The Integration of the Direct and Indirect Methods in Lichenometry for Dating Buddhist Sacred Walls in Langtang Valley, Nepal Himalaya

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Introduction

Buddhist sacred walls, called mani walls, are common above Ghoratabela in Langtang Valley (Nepal Himalaya) and especially between Langtang Village and Kyanjin Gompa (see Figs. 1-4). Although mani walls are prominent features of the landscape in the Bhutan, India and Nepal Himalaya, were described by early traveling scholars in the Himalaya, and are widely photographed in the tourist literature, the scholarly literature on mani walls is amazingly sparse. Recently Ardussi (2004) produced a translation and interpretation of the carved inscriptions on a mani wall in Bhutan. Weidinger (2002) suggested that the mani walls were constructed as landslide warnings, which is consistent with their location and alignment downslope of and parallel to the distal edges of prominent landslides (see Fig. 2).

Fig. 1 Buddhist sacred walls, called mani walls, are common above Ghoratabela in Langtang Valley (Nepal Himalaya) and especially between Langtang Village and Kyanjin Gompa. This mani wall is adjacent to the monastery in Kyanjin Gompa (see Figs. 3-4).

Fig. 2 This mani wall is aligned parallel to the distal edge of Landslide B (see Fig. 4), which is consistent with the view of Weidinger (2002) that the mani walls were constructed as landslide warnings.

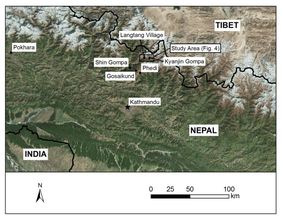

Fig. 3 The lichen *Rhizocarpon geographicum* was found above 3532 m a.s.l. east of Langtang Village, above 4080 m a.s.l. east of Gosaikund, and above 3760 m a.s.l. west of Phedi.

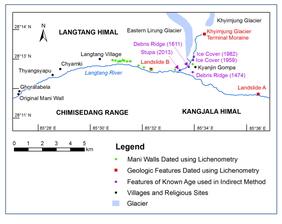

Fig. 4 The time since last cleaning of 24 mani walls between Langtang Village and Kyanjin Gompa was determined using lichenometry. The lichen apparent growth curve was calibrated using two debris ridges dated by Be-10, and two sites of former ice cover and a stupa whose dates were obtained from local knowledge. The revised apparent growth curve was used to re-date two landslides and a terminal moraine dated by Bunds et al. (2010).

Fig. 6 The stupa near Kyanjin Gompa (see Figs. 3-4) was constructed in May 2013. The lichen *Rhizocarpon geographicum* had appeared on the carved blocks of the foundation only 12 months later.

Fig. 5 According to local informants, the Tibetan writing on the mani walls does not state the date of construction or cleaning of the mani walls.

The original objective of this study was to use lichenometry to date GLOF (Glacial Lake Outburst Flood) deposits in Langtang Valley. Because lichen growth rates are variable, it is necessary to calibrate lichen growth rate of a selected lichen species for each study locality by measuring the growth rates of individual lichens over a period of years (called the direct method) or by measuring the maximum lichen diameters on surfaces for which age is known from independent evidence (called the indirect method). It was hoped that the inscriptions on the blocks of the mani walls (see Fig. 5) would date the mani walls and act as independent evidence for the indirect method. However, when it became apparent that the inscriptions did not date the mani walls, the objective changed to using lichenometry to date the mani walls themselves.

Materials and Methods

In June 2009, May 2011 and May 2014 interviews were carried out with local lamas, lay lamas, and hotel owners regarding the traditions of the mani walls, the locations and ages of previous ice cover, and the age of a stupa (Buddhist sacred monument, see Fig. 6). In May 2009 the maximum diameter of the lichen *Rhizocarpon geographicum* was measured on boulders on two debris ridges that had been dated at 1474 AD and 1611 AD by Be-10 dating (Barnard et al. 2006), and at two sites of previous ice cover (1959 AD and 1982 AD) (see Fig. 4). These data were used by Bunds et al. (2010) to construct an apparent growth curve using the indirect method and to date two prominent landslides and the terminal moraine of Khyimjung Glacier. The maximum lichen diameter was also measured on 15 mani walls between Langtang Village and Kyanjin Gompa (see Figs. 4,7). In May 2014 maximum lichen diameters were measured on the carved foundation blocks of the stupa that had been built the previous year and re-measured on 20 boulders that had been measured in 2009. These 20 boulders were unrelated to mani walls and in not-easily-accessible locations. Maximum lichen diameters were also measured on 21 mani walls between Langtang Village and Kyanjin Gompa, including re-measuring 12 mani walls measured in 2009. Three mani walls that had lichens in June 2009 were devoid of lichens five years later. The criterion of choosing circular to smoothly elliptical thalli to avoid measuring composite thalli was hampered by the tendency of *R. geographicum* to grow around quartz veins (see Fig. 8).

Fig. 7 The age (time since last cleaning) of each mani wall was estimated using the maximum lichen size found on each mani wall.

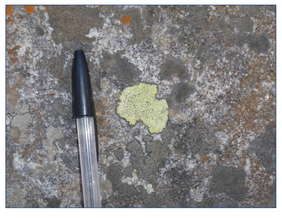

Fig. 8 The criterion of choosing circular to smoothly elliptical thalli to avoid measuring composite thalli was hampered by the tendency of *R. geographicum* to grow around quartz veins (close-up of Fig. 7).

Results

There was general agreement among the local informants of the following:

- There is no information on the mani walls or in any written source that says when any mani wall was constructed.
- The mani walls were constructed 400-600 years ago when Langtang Valley was first settled.
- The mani walls were constructed to keep dangerous animals out of the valley.
- The original mani wall was constructed at Ghoratabela (see Fig. 4) and has never been cleaned.

However, there was considerable disagreement as to whether, when and how the other mani walls are cleaned, especially as to whether they are cleaned of lichens. From this standpoint, the age of a mani wall, as determined by lichenometry, can be regarded as the time since the mani wall was last cleaned of *R. geographicum*, which would represent the most intense level of cleaning.

The lichen growth rate as measured by the direct method was uncorrelated with lichen size (see Fig. 9), implying a linear relationship between lichen size and time. Since the distribution of lichen growth rates was a better fit to a lognormal distribution than a normal distribution (see Fig. 10), the geometric mean (0.47 mm/yr) was chosen as the best estimate of constant lichen growth rate. Based on five sources of indirect data in the vicinity of Kyanjin Gompa (see Fig. 11), the apparent growth curve for *R. geographicum* is $y = 7.749x^{0.4745}$, where y is lichen size (mm) and x is age (ybp). The minimum and maximum growth rates based upon the direct method are the geometric mean divided by the geometric standard deviation and the geometric mean multiplied by the geometric standard deviation, respectively. The minimum and maximum growth rates based on the direct method form an envelope that includes the apparent growth curve based upon the indirect method. The implication is that, in the absence of sources of indirect data, the maximum growth rate based on the direct method could be used to estimate very young ages (< 50 years), while the minimum growth rate based on the direct method could be used to estimate very old ages (> 400 years).

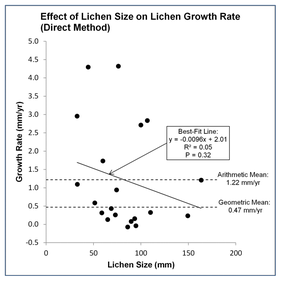

Fig. 9 The lichen growth rate as measured by the direct method was uncorrelated with lichen size (P = 0.32), implying a linear relationship between lichen size and time. The constant lichen growth rate could be estimated as 1.22 mm/yr (arithmetic mean) or 0.47 mm/yr (geometric mean).

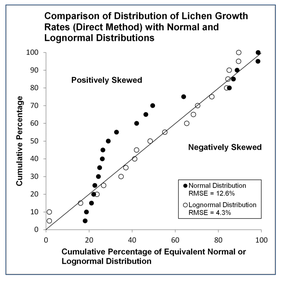

Fig. 10 The distribution of lichen growth rates as measured by the direct method was a much better fit to a lognormal distribution (RMSE (root mean square error) = 4.3%) than a normal distribution (RMSE = 12.6%). On that basis, the geometric mean (0.47 mm/yr) was a better estimate of the constant lichen growth rate (see Fig. 9).

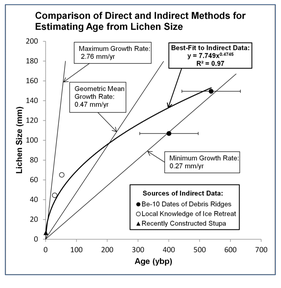

Fig. 11 Based on five sources of indirect data in the vicinity of Kyanjin Gompa (see Fig. 4), the apparent growth curve for *R. geographicum* is $y = 7.749x^{0.4745}$, where y is lichen size (mm) and x is age (ybp). The minimum and maximum growth rates based upon the direct method are the geometric mean divided by the geometric standard deviation and the geometric mean multiplied by the geometric standard deviation, respectively. The minimum and maximum growth rates based on the direct method form an envelope that includes the apparent growth curve based upon the indirect method.

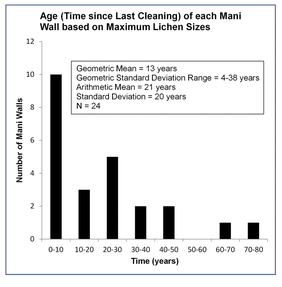

Fig. 12 The age (time since last cleaning) of each of 21 mani walls was estimated based on the maximum lichen size found on the mani wall in 2014 and the apparent lichen growth curve developed using the indirect method (see Fig. 11). The ages of the three mani walls with lichens in 2009 that were devoid of lichens in 2014 were estimated to be 2.5 years. The geometric standard deviation range is the range between the geometric mean divided by the geometric standard deviation and the geometric mean multiplied by the geometric standard deviation.

The age (time since last cleaning) of each of 21 mani walls was estimated based on the maximum lichen size found on the mani wall in 2014 and the apparent lichen growth curve developed using the indirect method (see Figs. 11-12). The ages of the three mani walls with lichens in 2009 that were devoid of lichens in 2014 were estimated to be 2.5 years. Since the distribution of mani wall ages as estimated from maximum lichen sizes was a better fit to a lognormal than a normal distribution, the geometric mean (13 years) is the best estimate of the typical mani wall age.

Discussion

The new apparent growth curve (see Fig. 11) was used to re-date geologic features previously dated by Bunds et al. (2010). Landslide B (see Figs. 2,4) was re-dated at 1913 AD, which is consistent with the hypothesis of Weidinger (2002) that the mani walls were constructed as landslide warnings, since the mani wall pre-dates the landslide. Weidinger's hypothesis may have some connection with the local view that the mani walls were constructed to keep out dangerous animals. The view of all of the local informants that the original mani wall at Ghoratabela had never been cleaned was consistent with its appearance in relation to the other mani walls as the mani wall at Ghoratabela was entirely covered by mosses (see Fig. 13). A future possibility for lichenometric dating may be the roofless stone huts (called kharkas, see Fig. 14), which are common between Shin Gompa and Phedi, especially in the vicinity of Gosaikund (see Fig. 3).

Fig. 13 The lowest mani wall (3001 m a.s.l.) in Langtang Valley is found at Ghoratabela (see Fig. 4). According to oral tradition, this is the original mani wall and has never been cleaned. This mani wall is almost entirely covered by mosses. However, note that this mani wall occurs far below the lower elevation limit for *R. geographicum* (3523 m a.s.l.).

Fig. 14 Roofless stone huts (called kharkas) are common between Shin Gompa and Phedi, especially in the vicinity of Gosaikund (see Fig. 3). Many of the stones are cut, although they lack the elaborate carvings found on the mani walls between Ghoratabela and Kyanjin Gompa (see Fig. 4). Although the roofless stone huts are rebuilt annually, there is probably a foundation that is rarely rebuilt.

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