The Use of Lichenometry for Assessment of the Destruction and Reconstruction of Buddhist Sacred Walls in Langtang Valley, Nepal Himalaya, Following the 2015 Gorkha Earthquake

Author: Emerman, Steven H.

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The use of lichenometry for assessment of the destruction and reconstruction of Buddhist sacred walls in Langtang Valley, Nepal Himalaya, following the 2015 Gorkha earthquake

Steven H. Emerman

Department of Earth Science, Utah Valley University, Orem, Utah 84058, U.S.A.
Author’s email address: StevenE@uvu.edu

ABSTRACT
Mani walls, Buddhist sacred walls constructed of carved blocks, are common in Langtang Valley, Nepal Himalaya. Fieldwork in 2009–2015 documented all 80 mani walls, including all occurrences of the lichen Rhizocarpon geographicum. According to local informants, the mani walls were constructed 400–600 years ago, and the original mani wall was in the village of Ghoratabela. Based on the indirect method, the oldest lichen on a mani wall dated only to 1942, which, within modeling error, was concurrent with the 1934 earthquake, the last major earthquake in Nepal prior to the Gorkha earthquake of 25 April 2015. In November 2015 it was found that 15% of mani walls could not be located and 20% were severely damaged. The original mani wall had apparently been reconstructed 170 m from its previous location. In two severely damaged and three fully intact mani walls, large lichens (12–49 mm) with unhealthy appearance were found that were not previously present. The most likely explanation was that the three intact mani walls had already been reconstructed using previously interior blocks as exterior blocks. This research raises the possibility that many Himalayan religious structures are not the original structures, but are replicates that are reconstructed after natural disasters.

INTRODUCTION
Mani walls, Buddhist sacred walls constructed of carved blocks with Tibetan letters and elaborate imagery, are common above Ghoratabela in Langtang Valley (Nepal Himalaya), and especially between the site of the former Langtang Village and Kyanjin Gompa (Figs. 1–5). 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 still 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 was 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. 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 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.
Bunds et al. (2010) and Emerman et al. (2016) began a program of lichenometry in Langtang Valley with the objective of dating GLOF (glacial lake outburst flood) deposits. 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 (or other statistical measure) of lichen diameters on surfaces for which age...
The British cemeteries in the Hill Stations of the Indian Himalaya, this approach has not yet been pursued. 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) has 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...
FIGURE 4. The 2015 Gorkha earthquake caused massive landsliding in Langtang Valley, resulting in loss of life and the destruction of villages and cultural artifacts.

FIGURE 5. Out of 80 mapped mani walls in Langtang Valley, 12 (15%) were completely destroyed and 16 (20%) were severely damaged. The remainder suffered no apparent damage, although there was evidence that at least four had been rebuilt.
that has been carried out anywhere in the Bhutan, Nepal, or Pakistan Himalaya aside from Ibetsberger (2005), Bunds et al. (2010), Carlson et al. (2012), and Emerman et al. (2016). 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 Miehe (1990) and 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. 2) 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 and for a stupa (sacred monument) in the vicinity of Kyanjin Gompa (Figs. 4–5). In the same vicinity, Barnard et al. (2006) had carried out [10Be dating of two debris ridges. The maximum diameters of R. geographicum were measured on boulders at the four geologic sites and on the carved blocks of the foundation of the stupa in 2009 and 2014, and were used to construct an apparent lichen growth curve for use by the indirect method of lichenometry (Bunds et al., 2010; Emerman et al., 2016). In addition, lichen diameters measured on 20 boulders in 2009 and 2014 were used to compare the results of the direct and indirect methods (Emerman et al., 2016). An earlier version of the apparent growth curve that did not include the stupa was used by Carlson et al. (2012) to date terrace evolution and incision rates along the uppermost Langtang River.

Since the mani walls could not be dated by their inscriptions and since an apparent lichen growth curve was developed from other geologic and cultural features of known age, the objective of the research program 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. Fieldwork in 2009, 2011, and 2014 involved mapping and photographing all mani walls in Langtang Valley, measuring and photographing all occurrences of the lichen R. geographicum on the mani walls, and interviewing local informants regarding the history and traditions of the 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.
- The mani walls were constructed 400–600 years ago when Langtang Valley was first settled.
- The mani wall near Ghoratabela at the mouth of the glacial valley (Figs. 4–5) has never been cleaned, although there was disagreement as to whether this was the original mani wall.
- The mani walls were originally constructed to keep dangerous animals out of the valley and, when they are destroyed by landslides, they are re-constructed to prevent further landslides.

However, there was considerable disagreement as to whether the mani wall blocks have ever been re-cut 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 (Emerman et al., 2016). 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.

Using the apparent growth curve, Emerman et al. (2016) found the geometric mean age (time since last cleaning) of the mani walls to be 13 years with geometric standard deviation range of 4–38 years. The best estimate for the earliest date of thorough cleaning of any individual mani wall was 1942. Out of the 12 lichens on mani walls that were measured in 2009 and re-measured in 2014, five had decreased in size. Moreover, three lichens measured in 2009 had disappeared by 2014. Based on the above results, Emerman et al. (2016) concluded 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. Further evidence for cleaning of the mani walls was the appearance of the mani wall near Ghoratabela (Figs. 4–5), which the majority of informants called the original mani wall, which was never cleaned. In contrast to every other observed mani wall in Langtang Valley, this mani wall was almost entirely covered by mosses and surrounded by many fallen blocks, which is consistent with several centuries of lack of maintenance (Emerman et al., 2016). To the best knowledge of the author, the study of Emerman et al. (2016) was the first use of lichenometry to resolve discrepancies in oral histories.

The discrepancies could be further investigated by comparing lichen sizes (reflecting time since last cleaning) with relative amounts of rock weathering (reflecting time since last cutting). However, any investigation of sacred objects would need to be carried out in a non-destructive manner.

On 25 April 2015, Nepal was struck by an earthquake of moment magnitude 7.8 with epicenter 21 km
The death toll of ~9000 was accompanied by massive destruction of the temples, monuments, and other religious and cultural heritage of Kathmandu Valley (Hossain et al., 2015). An icefall-debris avalanche triggered by the Gorkha earthquake completely buried Langtang Village, killing at least 350 people (Figs. 4–5; Fukuoka and Bhandary, 2015; Miehe and Weidinger, 2015; Lacroix, 2016). The avalanche accumulated $6.95 \times 10^6$ m$^3$ of deposits in the valley with thicknesses up to 60 m, and an additional $9.66 \times 10^6$ m$^3$ on the glaciated slopes above 5000 m a.s.l. (Lacroix, 2016). On 12 May 2015, Nepal was struck by another earthquake of moment magnitude 7.3 with epicenter 21 km SW of Kodari (Fig. 4; Collins and Jibson, 2015; Kargel et al., 2015). The second earthquake caused 157 fatalities in Nepal, India, and Tibet, but only relatively minor additional landsliding in Langtang Valley (Hossain et al., 2015; Kargel et al., 2015).

After learning of the tragedy in Langtang Valley, it occurred to the author that the date of the earliest mani wall was, within modeling error, concurrent with the 1934 earthquake, the last major earthquake (moment magnitude = 8.0) to strike Nepal prior to the 2015 Gorkha earthquake (Hossain et al., 2015). The error in lichen ages was almost entirely due to the misfit of the five data points to a power-law curve, as opposed to the error in measuring individual lichens [Emerman et al., 2016].] The concurrence of dates led to the following questions:

1. Are Himalayan religious structures actually the original structures or are they replicates that are reconstructed after natural disasters?
2. Could Himalayan religious structures be used to date natural disasters?

The latter question is related to the new field of archaeoseismology, in which damage to archaeological sites is being used to date earthquakes, thus far, mostly in the Mediterranean and Near East (Sintubin et al., 2009; Niemi et al., 2013).

The objective of this study was to repeat all fieldwork in Langtang Valley, including mapping and photographing mani walls, measuring the lichens on mani walls, and interviewing the local residents, in order to assess the destruction and possible reconstruction of the mani walls following the 2015 Gorkha earthquake. In contrast to the previous paper that reported on only the mani walls that hosted lichens (Emerman et al., 2016), this paper reports on all mani walls in Langtang Valley and, thus, is the first systematic compilation of mani walls for any part of the Himalaya. This study has built upon the impressive body of work carried out on the geomorphology and hydrology of the Langtang Valley since the 1980s, including, in addition to previously cited work, 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), Takagi et al. (2007), Owen et al. (2008), Kemp et al. (2012), Nuimura et al. (2012), Miles et al. (2016), and Wilson et al. (2016).

**Materials and Methods**

All post-earthquake fieldwork was carried out from 18 to 25 November 2015, almost exactly six months after the earthquake. All field measurements were made without reference to previous notes to avoid any biasing of measurements or documentation. Additional interviews with local residents did not follow a fixed set of questions, but concerned the history and traditions of the mani walls, the maintenance and cleaning of the mani walls, the damage caused by the 2015 earthquake, and any previous damage to the mani walls (Appendices A–F). With the exception of the last interview, which was carried out in English (Appendix F), all interviews were conducted in Tibetan, and were translated by Lhakpa Tsering Sherpa, who was fluent in both English and Tibetan. The Tibetan writing on the mani walls could not be read by any of the informants, the author, or the translator.

Damage to mani walls was assessed in the four categories (1) none, (2) slight, (3) severe, and (4) destroyed. No damage meant that no blocks were apparently out of place. Slight damage meant that one or more blocks had slipped out of place, but it was fairly obvious how to reconstruct the mani wall. Severe damage meant that so many blocks had fallen that it was not clear to a layman how to reconstruct the mani wall (Figs. 6–7). A mani wall was classified as destroyed if it could not be located at all. The location of each mani wall was measured in the middle of the mani wall using the Garmin eTrex 10 GPS Receiver. There are minor discrepancies with the locations reported by Emerman et al. (2016) since those studies reported the location at the position of the largest lichen on each mani wall.

This study followed the same lichen measurement procedures as Emerman et al. (2016). 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.
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). (Since no other lichens were studied, *R. geographicum* and “lichen” are used interchangeably throughout the remainder of this paper.)

Care was taken to measure thalli only 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 sufficient evidence that the large thallus may be composite and such thalli were not measured. The single lichen with the largest diametrical axis (including the hypothallus) on each mani wall was measured six times with a digital calipers with graduation of 0.01 mm. The major source of measurement error was 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 ±0.16 mm. As in previous fieldwork, all occurrences of *R. geographicum* on mani walls were photographed, although only the largest lichen was measured.

**RESULTS**

Additional interviews did not change the four areas of general agreement among the informants that were listed in the Introduction (Appendices A–F). However, one of the informants (Appendix F) said that the structure at Ghoratabela (Figs. 4–5) that was referred to as the original mani wall by other informants was not a mani wall at all, but a chorten (a word used to describe conical-shaped sacred monuments in this region). Based on appearance, the word choice of the informant (Appendix F) seems reasonable by comparing other structures that other informants described as chortens (Fig. 8, parts a and b), the structures that informants described as mani walls (Fig. 1), and the structures that other informants described as the original mani wall (Fig. 9, parts a and b). On the other hand, the structure at Ghoratabela had been described as the original mani wall by the lay lama at the monastery in Kyanjin Gompa in addition to other informants (Emerman et al., 2016). The distinction is not simply a matter of vocabulary, but a question as to whether the structure at Ghoratabela serves as an
artistic ancestor to the other mani walls. For completeness and because there was disagreement, the structure at Ghoratabela is included in the list of mani walls (mani walls nos. 4–5 in Table 1a; see further discussion below).

On the other hand, additional interviews showed the same disagreement as in previous fieldwork (Emerman et al., 2016) regarding whether the mani wall blocks have ever been re-cut and whether, when, and how the mani walls are cleaned, especially as to whether they are cleaned with an iron brush that would remove crustose lichens (Appendices A–F). The range of disagreement in this study was even greater since one of the informants (Appendix B) stated that the original mani wall at Ghoratabela had been cleaned in the past with a brush and chisel, and that even the lichens had been cleaned off. There was also a range of disagreement as to whether the mani walls had ever been damaged or repaired in the past. The oldest informant would have been born in 1935 (Appendix C), so that no informants would have had a personal memory of the 1934 earthquake (but see discussion of memories from ancestors in the Discussion).

Out of the 80 mani walls in Langtang Valley, it was found that 12 mani walls (15%) were completely destroyed and 16 mani walls (20%) were severely damaged (Figs. 5–7, Tables 1a–1f). It is certain that the damage was caused by the Gorkha earthquake and the resulting landslide and airblast (Kargel et al., 2015), since...
no damaged mani walls were seen during any previous fieldwork. The 12 destroyed mani walls included the five mani walls that had previously been present in Langtang Village and which were completely buried by the landslide (mani wall nos. 9–13, Table 1a). At the sites of the remaining seven destroyed by landslides, nothing could be seen that resembled a mani wall. However, at each of three sites of former mani walls (mani wall nos. 67, 76, and 77, Table 1d), a chorten was found that was topped by what was apparently a broken, carved block of a former mani wall (Fig. 8, parts a and b). This combination of a chorten topped by a mani wall block had never been seen by the author before anywhere in the Nepal Himalaya and could be regarded as a form of post-disaster religious art. It is important to note that there were no cases of slightly damaged mani walls and no transition zones between areas of undamaged and either severely damaged or destroyed mani walls (Fig. 5). It is most likely that the mani walls had already been repaired in cases where it was obvious how to put the blocks back into place.

The original mani wall in Ghoratabela could not be found among the scattered boulders and fallen trees at the location where it had been previously mapped (mani wall no. 4 in Table 1a, Figs. 5, 9, part a). However, a similar structure that had not existed prior to the 2015 Gorkha earthquake was found 170 m to the northeast of the previous original mani wall and closer to the trail that passes through Ghoratabela (mani wall no. 5 in Table 1a, Figs. 9, part b, and 10). The structure shown in Figure 9, part b, could be regarded as a post-earthquake memorial structure similar to the chortens shown in Figure 8, parts a and b. However, the structure shown in Figure 9, part b, was repeatedly referred to as the original mani wall by one of the informants (Appendix B) during an interview that took place within site of the structure. The most likely interpretation is that the original mani wall had been rebuilt in a more convenient location. The easiest mani wall to replicate would be a mani wall that looked as if it had received no maintenance for several centuries (Fig. 9, parts a and b), as opposed to replicating the intricate design of the maintained mani walls (Fig. 1). Note that the list of 80 mani walls counts the two original mani walls as separate mani walls (mani wall nos. 4–5 in Table 1a).

All 80 mani walls were placed into six categories depending upon the nature of the occurrence of R. geographicum on the mani walls:

1. No R. geographicum was seen during any fieldwork (Table 1a).
2. Growth of the largest R. geographicum took place over the 18 months from 2014 to 2015 (Table 1b).
3. The size of the largest R. geographicum decreased over the 18 months from 2014 to 2015 (Table 1c).
4. R. geographicum was present in 2014, but was missing in 2015 (Table 1d).
5. R. geographicum was present in 2009, but was missing in both 2014 and 2015 (Table 1e).
6. The largest R. geographicum in 2015 was not present in any previous fieldwork (Table 1f).

The six tables have a common numbering system that numbers all mani walls from west to east. Note that this differs from the numbering system of Emerman et al. (2016), which included only mani walls with R. geographicum.

In all cases in which there was either an increase or decrease in the size of the largest R. geographicum between 2014 and 2015 (Tables 1b and 1c), comparison of photographs verified that the same lichen was measured in both years. The geometric mean growth rate of 0.64 (0.34–1.21) mm yr\(^{-1}\) (Table 1b) was similar to the geometric mean growth rate of 0.47 (0.27–2.76) mm yr\(^{-1}\) that was obtained by Emerman et al. (2016) using the direct method. (The lower and upper range is the geometric mean divided by and multiplied by the geometric standard deviation, respectively. The use of geometric means was justified in Emerman et al. [2016].) There were four mani walls on which the largest lichen decreased in size during the 18-month period from 2014 to 2015, three on undamaged mani walls, and one on a severely damaged mani wall (Table 1c). By comparison, during the five-year period from 2009 to 2014, lichens decreased in size on five mani walls (Emerman et al., 2016). A decrease in size of an individual lichen is mostly likely due to cleaning with an iron brush without a commitment to completely remove a crustose lichen during each cleaning episode (Emerman et al., 2016). In that case, there seems to have been extra attention paid to the partial scrubbing of crustose lichens during the post-earthquake period. The geometric mean removal rate per lichen was 1.88 (0.48–7.36) mm yr\(^{-1}\) from 2014 to 2015, which was comparable to the geometric mean removal rate per lichen of 0.99 (0.35–2.80) mm yr\(^{-1}\) from 2009 to 2014.

There were eight mani walls on which R. geographicum was present in 2014, but on which R. geographicum could not be found in 2015 (Fig. 6, Table 1d). Four of these cases are probably irrelevant as the mani walls themselves could not be located (Table 1d). Two of the mani walls were severely damaged so that the block that hosted the lichen was most likely buried by other blocks, leaving two undamaged walls on which formerly present R. geographicum was no longer present (Table 1d). By contrast, three mani walls had the crustose lichen completely removed between 2009 and 2014 (Emerman et al., 2016), which again suggests extra attention to the cleaning of mani
TABLE 1a

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TABLE 1a
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<th>No.</th>
<th>Latitude (°N)</th>
<th>Longitude (°E)</th>
<th>Elevation (m a.s.l.)</th>
<th>Damage</th>
</tr>
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<tbody>
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</tr>
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<td>85.52518</td>
<td>3557</td>
<td>severe</td>
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<td>69</td>
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<td>3557</td>
<td>severe</td>
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<td>28.21250</td>
<td>85.53255</td>
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<td>none</td>
</tr>
</tbody>
</table>

1Mani walls are numbered consecutively from west to east.
2Latitude and longitude are based on WGS 84 coordinate system.
3Damage was classified as “severe” if it was not obvious how to reassemble the mani wall blocks and “destroyed” if the mani wall could not be located. There were no mani walls with fallen blocks, but for which it was obvious how to reassemble the blocks.

TABLE 1b

<table>
<thead>
<tr>
<th>No.</th>
<th>Latitude (°N)</th>
<th>Longitude (°E)</th>
<th>Elevation (m a.s.l.)</th>
<th>Damage</th>
<th>Maximum lichen size (mm)</th>
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<tr>
<td>18</td>
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<td>34.13 – 34.55</td>
</tr>
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<td>18.22 – 22.92</td>
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<td>3531</td>
<td>none</td>
<td>45.69 – 45.88</td>
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<td>50</td>
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<td>3543</td>
<td>severe</td>
<td>29.33 – 30.47</td>
</tr>
<tr>
<td>51</td>
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<td>85.51941</td>
<td>3541</td>
<td>severe</td>
<td>8.45 – 10.14</td>
</tr>
<tr>
<td>63</td>
<td>28.21577</td>
<td>85.52177</td>
<td>3552</td>
<td>severe</td>
<td>59.02 – 60.15</td>
</tr>
<tr>
<td>80</td>
<td>28.21370</td>
<td>85.56554</td>
<td>3871</td>
<td>none</td>
<td>16.17 – 17.40</td>
</tr>
</tbody>
</table>

Arithmetic mean growth rate (mm yr⁻¹): 0.94 ± 0.94
Geometric mean growth rate (mm yr⁻¹): 0.64 (0.34–1.21)

1Mani walls are numbered consecutively from west to east.
2Latitude and longitude are based on WGS 84 coordinate system.
3Damage was classified as “severe” if it was not obvious how to reassemble the mani wall blocks and “destroyed” if the mani wall could not be located. There were no mani walls with fallen blocks, but for which it was obvious how to reassemble the blocks.
4The same lichen was measured in both years.
5Annual growth rates are calculated based on 18 months between 2014 and 2015 observations.
6Arithmetic mean ± one standard deviation.
7Lower and upper ranges are geometric mean divided by and multiplied by geometric standard deviation, respectively.

TABLE 1c

<table>
<thead>
<tr>
<th>No.</th>
<th>Latitude (°N)</th>
<th>Longitude (°E)</th>
<th>Elevation (m a.s.l.)</th>
<th>Damage</th>
<th>Maximum lichen size (mm)</th>
</tr>
</thead>
<tbody>
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<td>46</td>
<td>28.21545</td>
<td>85.51846</td>
<td>3541</td>
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<td>44.97 – 36.90</td>
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<tr>
<td>47</td>
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<td>85.51847</td>
<td>3541</td>
<td>none</td>
<td>56.46 – 39.27</td>
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</tbody>
</table>

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### TABLE 1c
Continued

<table>
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<th>No.</th>
<th>Latitude (°N)</th>
<th>Longitude (°E)</th>
<th>Elevation (m a.s.l.)</th>
<th>Damage</th>
<th>Max. lichen size 2014</th>
<th>Max. lichen size 2015</th>
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</thead>
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<td>28.21555</td>
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<td>severe</td>
<td>33.99</td>
<td>33.83</td>
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<tr>
<td>79</td>
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<td>85.55436</td>
<td>3730</td>
<td>none</td>
<td>33.37</td>
<td>30.54</td>
</tr>
</tbody>
</table>

1. Mani walls are numbered consecutively from west to east.
2. Latitude and longitude are based on WGS 84 coordinate system.
3. Damage was classified as “severe” if it was not obvious how to reassemble the mani wall blocks and “destroyed” if the mani wall could not be located. There were no mani walls with fallen blocks, but for which it was obvious how to reassemble the blocks.
4. Annual removal rates are calculated based on 18 months between 2014 and 2015 observations.
5. Arithmetic mean ± one standard deviation.
6. Lower and upper ranges are geometric mean divided by and multiplied by geometric standard deviation, respectively.

### TABLE 1d

<table>
<thead>
<tr>
<th>No.</th>
<th>Latitude (°N)</th>
<th>Longitude (°E)</th>
<th>Elevation (m a.s.l.)</th>
<th>Damage</th>
<th>Max. lichen size 2014 (mm)</th>
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<td>60</td>
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</tr>
<tr>
<td>67</td>
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<td>85.52544</td>
<td>3556</td>
<td>destroyed</td>
<td>33.11</td>
</tr>
<tr>
<td>74</td>
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<td>76</td>
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<td>16.27</td>
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</table>

1. Mani walls are numbered consecutively from west to east.
2. Latitude and longitude are based on WGS 84 coordinate system.
3. Damage was classified as “severe” if it was not obvious how to reassemble the mani wall blocks and “destroyed” if the mani wall could not be located. There were no mani walls with fallen blocks, but for which it was obvious how to reassemble the blocks.

### TABLE 1e

<table>
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<tr>
<th>No.</th>
<th>Latitude (°N)</th>
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<th>Damage</th>
<th>Max. lichen size 2009 (mm)</th>
</tr>
</thead>
<tbody>
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</tr>
<tr>
<td>66</td>
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<td>3557</td>
<td>destroyed</td>
<td>17.72</td>
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<tr>
<td>68</td>
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<td>85.52557</td>
<td>3556</td>
<td>severe</td>
<td>24.97</td>
</tr>
</tbody>
</table>

1. Mani walls are numbered consecutively from west to east.
2. Latitude and longitude are based on WGS 84 coordinate system.
3. Damage was classified as “severe” if it was not obvious how to reassemble the mani wall blocks and “destroyed” if the mani wall could not be located. There were no mani walls with fallen blocks, but for which it was obvious how to reassemble the blocks.
TABLE 1f

<table>
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<th>No.</th>
<th>Latitude (°N)</th>
<th>Longitude (°E)</th>
<th>Elevation (m a.s.l.)</th>
<th>Damage</th>
<th>2014</th>
<th>2015</th>
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<td>severe</td>
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<td>11.59</td>
</tr>
<tr>
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<td>37.80</td>
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<tr>
<td>64</td>
<td>28.21540</td>
<td>85.52357</td>
<td>3556</td>
<td>severe</td>
<td>22.82</td>
<td>49.05</td>
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</tbody>
</table>

1Mani walls are numbered consecutively from west to east.
2Latitude and longitude are based on WGS 84 coordinate system.
3Damage was classified as "severe" if it was not obvious how to reassemble the mani wall blocks and "destroyed" if the mani wall could not be located. There were no mani walls with fallen blocks, but for which it was obvious how to reassemble the blocks.
4The lichen measured in 2015 was not present in an exterior block in 2009 or 2014.

walls during the post-earthquake period. Of those three mani walls, which still had no lichens in 2015, two were destroyed and one was severely damaged (Table 1e).

The most challenging observation is the existence of five mani walls on which the largest *R. geographicum* in 2015 was not even present during any previous fieldwork (Table 1f, Figs. 7, 11–13). In one case, there was a lichen present in 2014, but it was much smaller (22.82 mm) than the lichen present in 2015 (49.05 mm) and, by a comparison of photographs, was not the same lichen (mani wall no. 64 in Table 1f, Fig. 7). In the other four cases, no lichens at all were present in 2014, and even the smallest previously unseen lichen was too large (11.59 mm) to have colonized the mani wall and grown to its measured size over an 18-month period. Two of the mani walls were severely damaged, but the other three appeared to have suffered no damage at all (Table 1f, Figs. 7, 11–13). The challenging question is: Where did these previously unseen lichens and the mani wall blocks that hosted them come from? In previous fieldwork, no mani wall blocks were seen that were not part of a mani wall and there were no suggestions from any of the informants that any unattached mani wall blocks existed. Moreover, any freshly carved mani wall block would have hosted lichens no larger than a few millimeters.

The only plausible explanation for the post-earthquake appearance of previously unseen lichens is that mani wall blocks that were formerly interior blocks were present on the exterior. All of the previously unseen lichens were heavily bleached with a strong color contrast from white to pale yellow (Fig. 14), as opposed to the bright yellowish-green of healthy *R. geographicum* (Purvis et al., 1992; St. Clair, 1999). These lichen colors were consistent with a previous history as an interior block, where only diffuse light with a strong spatial heterogeneity of light intensity would be present. (Note the open spaces that would allow some light penetration in the apparently undamaged mani walls [Figs. 1, 11–13].) These previously interior blocks were present on the exterior either because the mani wall had been severely damaged (mani wall nos. 48 and 64 in Table 1f, Fig. 7) or because the mani walls had been severely damaged and then rebuilt in a way that was not an exact replication of the previous design (mani walls nos. 44 and 53–54 in Table 1f, Figs. 11–13). The three apparently reconstructed mani walls were all within 195 m of one another in the village of Mundu (note the houses in the background of Figs. 11 and 13). At the time of the fieldwork, aside from yak herders living in temporary dwellings above Ghorataabela (Appendix B), Mundu was the only inhabited village in Langtang Valley between Rimche and Kyanjin Gompa (Fig. 5), as all other villages were heavily damaged and still abandoned. It seems reasonable that an inhabited village would be one of the first places where mani walls would be reconstructed.

**Discussion**

There are five lines of evidence that, within six months of the 2015 Gorkha earthquake, at least four mani walls had been reconstructed in a manner similar to, but not identical to, the original designs:

1. The structure that had been called the original mani wall by pre-earthquake informants could no longer be located. After the earthquake, a structure with a similar, but not identical, appearance was found 170 m from the previous original mani wall and was referred to as the original mani wall by post-earthquake informants.
Three apparently undamaged mani walls in a single inhabited village were hosting previously unseen *R. geographicum* individuals. The exterior blocks that hosted these lichens must have previously been interior blocks, which was consistent with the bleached appearance of the lichens.

There were no slightly damaged mani walls and no transition zones between areas of undamaged mani walls and either severely damaged or destroyed mani walls.

Two apparently undamaged mani walls had no *R. geographicum*, although lichens had been seen on these walls before the earthquake 18 months previously. This rate of cleaning contrasted with pre-earthquake fieldwork that showed that lichens were completely removed from mani walls at the rate of three mani walls every five years.

Four mani walls showed a decrease in the size of the largest lichen over the previous 18 months. This rate of cleaning contrasted with pre-earthquake fieldwork that showed that the lichens were partially cleaned from mani walls at the rate of five mani walls every five years.
The last two observations would not constitute evidence for reconstruction by themselves, but they help to support a pattern of extra attention paid to the mani walls after the earthquake. It should be emphasized that the count of four reconstructed mani walls is an absolute minimum. Any apparently undamaged mani wall could have been reconstructed with no evidence as long as there were no previously unseen lichens and the mani walls had been reconstructed in a manner indistinguishable from the previous design, for a total of 47 possible reconstructed mani walls.

There are three lines of evidence that reconstruction of mani walls may have occurred after the previous major earthquake in 1934.

(1) No damaged mani walls were seen in any pre-earthquake fieldwork during 2009–2014, nor in visits to Langtang Valley in 2001 and 2003, which did not involve systematic documentation of mani walls.

(2) The earliest date of colonization of lichen on a mani wall was, within modeling error, concurrent with the 1934 earthquake (mani wall no. 63 in Table 1b).

(3) An informant from a previous study (Appendix C in Emerman et al., 2016) stated that the line of mani walls just east of the former site of Langtang Village (probably the line of mani walls beginning with mani wall no. 18 [Table 1b] and proceeding to the east) is where an even older Langtang Village used to be. The informant’s grandfather saw the earlier Langtang Village destroyed by a snow avalanche followed by a landslide. Since the informant was 58 years old in 2009, it is reasonable that his grandfather, but not his father, could have had a personal memory of the events surrounding the 1934 earthquake.

It is now appropriate to reconsider the hypotheses mentioned previously, namely, the hypothesis of Weidinger (2001a, 2002) that the mani walls were constructed as landslide warnings, and the hypotheses of this study that many Himalayan religious structures are not the original structures, but are replicates that are reconstructed after natural disasters, and that Himalayan religious structures could be used to date natural disasters. The locations of mani walls are not necessarily the sites of actual landslide danger, but are the sites of the local perception of landslide danger at the time of construction. Both the reality and the perception of landslide danger could change with time due to, for example, glacial retreat. On that basis, a fascinating exercise would be comparing a mani wall map (Fig. 5) with the various models regarding the evolving geomorphology of Langtang Valley over the past few centuries (Ono, 1985, 1986; Shiraiwa et al., 1990; Shiraiwa and Watanabe, 1991; Bäumler et al., 1996, 1997; Heuberger and Ibetsberger, 1998; Ibetsberger and Weidinger, 2004; Ibetsberger, 2005; Barnard et al., 2006; Bunds et al., 2010).
The hypothesis that many Himalayan religious structures are reconstructions has been strengthened and may be helpful in the emerging field of scientific study of ancient Himalayan religious structures (Bhatnagar and Singh, 2003). Moreover, the hypothesis may lead to a new context and set of questions for Himalayan oral history. For example, according to recent fieldwork in the Solo Khumbu District of Nepal Himalaya, many informants stated that the mani walls were only 40–50 years old, which were much younger than the ages reported in Langtang Valley (Goldsberry et al., 2016). The last hypothesis that Himalayan religious structures could be used to date natural disasters is probably not yet realistic until there is an improvement in the precision of lichenometry or some other method. For the same reason, the use of lichenometry for relating the GLOF and glacial cycles in Langtang Valley has not yet been successful (Bunds et al., 2010; Emerman et al., 2016).

Conclusions

This study has used lichenometry, as well as location and photographic records, to show that at least four mani walls in Langtang Valley, Nepal Himalaya, had been reconstructed within six months of a major earthquake and landslide that completely destroyed 15% of the mani walls and severely damaged another 20%. These reconstructed mani walls included the original mani wall at Ghoratabela and three mani walls in the inhabited village of Mundu. The reconstructed mani walls did not follow exactly the same design as the previous mani walls and, in the case of the original mani wall, the reconstructed mani wall was not in the same location. In terms of understanding the cultural and geological significance of the mani walls, it would be very worthwhile to document the continued reconstruction of the mani walls through time. However, regardless of what happens in the future, it is important to note that, with all of the pressing needs in the months following the tragedy of 25 April 2015, and the preparations for the winter of 2015–2016, the residents of Langtang Valley did not delay in the reconstruction of the religious and cultural heritage of the valley.

Acknowledgments

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APPENDIX


We are both 39 years old. We have lived here for 35 years. We migrated to Sherpagaon from a lower village. There are only two mani walls in Sherpagaon. We don’t know how old the mani walls are. No one has carved a new block since we have lived here. No one even knows how to carve the blocks. If a block falls and cracks, then the people just put it on top of the wall. If the block does not crack, then it is put back where it was. The villagers take off the mosses and grasses in the full moon ceremony, which occurs every full moon. There is no other maintenance of the mani walls. The villagers never scrub the walls or clean off the lichens. We never paid attention to the lichens until you [the author] pointed them out to us.

B: Summary of Interview with Dorje Tamang, 19 November 2015.

[The interview took place in a yak-herding hut very close to Ghoratabela and the original mani wall. The informant appeared to be 25–30 years old.] The original mani wall was covered with snow after the earthquake. This is what caused the damage. There was no repair to the mani wall. It is too expensive to do repairs. Most of the other mani walls have been destroyed. Some organization donated a budget for repair of the mani walls at higher elevations, but that budget is now finished. The original mani wall was cleaned in the past with a brush and chisel. Even the lichens were cleaned off the original mani wall. No new block has ever been carved for the original mani wall. However, a new block was carved for the mani wall on the bridge in Kyanjin Gompa. [Author’s note: This is mani wall no. 79 (Table 1f), which showed no apparent damage.]

C: Summary of Interview with Tsering Thendup, Caretaker of Gompa (Monastery) at Kyanjin Gompa, 21 November 2015.

I am 80 years old and I have lived in Kyanjin Gompa since I was born. My family came here from Langtang. I am the caretaker of the gompa. I am the only caretaker this year. The main caretakers live in Kathmandu. I do not live in the gompa. The gompa has never been damaged before.

D: Summary of Interview with Lachung Tamang, Resident of Mundu Village, 22 November 2015.

I am 60 years old. I have lived here since I was born. The mani walls were built for religious purposes. They make you feel at ease at the time of your death. The mani walls have never been damaged before and the blocks have never fallen off. The lichens are never removed, but the mosses are picked off.

E: Summary of Interview with Dhundu Tamang, Owner of Ganesh View Hotel, Rimche, 23 November 2015.

I live in Sherpagaon. I just go to Rimche to take care of the guests. Ghoratabela was named for the horses that were kept there by the government. The Khampas moved here from Kathmandu. They were brought here by the police. The Khampa capital was at Ghoratabela. The Khampas cut down the trees and made fields and built houses. Ghoratabela was a big village with wooden huts. Lama Hotel and Kyanjin Gompa were set up by the Khampas who built houses. A governor of Kyanjin Gompa acquired a house built by the Khampas after the Khampas were moved to Pokhara. The Khampas were heavily armed and the Tamangs were afraid of the Khampas. The Khampas butchered cows and dried meat on ice. They ate tsampa [roasted barley flour] with raw meat. The Nepali army removed the Khampas from Langtang and took them to Pokhara and took all of their weapons away. The Khampas never tried to cross into Tibet from Langtang.

The people in Langtang are from Tibet, but are not Khampas. The father of Dorje Tamang [the informant in Appendix B] was a Khampa. Everyone calls him Khampa Dorje. His mother’s last name was Tamang, but she was really Tibetan. His father left after Dorje was born.

“Langhisa” means “where the ox died.” A male and female oxen got lost and a monk went to look for them. The female ox was seen near Bridung, but then not seen again. A Gurung found the male ox around Sherpagaon. The Gurung had a rope, but there was no rope in Langtang.
no branch to tie the ox so he tied the ox’s nose to a stone. You can still see the stone in the shape of an ox nose. The ox ran away when the Gurung was sleeping. The ox was found in Langtang where it was eating a lot of grass. “Langtang” means “the ox is full” in Tibetan. The ox then died on the way to Langhisa. After that Langtang Village was founded by the Tamang.

In Langtang now, Tibetan is spoken, not Tamang. Tamang is spoken in Sindhupalchowk. Maybe there are a few Tamang in other villages. There used to be Sherpas in Sermagao. Some Sherpas died and others left. My mother told me about Sherpa-speaking people. “Sherpa” means “people from the east,” while “Tamang” means “horseman.” The Tamang came from Tibet before the Sherpas. The Sherpas are from Kham in Tibet. There were never Tamang living in Langtang. [This contradicts a previous statement.] They are all Tibetan who took the name Tamang to become Nepali citizens. I am Tibetan, but my mother and father took the name Tamang to get Nepali citizenship. Real Tamang women do not dress like the women here. Here the women dress like Tibetans. The people in Kyanjin Gompa are all from Mundu. The older houses are higher on the hillside.

I saw a yeti in a water mill. My parents sent me to grind flour. I opened the door. It was very hairy. The upper body was black, while the lower body was white. The feet were backwards.


I am now 35 years old. I was born in Mundu. When I was five, my family moved to Langtang Village. I have spent the last five years in Kyanjin Gompa. Sometimes avalanches destroyed the mani walls between Mundu and Sindhur. The damaged mani walls were always renovated in the past and some mani walls have been renovated this time. Only old blocks are used for renovation. To carve a new block, prayers are needed, and they need to be blessed by lamas or the reincarnations of previous lamas. Without a blessing, a block has no special value. The word “sung” means something a lama has prayed over, which has been put underground and combined with a valuable thing such as pure incense. In old monasteries, there is “sung” underground, including the monastery at Kyanjin Gompa.

Mani walls are not cleaned. There is no time set aside for cleaning. The mani walls clean themselves, sometimes the rainfall cleans the mani walls. There is no record of who built the mani walls or why or when. Maybe some lamas built them after meditation and enlightenment. Neither my grandfather nor I have ever seen a new mani wall built. I have seen a new mani wall built. The structure at Ghoratabela is not a mani wall, it is a chorten.