at or close to water level.

Compared to Presque Isle, Freeman's Landing had fewer primary exposure directions. Figure 2 shows a high frequency of main exposure directions ranging from the north to the east. Sixty-seven percent of the exposure directions ranged from 46 to 90 degrees. This fact seems to indicate a high potential for the strongest

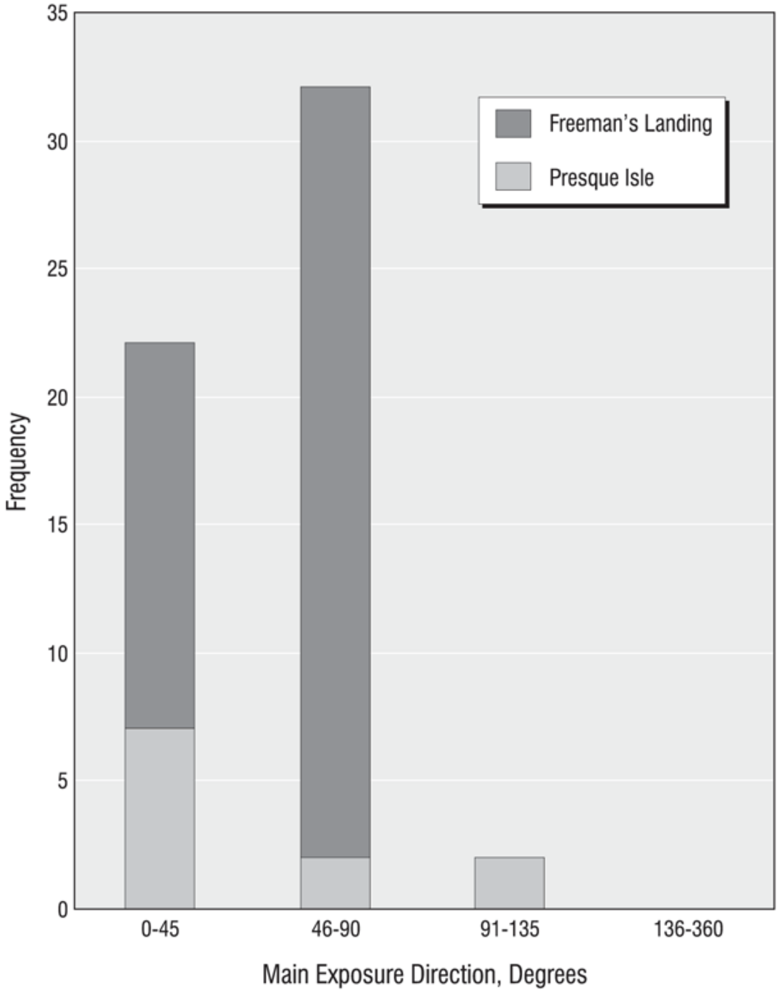

Figure 2: *Frequency distribution of main exposure direction for imbricated boulders at Presque Isle and Freeman's Landing.*

storms and the largest waves to roll inland from a northeasterly direction. Fewer storms come from the north because Little Presque Isle partially blocks that orientation to Lake Superior.

Holy Cross and Park Cemeteries:

Holy Cross and Park Cemeteries are both located in Marquette, Michigan. The differences between the two lie in their relative locations within the city and their contrasting topographic characteristics. Forty-eight samples of *Caloplaca* and 70 samples of *Parmelia* came from Holy Cross and Park Cemeteries.

Holy Cross Cemetery is located closer to Lake Superior on relatively flat ground. Twenty-eight (58 percent) of the *Caloplaca*, while 36 (51 percent) of the *Parmelia* were represented by this cemetery. The actual elevation of the cemetery varies less than five feet (USGS Marquette Quadrangle, 1975).

Park Cemetery is located on higher terrain within Marquette. Twenty (42 percent) of the *Caloplaca*, while 34 (49 percent) of the *Parmelia* were represented by this cemetery. The actual topography of the cemetery is quite varied with knolls and low areas common. The elevation of the cemetery varies between 720 and 820 feet (USGS Marquette Quadrangle, 1975).

Results

Different characteristics became evident by studying Presque Isle and Freeman's Landing comparatively. The different characteristics varied according to shoreline, imbrication, and relative boulder size. Nine (82 percent) of boulders on Presque Isle were imbricated compared to 40 (89 percent) on Freeman's Landing. Of all boulders measured at Presque Isle, two (18 percent) were small-sized, six (55 percent) were medium-sized, and three (27 percent) were large-sized. Freeman's Landing showed these size characteristics. Of the 45 boulders measured there, 13 (29 percent) were small-sized, 13 (29 percent) were medium-sized, and 19 (42 percent) were large-sized.

Main Exposure Direction:

Figure 2 shows the frequency distribution of main exposure direction for the boulders at Presque Isle and Freeman's Landing. The graph showing frequency versus wind direction suggests the most probable storm winds that would affect either shoreline site. The graph shows that Presque Isle varied more with exposure directions ranging from 0 to 135 degrees. This graphic indicates that Presque Isle is more apt to be open and exposed to the full onslaught of Lake Superior storms, especially those that harbor a northerly, northeasterly, or southeasterly fetch.

In contrast, the main exposure at Freeman's Landing is similar but not as broad. The exposure at Freeman's Landing ranges from 0 to 90 degrees, due mainly to land obstructions to the north and east. The most probable unobstructed wind route to these shores seems to be a northeast to east-northeasterly route. The presence of massive boulders at the Freeman's Landing site indicates that severe storms have occurred in the past, but the paths of clear fetch seem to be somewhat less when compared to Presque Isle.

Shoreline Boulder Data:

The lichen radius measurements that were obtained at Presque Isle and Freeman's Landing were highly varied. Large ranges in actual size were recorded at both sites for *Caloplaca* and *Parmelia*. The average radii for *Caloplaca* and *Parmelia* were similar for the two sites, but this fact is coincidence more than anything of statistical value.

At Presque Isle, the lichen radius measurements ranged from 3 to 76 mm. The *Caloplaca* sizes varied from 7 to 76 mm with an average radius of 26.9 mm. In comparison, the *Parmelia*, with a smaller spread in actual sizes at 3 to 55 mm, were smaller overall, with a 16.8 mm average. The *Caloplaca* and *Parmelia* data sets collected at Freeman's Landing varied more in terms of actual minimum and maximum sizes. *Caloplaca* ranged from 5 to 130 mm, while *Parmelia* ranged from 2 to 75 mm. The average size increased for *Caloplaca* (29.0 mm) and decreased for *Parmelia* (15.7 mm).

Cemetery Data:

The cemetery data is divided according to cemetery and lichen type, *Caloplaca* and *Parmelia*. This fact indicates four data sets in this section: Holy Cross – *Caloplaca*; Holy Cross – *Parmelia*;

Park – *Caloplaca*; and, Park – *Parmelia*. Each set of information is recorded according to lichen size, average radius, and growth rate (mm/yr).

Caloplaca at Holy Cross Cemetery ranged in size from 9 to 47 mm with an average radius of 23.2 mm. The growth rate for *Caloplaca* at Holy Cross was 0.31 mm/yr. *Caloplaca* lichens at Park Cemetery were similar to those at Holy Cross. The growth period for *Caloplaca* at Park Cemetery was similar to that recorded at Holy Cross Cemetery (72 versus 71 years). In contrast to Holy Cross Cemetery, *Caloplaca* at Park Cemetery were larger on average (26.2 versus 23.2 mm) but were slower growing at 0.27 mm/yr.

Parmelia at Holy Cross Cemetery ranged in size from 10 to 72 mm with an average radius of 24.8 mm. *Parmelia* at Holy Cross actually were larger both in terms of actual size and average size even though *Caloplaca* grew at a faster rate (0.31 versus 0.26 mm/yr). *Parmelia* at Park Cemetery were less varied than those at Holy Cross Cemetery (16-41 mm versus 10-72 mm). The average radius for *Parmelia* at Park Cemetery is also larger at 27.4 mm. Also, the growth rate for *Parmelia* at Park Cemetery is slower than at Holy Cross Cemetery (0.24 mm/yr versus 0.26 mm/yr).

Regression Analysis:

Mathematical analysis of the *Caloplaca* and *Parmelia* data collected at Holy Cross Cemetery and Park Cemetery indicated extremely low correlation values. The calculations showed extremely poor data that could not be used for any serious analysis. This fact was supported by the low R-squared values evident for *Caloplaca* (0.05) and *Parmelia* (0.00).

Discussion

The graphs indicating the poor success of the regression analyses indicate that the derived lichen data show no strong correlation between lichen size and lichen growth rate. Essentially, the mathematics indicate that the data is weak and should not be relied on for accurate analysis of shoreline boulder placement.

Shoreline boulder placement also subsequently indicates those years of storm events over Lake Superior. For *Caloplaca*, this regression formula indicated storms occurring between 82 and 107 years ago. For *Parmelia*, the same equation indicated storms occurring 108 to 111 years ago. Since the data was collected in 1999, this would indicate storms capable of transporting boulders occurring between 1888 and 1917. Clearly, this data is not reliable, and it is only an indicator of severe storms that did occur on the lake during that time period. In no way can this data be considered an absolute in terms of pinpointing specific times of actual storm events. This data is poor and should not be used for any type of analysis, although it does still provide evidence of violent Lake Superior storms on a broad scale.

Potentially, the worst storm in the recorded history of Lake Superior was the November 28th storm of 1905. This storm claimed 78 lives and 21 ships in the worst navigational seasons on the lake (Wolff, 1990). This violent storm is documented well, and it acts as a permanent warning to brave sailors and other folk who embark on Lake Superior during the fall. The 1905 storm on Lake Superior is similar to a Lake Huron example of huge waves and extremely strong winds. On November 10, 1913, a gale on that lake was recorded at 145 kilometers per hour with waves running 12.2 meters (Harrington 1998).

Limitations of Lichenometry:

One problem with studying lichens is knowing and properly identifying_all the different genus types and species. Different lichen species can grow at different rates based on many factors: colonization time of the lichen, climatic factors, exposure direction, height above the ground, and parent rock material.

Colonization time of the lichen refers to the initial time that a particular lichen attached to a boulder. It can be difficult to ascertain colonization time. For this study, it was assumed that colonization time was immediately after shoreline boulder placement occurred. This assumption was used for convenience, but Goudie highlights the problem with this by indicating that even if colonization is immediate, the initial growth can be non-linear (Goudie, 1990).

Another source of error in this study was the climatic factors and lichen interaction with those factors. All lichens are different, and the climatic requirements for different species are as complex as the plants themselves. Knowing this, it is assumed that different species require different amounts of moisture for ideal growing conditions.

As the *Caloplaca* seemed larger near the shoreline, it appeared that they desired more moisture for optimum growth. If this was true, it would follow that *Caloplaca* should grow larger in Holy Cross Cemetery and smaller in Park Cemetery (located on a hill further south in the city). This suggestion was not supported by the average lichen sizes in the cemeteries. It was assumed that the close proximity of Holy Cross Cemetery to the lake would enhance the lichen growth pattern because fog and moisture would be more apt to linger here than on a hill further south in the city (at the location of Park Cemetery).

Another factor that may affect lichen growth patterns is the exposure direction. Some lichens may not thrive in area buffeted by wind. This exposure force may affect the creatures enough that they seek shelter in a more protected area of the boulder or cemetery marker. Some of the cemetery markers showed areas were no lichens existed, but in other areas on the same stone, lichens thrived. This spatial distribution may be due to exposure.

Another climatic factor that may influence lichen growth is height above the ground. If microclimate is a factor in lichen growth rates, this simple idea of elevation could be very important. Within a cemetery or other area, cold air can sink into low areas. Also, air cools through radiational cooling. Fog forms first near the earth's surface. These may be minor in the whole realm of macro or mesoscale climate, but these seemingly small factors could mean the difference between impossible odds and lichen survival.

Additionally, lichens may also favor a certain type of boulder/ marker or base material. The lichens also could favor a certain chemical composition in the minerals that make up the boulders and the cemetery markers. For example, some lichens may prefer a sandy base material such as sandstone, while others may prefer the solid foothold provided by granite outcrops. It all could depend on parent material.

Each of these unique factors was real and potentially could be considered. Every factor could have led to errors regarding the accuracy of dates for shoreline boulder placement and the subsequent storm timeline for Lake Superior.

Conclusions

Lichenometry is a very complex geographic application that needs to be designed very carefully based on the purpose of the research and the desired result. Many factors must be considered to accurately use lichen data. The first priority is to design a strategy for collection that is consistent and accurate and is designed to deal with problems such as lichen overlap and poor lichen samples. After the basic collection principles are in place, there are myriad other factors to consider. Further lichenometric research in this region will require more stringent sampling controls and awareness of other factors that influence the growth rates of certain lichens.

Some of the limitations of lichenometry that were discovered in this study include, but are not limited to, lichen colonization time, climatic factors that could affect the lichen's growth, lichen proximity to sources of moisture, lichen exposure direction, threshold height requirements for lichens, and lichen preference regarding chemical composition of parent surfaces. All of these factors potentially can create errors in data results.

The specific reconstruction of extreme storms over Lake Superior was not an outcome of this study. The data was too broad; and, based on the poor regression correlation parameters, it was not reliable or useful for an accurate reconstruction. The shipwreck data that was studied did indicate the experiences of many a poor navigator that faced the fury of Lake Superior at specific times in the past. Two of the more violent tempests over the lake occurred in November, both in 1905 and 1913. What this study cannot do in a specific sense, it can do in a general sense. This study failed to pinpoint single, extreme storms over the lake, but it has the potential to scope regional Lake Superior storms on a broad, decadal scale.

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