



Archeological and Historical Database on the Medieval Earthquakes of the Central Himalaya: Ambiguities and Inferences

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INTRODUCTION

Global Positioning System-based convergence rate between India and southern Tibet is estimated as 20 ± 3 mm/yr (Larson *et al.*, 1999). Despite this fast convergence, the seismicity rate of the Himalaya has been remarkably low, as only $\sim 50\%$ of this plate boundary has ruptured during the last 200 years. This long-lived deficit in seismic productivity has led many to believe that the region holds potential for more than one magnitude ≥ 8.0 earthquake (Ambraseys and Jackson, 2003). The Himalaya plate boundary has generated three great earthquakes during the last century; however, since the 1950 Assam earthquake (M_w 8.0), there has been quiescence, with the gap in time and space particularly noted on its central segment. Khattri (1987) proposed that the region comprising the Garhwal and Kumaun provinces and the western parts of Nepal falls in a seismic gap. Referred to as the “Central Gap,” this region covers ~ 600 km length of the Himalayan arc, and it arguably represents an unruptured segment between the sources of the 1905 Kangra M 7.8 and 1934 Nepal–Bihar M 8.0 earthquakes (Fig. 1). However, the extent to which older earthquakes might have filled the gap is contested on various counts. The uncertainties in locations and magnitudes of pre-twentieth century earthquakes; in particular the 1803 and 1505 events, are also being debated (Ambraseys and Douglas, 2004; Rajendran and Rajendran, 2005, 2011). Considering the large and densely populated regions that are likely to be affected, reconstructing the seismic history of the Himalaya is a key issue in the seismic-hazard assessment.

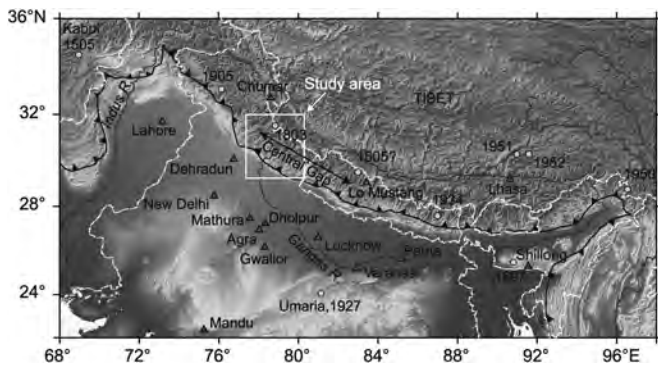
The history and cultural heritage of the regions within the central gap is much longer than the currently estimated inter-seismic interval of ~ 500 years for great earthquakes; and, therefore, it provides opportunity to interrogate these issues. For example, the state of the Hindu temples built as early as fifth–sixth century A.D. is suggestive of the events that might have affected them. Thus, we regard the heritage structures of the Kumaun–Garhwal Himalaya as archeological seismic sensors that can be used to assess the history of damaging

earthquakes. We are not aware of any studies on the seismic performance of the temples in the Garhwal Himalaya, but models of the performance of similar multistoried structures in Nepal show a fundamental time period less than 0.6 s (Jaishi *et al.*, 2003). Because this is within the range of natural period of a wide variety of soils, there is a high probability for such structures to approach a state of partial resonance during large earthquakes. The spatial distribution of damage, response of specific structures, and models based on their structural elements could lead to the location and magnitude of pre-twentieth century earthquakes.

The architectural style showed only minor variations between different clans and their rulers, and the constructions generally consist of a common plan, which used large and heavy rock units arranged on top of each other, without mortar (Fig. 2). As a society whose social milieu revolved around the temples for ages (> 1000 years), the temple archives carried through generations serve as an important and often the only source of information on its history including the impact of major natural calamities. Interpretation of such records is, however, challenging due to biases in reporting, inconsistencies in the calendars, errors in translating scripts, shifting of the province capitals, and renaming of towns and cities. Further, the historical structures have often been affected by territorial wars, vandalism, and other nondocumented reasons. Despite these interpretational limitations, we believe that the historical archives provide useful clues for isolating time windows for potential earthquake-related damage (e.g., Rajendran and Rajendran, 2002). In this paper we use the historical background and the present state of some of the heritage structures to obtain spatial and temporal constraints on three significant earthquakes: A.D. 1255, 1505, and 1803. The 1803 earthquake is used as a calibration event because its effects on heritage structures are well evidenced even in the Gangetic plains. Observations from the 1991 Uttarkashi (M_w 6.8) and the 1999 Chamoli (M_w 6.6) earthquakes provide additional comparative constraints (Figs. 1 and 3 for locations).

SEISMIC RESPONSE OF HERITAGE STRUCTURES

Ancient Himalayan stone temples are broad-based and stable structures, usually ~ 3 – 5 m high and with tapering tops (Fig. 2). Depending on the magnitude and ground conditions, their seismic responses can typically be through sliding, rocking, or toppling, based on the intensity of ground shaking and the geometry of the structure. If the material strength of the construction material is low, either a permanent deformation or

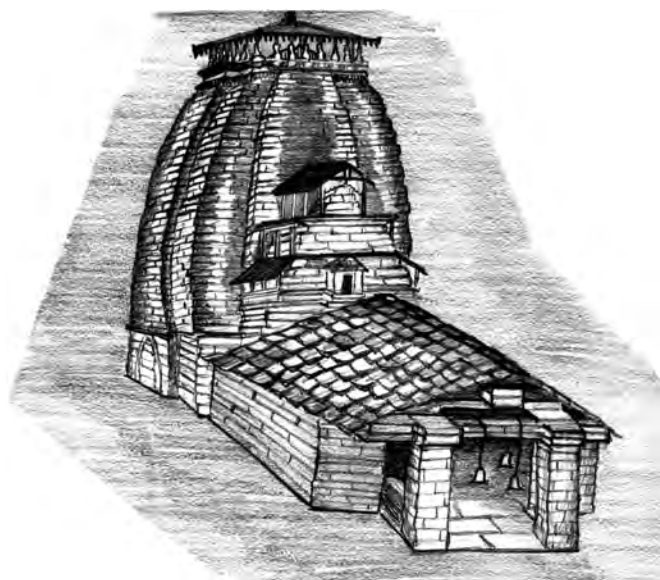


▲ **Figure 1.** Locations of the significant earthquakes in the central Himalaya and the study area, comprising the Garhwal–Kumaun provinces.

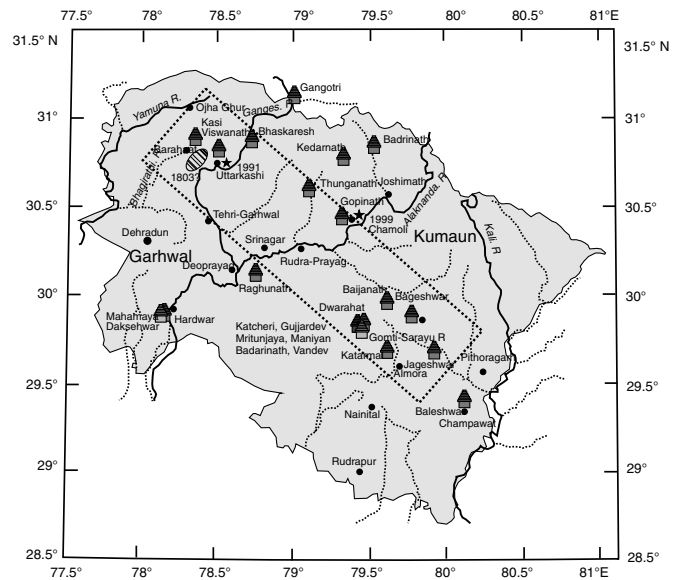
even a collapse of the whole structure may happen (e.g., Stiros, 1996). We have visited several temples in the region, and here we discuss our observations (Tables 1 and 2; Fig. 3).

Temples of Garhwal and Kumaun Himalaya

The $M_w \sim 7.5$, 1803 earthquake is the most recent earthquake to have occurred in the Garhwal–Kumaun region, and reports are unanimous about damage to ancient structures (Raper, 1810; Hodgson, 1822; Baird-Smith, 1843). Damage was most intense around Garhwal in comparison to Kumaun (Fig. 3). For example, Almora and its neighborhood, famous for the ancient stone temples (tenth–twelfth century A.D.), were not significantly affected. Several of its temples have survived in their original forms, although some are in somewhat dilapidated condition due to aging and vandalism. Although fragmentary and jumbled but decipherable from the available copper plate inscriptions, historical information suggests considerable damage from insurgency (Atkinson, 2002; Handa



▲ **Figure 2.** A pencil sketch of a typical central Himalayan temple.



▲ **Figure 3.** Locations of temples in Garhwal–Kumaun provinces. Locations of the 1803, 1991, and 1999 earthquakes are shown. The possible source zone of the 1803 earthquake is also shown. The box outlined by dashed lines is used to develop the timeline in Figure 10b.

and Jain, 2009). Restoration work initiated by the Archeological Survey of India has obscured some of the original damage, but evidence for translation and/or rotation of individual blocks and pillars, movement of stone blocks, and partial collapse of roof top stones is still preserved at many sites.

Kashi Viswanath Temple (Uttarkashi, Garhwal)

Kashi Viswanath temple is a major landmark of Uttarkashi (Barahat) town. Raper's description is clear about its total destruction in 1803, except for its upright trident. Raper (1810) writes:

Near the village is a curious trisul or trident, the base or pedestal of which is made of copper, in size and shape of a common earthen pot; the shaft is of brass, about twelve feet long, the two lower divisions decagonal, and the upper one spiral. The forks of trident are about six feet in length. From each of the lateral branches, is a chain, to which bells were originally suspended. By what means it came hither, or what purpose, it was constructed, no person could tell; and although the inscription be legible, and most probably contains the information, no one could tell us in what language the characters are written. We had with us two or three men, who could read Nagri, Persian and Sanskrit, but they were unable to decipher a single letter. The lower part of the inscription bears some resemblance to the Chinese characters.... The only reason they assign for holding it in reverence is its form being the emblem of one of their deities. It had formerly a temple erected over it, but in the earthquake

Table 1
Major Temples in Garhwal Province and Their Damage History (See Fig. 3 for Locations)

Name of the Temple	Age: Century (A.D.)	Location	Year of Damage	Restoration Period
Mahamaya	10–11	Between Mayapur and Jwalapur near Hardwar	1803	Not known
Daksheswar	6 (?)	South of Kanhal near Haridwar	1803	1810
Kedarnath	8–12	Near Mandakini River; 30.73° N, 79.2° E	1803; partly damaged	1803, 1815, 1842, 1850, 1891
Badarinath	10–11	Located on the bank of Alaknanda River in the hill town of Badarinath; 30.73° N, 79.49° E	1803; partly damaged	Possibly many times since 1803; definitely in 1890
Gopinath	10–12	Gopeshwar village, Chamoli; 30.41° N, 79.3° E	1803	1803, 1813
Raghunath	19 (?)	Deoprayag; 30.15° N, 78.59° E	1803; partly damaged	1803
Kashi Viswanath	10–12	Located on the bank of the river Bhagirathi, Uttarkashi; 30.72° N, 78.44° E	1803	1857
Gangotri	18 (1794)	Located on the banks of the Bhagirathi River; 31.0° N, 78.95° E	1803	1807
Thunganath	Not known	Located on the Alaknanda River Makkumath; 30.48° N, 79.14° E	Completely damaged in 1803	1803

of 1803, the mansion was thrown down, and wonderful to relate, the pillar escaped without injury.

The exact date of initial construction of the temple is not known, but the local tradition associates its foundation with the installation of a victory trident between A.D. 1050 and 1100 (Handa and Jain, 2009). The Chinese inscription mentioned by Raper (1810) probably dates back to the ruler of Guge (in Tibet) of eleventh century A.D., concurring with the time of the installation of the trident. Following the damage by the 1803 earthquake, the temple was rebuilt in A.D. 1857 by Maharani Khaneti, wife of King Sudarshan Shah (Handa and Jain, 2009), retaining the classical style but using the stones from the original structure as evidenced by the misalignment and mismatch between stone slabs.

Gopinath Temple (Eastern Garhwal)

Gopinath temple at Gopeshwar is an archeologically important monument, initially constructed sometime in the tenth century A.D. (A.D. 1191), as evident from the inscription on a victory trident in the courtyard ascribed to the Malla King of Nepal (Handa and Jain, 2009). The temple stands well over 23 m tall and is stylistically comparable to temples in Kumaun, such as Bageshwar as discussed below. A stone inscription (in the ancient script of *Devnagari*) on its outer wall testifies that it was reconstructed after the damage from the 1803 earthquake. Several rectangular blocks with inverted *Devnagari* script on the main wall of this temple provide evidence for this reconstruction (Rajendran and Rajendran, 2005). However, the general arrangement of blocks suggests that the reconstruction must have reproduced the pre-1803 style. During the Chamoli earthquake, sourced 5 km away, the Gopinath temple sustained

only minor vertical cracks, suggesting that the acceleration was lower compared with that of 1803 (Rajendran *et al.*, 2000). There are no records on damage from pre-1803 earthquakes (Table 1, Fig. 3).

Baijanath Temple (Kumaun)

Baijanath was the capital city of the Katyuri kings, the earliest ruling dynasty of the central Himalayan region, and the Baijanath temple complex was built during the tenth to twelfth centuries A.D. (~A.D. 1150) (Nautiyal, 1969). The top part of the main temple was destroyed in the year of A.D. 1743–1744 by an insurgent army, thus the main temple lacks its original tower. The construction style is typical of contemporary architecture wherein large blocks are arranged on top of each other without any cementing material. The blocks are anchored using iron brackets. The temple complex as a whole shows tilting toward the south and pillars of some of the smaller structures show rotation and displacement of the building stones (Fig. 4a,b).

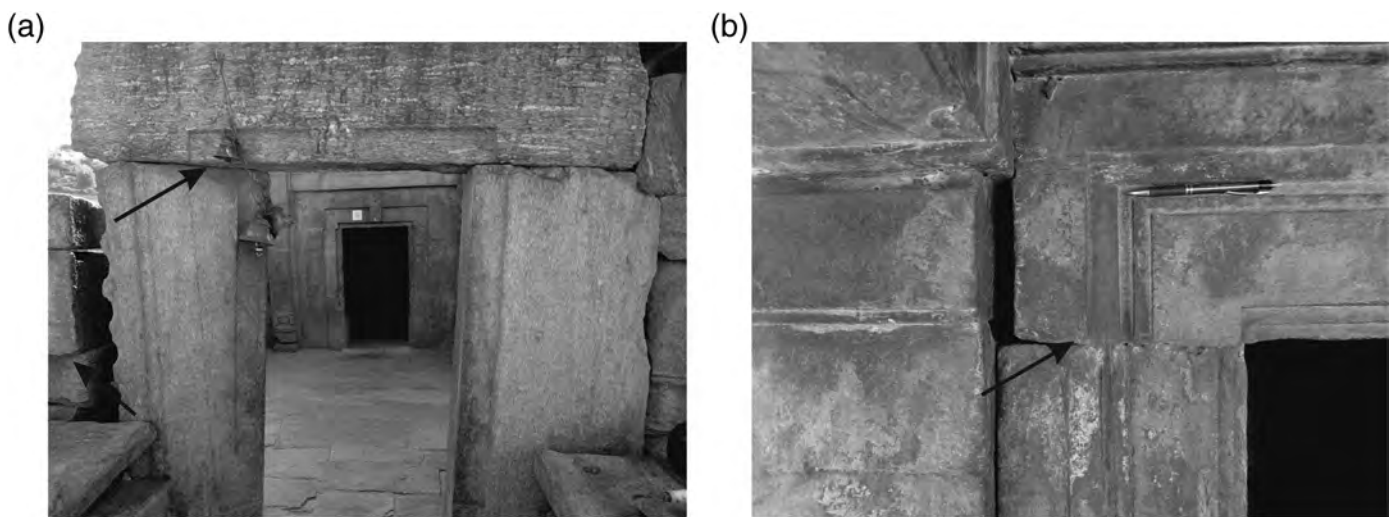
Temples at Dwarahat (Kumaun)

The village of Dwarahat, located to the northwest of Almora, is famous for its ~tenth to eleventh century A.D. temples (Fig. 3), which are now in partially ruined condition. We discuss here the evidence for deformation of those structures.

Mrityunjaya Group of Temples. The Mrityunjaya group of temples located northwest of Almora and probably dating to the first half of the eleventh century A.D. is currently in a ruined state (Handa and Jain, 2009). The west side of the temple shows displacement (~4 cm) of blocks toward the southeast and clockwise rotation of pillars by ~5°.

Table 2
Major Ancient Temples of 10th–12th Century A.D. in Kumaun Province and Their Damage History (See Fig. 3 for Locations)

Name of the Temple	Age: Century (A.D.)	Location	Nature of Deformation	Details on Restoration/Renovation
Bageshwar	10–12	Near Almora; at the confluence of Gomti and Sarayu Rivers; 29.83° N, 79.77° E	Present structure intact; artifacts of an earlier vintage temple seen in the premises	A.D. 1602
Baijanath	12	Built on the banks of Gomti River; 29.91° N, 73.61° E	Tilting and rotation	No indication of restoration
Jageshwar	11–12	Near Almora town; 29.63° N, 79.85° E	The original stone roof has fallen and been replaced by metallic roof in recent times	Reconstructed later
Dandeshwar	9–10	In the vicinity of Jageshwar temple; 29.63° N; 79.85° E	Porch is completely missing	Not restored
Katarmal	11–13	Near Almora; 29.63° N, 79.61° E	Pillars of subordinate temples rotated. Roof of the main shrine has fallen off	Restoration work is going on currently
Mritunjaya group of temples	11	Dwarahat; 29.77° N, 79.42° E	Pillars rotated; displacement of stone blocks	No indication of restoration
Badarinath group of temples	11	Dwarahat; 29.77° N, 79.42° E	Pillars appear rotated and fallen; partial collapse of structure	No restoration since the damage
Vandev (Bandeo)	11	Dwarahat; 29.77° N, 79.43° E	Temple tilted to the west; the whole structure twisted about its axis to the east; fractures at the corners	No restoration since damage
GujjarDev	12	Dwarahat; 29.77° N, 79.43° E	Whole superstructure collapsed	Not restored
Katcheri group of temples	11–13	Dwarahat; 29.77° N, 79.43° E	Pillars of most of the temples tilted toward east; the easternmost temple lacks <i>mandapa</i> (porch)	Not restored



▲ **Figure 4.** View of Baijnath temple showing (a) rotation of a pillar and (b) block displacement.



▲ **Figure 5.** View of Vandev temple at Dwarahat, twisted about its axis.

Badarinath Group of Temples. Badarinath group of temples, situated immediately east of the Mrityunjaya group, can be assigned an age of eleventh century A.D. (Goetz, 1955). The black stone image of the main deity, *Vishnu*, bears an inscription of *Bikram Samvat* 1105 (the lunar calendar), suggesting that it was constructed around A.D. 1048. The temple stands on a highly raised platform and, following the Katyuri style, is likely to have originally comprised three units: sanctum (*garbhagriha*), vestibule (*antrala*), and porch (*mandap*). However, the porch is missing, and some fallen pillars in the vicinity attest to their partial collapse. An east-facing smaller temple appears rotated by $\sim 2^\circ$ counter clockwise, relative to the main structure.

Vandev Temple. Vandev (eleventh to twelfth century A.D.) is a south facing temple situated ~ 150 m east of the Badarinath group (Fig. 3). Standing in the midst of cultivated fields on the bank of a small river, this pyramidal shrine is rectangular in plan and is presently without any idol. The whole structure appears to have been rotated about its axis in the clockwise direction (Fig. 5). Significant gaps at its corners are taken as evidence for tilting and shearing.

The Katcheri Group of Temples. The Katcheri group (mid-twelfth century or early twelfth century A.D.; Nautiyal, 1969) of temples comprises 12 shrines, 5 each in two rows and the remaining 2 on a higher terrace. They have common porticos with a series of freestanding pillars with plain shafts and brackets in the front. The pillars show tilting and eastward displacement. The easternmost temple seems to be missing the porch, and the whole structure is tilted eastward.



▲ **Figure 6.** (a) View of Katarmal temple and (b) a rotated and damaged pillar of one of the subsidiary smaller temples.

The Katarmal Sun Temple. The Katarmal Sun temple complex (eleventh and thirteenth century A.D.; Nautiyal, 1969) consists of a main temple and an assortment of 45 variously sized miniature structures. Located about 14 km from Almora on a hilltop, the temple is presently in ruins. During the canon firing by British forces in 1815 to evacuate Gorkha troops, the top of the main temple was destroyed (Fig. 6). Located toward the southern end of the complex, one of the pillars of the main temple carries an obscure inscription, dating to the thirteenth century A.D. (Goetz, 1955). The smaller temple units are believed to be older, probably dating to mid-twelfth century (Handa and Jain, 2009). However, our observations on the subsidiary smaller temples indicate evidence for clockwise rotation of pillars ($\sim 15^{\circ}$ – 20°).

State of Post-Twelfth Century Temples of Kumaun

Although several of the pre-twelfth temples show damage from ground motions, the younger temples seem unaffected. In some cases, the reconstruction histories have been documented, allowing us to isolate the potential time windows during which damage occurred. Here we discuss the example of Bageshwar temple, which is well documented.

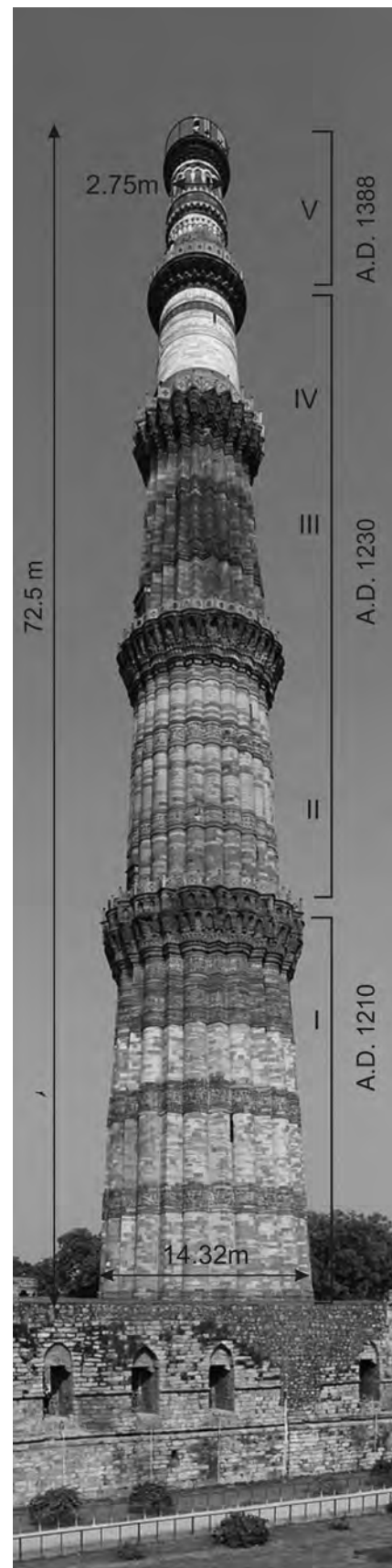
The Bageshwar Temple

Located on the bank of Sarayu River, the Bageshwar temple was constructed during A.D. 1592–1602, but several lines of evidence suggest that the present structure is built on an earlier foundation (Handa and Jain, 2009). Artifacts of the A.D. sixth–seventh and tenth–eleventh centuries obtained from its premises testify to the presence of older generation structures. For example, an inscription on a stone slab indicates that the grant of land from a Katyuri king dates to the eleventh century A.D. (Oakley, 1905). Oakley attributes the construction of the current edifice to *circa* A.D. 1450, although the interpretation is based on the extant calendar. This would be A.D. 1534 and A.D. 1590, respectively, by the lunar and Gregorian calendars. The present structure seems to be structurally intact and apparently free of any damage.

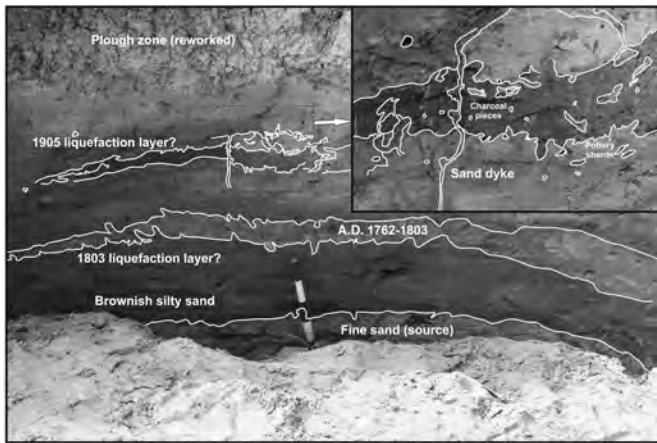
Damage to Monuments in Delhi (The Gangetic Plains)

Delhi, the capital of India during the medieval period, features several monuments dating to ~ 700 years. The only known case of earthquake-related damage is that of Qutb Minar, a long-standing tall structure located in the heart of the capital city of Delhi (Fig. 7). This 72.5 m high, whose history is quite well documented, is a landmark of Delhi. Built in stages, the first story was completed in A.D. 1210 and the second, third, and fourth stories by A.D. 1230. Lightning damaged its tower in A.D. 1368, and the construction was resumed with the completion of the topmost (fifth) story in A.D. 1388 (Munshi, 1911). There is an inscriptional evidence to suggest that lightning damaged Qutb Minar again in A.D. 1503 (Hijri year AH 909; Munshi, 1911).

The next report of damage to Qutb Minar was from the A.D. 1803 earthquake, affecting the balustrades, balconies, and the entrance. The cupola (i.e., a plain square top on four stone



▲ **Figure 7.** View of Qutb Minar (Delhi), showing dimensions of the different stories and their respective years of construction.



▲ **Figure 8.** A sedimentary section exposed at Biharigarh, a location ~45 km from Dehradun on the Dehradun–Delhi road showing two out-of-sequences sand layers that may represent soil liquefaction; the lower layer provides a calibrated calendric age. Shovel handle for scale: 40 cm.

pillars) is reported to have toppled (Archaeological Survey, 1864; Sharma, 2001). A remodeled cupola replaced it but was brought down in 1847, and the pillar has been without a cupola since then (Munshi, 1911). Damage due to the 1803 earthquake in the Gangetic plain was widespread and coseismic liquefaction was reported from locations as far as Mathura, ~150 km south of Delhi (Oldham, 1883).

The field evidence for widespread coseismic liquefaction during the 1803 earthquake was indicated in a pit dug at Biharigarh ($30^{\circ}05'56.4''$ N and $77^{\circ}49'13.7''$ N), located ~45 km from Dehradun on the Dehradun–Delhi road, that exposed a 1.35 m thick sedimentary section showing two out-of-sequence fine sand layers within the host sediment of brownish silty sand (Fig. 8). The out-of-sequence layers contained rip-up clasts of brownish silty sand and were linked to 1–2 cm wide vertical dikes. Association with vertical dikes suggests that the two sand layers are emplaced material from the lower part of the section and are associated with earthquake-induced liquefaction. Obtained from within the lower thicker liquefaction layer, the charcoal is dated at 203 ± 20 yr B.P. (conventional radiocarbon date), and two-sigma range of 1762–1803 cal yr A.D. (45.4% of area), using Calib 6.1 and the IntCal09 calibration program. It may suggest the earlier event may be associated with the 1803 earthquake. The undated upper thinner liquefaction layer could be due to a local younger event or distant large event, for example, the 1905 Kangra earthquake (Fig. 8). It should, however, be noted that the Kangra earthquake occurred during a drier period that exists in the month of April, whereas the 1803 event was in the month of September, which generally corresponds to a wetter period. Aside from the distance to the source zones, such seasonal differences do have a bearing on the depth of ground water table and in turn on the regional liquefaction vulnerability.



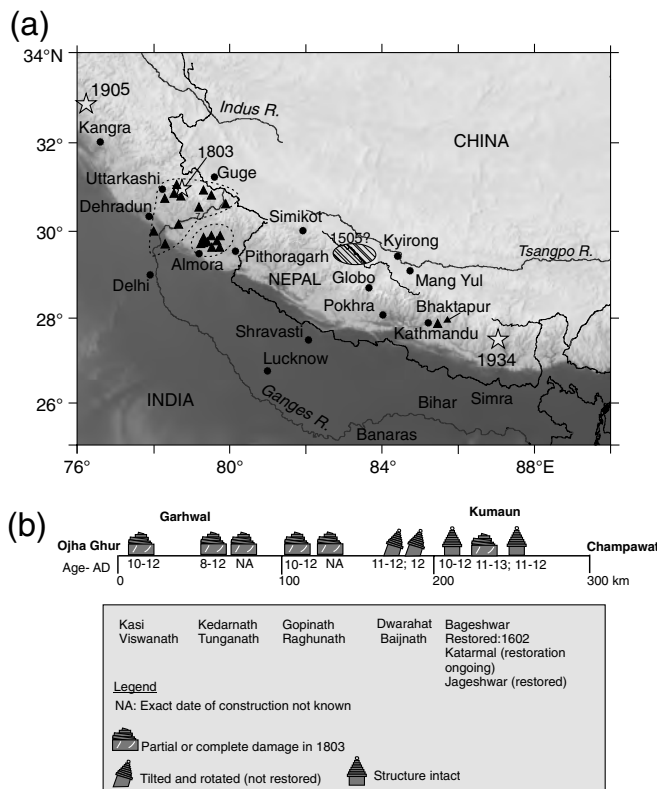
▲ **Figure 9.** Sketch showing the lost town of Srinagar and its palace, located on an elevated terrace. (Drawing by Jwala Ram, a contemporary artist; courtesy of Handa and Jain, 2009).

CONSTRAINTS ON PAST EARTHQUAKES

The Garhwal Earthquake of 1803

Earthquake of 1803 is the largest and the best documented from Garhwal, but its magnitude is reported as ranging between M 7.5 and 8.0. (Rajendran and Rajendran, 2005). Its exact location is not known; however, based on the damage intensity, both Uttarkashi and Srinagar (located ~60 km apart) are likely candidates (Fig. 3). It is reported that nearly 1000 houses, mostly two storied in rubble masonry, were destroyed in Srinagar, and the destruction to the palace was most severe (Raper, 1810; Fig. 9). During his stay at Srinagar in early 1820, Moorcroft reported “the Raja’s residence, a spacious structure four stories high of blue slate-stone begun by Raja Bahadur Singh about 245 years ago and finished by his successors, was so much injured by the earthquake as to be rendered nearly uninhabitable and soon after was wholly deserted” (Moorcroft and Treback, 1986). Whatever remained of the structure was completely washed away in the great floods in the years of 1804 and 1894.

Reports from multiple sources suggest the impact was more intense near Uttarkashi and to its north. Raper (1810) suggests that Uttarkashi was the most severely affected in terms of destruction and casualties. Baird-Smith (1843) also reported intense damage including shattered condition of temples and houses from this region. Hodgson (1822) also provides vivid details of destruction to settlements and temples, including damage at Ojha Ghur, ~20 km north of Uttarkashi, where rock falls buried a small fort and the village. A temple was destroyed at Gangotri, located farther north and at an elevation of 3100 m (Fig. 3; Tables 1 and 2). The earthquake was severe at Srinagar, the economic center and capital of Gharwal; the impact was likely compounded by the Gorkha invasion and the huge flooding event in the same year (Moorcroft and Treback, 1986). Thus, a conflation of several events, natural and man-made, site conditions, and the population density might have added to the perception of severity.



▲ **Figure 10.** (a) Locations of the possible source zone of the 1505 earthquake and the temple towns of Nepal, Kumaun, and Garhwal Himalaya. (b) A timeline profile showing damage to temples along a corridor, as shown in Figure 3.

Medieval Earthquake of the Twelfth/Thirteenth Century (A.D. 1255)

The A.D. 1255 earthquake in the western Nepal is another historically known earthquake for which details are sparse (Mugnier *et al.*, 2011). Reports, mostly from the Kathmandu Valley, describe it as a highly damaging earthquake in which “one third of the population of the Kathmandu was wiped out.” Destruction to the palace of Ajaya Malla, the medieval king of Nepal who was also killed during the earthquake, exemplifies the severity of damage (Rana, 1936). Based on the damage to the unrestored contemporary temples Kumaun it appears the damage zone extended westward from Nepal (e.g., temples in Dwarahat, Table 2; Fig. 10b). The temples in Garhwal, situated on the revenue earning pilgrimage route, were probably renovated soon after, obscuring any clues of damage.

Contemporary reports from Nepal provide constraints on early medieval earthquakes. Major sites of ancient temples are located around Kathmandu valley, including the three-storied Dattatreya temple, at Bhaktapur (Fig. 10, for location). Built by the King Jaya Yaksha Malla in A.D. 1427, it was repaired and renovated by King Vishwa Malla in A.D. 1454. The only other earthquake-related destruction to this temple is associated with the great 1934 Nepal–Bihar earthquake, which also destroyed an A.D. 1460 Shiva temple at the same location (Pandey and

Molnar, 1988). Earthquake-related destruction has not been recorded during the intervening period. The geological excavations suggest the penultimate earthquake occurred around A.D. 1255 (Sapkota *et al.*, 2013).

Twin Earthquakes of A.D. 1505: 6 July Kabul and 5 June Lo Mustang

Historic documents indicate two destructive earthquakes in 1505, separated by a month’s gap, one near Kabul (July 6) and the other near the Nepal–Tibet border (5 June), and these earthquakes reportedly affected some common areas. Sources such as *Akbar-nama*, an ancient book of medieval Indian history, written sometime in A.D. 1590–1596 (Beveridge, 1939; page 234), and an earlier dated *Babar-nama* (Beveridge, 1979; page 247), also can be explored to find out references to the medieval earthquakes.

Akbar-nama describes the Kabul earthquake as follows:

In the beginning of this year there was a great earthquake in Kabul and its environs. The ramparts of the fort and many buildings in the citadel and city fell down. All the houses in the village of Pemghan fell down and there were three-and-thirty shocks in one day and for a month the earth shook two or three times day and night. Many persons lost their lives, and between Pemghan and Baktub a piece of ground a stone’s throw in breadth separated itself and descended the length of a bowshot and springs burst out from the breach. From Istirghac to Maidān, a distance of six farsangs, (cir. 24 m) the ground was so contorted that part of it rose as high as an elephant. In the beginning of the earthquake, clouds of dust rose from the tops of the mountains. In the same year there was a great earthquake in India [emphasis added by us].

These words, repeated from an earlier dated memoir, *Babar-nama*, also describe the effect of the great Kabul earthquake of July 1505, but the last sentence about an earthquake in India was an addition. According to Ambraseys and Jackson (2003), this last sentence probably refers to the 5 June 1505 Lo Mustang earthquake.

The June 1505 Lo Mustang Earthquake

Jackson (2000) and Ambraseys and Jackson (2003) have described the 5 June 1505 earthquake as an event that was strongly felt from Guge in the northwest to Lo Mustang and Kyrong (Gyirong) in the southwest, and they ascribed a moment magnitude of 8.2 (Fig. 10a). Quoting Tibetan sources, Jackson (2000) reported large-scale destruction reaching all the way across mNgaris province, western Tibet, from Mangyul Gungtang to Purangs and Guge, ~550 km apart (Fig. 10a). Collapse of buildings and loss of life were also reported from Thakali province (in Nepal), south of Globo. Estimating the magnitude and source location of this earthquake is important, although the information does not constrain its magnitude and location very well.

A.D. 1505 Earthquake: References from a Historical Novel Iyengar *et al.* (1999) refer to *Mrignayani*, a historical novel by Verma (2003), for earthquake and associated damage at places such as Dholpur, Gwalior, and Mandu (all within 100 km radius of Agra; Fig. 1). Ambraseys and Jackson (2003) also cite this novel to suggest the event referred might be the June 1505, Lo Mustang earthquake. Although it deals with reign of Raja Mansingh Tomar of Gwalior (A.D. 1486–1516), we believe the novel cannot be treated as contemporary, as it was actually written in 1950 (Verma, 2003). We have reexamined this novel and here summarize the following contents translated from Hindi. The background of events is set at a time when Sultan Sikandar was getting ready to attack Gwalior. Thus it reads, “Sultan Sikandar has formed a force against Raja Mansingh Tomar and, entrenching himself at Agra in AD 1504. Sultan was ready to attack and destroy Gwalior, which was ruled by Raja Mansingh.”

Then it reports happenings from different locations, as follows:

Agra: *One soldier suggested that there are three to four months left before the onset of rain and there should not be much delay on the planned attack on Gwalior. Sikandar agreed to this suggestion and at the same time they heard a sound of rumbling, the roof, walls, pillars, floor everything started to shake and it seemed like the time for “Great Destruction”. The head of Mullah (priest) and Sardars started swaggering and the king fell on his face from his throne. And, his gulam (slave) who was fanning him fell on him and the fan fell on the top of them. Darkness predominated and people started screaming for mercy. Rocks and boulders started to roll down from the hill, and the hill started creeping down. And the trees started falling with a sound and water in rivers and lakes started shaking. This was an extreme shaking of a great earthquake.*

Mandu: *A ruined city in the Dhar district in the Malwa region of western Madhya Pradesh state situated at an elevation of 633 m and extended for 13 km along the crest of the Vindhyan Range, this fortress town is constructed on a rocky outcrop; the King of Mandu was Sultan Nasir-ud-din. Mandu Fort on the hilltop started shivering, the throne fell down and the people started falling on each other. Firelights dropped down from their hands and they started rolling on the ground. They realize it’s an extreme shaking of a great earthquake.*

A location distant from Mandu: *Mahamood Bagharra has pitched his tents far but on the way to Mandu in a selected place. As soon as he was fast asleep his bed started shaking and the tremor turned him onto the other side and he could not save himself from falling to the floor. He started rolling on the ground. This was an extreme tremor of an earthquake.*

There are descriptions from many more locations, which seem consistent, but their authenticity need to be checked with

other historical sources. However, some discrepancies between the incidents in the novel and the historic information are noteworthy. For example, there is a specific mention by a soldier in Sikandar’s army about the rainy season (namely that it is three to four months away) and the desirability of conducting the raid during a dry period. As per the earlier quote, the earthquake may have occurred in March or April, and the monsoon intensifies in Agra in the month of July (source: Yearbook-1995 to 2001, Central Ground Water Board, New Delhi, India). The Lo Mustang and Kabul earthquakes occurred in June and July of 1505, respectively. The descriptions from Mandu, located about 600 km from Agra, suggest the earthquake mentioned in the novel may have occurred in the late evening, whereas the Lo Mustang earthquake is reported to have occurred in the very early morning (Jackson, 2000). Further, an earthquake located in the Himalaya cannot have similar effects both in Agra and the distant Mandu. Assuming earthquake description in the novel is factual, the effect on Gwalior and Mandu appears to be somewhat similar.

Accepting for normal allowances of exaggerations in a historical novel, it is reasonable to assume that, like Agra, Gwalior and Mandu were also badly shaken, but damage to major constructions like forts and palaces was nominal. It becomes evident from the work of medieval writers and historians that the earthquake affected Agra badly, but there are no specific details of any serious damage (e.g., Ranking, 1898, as referred in Ambraseys and Jackson, 2003). There are no historical data that support the contention that Agra was “rebuilt” in A.D. 1505. There was no apparent evidence of reconstruction in the Kathmandu valley following the July 1505 earthquake. Interestingly, there are no historical reports of related damages from Nepal, suspected source area located only 100 km north of Kathmandu, where much of the reconstruction supposedly took place during 1382–1395 (Markovitz, 2004). The lack of damage to ancient structures from the two earthquakes that occurred in the months of June and July of A.D. 1505 is equally apparent from the Gangetic plains, epitomized by the long-standing thirteenth century structure of Qutb Minar in Delhi.

SUMMARY AND CONCLUSIONS

This study uses the histories of long-standing temples in the Garhwal and Kumaun Himalaya since the eleventh century (Fig. 10b). Considering the damage to temples and concentration of other earthquake-related hazards such as landslides and rock falls, we infer that the epicentral location of the 1803 earthquake was closer to Uttarkashi than to Srinagar, an inference different from what is reported in our earlier work (Rajendran and Rajendran, 2005, 2011). The 1999 Chamoli earthquake caused no damage to the Gopinath temple, but the temple records testify to severe damage from the 1803 earthquake. It affected not just the traditional houses in its meizo-seismal area, but also caused damage in distant regions, including locations close to Delhi. The damage pattern of the 1803 earthquake also shows many local and distant peaks, such as those in Mathura and Aligarh in the Gangetic plains.

Damage in Delhi from the 1991 and 1999 central Himalayan earthquakes (both of magnitude <7.0) was confined to regions of alluvial fill, and structures like Qutb Minar remained unaffected. Strong earthquakes are known to generate long wavelength waves and can affect distant long period, tall buildings, like minarets and tall towers (Stiros, 1996). Thus, the damage to 72 m high Qutb Minar during the 1803 earthquake could have occurred from the low-frequency waves (2–8 s). There is no mention of any damage to this structure by the June 1505 (Lo Mustang) earthquake, suggesting its source was either too far away or was too small.

It is important to distinguish between effects of vandalism or other ways of destruction from earthquake-related damage. It seems likely that some of the temples in Kumaun Himalaya were damaged during A.D. 1338–1338, 1574, and 1747–1830 by invading armies (Handa and Jain, 2009). As the smaller temples were not the usual targets of the attackers, we have used such structures to identify the effects of ground shaking. The pattern of rotation of pillars and of the sliding and offsets exhibited by the temple stones are visible evidence of ground shaking due to earthquakes.

Our field observations, backed also by inscriptional and historical archives, imply that a major earthquake may have occurred in central Himalayan region between eleventh and thirteenth centuries A.D. Almost all the temples of this period distributed in an area of 1000 km² showed a pattern of damage that we believe is due to ground shaking. The intact conditions of later generation temples in the same area, such as the Bageshwar temple, are useful to bracket the period of the earthquake at about twelfth century A.D. (Fig. 10b).

The historical and geological data provide evidence for at least two significant earthquakes that appear to have affected parts of the central gap during the twelfth–thirteenth century A.D. and again in A.D. 1803. From the disposition of heritage structures and relatively higher damage in Kumaun, we infer that the ~twelfth century earthquake was probably located near the border of Kumaun and eastern Nepal. The effect of the 1803 earthquake was minimal on the temples of Kumaun, an argument that helps to exclude the possibility of damage to the Katarmal temple from the 1803 earthquake. That the younger structures such as the Bageshwar temple (built in A.D. fifteenth century) have remained intact is another indication of the low level of damage from the 1803 earthquake in the Kumaun province.

Geological evidence for an older earthquake obtained from trenches near Almora dates the last major earthquake in the Central Himalaya at A.D. 1119–1292 (Rajendran and Rajendran, 2011). Thus, from the historical and geological data, the earthquake that affected the Kumaun region appears to have occurred during eleventh–twelfth century. The only earthquake known to have marginally damaged Qutb Minar—constructed in stages, with the final story completed by A.D. 1388—occurred in 1803, and the absence of any previous earthquake-related damage makes it difficult to reconcile with the magnitude $M \geq 8.6$ attributed to the 1505 Lo Mustang earthquake, as proposed by some workers (Bilham and Ambra-

seys, 2005). That many of the post-fourteenth century temples of Garhwal and Kumaun show no sign of earthquake-related damage is another point in support of its lower magnitude. The available historic data have not been of much help in constraining either the actual size of the 5 June 1505 Lo Mustang earthquake or its location. The twelfth–thirteenth century A.D. event probably had a far greater impact in the central Himalaya. Further, paleoseismological studies on the frontal faults of central Nepal provide geological evidence dated around A.D. 1255 (Sapkota *et al.*, 2013). Thus, we conclude:

1. The location of the 1803 earthquake was probably in the vicinity of Uttarkashi, Garhwal Himalaya.
2. The twelfth–thirteenth century earthquake (A.D. 1255?) is probably a great earthquake that ruptured the central Himalaya.
3. The historical data and the fault excavation studies remain inconclusive about the size and location of the 5 June 1505 earthquake. ❏

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