The Geological Society of America
Special Paper 471
2010

Historical earthquakes in Srinagar, Kashmir: Clues from the Shiva Temple at Pandrethan

Roger Bilham
Cooperative Institute for Research in Environmental Science and Department of Geological Sciences, University of Colorado, Boulder, Colorado 80309-0399, USA

Bikram Singh Bali
M. Ismail Bhat
University of Kashmir, Srinagar 190 006, Jammu and Kashmir, India

Susan Hough
U.S. Geological Survey 525 South Wilson Avenue, Pasadena, California 91106, USA

ABSTRACT

Srinagar, the capital city of Kashmir, has been shaken numerous times by earthquakes in the past millennium, most recently by damaging earthquakes in 1885 (M 6.2, 30 km to the west) and 2005 (M 7.6, 200 km to the west) with estimated EMS (European Macroseismic Scale) intensity VI–VII. Earthquakes in Kashmir in earlier historical times are known only from fragmentary archival sources. We present and analyze unique, repeat photographs of the Pandrethan Temple near Srinagar, which we conclude can provide clues to the severity of nineteenth-century earthquakes. Photos taken in 1868 and 1885 and recently show that the temple, a 5.5-m-square masonry-block structure constructed ca. A.D. 920, was undamaged by these two earthquakes. We conclude that displaced blocks visible in the earliest extant photograph are the result of stronger shaking in the past, the most probable causal earthquake being in 1828. Considering the fragility of the structure, we conclude that anything greater than EMS intensity IX would have caused structural collapse. We thus conclude that Pandrethan has not experienced EMS intensity greater than VIII in the past 200 yr, and possibly not in the past millennium.

INTRODUCTION: THE TEMPLE

The Shiva Temple at Pandrethan, at 74.860°E, 34.056°N, ~3 km east of Srinagar, Kashmir, is believed to have been constructed ca. A.D. 913–921. Visitors describing the temple have used various spellings in their accounts: Pándenthán (Moorcroft and Trebeck, 1841), Pandriton (Hügel, 1845), Pandrenton (Vigne, 1844), Pandrynton (Temple, 1887), and Pandrinton/Padrenton (Hunter, 1881). It consists of a symmetrical stone structure measuring 5.5 m square aligned N20W with a portal on each side. Its stone-block pyramidal roof is interrupted by an overhanging step and four small windows. Tradition has it that for religious reasons, the temple was erected at the center of a pond fed by a natural spring. Kak (1933), however, suggests that the temple was originally constructed in a swamp that has been drained, and that the temple may have been constructed as late as the early

Bilham, R., Singh, B., Bhat, I., and Hough, S., 2010, Historical earthquakes in Srinagar, Kashmir: Clues from the Shiva Temple at Pandrethan, *in* Sintubin, M., Stewart, I.S., Niemi, T.M., and Altunel, E., eds., Ancient Earthquakes: Geological Society of America Special Paper 471, p. XXX–XXX, doi: 10.1130/2010.2471(10).

twelfth century. The temple now tilts at ~5° as a result of uneven settlement in the past 1000 yr.

The temple was originally part of a much larger complex. The old city of Pandrethan is believed to have been founded by Asoka (ca. 200 B.C.), but to have been abandoned ca. A.D. 500 (Kak, 1933). In the tenth century it was reconstructed by a former Kashmiri King but burned down shortly thereafter. By the time of the Mughal administration (sixteenth century), most of its building materials had been scavenged for the construction of the new capital of Srinagar (Bernier, 1891; Temple, 1887). Stone relicts of early Buddhist stupas have surfaced from time to time, but the archaeological site is now covered by the Badami Bagh military cantonment, which has obliterated surface evidence of the former extent of the old city. The temple itself lies hidden from public view within the walls of the cantonment.

In Figure 1, we show the 1885 earthquake epicentral region with smoothed EMS (European Macroseismic Scale) intensity VI and VII contours to the east and west of Pandrethan. The 1885 earthquake was assessed at Mw = 6.3 by Ambraseys and Douglas (2004), and as Mw = 6.2 by Szeliga et al. (2010). We visited Pandrethan in early December 2008 and again in June 2009 to learn what could be deduced about former earthquake shaking from damage to the temple. However, extensive repairs have been undertaken in recent years, leaving few clues about former damage. Fortunately, the structure was photographed both before and after the 1885 earthquake, and before preservation was attempted.

The temple was constructed from close-fitting dressed limestone blocks, with no evidence for cement between courses. Four squat, equally spaced columns support a hollow pyramidal roof of tapered blocks (Fig. 2). It is not known whether pins hold the columns in alignment, although it is possible, because the practice is evident in the pillars of the Martand Sun temple, which was constructed at the same time using similar architectural features. The rectangular and trapezoidal roof blocks were probably not doweled, since they are smaller and ornamental in function. The recent repairs and realignment of the roof blocks since Kak's visit in 1933 have incorporated liberal quantities of cement. The ceiling of the interior described by Cole (1869) and Kak (1933) is surfaced by three layers of stone blocks that structurally serve to hold the walls together. Large triangular blocks first cover the stout corner walls and overhang the interior corners. The resulting enclosed diagonal square space is overlain by blocks parallel to the sides of the structure, and these in turn are covered by a single ceiling block. The lower surfaces of these ceiling layers are embellished with carvings (Fig. 2).

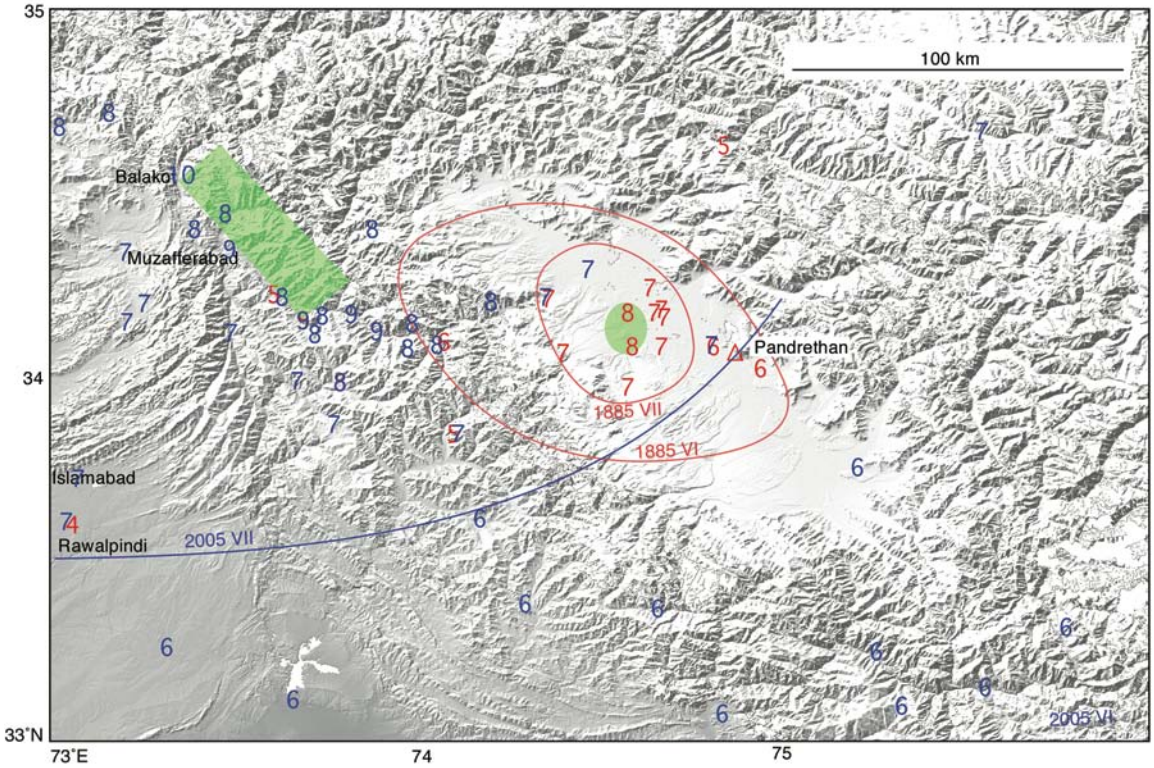
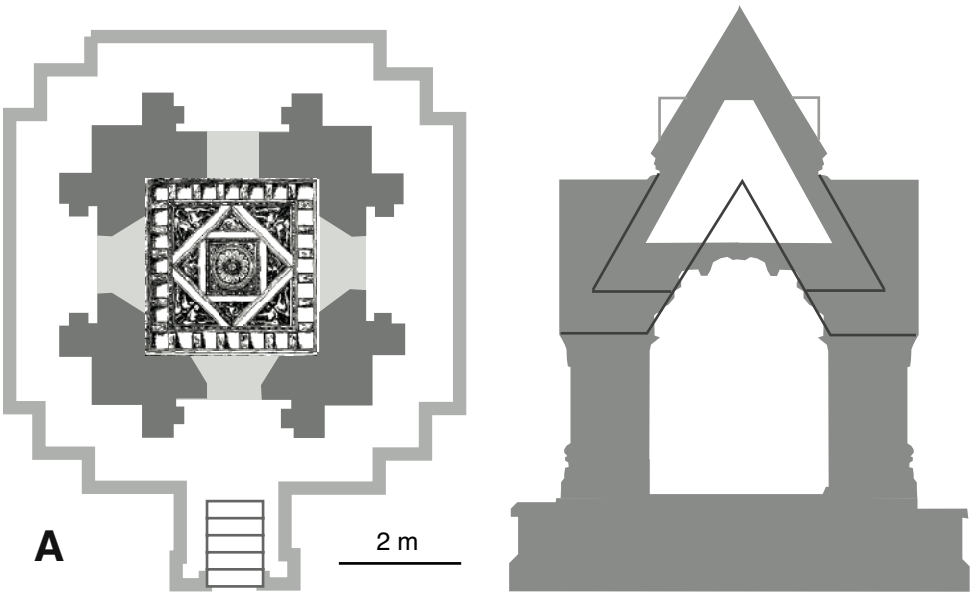


Figure 1. Kashmir Valley shaking intensities (red—1885; blue—2005). EMS (European Macroseismic Scale) intensities are shown as assessed by Martin and Szeliga (2010). The 1885 earthquake is believed to have been Mw 6.2, roughly 50 km to the west of Pandrethan, resulting in EMS VI near the temple. Intensities from the 2005 Mw 7.6 Kashmir earthquake, which occurred 200 km west of Pandrethan, were VI to VII. Areas in green indicate epicentral regions.



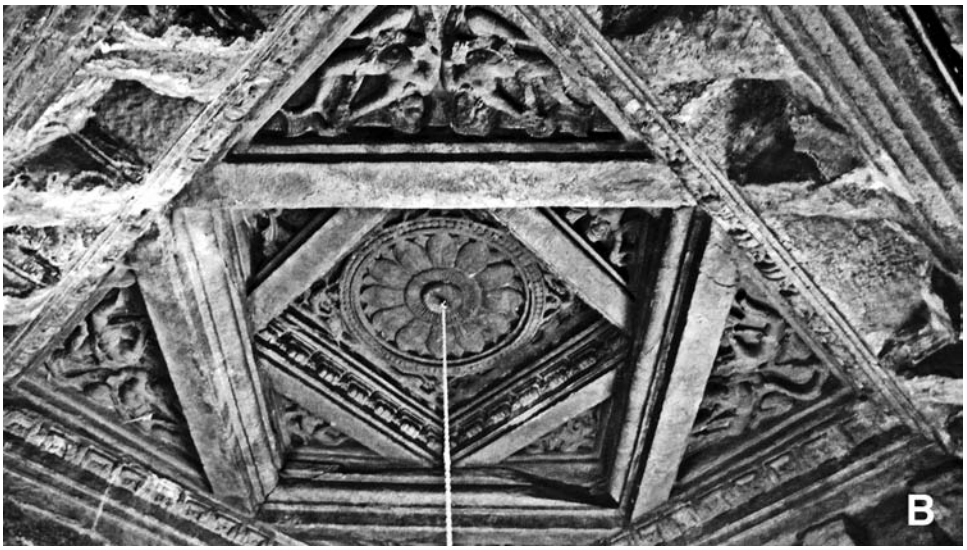


Figure 2. (A) Plan and section through the Pandrethan temple after Kak (1933). Kak's sketch of the decorated ceiling from below is placed on his plan view facing upward. The plinth is currently underwater and extends to an unknown depth. The summit pyramid has been lost and replaced by an artificial capstone. Cunningham (1848) suggested that the original may have consisted of a frieze supporting a third overhanging pyramid, as is evident in other Kashmir temples of similar age. (B) View of the decorated ceiling, June 2009, illustrating absence of impact damage.

In 1665, Francois Bernier (1891) almost certainly visited the temple during his visit to Kashmir with Aurangzeb. He mentions the numerous ruins near Srinagar but describes in detail only the larger temples in the valley. In 1823, Moorcroft and Trebeck (1841) visited the temple twice. On their second visit on 15 May, Trebeck, in the absence of a boat, swam inside to describe its decorated ceiling to Moorcroft. They were disappointed to find no inscriptions within the temple. In 1835, Baron Hügel (1845) contented himself with a view from the banks of its surrounding pond, speculating erroneously on Buddhist sculptures contained therein. In the same year, the temple was visited by Vigne (1844), who sketched it. According to Cunningham (1848), Elphinstone visited the temple in 1846 and discovered the interior coated with plaster. Cunningham (1848) had the plaster removed and made a sketch of the internal ceiling, and the exterior setting of the temple. This outside view was reproduced by Fergusson (1867), who repeated Cunningham's speculation that a third overhanging tier of triangular roof may have been lost. The fact that Trebeck noted the large lotus design at the center of the ceiling (Fig. 2) that was sketched and described by Cunningham suggests that the plastered layer was not complete, or not thick. In 1859, Richard Temple (1887) described and sketched the structure, but his sketches, like those of Vigne, were not included in his published accounts. In 1860, Knight (1863), lacking a boat, sketched Pandrethan from the banks of the pond.

In 1868, the Pandrethan temple was photographed from the south by John Burke (Fig. 3) and is one of three views published by Cole (1869), who writes:

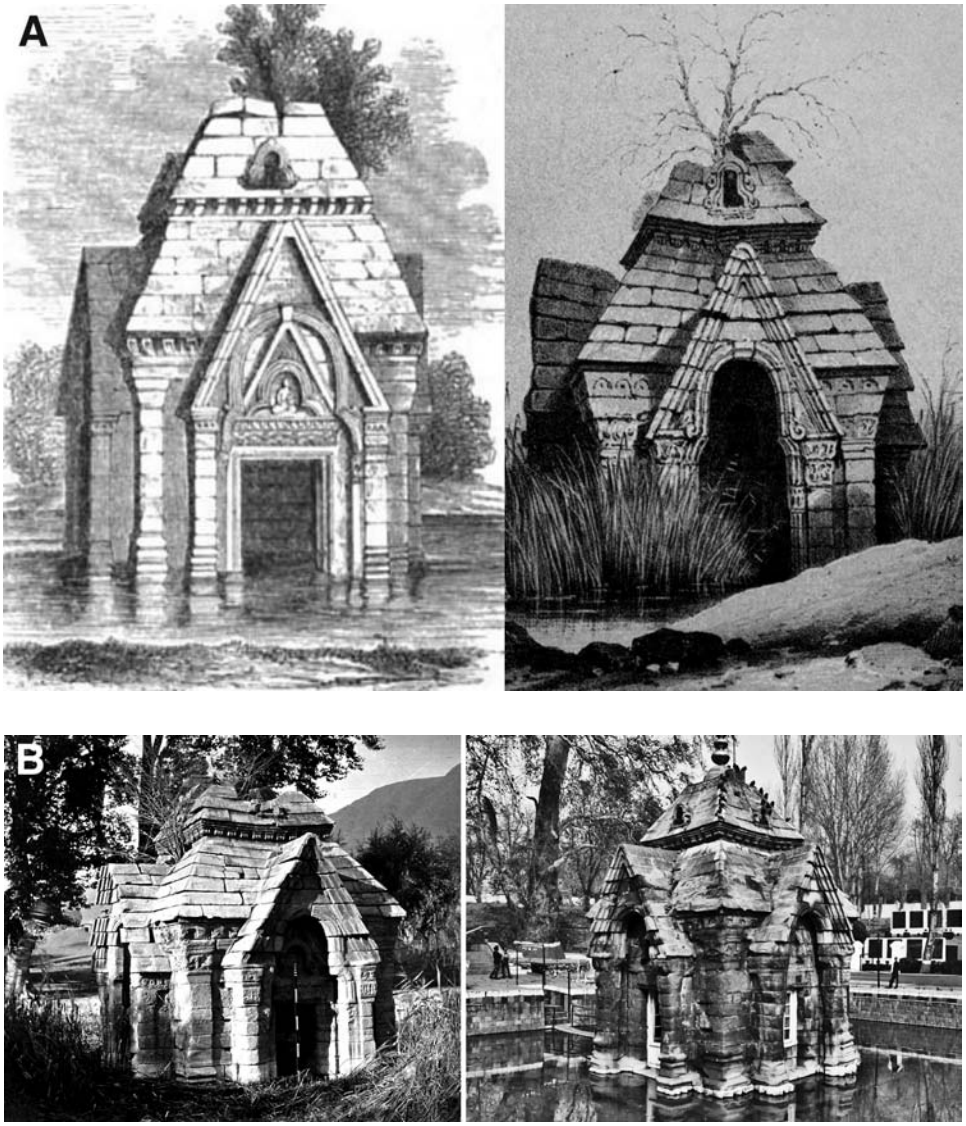


Figure 3. (A) Our earliest glimpse of Pandrethan (left) may be a sketch published by Cunningham (1848), here reproduced by Fergusson (1867), which shows a tree with abundant foliage sprouting from the roof. In the 18 July 1860 painting of Pandrethan from the north (Knight, 1863, p. 354), the internal tree is devoid of leaves (right). "The building which alone remained in at all a perfect state was situated in a sort of pond or tank of slimy green and was quite inaccessible without a boat." He complains of mosquitoes plaguing his sketching and ants eating his paints. (B) Left: John Burke's 1868 photo of the Pandrethan temple from the south, compared to approximately the same view in December 2008. The three upper roof courses were missing on the SE side in 1868, but are present, though dislodged on the NW side (Fig. 4). Note scale with 1 ft gradations in doorway on left.

The small village of Pandrethan is situated on the Jhelum, about a mile and a half to the south-east of Srinagar....The Temple is close to the village, and stands in the centre of a tank of water....At the time of my visit, the water was about two feet over the floor of the Temple, and I had to obtain a small boat to enable me and my surveyors to take measurements. The stone ceiling is elaborately carved in bas-relief figures, and it is one of the most perfect pieces of ancient carving that exists in Kashmir....The pyramidal roof is divided into two portions by an ornamental band. The corner pilasters are surmounted by carved capitals, and the pediments of the porches appear to have terminated with a melon-shaped ornament. The ceiling is formed of nine blocks of stone; four resting over the angles of the cornice, reduce the opening to a square, and an upper course of four stones still further reduces the opening, which is covered by a single block decorated with a large lotus. (p. 42)

The survival unscathed of Pandrethan's ornately carved ceiling (Fig. 2) to the present suggests that total collapse of the monument and subsequent reconstruction have not occurred, although one cannot exclude the possibility that the structure was damaged in early historical times and repaired by expert masons.

The lower thirds of Oldham's 1887 glass half-plate negatives have been damaged by water, and it was necessary to reassemble the broken halves of his NW view digitally. The date of the photo is recorded as August 1887 in the Calcutta photographic archive of the Geological Survey of India, and Oldham's visit is recorded by Tom LaTouche in a letter from Srinagar to his mother dated 12 August 1887 (Bilham, 2008).

The early sketches, the 1868 photograph, and two others reproduced by Cole (1869) show many of the same roof blocks in the temple displaced from their original positions. The tree that grew from, or through the roof in 1887, was evidently growing in 1848 and in 1860. The similarity between the 1868 and 1887 views suggest that shaking in 1885 was insufficient to cause further damage to this masonry structure, and hence that

accelerations in Pandrethan in 1885 were less than intensity VII, consistent with shaking estimates from other sources (Martin and Szeliga, 2010). No damage was done to the temple in 2005 when intensity VII shaking was recorded in nearby Srinagar.

One is left to consider the damage to the temple that is evident in the 1868 photograph. The damage to the roof as well as the displaced blocks lower in the structure are, we conclude, more consistent with earthquake damage than vandalism or natural weathering. In particular, close inspection of the roof shows consistent offsets of the six lower courses of roofing blocks, no offset of the decorated overhang and sequentially increasing offsets of the five uppermost courses (Fig. 4), suggestive of oscillatory jostling. The uppermost blocks are perched precariously. Vandals, had they removed the missing pyramid, would surely have toppled this penultimate layer (Fig. 5).

DISCUSSION

Buildings that survive earthquakes may do so for several reasons: their structure and assembly may be unusually resilient to any form of shaking (e.g., the pyramids of Egypt), they may be isolated by their local seismic setting (a vibratory node or some form of base isolation), or they may have been reconstructed following damage. Thus, although it is tempting to consider Pandrethan a strong motion seismometer that has recorded the past thousand years of shaking in the Kashmir Valley, conclusions about the maximum severity of shaking are likely to be purely local at best, and completely wrong, if major repairs have been made following large earthquakes.

The fact that the Pandrethan temple survived the two most recently damaging earthquakes in Kashmir with no apparent damage, however, provides us with an indication of its resilience to moderate (EMS intensity VI–VII) shaking. We examine details of its construction and setting that relate to its vulnerability: what intensity caused the shaking recorded in nineteenth-century photographs, and what intensity of shaking would it take to destroy the temple?

Construction

Its masonry construction notwithstanding, the symmetry of the Pandrethan temple (Fig. 2), and its compact design appear to be well disposed to resist moderate shaking. The thickness and structure of its foundations are unknown, but though close to the hill, they are unlikely to extend to bedrock. The tilt of the temple is easy to recognize in 1859 and 1887 photographs relative to the surface of the pond. Although the base has settled, it has not flexed, nor is there any sign of differential settlement other than tilt and roof sag. Hence, the foundations have behaved monolithically, again a recognized feature of sound seismic resistant design.

Geological and Historical Setting

If the local site experiences significantly lower amplification than the surrounding region, then intensities in any earthquake are likely to have been locally lower than the overall intensity experienced in the region. Although there is no historical support for the notion, it is possible that the old city of Pandrethan was damaged by an earthquake, leading to the establishment of the new capital 3 km to the west. If so, the survival of the temple may imply that the local geology at the temple site is associated with lower site amplification than occurs in the old city of Pandrethan. Though sited 100 m from the Jhelum (Figs. 6 and 7), the temple has been constructed near the slope-break to the hills to the north. The spring that fed the tank, or pond, in which the temple is located, issues from the base of this hill.

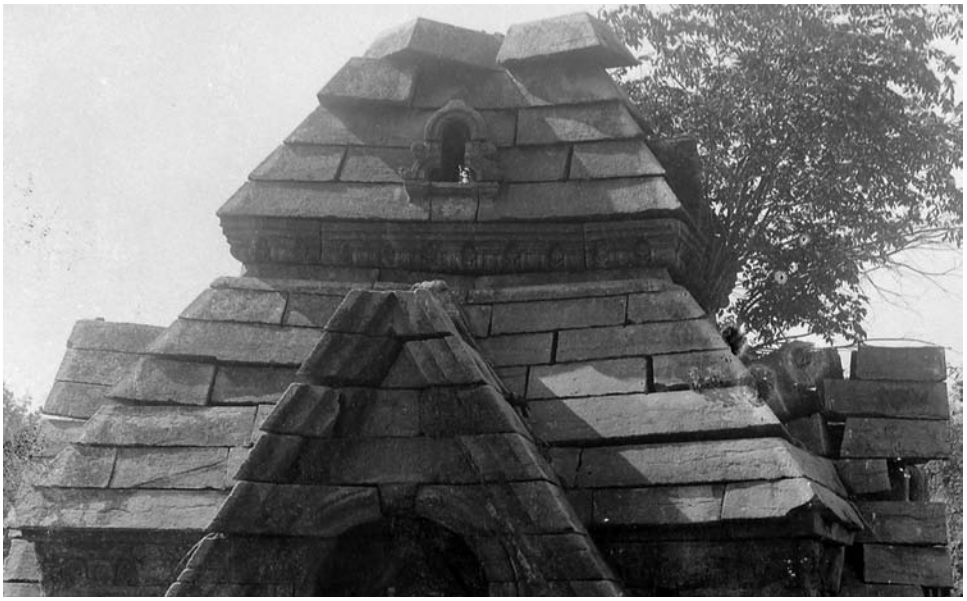


Figure 4. Close-up of Oldham's 1887 view of the temple from the NW. Note the parted SW gable (lower right) with its missing third block, also missing in Burke's 1868 photo and Kak's 1933 sketch. Note the irregular offsets to the SW of the six lower blocks, and sequentially increasing offset of the five upper blocks. The summit pyramid has been lost, and is now replaced by a modern dome with a triple-orbed pinnacle.

Figure 5. Pandrethan Temple now, and before and after the 1885 earthquake (Cole, 1869; Oldham, 1887). Left-hand panels are viewed from NW and right-hand panels from NNW (see Fig. 6). Roof vegetation was recorded in a photograph by Marion Doughty (1902).

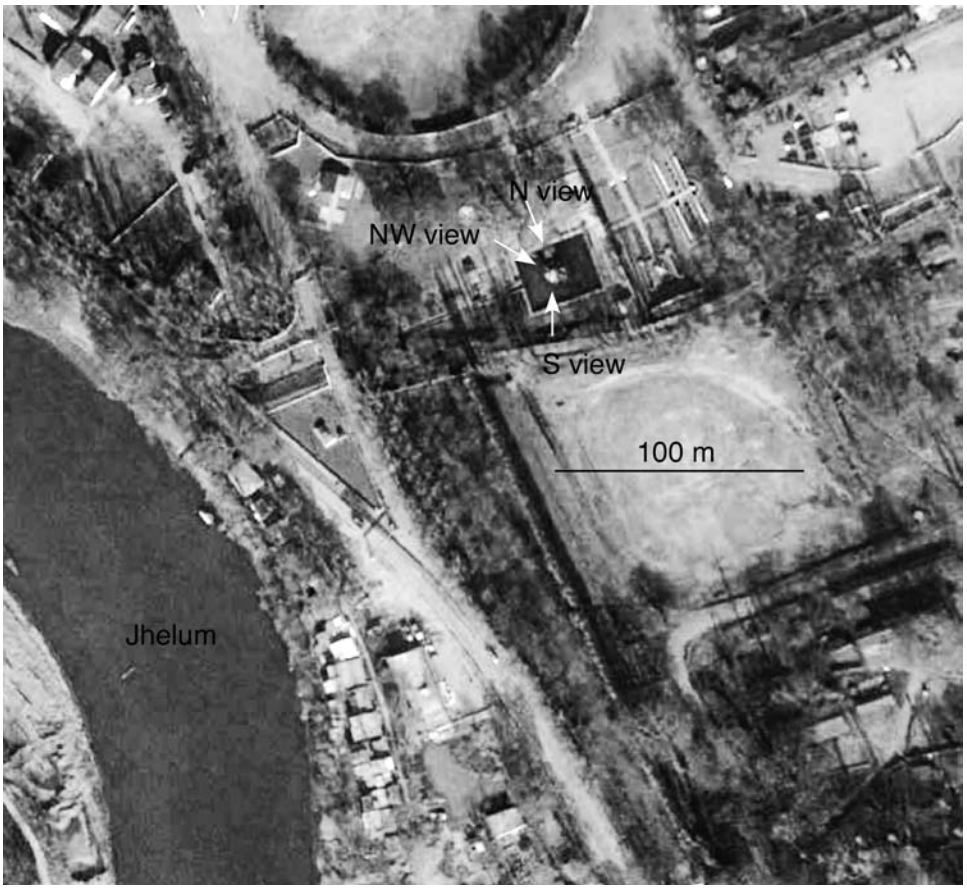


Figure 6. Google map of Pandrethan temple site showing view-directions of photos and proximity to the Jhelum.

Figure 7. The temple prior to repairs in 1901 (Doughty, 1902). A boat is visible in the foreground.

What Shaking Intensity Would Cause the Temple to Collapse?

We speculate that the temple could probably be shaken with intensity VIII without collapse, based on the dissipative effects of its blocks, especially if the columns are held in place with alignment pegs. Intensity XI or X would probably cause collapse. The weight of the triangular roof would tend to bring down the entire structure if the building drifted significantly, and it is thus difficult to envisage partial collapse.

Had collapse occurred we should expect to see damage to the stone blocks and ornamentation—splintered edges of blocks, or fractured corners. Some of the wall blocks are cracked, but the only substantial corner fracture damage seems to be to the roof overhang on the south side. The original summit pyramid is missing and this may have been projected southward during shaking, splintering the overhang as it descended. The ornately carved ceiling is apparently undamaged and is frequently cited as the best-preserved tenth-century stone carving in Kashmir (Kak, 1933; Bernier, 1997). We consider it unlikely that the stonework of the ceiling could have survived collapse and reconstruction, but we cannot exclude the possibility that the temple was refurbished by expert masons after an early historical earthquake.

Several stone blocks in the roof remain misaligned. These, and those that were repositioned in recent repairs, testify to the building being shaken to the extent that many blocks were moving differentially during a former earthquake. The displaced blocks are found at high levels (in the roof) and not at lower levels near the pediment.

Which Earthquake(s) Damaged the Temple?

In a hand-written note on the 1887 protective envelope that contained his half-plate glass negative, R.D. Oldham states "Temple at Pandrethan, Srinagar, showing stones displaced by earthquakes." Writing this 2 yr after the 30 May 1885 Kashmir valley earthquake, his use of the plural indicates that he does not ascribe damage to any single earthquake. He was, moreover, in the Andaman Islands at the time that the 1885 earthquake occurred. From earlier photographs, it is clear that the disposition of the uppermost blocks is identical before and after the May 1885 earthquake. The 1885 earthquake resulted in estimated EMS intensity VI shaking to the east and west of Pandrethan. We conclude that that the damage to the temple was the result of one or more earthquakes prior to 1868. Since the temple was unaltered by estimated intensity VII shaking in 2005, we deduce that the causal earthquake that shifted the summit blocks was caused by shaking with intensity VIII or IX.

In Table 1, we list earthquakes known to have occurred in the Kashmir Valley in the past millennium, and estimates of maximum shaking intensity deduced from the somewhat sparse descriptions of damage they contain, mostly from Srinagar (Iyengar and Sharma, 1998; Iyengar et al., 1999; Bashir et al., 2009). With the caveat that these estimates of shaking are necessarily very approximate, earthquakes in 1555, 1736, 1779, 1784, and 1828 appear to be candidate events.

We argue for later rather than earlier damage for the following reason. The tree that grew from, or through the roof in 1887, and visible in Knight's 1860 sketch, was evidently growing in 1868 and 1887. The temple was obviously in a neglected condition prior to 1868, but the rate of growth of the tree suggests that it had not been long established. We thus conclude that the displacement of the summit blocks probably occurred in the previous several decades. The most likely event then to have caused the roof damage is the 1828 earthquake, or possibly the late eighteenth-century events.

What little is known of the 1828 earthquake is mentioned by Vigne (1844), who visited Kashmir in 1839. Although he was not in Kashmir at the time of the earthquake, his account of its effects 11 yr earlier includes numerous details that he must have assembled from eyewitnesses. He writes as follows (vol. 1, p. 281–283):

> On the night of the 26th of June, 1828, at half past ten, a very severe shock was felt, which shook down a great many houses, and killed a great number of people: perhaps 1000 persons were killed, and 1200 houses shaken down; although; being built with a wooden framework, the houses were less liable to fall than an edifice of brick or stone. The earth opened in several places about the city; and fetid water, and rather warm, rose rapidly from the clefts, and then subsided. These clefts, being in the soil, soon closed again, and scarcely left any traces. I saw the remains of one fifteen yards long and two wide; but it was filled up, or nearly. Huge rocks and stones came rattling down from the mountains. On that night only one shock took place; but just before sunrise there was another, accompanied by a terrific and lengthened explosion, louder than a cannon. On that day there were twenty such shocks, each with a similar explosion.
>
> The inhabitants were, of course in the open country. The river sometimes appeared to stand still, and then rushed forward. For the remaining six days of Zilheja, and the whole of the two next months of Moharrem and Safur, there were never less than 100, and sometimes 200 or more shocks in the day, all accompanied with an explosion; but it was remarked, that when the explosion was loudest, the shock was the less. On the sixth day, there was one very bad shock, and on the fifteenth, at three o'clock, was the worst, and there were three out of the whole number that were very loud.
>
> At the end of the two above-mentioned months, the number decreased to ten or fifteen in the twenty-four hours, and the noise became less, and the earthquakes gradually ceased. About this time the cholera made its appearance. A census of the dead was taken at first, but discontinued when it was found that many thousands had died in twenty one days.
>
> In Kashmir there had been no great earthquake before, within the memory of any living person, excepting one about fifty years ago, which was rather severe, that lasted, at intervals, for a week. An earthquake is mentioned in Prinsep's tables as having taken place in A.D. 1552. Shocks are now common, and the houses are built with a wooden framework, so as to resist them. (p. 406)

Vigne (1844) knew of the Pandrethan temple, "the curious building at Pandrynton, near the present city, which stands in a

TABLE 1. HISTORICAL EARTHQUAKES REPORTED IN KASHMIR (PRINCIPALLY SRINAGAR) SINCE THE TENTH CENTURY

	Date	Maximum estimated intensities		Comments
		Iyengar and Sharma (1998); Iyengar et al. (1999)	Bashir et al. (2009)	
1	1123	–		No details.
2	24 September 1501	VII		Three months of aftershocks.
3	1552			(not an earthquake) Cited by Vigne and copied by others but a misinterpretation of Prinsep's p. 312 one-line entry on the ascendency of Ibrahim II and the notable terminal event of his short reign.
4	1 September 1555	XII		Earthquakes continued for several (7) days. Landslides and liquefaction. Several accounts (Ambraseys and Jackson, 2003), some assign date as 1554.
5	ca. 1560/1561	–		No details.
6	1569–1577	–		No details.
7	23 June 1669	IV		The buildings rocked like cradles. No loss of life.
8	ca. 1678/1679	VII		Persistent shaking. Reconstruction needed.
9	1683			Bashir et al. (2009).
10	24 March 1736	VIII		Earthquakes for 3 mos. Buildings of the city and hamlets razed to the ground (Bashir et al., 2009, list as 1735).
11	1779	VII		Srinagar and hamlets flattened and aftershocks for 14 d. People took shelter in the open. Bashir et al. (2009) list event as 1778; Oldham (1883) as 1780.
12	ca. 1784/1785	VIII		People thrown. Shocks persisted 6 mo.
13	1803		VII	Earth ripped apart, houses collapsed, people buried under walls (Bashir et al., 2009).
14	26 June 1828		VIII	Vigne (1844) 1200 houses collapsed, 15 d of aftershocks (Bashir et al., 2009).
15	1863			Bashir et al. (2009); Lawrence (1895) indicates 1864.
16	30 May 1885		VI	Bashir et al. (2009); Jones (1885) M = 6.2–6.3 (Ambraseys and Douglas, 2004; Szeliga et al., 2010).
17	8 October 2005		VII	Mw = 7.6 instrumental period.

Note: Discrepancies in timing of a year or more can occur where historians are using secondary texts, or where chronological conversions are sometimes ambiguous. We have attempted to reconcile close dates as single events, and have indicated known discrepancies. Item 3 is a spurious event that should not be repeated. The estimated intensities are no more than educated gues ses by the authors cited.

tank," and although the Cambridge architectural historian R. Willis describes a sketch that Vigne sent him of the building, and of others, Vigne omits the sketch of Pandrethan from his book, as does Temple (1887) from the edited version of his father's 1859 diary. Vigne groups Pandrethan among the top four well-preserved Hindu "ruins," which visitors should see in Kashmir (if short on time to see all 70–80 surviving monuments). Of Pandrethan, Vigne comments that "the upper part was certainly pyramidical," implying that the summit cap-stone was absent in 1839. He also remarks that many of ruins were once much taller but have "been diminished by earthquakes, even within the memory of man" (p. 391).

We conclude from these descriptions of lateral spreading and structural collapse in Srinagar in 1828 that Pandrethan was more severely shaken in 1828 than in 1885 and 2005. We provisionally ascribe the damage to the temple to this date, although clearly it may have inherited damage from previous earthquakes (Table 1). The earthquake mentioned by Vigne as occurring ~50 yr previously would be the 1778/1779 or 1784/1785 earthquakes, for which independent descriptions exist (Iyengar and Sharma, 1998; Bashir et al., 2009), which appear also to have been a main shock–aftershock sequence persisting for 2 wk.

Prinsep's 1552 alleged earthquake (Prinsep, 1858, p. 312), cited by Vigne (1844) and repeated by Constable (p. 395 footnote *in* Bernier, 1891) and by Bhat et al. (2009), refers to the start of the rule of Ibrahím II, not to the date of events during his short rule, which terminated in the year of the 1555 earthquake. In table 75, in which he summarizes Ferishta's list of kings of Kashmir, Prinsep's 960 A.H. (A.D. 1552) entry consists of the seven words "Ibrahím II., set up by Daulat Chakk: earthquake" and is followed, on the next line, by an entry for 1555 identifying the succeeding king as Ism'aíl. That is, the 1552 event is bogus, and although listed here, should not be repeated (Table 1).

Pandrethan as a Strong-Motion Seismometer?

The vivid account Vigne has left us for the 1828 earthquake appears to be largely based on effects observed in Srinagar and

its surroundings. The accounts of loud explosions accompanied by lesser shaking may refer to P waves from nearby aftershocks unaccompanied by surface waves. In contrast, accounts for the 1555 earthquake have survived from several parts of the valley, which seismologists have taken to imply a significant earthquake with large rupture zone (Ambraseys and Jackson, 2003). Others have concluded that this large rupture may have occurred beneath the Pir Pinjal (Hough et al., 2009). Iyengar and Sharma (1998) assigned maximum intensity XII to the 1555 earthquake, but it is not clear how this intensity was quantified or where it is considered applicable. Historical accounts tend to record the most severe damage, or the most remarkable effects of earthquakes. We suspect, however, that intensity XII (or even IX) shaking would have destroyed the Pandrethan temple. Ambraseys and Jackson (2003) estimated an approximate magnitude of 7.6 based on its felt area, but this magnitude should be used with caution.

If one assumed that the Pandrethan temple has survived unscathed since its construction, this suggests that shaking in the 1828 earthquake was probably more severe at this location than shaking in 1555. The descriptions of lateral spreading, river reversals, and weeks of aftershocks indicate that a major earthquake occurred in 1828 during the Sikh administration of the valley (1819–1846), but the absence of reports from other parts of the valley, or from large cities in northern India (e.g., Lahore or Amritsar), suggests that the earthquake, unlike the 1555 earthquake, was probably close to Srinagar, and not beneath the Pir Pinjal. That shaking at any one site is more severe during a moderate earthquake than a larger event is not surprising, because shaking intensity at any site depends on myriad factors, such as source radiation pattern, distance to the event (or distance to largest asperities within an extended rupture), and three-dimensional propagation effects. However, conclusions about earlier historical events are tenuous at best because one cannot know if reconstruction/repair was undertaken in early historical times by devotees of the temple. It is further possible that early earthquakes weakened the temple, rendering it more susceptible to damage in subsequent earthquakes.

CONCLUSIONS

The survival of the small masonry tenth-century Shiva Temple at Pandrethan, near Srinagar, through more than a dozen damaging earthquakes suggests that shaking greater than intensity IX has not occurred in the past 200 yr, and possibly the past 1000 yr. The case is based on "calibration" earthquakes in 1885 and 2005 that shook the temple with intensities of VII or less. From photographs in 1868 and 1887 that show the rapid growth of a small tree that grew through cracks in its roof, we deduce that the temple had been damaged by an earlier earthquake, probably in 1828, and/or between 1778 and 1885, in which local intensities must have exceeded VIII.

The absence of damage to the ornate ceiling of the Pandrethan temple and most of the temple blocks suggests that accelerations in the past millennia have been insufficient to destroy the structure, and cause it to be reassembled from a heap of rubble. One would thus infer an absence of intensity >IX shaking in the past millennium. This conclusion is, however, more tenuous than the conclusions one can draw about shaking during nineteenth- and twentieth-century earthquakes.

Estimates of shaking intensity at a single site provide little indication of earthquake magnitude; instrumental recordings of recent earthquakes reveal that very high (PGA [peak ground acceleration] >1 g) accelerations can be generated by relatively moderate (M 6.5–7) earthquakes, while surprisingly low accelerations are sometimes recorded in the near field of very large events. Our findings are thus clearly insufficient to draw conclusions about the magnitudes of earthquakes that have shaken Kashmir Valley in the past millennium, nor do our results provide upper limits to the shaking experienced in historical times in nearby Srinagar, where thick sediments in the Jhelum River valley and around lakes are likely to amplify shaking significantly. Careful analysis of other ancient monuments in the valley, in particular dating of damage, may usefully supplement the sparse historical record.

We note in closing that the Pandrethan Temple serves as both an encouraging and a cautionary case study: encouraging to the extent that the structure does provide useful clues that help elucidate the earthquake history of the region; cautionary to the extent that, if not for the fortuitous existence of repeat historical photographs, one could easily be led to the same obvious but mistaken conclusion implied by R.D. Oldham's 1887 photograph, that damage to the temple evident in 1887 was caused by the 1885 earthquake.

ACKNOWLEDGMENTS

We thank the British Library for permission to publish Burke's 1859 photo, and the director general of the Geological Survey of India for permission to reproduce R.D. Oldham's photographs of Pandrethan. The investigation was funded by the U.S. National Science Foundation.

REFERENCES CITED

Ambraseys, N.N., and Douglas, J., 2004, Magnitude calibration of North Indian earthquakes: Geophysical Journal International, v. 158, p. 1–42, doi: 10.1111/j.1365-246X.2004.02323.

Ambraseys, N.N., and Jackson, D., 2003, A note on early earthquakes in India and southern Tibet: Current Science, v. 84, p. 570–582.

Bernier, F., 1891, Travels in the Mogul Empire, A.D. 1656–1668 (translated by I. Brock and revised by A. Constable): London, Constable & Co., 497 p.

Bernier, R.M., 1997, Himalayan Architecture: Madison, Fairleigh Dickinson University Press, 196 p.

Bashir, A., Bhat, M.I., and Bali, B.S., 2009, Historical record of earthquakes in the Kashmir Valley: Journal of Himalayan Geology, v. 30, no. 1, p. 75–84.

Bilham, R., 2008, Tom LaTouche and the Great Assam Earthquake of 12 June 1897; letters from the epicenter: Electronic supplement: Seismic Research Letters, v. 79, no. 3, p. 426–437. (Transcriptions of LaTouche's letters 1882–1913 illustrated by archival photographs from Calcutta and London: http://www.seismosoc.org/publications/SRL/SRL_79/srl_79-3_hs.html [accessed 3 August 2010].)

Burke, J., 1868, "Temple of Meruvarddhanaswami at Pandrethan near Srinagar," British Library: Shelfmark: Photo 981/1(40).

Cole, H.H., 1869, Illustrations of Ancient Buildings in Kashmir, India Museum: London, India Museum, W. H. Allen and Co., publishers to the India office, 31 p.

Cunningham, A., 1848, An essay on the Arian Order of Architecture, as exhibited in the Temples of Kashmir: Journal of the Asiatic Society of Bengal, September 1848, p. 241–327.

Doughty, M., 1902, Afoot through Kashmir Valleys: London, Sands and Co., 276 p.

Fergusson, J., 1867, History of Indian and Eastern Architecture: London, Murray, v. 3, 756 p.

Hough, S.E., Bilham, R., and Bhat, I., 2009, Kashmir Valley megaearthquakes: American Scientist, v. 97, no. 1, p. 42–49, doi: 10.1511/2009.76.1.

Hügel, C.A., 1845, Travels in Kashmir and Panjab: Containing a Particular Account of the Government and Character of the Sikhs (translated by T.B. Jervis, East India Company): London, J. Petheram, v. 1845, 423 p.

Hunter, W.W., 1881, Gazetteer of India, v. VIII, 284 p.

Iyengar, R.N., and Sharma, D., 1996, Some earthquakes of Kashmir from historical sources: Current Science, v. 71, no. 4, p. 300–331.

Iyengar, R.N., and Sharma, D., 1998, Earthquake History of India in Medieval Times: Roorkee, Central Building Research Institute, 124 p.

Iyengar, R.N., Sharma, D., and Siddiqui, J.M., 1999, Earthquake history of India in medieval times: Indian Journal of History of Science, v. 34, no. 3, p. 181–237.

Jones, E.J., 1885, Report on the Kashmir earthquake of 30 May 1885: Records of the Geological Survey of India, v. 18, no. 4, p. 221–227.

Kak, R.C., 1933, Ancient monuments of Kashmir: Delhi, India Society, 172 p., 1971 reprint.

Knight, W.H., 1863, Diary of a Pedestrian in Cashmere and Thibet: London, Bentley, 385 p.

Lawrence, W.R., 1895, The Valley of Kashmir: Gulshan, 478 p., 2007 reprint.

Martin, S., and Szeliga, W., 2010, A catalog of felt intensity data for 589 earthquakes in India, 1636–2008: Bulletin of the Seismological Society of America, v. 100, no. 2, p. 562–569, doi: 10.1785/0120080328.

Moorcroft, W., and Trebeck, G., 1841, Travels in the Himalayan Provinces of Hindustan and the Panjab, in Ladakh and Kashmir, in Peshawar, Kabul, Kunduz, and Bokhara from 1819 to 1825, Volume 2: London, J. Murray, 565 p.

Oldham, R.D., 1887, Photographic Archives #257(288): Temple at Pendrethan showing stones displaced by earthquakes, location: near Srinagar; and #258(289): Temple at Pandrethan, location: Srinagar, Kashmir: Calcutta, Geological Survey of India.

Oldham, T., 1833, A catalogue of Indian earthquakes from the earliest times to the end of AD 1869 (edited by R.D. Oldham): Memoirs of the Geological Survey of India, v. 19, no. 1, p. 163–215.

Prinsep, J., 1858, Essays on Indian Antiquities, Historic, Numismatic, and Palæographic, of the Late James Prinsep: To which are Added His Useful Tables, Illustrative of Indian History, Chronology, Modern Coinages, Weights, Measures, Etc., Volume 2: London, J. Murray, 336 p.

Szeliga, W., Martin, S., Hough, S., and Bilham, R., 2010, Intensity, magnitude, location and attenuation in India for felt earthquakes since 1762: Bulletin of the Seismological Society of America, v. 100, no. 2, p. 570–584, doi: 10.1785/0120080329.

Temple, R., 1887, Diary of a Journey into Jammun and Kashmir between 8th June and 8th July 1859, *in* Temple, R.C., ed., Journals kept in Hyderabad, Kashmir, Sikkim and Nepal, v. 2: London, W. H. Allen, 303 p.

Vigne, G.T., 1844, Travels in Kashmir, Ladak and Iskardo, the Countries Adjoining the Mountain Course of the Indus, and the Himalaya, North of Panjab, with Map, Volume 1 (2nd ed.): London, H. Colburn, 406 p.

Manuscript Accepted by the Society 19 May 2010