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The integration of the direct and indirect methods in lichenometry for dating Buddhist sacred walls in Langtang Valley, Nepal Himalaya

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ABSTRACT

Buddhist sacred walls, called mani walls, are common between Langtang Village and Kyanjin Gompa in Langtang Valley, Nepal Himalaya. The objective of this study was to interview local informants about the mani wall traditions and to use lichenometry to resolve discrepancies regarding the maintenance of the mani walls. The maximum diameters of the lichen *Rhizocarpon geographicum* were measured on each of 24 mani walls. An apparent lichen growth curve was developed using five sources of indirect data, including the foundation of one stupa (sacred monument) and two locations of former ice cover, for which ages were obtained from local informants, and two debris ridges that had been dated by ^{10}Be. The direct method was pursued by measuring the maximum diameters of 20 lichens in remote locations in both 2009 and 2014. Based on the indirect method, the mani walls are cleaned on a geometric mean cycle time of 13 years. The direct and indirect methods yield equivalent ages when the minimum direct growth rate (geometric mean divided by geometric standard deviation) is used for older ages (>400 years), while the maximum direct growth rate (geometric mean multiplied by geometric standard deviation) is used for younger ages (<50 years).

Introduction

Buddhist sacred walls, called mani walls, are common above Ghoratabela in Langtang Valley (Nepal Himalaya) and especially between Langtang Village and Kyanjin Gompa (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 (Pranavananda, 1939; Hamond, 1942); and are widely photographed in the tourist literature, the scholarly literature on mani walls is amazingly sparse. Recently, Ardussi (2004, 2007) produced the first translations and interpretations of the carved inscriptions on a mani wall in Bhutan. The geologic interest in mani walls has been awakened by the suggestions of Weidinger (2001a, 2002) 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 (Fig. 2). Stolle et al. (2015) found that two-thirds of the mani walls in their study area in the Trans-Himalayan Ladakh and Zanskar Ranges (northwestern India) were oriented perpendicular

FIGURE 1. Buddhist sacred walls, called mani walls, are common above Ghoratabela in Langtang Valley (Nepal Himalaya) and especially between Langtang Village and Kyanjin Gompa (Figs. 3–4). This mani wall is adjacent to the monastery in Kyanjin Gompa (Mani Wall #24, Table 2).

FIGURE 2. Mani Wall #22 (Table 2) is aligned parallel to the distal edge of Rock Avalanche Deposit B (Fig. 4), which is consistent with the view of Weidinger (2001a, 2002) that the mani walls were constructed as landslide warnings.

to river channels. Moreover, during the catastrophic debris flows of August 2010, many of these mani walls acted as local flow barriers that deflected and diverted the debris flows.

The original objective of this study was to use the relatively inexpensive method of lichenometry to date glacial lake outburst flood (GLOF) deposits in Langtang Valley (Bunds et al., 2010). Only a small number of prehistoric mass wasting deposits in the India and Nepal Himalaya had been dated previously, and they were dated by the relatively expensive methods of ^{10}Be, ^{26}Al, and fission-track dating (Barnard et al., 2001, 2006a, 2006b; Abramowski, 2004; Mitchell et al., 2007;

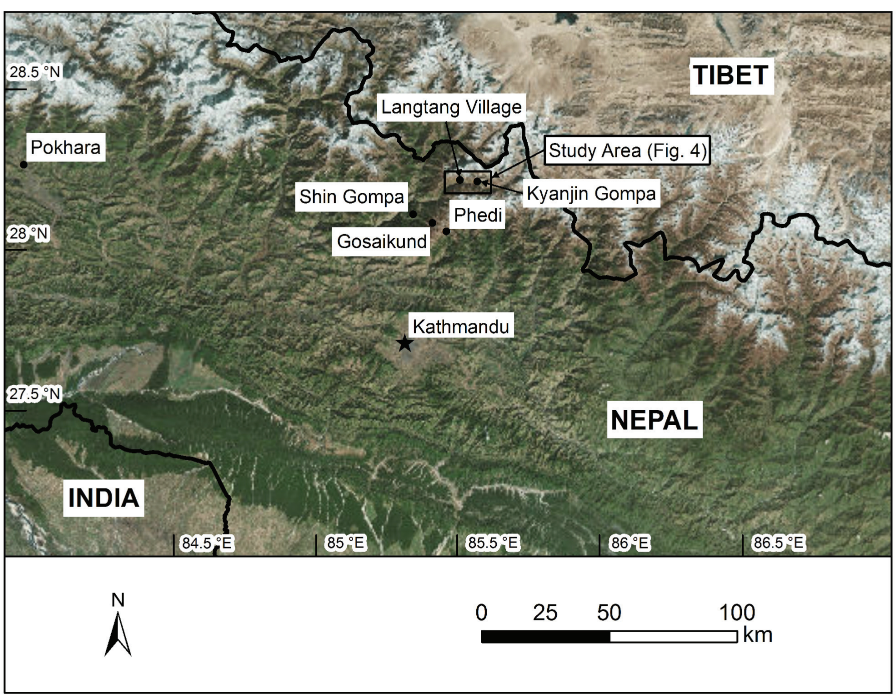

FIGURE 3. The lichen *Rhizocarpon geographicum* was found above 3532 m a.s.l. east of Langtang Village, above 4080 m a.s.l. west of Gosaikund, and above 3760 m a.s.l. west of Phedi.

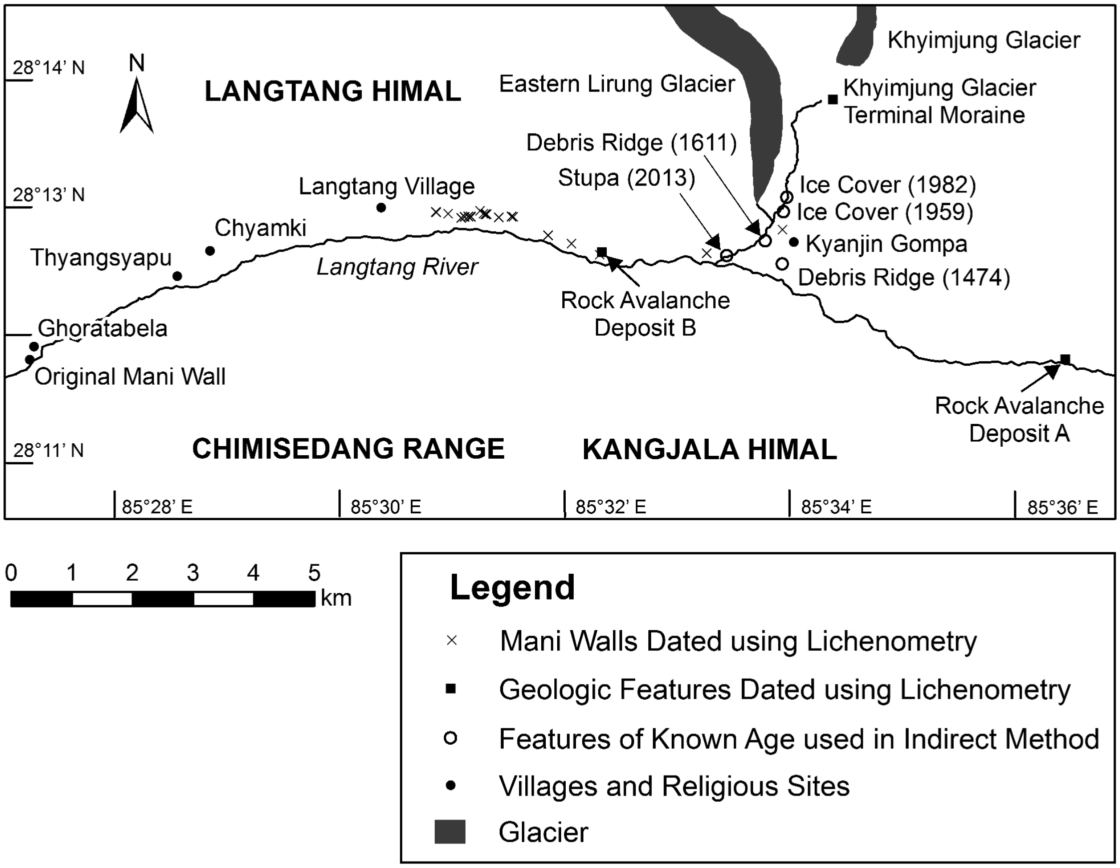

FIGURE 4. The time since last cleaning of 24 mani walls between Langtang Village and Kyanjin Gompa was determined using lichenometry. The lichen apparent growth curve was calibrated using two debris ridges dated by ^{10}Be, and two sites of former ice cover and a stupa whose dates were obtained from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

Takagi et al., 2007). Because lichen growth rates are variable, it is necessary to calibrate the 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 (or other statistical measure) of lichen diameters on surfaces for which age is known from independent evidence (called the indirect method) (Innes, 1988). Gravestones have often been used as surfaces of known age. There have been only a handful of lichenometric studies in the Himalaya, partly due to the lack of gravestones that can be used for calibration. Vohra (1981) and Srivastava et al. (1995) mentioned lichenometric studies on moraines of the Gara and Gor-Garang Glaciers in the India Himalaya, but did not present the results. Sah (1995) discussed the prospects for lichenometry in the Himalaya. Srivastava et al. (2004) and Awasthi et al. (2004) used lichens to date the moraines of Gangotri Glacier in the India Himalaya. In those studies, lichen growth was calibrated by measuring lichens on boulders of two moraines whose ages were known from prior fieldwork early in the 20th century. Gupta (2005) carried out relative dating of portions of a major landslide in Himachal Pradesh (India Himalaya) using percent lichen cover without regard to lichen species. Ibetsberger (2005) measured the diameters of *Rhizocarpon geographicum* on moraine boulders in Langtang Valley (Nepal Himalaya). Since there was no local calibration of growth rates, the interpretation was only qualitative and was used to distinguish between Holocene and Little Ice Age moraines. Chaujar (2006) calibrated the growth of *R. geographicum* at four sites in Himachal Pradesh using dated monuments. Most recently, Chaujar (2009) calibrated the growth of *R. geographicum* in the Garhwal Himalaya by monitoring the diameters of seven lichens over a four-year period and using the absence of *R. geographicum* on a dated bridge to establish a minimum time for initial colonization of the surfaces by lichen (called the colonization delay). Chaujar (2009) used the results to date the moraines of the Chorabari Glacier. Yang et al. (2008) used the maximum diameter of *R. geographicum* growing on a fan formed by a GLOF of known age to date moraines on the Tibetan Plateau. We are not aware of any lichenometry that has been carried out anywhere in the Bhutan, Nepal, or Pakistan Himalaya aside from Ibetsberger (2005) and Bunds et al. (2010). Even the description of lichens in Nepal could be regarded as in its infancy. *R. geographicum*, which was used in this study, was not reported by Sato (1962), Awasthi (1988, 1991), or Sharma (1999), but was mentioned by Baniya et al. (2010). Recently, Olley (2008) reported on a lichen-collecting expedition to the Langtang Himalaya and Olley and Sharma (2013) produced a preliminary list of species.

It was hoped that the inscriptions on the blocks of the mani walls (Fig. 5) would date the mani walls and act as the independent evidence required by the indirect method. However, it became apparent from interviews with local informants that the inscriptions, in fact, did not date the mani walls. On the other hand, some of those same informants were able to identify and provide dates for two positions of former ice cover in the vicinity of Kyanjin Gompa (Figs. 3 and 4). In the same vicinity, Barnard et al. (2006a) had carried out ^{10}Be dating of two debris ridges (Fig. 4). Although the two ridges were interpreted by Barnard et al. (2006a) as lateral moraines, Bunds et al. (2010) suggested that they were deposited by hyperconcentrated stream flows or debris flows, which possibly were the result of GLOF events. The maximum diameters of *R. geographicum* were measured on boulders at all four sites and were used to construct an apparent lichen growth curve for use by the indirect method of lichenometry (Bunds et al., 2010). The apparent growth curve was used to date Rock Avalanche Deposits A and B (referred to as Landslides A and B by Bunds et al., 2010) and the terminal moraine of Khyimjung Glacier (Figs. 2 and 4). Bunds et al. (2010) chose Rock Avalanche Deposit B because its front is very near and parallel to a mani wall and an age younger than the time of human settlement of the area would be consistent with the view of Weidinger (2001a, 2002) that mani walls were constructed as warnings of landslides, which are a significant hazard in Langtang Valley (e.g., Weidinger, 1998). The same apparent growth curve was later used by Carlson et al. (2012) to date terrace evolution and incision rates along the uppermost Langtang River.

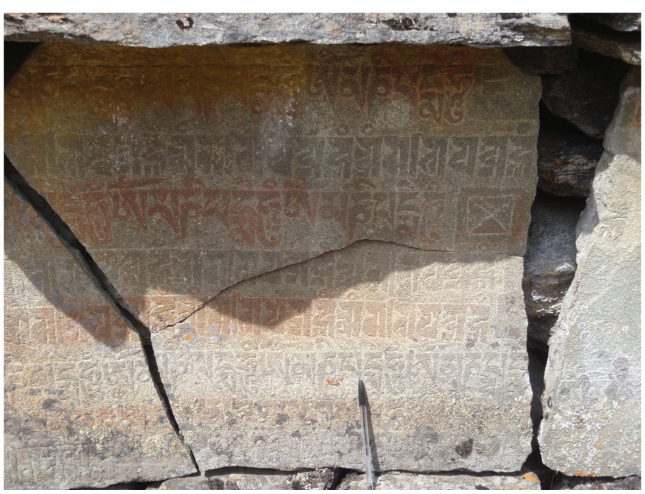

FIGURE 5. According to local informants, the Tibetan writing on the mani walls does not state the dates of construction or cleaning of the mani walls.

Since the mani walls could not be dated by their inscriptions and since an apparent lichen growth curve was developed from other geologic features of known age, the objective of this research changed to using the lichens on the mani walls to date the mani walls themselves. Benedict (2009) has reviewed the application of lichenometry to archaeology and Winchester (1988) also used lichenometry to date stone monuments. The initial set of lichen measurements on mani walls was carried out in 2009 at the same time as the fieldwork described in Bunds et al. (2010). Five years later, the opportunity arose to remeasure the same lichens and to search for lichens on additional mani walls in conjunction with other fieldwork. Therefore, a secondary objective of this research became a comparison of the mani wall ages that would be obtained by the direct and indirect methods. It cannot be assumed that lichenometric dating by the direct and indirect methods will produce the same results. The plot of lichen size versus time developed by the indirect method is often called an apparent growth curve because it does not directly reflect the actual biological growth rate of individual lichens. Rather, the largest measured lichen diameter or other statistical measure of lichen size reflects lichen growth and mortality rates (e.g., Loso and Doak, 2006), the colonization delay, the probability of finding and recognizing the oldest lichen on a set of rock surfaces formed in a single event, the probability that an individual thallus has not grown into other thalli and become an immeasurable composite thallus, and the probability that the largest thallus has not grown in an irregular fashion so as to be mistaken for a composite thallus (Bunds et al., 2010). The vast majority of lichenometric studies have used the indirect method because it automatically includes the effect of colonization delay, it avoids any bias that could result from a variation between the climate over the period of direct measurements and the climate since the initial exposure of rock surfaces and due to the challenge of repeated expeditions to remote locations (Benedict, 2009). We are aware of only three other studies that have compared the results from the direct and indirect methods (McCarthy, 2003; Trenbirth and Matthews, 2010; O'Neal et al., 2013).

This study has built upon the extensive work carried out on the geomorphology and glacial history of the Langtang Valley since the 1980s (Heuberger et al., 1984; Ono, 1985, 1986; Fukushima et al., 1987; Shiraiwa et al., 1990; Shiraiwa and Watanabe, 1991; Watanabe, 1994, 1998; Weidinger and Schramm, 1995; Weidinger et al., 1996, 2002; Bäumler et al., 1996, 1997; Heuberger and Ibetsberger, 1998; Schramm et al., 1998; Watanabe et al., 1998; Weidinger, 1997, 1998, 2001b; Abramowski, 2004; Ibetsberger and Weidinger, 2004; Barnard et al., 2006a; Owen et al., 2008; Kemp et al., 2012; Nuimura et al., 2012). Recently, Osborn et al. (2014) compiled all of the criticisms of lichenometric dating that have accumulated since the method was introduced in the 1950s and asked whether lichenometric dating is a "pseudo-science." This paper is not the place to respond to all of the criticisms listed in Osborn et al. (2014), most of which derided a creep toward low standards of research in some lichenometric studies. However, we have taken to heart the concerns of Osborn et al. (2014) and have been particularly careful in regard to the quantification of uncertainties.

Materials and Methods

Interviews

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, Fig. 6). All interviews were carried out in Nepali and included at least one of the authors fluent in both Nepali and English. Although the informants were fluent in Nepali,

FIGURE 6. The stupa near Kyanjin Gompa (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.

their native language was Tamang, which was not spoken by any of the authors. The Tibetan writing on the mani walls could be read by only one of the informants (Appendix E) and none of the authors. The interviews did not follow a fixed set of questions, but concerned the history and traditions of the mani walls, the maintenance and cleaning of the walls, and the existence and location of objects of known age (Appendices A–F). One of the interviewees (Pasang Wangdi, Peon of the Department of Hydrology and Meteorology, Government of Nepal) identified the younger site of previous ice cover. Since he had no further information about the mani walls, his interview is not summarized in the appendices. (Note that in Nepal, "peon" is a job title and not a derogatory term.)

Lichen Sampling Sites

In June 2009 the maximum diameter of the lichen *R. geographicum* was measured at two sites that were described by local informants as permanently covered by ice (Appendix C) until A.D. 1959 and 1982, respectively, along a stream fed by Khyimjung Glacier (Fig. 4). These were not former positions of the glacier (Appendix C), but more likely remnants of ice from the glacial retreat. Cover by ice for greater than five years should have resulted in complete mortality of *Rhizocarpon* (Benedict, 1990), so that lichen sizes should reflect time since melting of an ice remnant. Lichen measurements were restricted to boulders within one vertical meter of the present stream bed to ensure that the sampled surfaces were not exposed prior to the indicated dates, and larger lichens were visible higher above the stream bed. Maximum lichen diameters were also measured on boulders on two debris ridges that had been dated at A.D. 1474 and 1611 by ^{10}Be dating (Barnard et al., 2006a). The exact sampling sites of Barnard et al. (2006a) were located and lichens were measured within 30 m of their sampling sites. To aid in relocating lichens, all measured lichens were photographed from multiple angles and distances; the location was determined using the Trimble Juno GPS Receiver; and the rock substrate, elevation above the ground, and dip and strike of the lichen exposure were recorded. The above four sources of indirect data were used by Bunds et al. (2010) to construct an apparent lichen growth curve, which was used to assign dates to Rock Avalanche Deposits A and B and to the terminal moraine of Khyimjung Glacier (Tables 1 and 2, Figs. 2 and 4). During the same field season, the maximum diameters of *R. geographicum* found on each of 15 mani walls (Table 3, Fig. 7) between Langtang Village and Kyanjin Gompa (Figs. 3 and 4) were measured

TABLE 1

Maximum lichen sizes on features of known age used in indirect method.[1]

Feature[2]	Date[3] (A.D.)	Latitude[4] (°N)	Longitude[4] (°E)	Maximum size (mm) 2009	Maximum size (mm) 2014	Growth rate[5] (mm/yr)
Debris ridge	1474 ± 94	28.2093	85.5655	148.92	150.08	0.23
Debris ridge	1611 ± 95	28.2123	85.5630	99.75	113.92	2.83
Ice cover	1959	28.2161	85.5657	64.72	65.37	0.13
Ice cover	1982	28.2180	85.5662	33.73	55.20	4.29
Stupa	2013	28.2104	85.5573	—[6]	6.69	6.69

[1]Table modified from Bunds et al. (2010) with additional data collected in 2014.
[2]See Figure 4.
[3]Debris ridges were dated by Barnard et al. (2006a) using ^{10}Be. Uncertainties in debris ridge ages are standard errors. The locations and ages of former ice cover and the age of the stupa were obtained from local knowledge.
[4]Latitude and longitude are based on WGS 84 coordinate system.
[5]Growth rate was calculated by the direct method of comparing lichen size in 2014 with 2009, except for the stupa, which was constructed 12 months previously.
[6]The stupa had not yet been built in 2009.

TABLE 2

Geologic features re-dated using maximum lichen sizes.

Geologic feature[1]	Latitude[2] (°N)	Longitude[2] (°E)	Previous date[3] (A.D.)	New date[4] (A.D.)
Rock Avalanche Deposit A	28.1969	85.6074	1683	1773 (1389–1898)
Rock Avalanche Deposit B	28.2109	85.5388	1904	1912 (1774–1961)
Khyimjung Glacier Terminal Moraine	28.2308	85.5730	1966	1959 (1890–1981)

[1]See Rock Avalanche Deposit B in Figure 2 and all locations in Figure 4.
[2]Latitude and longitude are based upon WGS 84 coordinate system.
[3]Bunds et al. (2010).
[4]New dates were calculated based on a revision in the lichen apparent growth curve and averaging the sizes of the largest lichens measured in 2009 and 2014. The age ranges are the ± one standard error confidence intervals based on the misfit of the growth curve to the indirect data (Table 1, Fig. 12) and the uncertainties in lichen measurements. The range of uncertainty in dates due to uncertainty in lichen measurements alone was less than two years, even for the oldest dates.

with the same record-keeping for future measurements.

During the field season of May 2014, we learned that a stupa (Buddhist sacred monument) had been constructed 12 months earlier and the maximum lichen diameters were measured on the cut blocks of the foundation (Fig. 6). Out of the lichens that were measured at the four sites of indirect data and at Rock Avalanche Deposits A and B in 2009, 20 were relocated and remeasured. The 20 remeasured lichens included the lichens that were used to construct the apparent growth curve and to date Rock Avalanche Deposits A and B (Table 1) (Bunds et al., 2010). All of these lichens were located in relatively remote areas (not along foot paths), so that there was no reason to believe that the lichens would have been disturbed by people. The largest lichen on each of the mani walls between Langtang Village and Kyanjin Gompa was also remeasured. Based on the interviews, there was reason to believe that some of these lichens could have been partially or wholly removed by people (Appendices B and C). For each mani wall, the largest lichen in 2009 was also the largest lichen in 2014. Three mani walls that had lichens in 2009 were devoid of lichens in 2014, although the blocks that supported the lichens were still in place. Nine additional mani walls were found in 2014 that were not noticed in 2009 and lichens were measured on those mani walls, so that lichens were measured on 24 mani walls during at least one field season (Table 3). The same site information was collected in 2014, except that location was determined with the Garmin eTrex 10 GPS Receiver.

Lichen Sampling Procedures

This study followed the same lichen sampling procedures as Bunds et al. (2010) with the exception of repetition of measurements for increased accuracy. Innes (1988) reviewed the range of measuring procedures used in lichenometry. Lichens that met the description of Purvis et al. (1992) and St. Clair (1999) were assigned to *Rhizocarpon geographicum*, the most common lichen used for lichenometric dating (Bradwell and Armstrong, 2007). These lichens may have included species of similar appearance within *Rhizocarpon* subgenus *Rhizocarpon*, but precise identification to the species level was unrealistic in the current absence of a *Rhizocarpon* taxonomy for the Himalaya. Even when taxonomies have been developed, the lumping of species of similar appearance into *R. geographicum* (sometimes referred to as *R. geographicum* agg.) is a common practice in lichenometry (Benedict, 1988, 2009). Care was taken to measure only thalli of individuals, as opposed to composites that form when two or more individuals grow together. Discrimination between individual and composite thalli used the following criteria: approximate circular to smoothly elliptical shape (Ellis et al., 1981; Proctor, 1983), sharp margins, well-defined hypothallus, and homogeneity of color and texture within the thallus. In addition, the presence of numerous much smaller thalli in close proximity to each other around an anomalously large thallus was considered

TABLE 3

Maximum sizes of lichens sampled on mani walls in 2009 and 2014.

No.	Latitude[1] (°N)	Longitude[1] (°E)	Maximum size (mm) 2009	Maximum size (mm) 2014	Change rate[2] (mm/yr)	Age[3] (yr B.P.)
1	28.21610	85.51419	—[4]	40.30	—	32.3 (18.1–69.0)
2	28.21607	85.51428	36.80	34.13	−0.53	22.8 (13.1–46.9)
3	28.21589	85.51603	—	18.22	—	6.1 (3.9–10.9)
4	28.21533	85.51794	23.03	45.69	4.53	42.1 (23.0–92.3)
5	28.21545	85.51848	28.39	44.97	3.32	40.7 (22.3–89.0)
6	28.21543	85.51846	—	56.46	—	65.7 (34.6–151.1)
7	28.21551	85.51903	15.38	33.99	3.72	22.5 (13.0–46.4)
8	28.21549	85.51933	—	29.33	—	16.5 (9.8–32.9)
9	28.21548	85.51942	—	8.45	—	1.2 (0.9–1.8)
10	28.21623	85.52074	—	35.99	—	25.4 (14.5–53.0)
11	28.21586	85.52126	34.41	41.20	1.36	33.8 (18.9–72.6)
12	28.21581	85.52155	33.39	missing[5]	—	2.5 (0.0–5.0)[6]
13	28.21581	85.52155	45.62	22.91	−4.54	9.8 (6.1–18.5)
14	28.21580	85.52170	56.20	59.02	0.56	72.1 (37.7–167.5)
15	28.21540	85.52351	25.68	22.82	−0.57	9.7 (6.0–18.4)
16	28.21550	85.52544	17.72	missing	—	2.5 (0.0–5.0)[6]
17	28.21550	85.52544	27.02	33.11	1.22	21.3 (12.4–43.7)
18	28.21548	85.52567	24.97	missing	—	2.5 (0.0–5.0)[6]
19	28.21305	85.53082	19.87	20.35	0.10	7.7 (4.8–14.1)
20	28.21198	85.53427	—	24.15	—	11.0 (6.7–21.0)
21	28.21196	85.53428	—	27.30	—	14.2 (8.5–27.9)
22	28.21051	85.53845	25.39	16.27	−1.82	4.8 (3.1–8.4)
23	28.21070	85.55430	35.25	33.37	−0.38	21.7 (12.6–44.5)
24	28.21381	85.56550	—	16.17	—	4.7 (3.1–8.2)
			Mean positive change rate ($mm\ yr^{-1}$)		2.11 ± 1.72[7]	
			Mean negative change rate ($mm\ yr^{-1}$)		−1.57 ± 1.76[7]	

[1]Latitude and longitude are based upon WGS 84 coordinate system.
[2]Change rate is calculated only for mani walls for which the maximum lichen size was measured in both 2009 and 2014.
[3]Age refers to the time since last cleaning prior to 2014. The age ranges are the ± one standard error confidence intervals based on the misfit of the growth curve to the indirect data (Table 1, Fig. 12) and the uncertainties in lichen measurements. The range of uncertainty in ages due to uncertainty in lichen measurements alone was less than two years, even for the greatest ages.
[4]— indicates that the mani wall was not examined in 2009.
[5]Missing indicates that a mani wall that had *R. geographicum* in 2009 was devoid of *R. geographicum* in 2014.
[6]Mani walls for which lichens were seen in 2009 but were missing in 2014 were assumed to have been cleaned 2.5 years prior to 2014 with uncertainty ± 2.5 years.
[7]Arithmetic mean ± one standard deviation.

sufficient evidence that the large thallus might be composite and such thalli were excluded from the study. On the other hand, it is known that physiological stress can cause an individual to develop an irregular shape (Benedict, 1993), and the observed tendency of *R. geographicum* to grow around quartz veins in the study area (Fig. 8) introduced a degree of subjectivity into the choice of appropriate lichens. The single lichen with the largest diametrical axis (including the hypothallus) was used for develop-

FIGURE 7. The age (time since last cleaning) of each mani wall was estimated using the maximum lichen size found on each mani wall. Mani Wall #8 (Table 2) is shown.

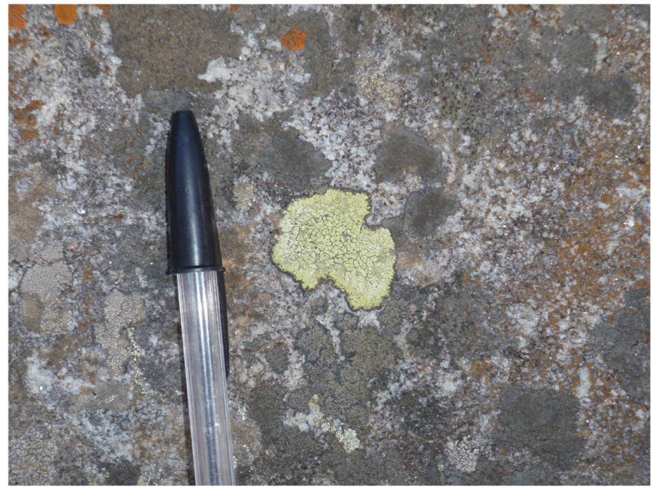

FIGURE 8. The criterion of choosing circular to smoothly elliptical thalli to avoid measuring composite thalli was hampered by the tendency of *R. geographicum* to grow around quartz veins (close-up of Fig. 7).

ment of the apparent growth curve and to estimate the time since cleaning of each mani wall. It is possible that cutting of the blocks to construct the foundation of the stupa (Fig. 6) did not remove all *R. geographicum* that may have been present before cutting. This inheritance of preexisting lichens was unlikely on the blocks of the mani walls because they are so elaborately carved (Fig. 5). Inherited lichens on the blocks of the stupa foundation were avoided by excluding any lichens that were more than 20% larger than the next largest lichen, a common practice (Calkin and Ellis, 1980; Loso and Doak, 2006) that has not yet been quantitatively justified.

In this study, the longest diametrical axis of each lichen was measured six to nine times, in contrast to the previous study of Bunds et al. (2010), in which each lichen was measured only once. Although both studies used the same digital calipers with graduation of 0.01 mm, the major source of measurement error is the difficulty in repeatedly placing the calipers in the same position on a rough rock surface. The standard error of the mean of each lichen size averaged over all lichens in this study was ±0.13 mm. Although Bunds et al. (2010) assumed that the uncertainty in lichen size was ±0.05 mm, this was not quantitatively justified, and the uncertainty was probably closer to the standard deviation of each lichen size averaged over all lichens in this study, which was ±0.64 mm. O'Neal et al. (2013) suggested that ±1 mm is a reasonable accuracy in the absence of repeat measurements, regardless of the graduation of the calipers.

Results

History and Interpretation of Mani Walls

The local informants agreed or did not disagree regarding the following:

- There is no information on the mani walls or in any written source that says when any particular mani wall was constructed (Appendices A, D, E).
- The mani walls were constructed 400–600 years ago when Langtang Valley was first settled (Appendices A, B, E).
- The mani wall near Ghoratabela (Fig. 4) has never been cleaned, although there was disagreement as to whether this was the original mani wall (Appendices B, C, E).
- The mani walls were originally constructed to keep dangerous animals out of the valley and, when they are destroyed by landslides, they are reconstructed to prevent further landslides (Appendix C).

However, there was considerable disagreement as to whether the mani wall blocks have ever been recut and whether, when, and how the mani walls (besides the mani wall near Ghoratabela) are cleaned, especially as to whether they are cleaned with an iron brush that would remove crustose lichens (Appendices A–E). 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 with an iron brush.

Use of Direct Method

Out of the 20 lichens that were remeasured in 2014 at four sites of indirect data (two sites of former ice cover and two debris ridges) and at Rock Avalanche Deposits A and B, only two lichens showed negative growth rates of –0.04 and –0.07 mm yr^{-1}, which were well within the observational error (Fig. 9). The positive growth rates were consistent with the assumption that these lichens would not be disturbed by people, as they were not located on foot paths and were not found on objects of religious significance. The lichen growth rates measured by the direct method were uncorrelated with lichen size (P = 0.32) (Fig. 9). The implied constant growth rate was inconsistent with typical apparent growth curves developed by the indirect method, which tend to show an initial period of rapid growth followed by an extended period of slower growth (e.g., Benedict, 2009; Bunds et al., 2010). Because the distribution of lichen growth rates was a better fit to a lognormal (RMSE [root mean square error] = 4.3%) than a normal (RMSE = 12.6%) distribution, the constant growth was calculated as the geometric mean of 0.47 mm yr^{-1} (Figs. 9 and 10). By contrast, the arithmetic mean of 1.22 mm yr^{-1} was considerably larger (Fig. 9). The lichen growth rate was uncorrelated with elevation (P = 1.00), even though measured lichens were growing only 110–408 m above the lower elevation limit (3532 m a.s.l.) for *R. geographicum* (Fig. 11). (The lichen at the lower elevation limit was found on Mani Wall #1, Table 3.) In a similar way, lichen growth rates were uncorrelated with dip or strike of exposures, elevation above the ground surface, rock substrate, or any combination of measured parameters.

Use of Indirect Method

Based on the five sources of indirect data in the vicinity of Kyanjin Gompa (Fig. 4) and averaging the sizes of the largest lichens measured in both

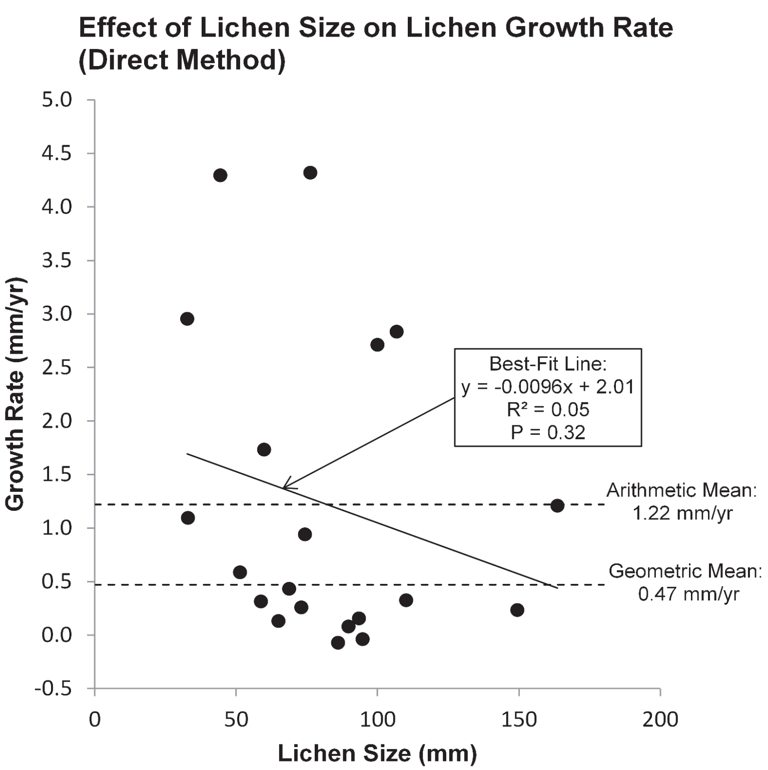

FIGURE 9. The lichen growth rate as measured by the direct method was uncorrelated with lichen size (*P* = 0.32), implying a linear relationship between lichen size and time. The constant lichen growth rate could be estimated as 1.22 mm yr^{-1} (arithmetic mean) or 0.47 mm yr^{-1} (geometric mean).

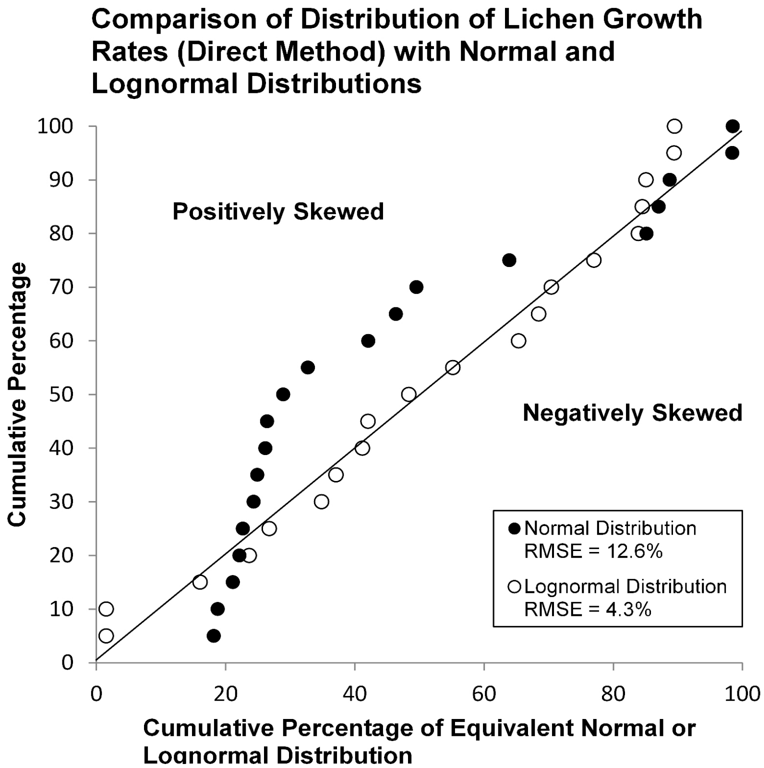

FIGURE 10. The distribution of lichen growth rates as measured by the direct method is a much better fit to a lognormal distribution (RMSE [root mean square error] = 4.3%) than a normal distribution (RMSE = 12.6%). On that basis, the geometric mean (0.47 mm yr^{-1}) is a better estimate of the constant lichen growth rate (Fig. 9).

2009 and 2014 at the two positions of former ice cover and two debris ridges (Table 1), the apparent growth curve was chosen as the best-fit power-law curve (Fig. 12)

$$y = (7.749 \pm 1.223)\ x^{(0.4745 \pm 0.0445)} \quad (1)$$

where y is lichen size (mm), x is age (yr B.P.), and the uncertainties are standard errors. Equation 1

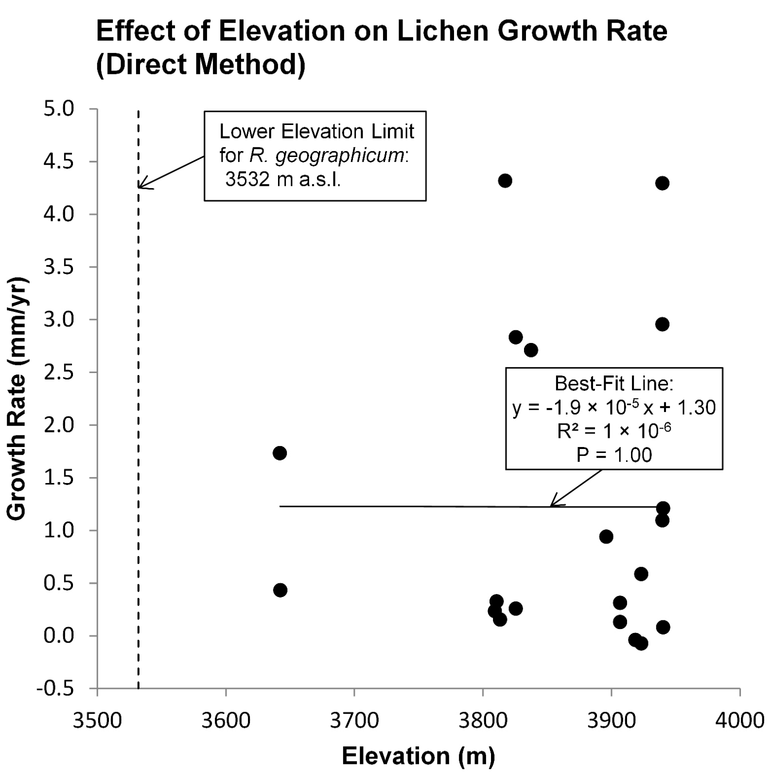

FIGURE 11. The lichen growth rate as measured by the direct method was uncorrelated (P = 1.00) with elevation even though measured lichens were growing only 110–480 m above the lower elevation limit (3532 m a.s.l.) for *R. geographicum*. The lichen at the lower elevation limit was found on Mani Wall #1 (Table 2).

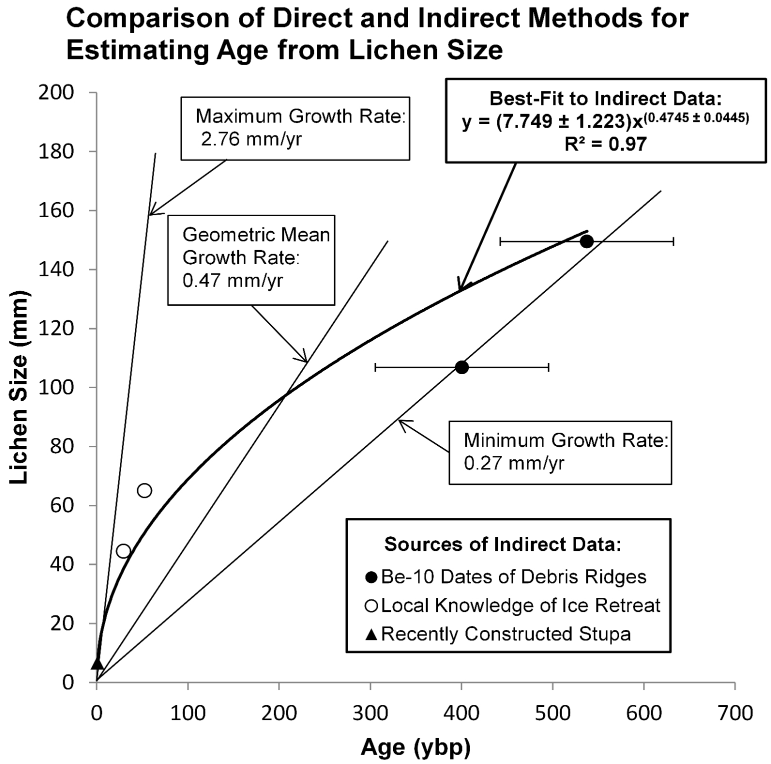

FIGURE 12. Based on five sources of indirect data in the vicinity of Kyanjin Gompa (Fig. 4), the apparent growth curve for *R. geographicum* is $y = (7.749 \pm 1.223)x^{(0.4745 \pm 0.0445)}$, where y is lichen size (mm), x is age (yr B.P.), and uncertainties are one standard error confidence intervals based upon the deviation of measurements from the best-fit power-law curve. The minimum and maximum growth rates based on 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 on 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 yr). Error bars reflect the standard errors of the ^{10}Be dates (Barnard et al., 2006a).

implies an average growth rate of 0.99 mm yr^{-1} (range of ± one standard error = 0.70–1.37 mm yr^{-1}) for the first 50 years and an average growth rate of 0.21 mm yr^{-1} (range of ± one standard error = 0.13–0.34 mm yr^{-1}) for ages between 50 years and 540 years (age of oldest debris ridge as of 2014). Power-law curves are common fits (Innes, 1988) and reflect the general tendency for apparent decreased growth with age. It would be difficult to justify more complex fits in light of the very large uncertainties in ^{10}Be dating for the older lichens (Fig. 12). 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 (equivalent to the confidence interval defined by the arithmetic mean and one standard deviation for a normal distribution). The minimum (0.27 mm yr^{-1}) and maximum (2.76 mm yr^{-1}) growth rates based upon the direct method form an envelope that contains the apparent growth curve based upon the indirect method and are good predictors of the very old ages (>400 yr) and very young ages (<50 yr), respectively (Fig. 12).

Out of the 12 lichens on mani walls that were measured in 2009 and remeasured in 2014, seven increased in size, while five decreased in size (Table 3). Together with the observation that three lichens measured in 2009 had disappeared by 2014, the nearly equal mix of positive and negative growth rates was consistent with partial or complete removal of lichens off the mani walls by the local residents (Appendices B and C). The decreases in size and disappearances of lichens were probably not due to natural mortality because these results were not seen in the lichens that were not found on mani walls. The maximum lichen sizes found on each of the 24 mani walls (21 mani walls measured in 2014 plus the 3 mani walls measured in 2009 that were devoid of lichens in 2014) were uncorrelated with elevation ($P = 0.16$), even though all but two mani walls were found within 97 m of the lower elevation limit for *R. geographicum* (Fig. 13). (It is possible that the lichen at the highest elevation [3873 m a.s.l.] may have received extra cleaning as it was found on Mani Wall #24, which was adjacent to the monastery in Kyanjin Gompa [Table 3, Figs. 4 and 13]). As was found for lichens in remote locations, lichen growth rates on mani walls were

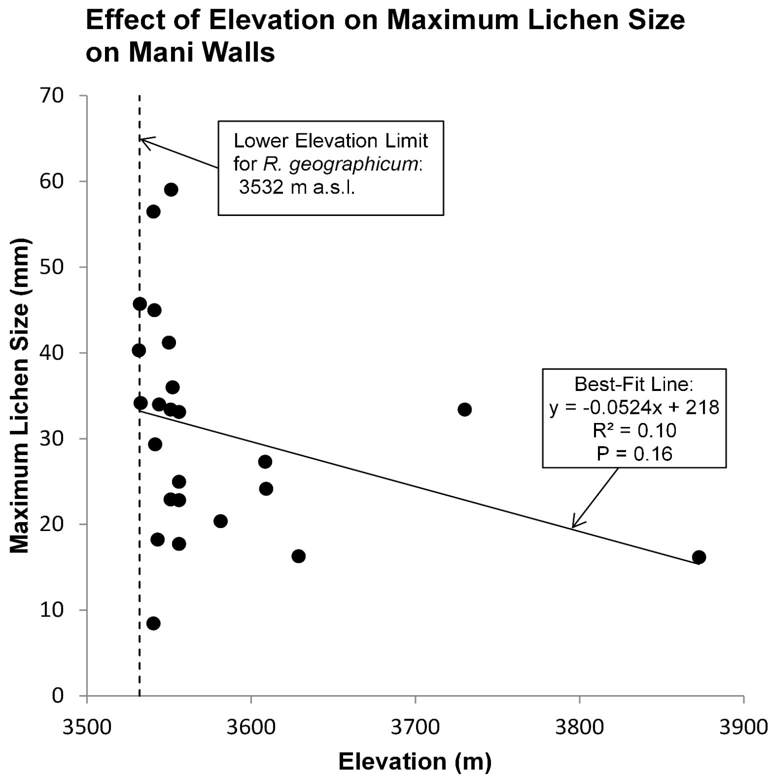

FIGURE 13. The maximum lichen size found on each of 24 mani walls was uncorrelated (P = 0.16) with elevation even though all but two mani walls occurred within 97 m of the lower elevation limit (3532 m a.s.l.) for *R. geographicum*. The maximum lichen sizes include the 21 mani walls measured in 2014 in addition to the three mani walls measured in 2009 that were devoid of lichens in 2014. The lichen at the lower elevation limit was found on Mani Wall #1 (Table 2), while the lichen at the highest elevation (3873 m a.s.l.) was found on Mani Wall #24 adjacent to the monastery in Kyanjin Gompa (Table 2, Fig. 4).

uncorrelated with dip or strike of exposures, elevation above the ground surface, rock substrate, or any combination of measured parameters.

The age (time since last cleaning) of each of the 21 mani walls measured in 2014 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 (Equation 1, Fig. 14). 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 (Fig. 14). The expected mani wall age could be estimated as 13 years (geometric mean) or 21 years (arithmetic mean). However, the geometric mean was preferred, as the distribution of mani wall ages was a better fit to a lognormal (RMSE = 4.5%) than a normal (RMSE = 9.5%) distribution (Fig. 15). The geometric standard deviation range (range between the geometric mean divided by the geometric standard deviation and the geometric mean multiplied by the geometric standard deviation) of mani wall ages was 4–38 years.

Based on the new apparent growth curve of this study, the best estimates for the geologic features dated by Bunds et al. (2010) were adjusted from A.D. 1683 to 1773, from A.D. 1904 to 1912, and from A.D. 1966 to 1959, for Rock Avalanche Deposit A, Rock Avalanche Deposit B, and the Khyimjung Glacier Terminal Moraine, respectively (Table 2, Figs. 2 and 4). The earliest dates were calculated by taking the lower bounds on the coefficients in Equation 1 and the mean lichen size plus one standard error, while the latest dates were calculated by taking the upper bounds on the coefficients and the mean lichen size minus one standard error (Table 2). Uncertainties were due almost entirely to the misfit between the indirect data and the best-fit power-law curve, as uncertainties in dates due to uncertainties in lichen measurements alone were less than two years, even for the oldest dates. Within the range of uncertainties, there was, in fact, no change to the ages estimated by Bunds et al. (2010). Bunds et al. (2010) estimated uncertainties to be ±100 years for older ages (>100 yr B.P.), ±50 years for intermediate ages (~50 yr B.P.), and 20 years for the younger ages (<50 yr B.P.), although these uncertainty ranges were not justified quantitatively. Based on the calculation of this study, the uncertainties are somewhat greater (Table 2). The long-term research program described in Bunds et al. (2010) was to use lichenometry

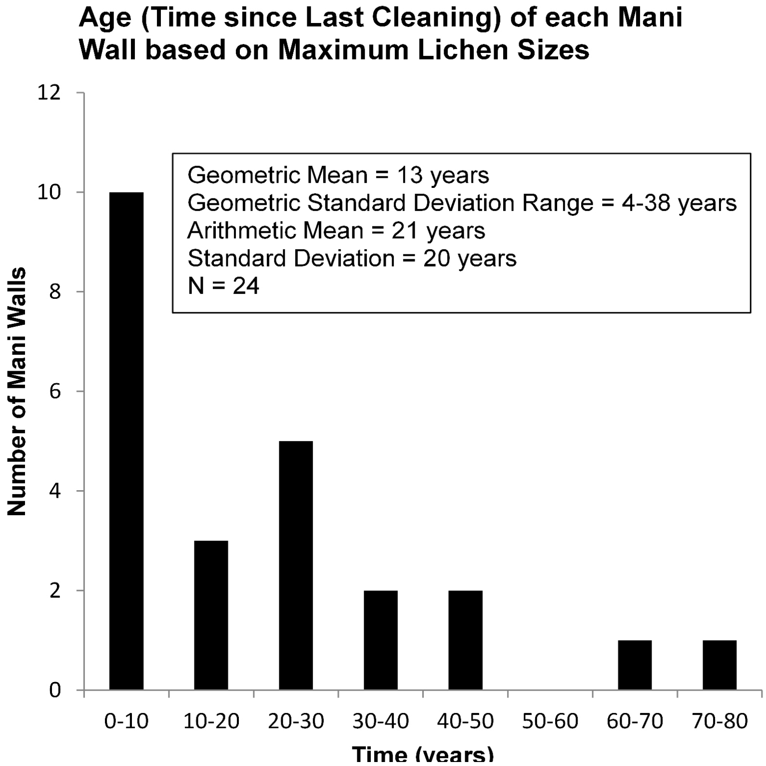

FIGURE 14. The age (time since last cleaning) of each of 21 mani walls was estimated based on the maximum lichen size found on the mani wall in 2014 and the apparent lichen growth curve developed using the indirect method (Fig. 12). The ages of the three mani walls with lichens in 2009 that were devoid of lichens in 2014 were estimated to be 2.5 yr. The expected mani wall age could be estimated as 13 yr (geometric mean) or 21 yr (arithmetic mean). 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.

to determine whether there has been a change in the frequency of GLOF events as a result of climate change and to determine where GLOF events are most frequent in the cycle of glacial advance and retreat. Based on the uncertainties found in this study, it is unlikely that lichenometric dating has sufficient temporal resolution to address the above questions, especially consider-

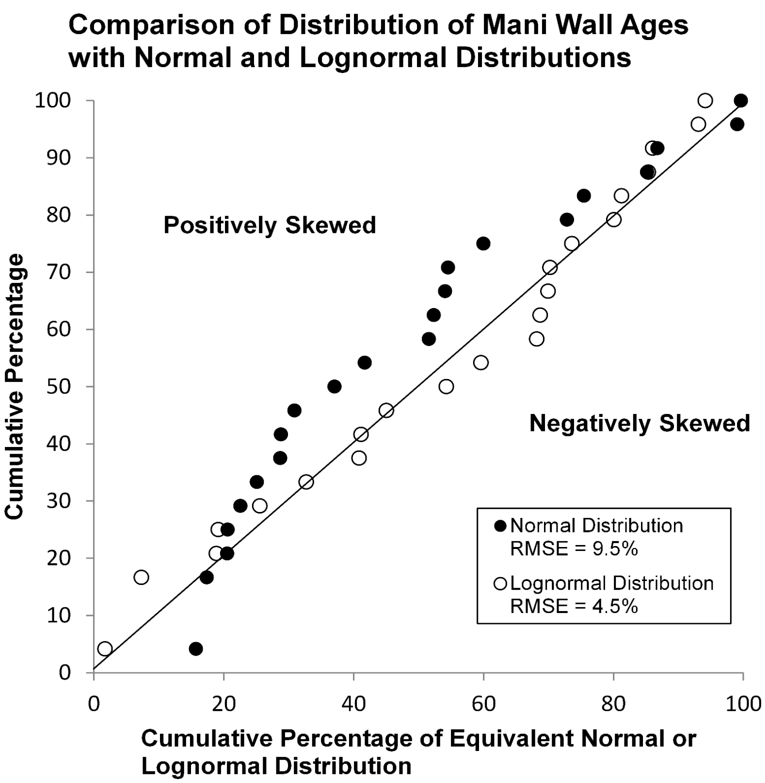

FIGURE 15. The distribution of mani wall ages as estimated from maximum lichen sizes is a much better fit to a lognormal distribution (RMSE [root mean square error] = 4.5%) than a normal distribution (RMSE = 9.5%). On that basis, the geometric mean (13 yr) is a better estimate of the expected mani wall age (Fig. 12).

ing that Watanabe et al. (1998) and Barnard et al. (2006a) used ^{14}C and ^{10}Be ages to date a Yala II Glacial Stage at A.D. 1910 and a Yala I Glacial Stage at 450–550 yr B.P. The uncertainty ranges for the ages of the mani walls were calculated in the same manner as described above (Table 3).

Discussion

History and Interpretation of Mani Walls

The chief result of this study is that it is very likely that the mani walls in Langtang Valley are occasionally thoroughly cleaned to the extent that the crustose lichen *R. geographicum* is removed. The geometric standard deviation range for times since thorough cleaning of 24 mani walls was 4–38 years. The best estimate for the longest time since thorough cleaning of any individual mani wall was 72 years with an upper bound of 168 years (Table 3). The strongest evidence for thorough cleaning as a contemporary practice is that three mani walls on which *R. geographicum* was observed in 2009 were devoid of the lichens five years later. According to two of the informants (Appendices B and C), the mani wall near Ghoratabela is the original mani wall, and, according to one of the informants (Appendix B), that mani wall has never been cleaned. These reports are consistent with the appearance of the mani wall near Ghoratabela (Figs. 4 and 16). In contrast to every other observed mani wall in Langtang Valley, this mani wall is almost entirely covered by mosses and is surrounded by many fallen blocks, which is consistent with several centuries of lack of maintenance (Fig. 16). It should be noted that Ghoratabela is 531 m below the lower limit for *R. geographicum* (3532 m a.s.l.) and is still within the tree line (Fig. 16). According to one of the informants (Appendix E), the oldest mani wall is found in Langtang Village and has also never been cleaned (Fig. 4). Although this mani wall is 87 m below the lower limit for *R. geographicum*, it was devoid of any other crustose lichen and had the same state of repair as all of the other mani walls, aside from the mani wall near Ghoratabela. In summary, the most likely possibilities are that the mani wall near Ghoratabela is the oldest mani wall and has never been cleaned, while all other mani walls are thoroughly cleaned on cycles of no more than several decades. To the best of our knowledge, this is the first use of lichenometry to resolve discrepancies in oral histories.

Based upon the locations of the mani walls, Weidinger (2001a, 2002) proposed that the mani walls were constructed as landslide warnings. It is interesting that, based upon the lichenometric dating of Rock Avalanche Deposit B, the mani wall in front of Rock Avalanche Deposit B (Mani Wall #22, Table 2, Figs. 3 and 4) was certainly constructed before the landslide, which suggests that a correct prediction was made. One of the informants first stated that the original mani wall was constructed to keep tigers and other dangerous animals out of Langtang Valley and later stated that the mani walls just east of Langtang Village (which would include the mani wall in front of Rock Avalanche Deposit B, Figs. 2–4) were constructed to prevent landslides (Appendix C). It is possible that the informant was regarding a landslide as a kind of dangerous animal. This possibility could not be explored further without fluency in the Tamang language.

Comparison of Direct and Indirect Methods

The best estimates for the growth rates determined by the direct method (0.47 mm yr^{-1}) and the indirect method (0.99 mm yr^{-1} for ages <50 yr B.P. and 0.21 mm yr^{-1} for ages 50–540 yr B.P.) are consistent with rates determined by both methods in many other parts of the world (e.g., Armstrong, 1983; Benedict, 1993; Winchester and Chaujar, 2002; Armstrong, 2004; Bradwell and Armstrong, 2007), which have commonly found rates in the range 0.02–2 mm yr^{-1}. For example, Winchester and Chaujar (2002) measured a growth rate for *R. geographicum* of 1.47 mm yr^{-1} from gravestones in North Wales using the direct method, and Armstrong (1983) found many growth rates in the range 1–2 mm yr^{-1} using the direct method in Wales. Previous studies of *R. geographicum* growth rates in the Himalaya, while sparse, are also broadly consistent with our results. Chaujar (2006, 2009) reported growth rates for *R. geographicum* from two locations in the India Himalaya. Chaujar (2006) used measurements on monuments that date from 1863 to 1949 in four towns in Himachal Pradesh (In-

FIGURE 16. The lowest mani wall (3001 m a.s.l.) in Langtang Valley is found near Ghoratabela (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. Note that this mani wall occurs far below the lower elevation limit for R. geographicum (3523 m a.s.l.).

FIGURE 17. Roofless stone huts (called kharkas) are common between Shin Gompa and Phedi, especially in the vicinity of Gosaikund (Fig. 3). Many of the stones are cut, although they lack the elaborate carvings found on the mani walls between Ghoratabela and Kyanjin Gompa (Fig. 4). Although the roofless stone huts are rebuilt annually, there is probably a foundation that is rarely rebuilt.

dia Himalaya) at elevations ranging from 1980 to 2360 m a.s.l. to find diametrical growth rates of 0.54–0.79 mm yr^{-1} and colonization delays of 24–86 years. Chaujar (2009) used the direct method in the Garhwal Himalaya (India) to find a growth rate of 1.0 mm yr^{-1} on moraine boulders at elevations ranging from 3160 to 3640 m a.s.l. Chaujar (2009) used the absence of any lichens on an 85-year-old bridge at Kedarnath Temple in the same region to argue that the colonization delay for *R. geographicum* is at least 85 years. While growth rates determined in this study are similar to those of Chaujar (2006, 2009), no evidence for a colonization delay was found. Moreover, there are other lichenometric studies in which no colonization delay was assumed or inferred from data. For example, in a study on the Tibetan Plateau, Yang et al. (2008) assumed immediate colonization and determined a *R. geographicum* growth rate of 0.6 mm yr^{-1} based on the size of lichens found on a fan formed by a GLOF event in 1940. Sancho and Pintado (2004) reported on immediate colonization of *R. geographicum* in the maritime Antarctic.

In terms of the other studies that compared the direct and indirect methods, McCarthy (2003) and O'Neal et al. (2013) both found the direct and indirect methods to predict very similar lichenometric ages. On the other hand, the most complete study of the direct method was carried out by Trenbirth and Matthews (2010), who monitored the sizes of 2795 individual lichens at 47 sites over 25 years. They found the mean annual growth rate to range from 0.43 to 0.87 mm yr^{-1} between sites, which they attributed to local habitat differences. At some sites, the interannual variability in annual mean growth rate exceeded 1.0 mm yr^{-1}. At most sites, the annual growth rates for individual lichens ranged widely from zero to >3.0 mm yr^{-1}. For the vast majority of sites and years, Trenbirth and Matthews (2010) found no support for any growth curve more complex than a constant lichen growth rate independent of lichen size. This was inconsistent with an apparent growth curve developed by the indirect method for the same area, which showed growth rates declining with time (equivalent to lichen size), which has been commonly found in many other areas, such as the Colorado Front Range (e.g., Benedict, 1993). Trenbirth and Matthews (2010) suggested five hypotheses to explain the discrepancies between the direct and indirect methods, including competition, recent global warming, post–Little Ice Age climatic warming and glacier retreat, nutrient enrichment, and high death rates.

The results of this study are generally consistent with those of Trenbirth and Matthews (2010), especially with regard to the wide variation in individual lichen growth rates over a relatively small area and the independence of growth rate from lichen size (Fig. 9). The largest growth rate for this study (4.32 mm yr^{-1}, Fig. 9) was larger than what appears in the figures for selected sites in Trenbirth and Matthews (2010), although Trenbirth and Matthews (2010) did not report maximum growth rates at all sites. This study estimated a growth rate of 6.69 mm yr^{-1} for a lichen on a one-year-old stupa (Table 1). This may have been an inherited age, although high apparent growth rates for very young ages are consistent with the power-law fit implied by the indirect data at the four other sites used to develop the apparent growth curve (Fig. 12).

Since the direct and indirect methods imply different growth curves and lichenometric ages, the obvious questions are which method is closer to correct when used by itself and how the two methods might be integrated to yield results closer to correct than would be found by either method used by itself. On first consideration, the indirect method should be closer to correct because it involves a longer time scale and avoids the errors inherent in the possibly anomalous short period over which direct measurements might be made (Benedict, 2009). Moreover, as opposed to the direct method, the process of creating the apparent growth curve (finding the largest lichen at a site of known age) is analogous to the process of using the apparent growth curve (finding the largest lichen at a site of unknown age). The key to integrating the two methods is noting that the minimum growth rate obtained by the direct method (defined as the geometric mean divided by the geometric standard deviation) gives results very close to the indirect method for very old ages (>400 yr), while the maximum growth rate (defined as the geometric mean multiplied by the geometric standard deviation) gives results very similar to the indirect method for very young ages (<50 yr) (Fig. 12). It should be noted that the choice of one geometric standard deviation is fairly arbitrary, and a better fit to the results of the indirect method could be achieved with some multiple of the geometric standard deviation. The choice of the appropriate multiplier that would be applicable over a wide range of data sets could not be addressed with the limited data of this study, but could, perhaps, be addressed using the more extensive database of Trenbirth and Matthews (2010). The hypotheses developed by this study are that the population of large lichens on recently exposed surfaces is dominated by the faster-growing lichens, while the population of large lichens on long-exposed surfaces is dominated by the slower-growing lichens. An alternative formulation of the second hypothesis is that the lichens with the greater lifespan are the slower-growing lichens. We are not aware of any other consideration of the above hypotheses in the literature on lichenometry, although the hypotheses could be tested using the extensive database of Trenbirth and Matthews (2010).

It is important to note that the individual lichens that are slow-growing or fast-growing could not have been identified from measurements over a five-year span. Based on the direct method, the growth rates of the largest lichens found on the two debris ridges dated by ^{10}Be (coincident with the edge of the envelope defined by the minimum growth rate) are 0.23 mm yr^{-1} and 2.83 mm yr^{-1} (Fig. 12, Table 1). The growth rates of the largest lichens found on the two positions of former ice cover (coincident with the edge of the envelope defined by the maximum growth rate) are 0.13 mm yr^{-1} and 4.29 mm yr^{-1} (Fig. 12, Table 1). These short-term growth rates for these individual lichens could be poorly correlated with the long-term growth rates of the same lichens as averaged over the time since exposure of the rock surface. These observations are consistent with the considerable interannual variability observed by Trenbirth and Matthews (2010) and could be further tested using their database. The important point is that sufficient lichens must be measured by the direct method for an adequate statistical estimation of the minimum and maximum growth rates.

Conclusions

This study has used lichenometry to resolve a discrepancy in oral history, namely, it has been shown that the mani walls are occasionally cleaned with sufficient thoroughness to remove the crustose lichen *R. geographicum*, contrary to the claims of some of the local informants that the mani walls are never cleaned. This study has also pointed the way forward to proper use of the direct method in cases where the indirect method is impossible due to a lack of dated surfaces. For example, roofless stone huts (called kharkas) are common between Shin Gompa and Phedi, especially in the vicinity of Gosaikund (Figs. 3 and 17). Although these features are shown on tourist maps (e.g., Gondoni, 2001), we are not aware of any discussion of these curious features in the scholarly literature. Many of the stones are cut, although they lack the elaborate carvings found on the mani walls between Ghoratabela and Kyanjin Gompa (Fig. 4). Although, according to locals, the roofless stone huts are rebuilt annually, there is probably a foundation that is rarely rebuilt. The foundations of these huts could not be dated by the indirect method because an apparent growth curve developed only for Langtang Valley could not be trusted on the other side of Chimisedang Range, which separates Langtang Valley from the Gosaikund area (Figs. 3 and 4), and because we were unable to find any dated surfaces in the Gosaikund area (Appendix F). However, according to the results of this study, the foundations of the huts could be dated using the direct method if sufficient lichens were measured to establish a maximum growth rate. It is our hope that this study will inspire further use of the lichenometric method both in archaeology and in areas for which there is a lack of surfaces of known ages. The ultimate goal of lichenometry must be the development of a model for lichen growth based on microclimatic factors, such as shelter from sun and wind (Denton and Karlen, 1973; Bull et al., 1994; Karlen and Black, 2002), that does not require calibration at each site of interest using either the direct or indirect method.

Acknowledgments

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Appendix

A: Summary of Interview with Dorje Jangba, Owner of Lama Hotel, Langtang Village, 6 June 2009

The mani walls were built 400–500 years ago when Langtang Valley was first inhabited. The writing on the walls says who built the walls and the date of construction. However, the lamas are no longer educated as they used to be and they can no longer read the Tibetan letters. Even so, the writing on the walls does not give an actual date, but may say, for example, "Tiger Year" or "Snake Year" and the lamas no longer know what those expressions mean. There was oral knowledge regarding when the mani walls were built, but that knowledge has been lost. There are Tibetan books in the gompa (monastery) that say how to build a mani wall, but the lamas can no longer read these books. Some of the mani wall blocks do look relatively freshly cut. The newer blocks do not replicate the writing on the original blocks, but simply repeat "Om Mani Padme Hum" over and over.

B: Summary of Interview with Tendon Pasan Lopchan, President of Langtang Buffer Zone Consumer Committee, "Lay Lama" at Kyanjin Gompa, 8 June 2009

The gompa was built 400 years ago. At that time the glacier was alongside the gompa. After the gompa was built, the first mani wall was constructed at Ghoratabela. The rest of the mani walls in Langtang Valley were built in a sequence from Ghoratabela to Kyanjin Gompa and were completed within two years. The original mani wall at Ghoratabela has never been cleaned of lichens. The walls of the gompa have also never been cleaned, either inside or outside. All other mani walls have been cleaned of lichens at various times. In Langtang Village a snow avalanche destroyed the mani walls 40 years ago. The mani walls were repaired by the local people. The blocks were cleaned, but not recut. No mani wall blocks have been cut or recut since the original construction 400 years ago. No lama lives at the gompa now. No lama has lived here for 20 years.

C: Summary of Interview with Dorje Jangba, Owner of Lama Hotel, Langtang Village, 10 June 2009

I am now 58 years old. My son has shown you the spot where I used to play on the glacier 50 years ago. At that place and time the glacier was a thin ribbon of ice at the river bed level. The thin ribbon was more ice than rock. It was not continuous with Khyimjung Glacier. There were isolated blocks of ice along the river valley with meltwater between the blocks. There used to be a lake between Khyimjung Glacier and its end moraine. There was a snow avalanche into the lake and it filled with sediment. Now the lake is gone. I know there is buried ice beneath Kyanjin Gompa because I constructed a building that collapsed due to melting ice.

The original mani wall at Ghoratabela was built to prevent tigers and other dangerous animals from moving up Langtang Valley. The mani walls are cleaned by old people with an iron brush, but not on any regular schedule. Now there are 740 people in Langtang Valley, but 40 years ago there were only 90 people. There is a line of mani walls just east of Langtang Village. This is where Langtang Village used to be. But my grandfather saw the former

Langtang Village destroyed by a snow avalanche followed by a landslide. The lamas ordered the mani walls to be rebuilt to prevent further landslides. Some blocks were recut. Other blocks were just picked up and put back into a mani wall.

D: Summary of Interview with Chhoten Lama, Owner of Hotel View Point, Kyanjin Gompa, 30 May 2011

I am 37 years old and I have lived in Kyanjin Gompa for 9–10 years. Before marriage I lived in Langtang Village. My husband is also from Langtang Village. Right after marriage we built the Hotel View Point.

There are no new mani walls being built now, they are only cleaned. Once a year two or three lamas in Langtang Village write inscriptions on stones and place a fresh stone in each mani wall. The only words on the stones in the mani walls are "Om Mani Padme Hum." I can read those words, but no other words in Tibetan. Ancient people did not clean the mani walls. The cleaning started during my mother's time. Two or three times a year, all of the women, including me, thoroughly clean all of the mani walls, including the corners and tops. The mani walls are cleaned with rubber brushes that are kept in Langtang Village. Six or seven days ago all of the mani walls were cleaned by about 15 women. Men help sometimes. We can't take off the lichens with the rubber brushes, just the dust and plants and grasses.

There is still no lama in the gompa. The lamas live in Langtang Village. They come to the gompa just for worship two or three times a month. There are 11 or 12 lamas in Langtang Village. Each lives in his own house. Some of the lamas have families, while others don't. Both my younger brother (same mother) and an older cousin are lamas living in Langtang Village. They will come here in about five days on the new moon. I have a calendar, but it's a year old. I'll just wait and see when my brother comes. (Author's note: The new moon occurred on 1 June 2011, two days after the interview.)

E: Summary of Interview with Jhandu Lama, Caretaker of the Gompa and Owner of Lovely Guest House, Kyanjin Gompa, 30 May 2011

I am 33 years old. I have been in charge of the gompa for one year. I light the butter lamps on four special days each month. Previously my father was in charge. Two people work in rotation to maintain the gompa. Now it is my turn. We rotate every six months, but it is not so strict. We trade if one is busy. Sometimes we both work together. The two people in the rotation signed a paper in front of everyone, accepting responsibility for everything in the gompa. Local people can borrow objects from the gompa, but they must be returned. The gompa was built by Kyungsang Gurme, the elder son of Minguer Dorje. His other son, Pema Dorje, built the gompa in Langtang Village. The lamas are not coming until July.

The mani walls were built before the gompa, which is 600 years old. The mani walls were here before the people. Nobody knows who built the mani walls. Only foreigners ask about the ages of mani walls. The oldest mani wall in Langtang Valley is in front of Shangri-La Hotel in Langtang Village, next to the longest white flag. There are nine or ten flags surrounding the mani wall, each one is 15 meters tall. I know about the mani wall in Ghoratabela, but it is not the oldest. Sometimes literate people with a holy spirit will carve a new block, but there is no schedule for carving new blocks. Most of the blocks were carved long ago. Many of the blocks say "Om Mani Padme Hum," but there are other words, mostly the names of gods. Sometimes the names of parents are carved. I can read Tibetan and I can read the books in the gompa. Nothing on the mani walls says when the mani walls were constructed. There are just prayers, but they do not give dates of construction. A particular prayer cannot be used to date a mani wall because all of the prayers go back to the time of Buddha. There are no more recent prayers. There was no religion before Buddha.

The mani walls are never cleaned. People take off the mosses, but that is all. There is no regular cleaning day. Anything besides picking off mosses would disturb the writing. Even the mosses are picked very lightly and carefully. Women clean the mani walls with rubber brushes or steel wool (like the steel wool used for cleaning dishes) so that the letters can be seen. A broom that is used to sweep the floor cannot be used to clean mani walls. Only new tools can be used to clean mani walls. They can have no other use and must be fresh and clean. Lichens are not cleaned off the mani walls because they don't bother anybody, but if a lama says to clean off the lichens, the women will clean off the lichens.

The stones for the roof were obtained from a site a 2-½ hour walk away. (Authors' note: *Rhizocarpon geographicum* were clearly visible on the roof, although there was no access to the roof.) These stones can no longer be found. The roof is 600 years old, the same age as the rest of the gompa. Sometimes the stones must be replaced, but they are obtained locally.

F: Summary of Interview with Nawang Palchur, Lama at Shin Gompa, 14 May 2014

There has been no cleaning of the gompa at Shin Gompa for 30–40 years because there has been no need. The gompa is cleaned by painting the statues and is very expensive. There are many chuchisyals (statues with 11 heads and 500 hands) made of cement. Three statues have been stolen. The roof of the gompa used to be wood. I remember only a stone roof. It was replaced by a tin roof 5–7 years ago. Information about the date and building of the gompa is stated on the gompa. (Authors' note: The sign stated only that a particular statue was brought here 70 years ago.) Three gompas were built ten generations ago by Narbhupal Shah. The first gompa, called Dhomche Gompa, is at lower elevation to the north. The gompa is abandoned and its statue is gone. The statue is in a village, where people worship it, but do not come to the gompa. The second gompa, called Thulung Gompa, is at higher elevation to the east. All of the statues have been stolen from Thulung Gompa. Thulung Gompa is often visited by the people from Helambu and is the oldest gompa in this VDC (Village Development Committee). The lama of Thulung Gompa is a colleague of the Dalai Lama and his 25-year-old successor now serves as a lama. Shin Gompa is the third of the three gompas.