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Key Points:

- Previous interpretation of 800 km rupture along Himalayan Frontal Thrust compromised by incorrect interpretation of trench logs
- Misuse of Oxcal has lead to unsubstantiated assertion that 1255 A.D. earthquake ruptured specific 800 km section of Himalayan Frontal Thrust
- Defining extent of rupture during the historically damaging Nepal earthquake of 1255 A.D. remains problematic

Supporting Information:

- Supporting Information S1

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On a flawed conclusion that the 1255 A.D. earthquake ruptured 800 km of the Himalayan Frontal Thrust east of Kathmandu

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Abstract A reexamination of the observations and analysis recently reported to conclude that an 800 km section of the Himalayan Frontal Thrust ruptured in 1255 A.D. shows that the conclusion is flawed and without merit because of misinterpretations of trench logs and incorrect interpretation of radiocarbon statistics.

1. Introduction

A recent article in Geophysical Research Letters put forth by *Mishra et al.* [2016] "concludes that the 1255 [AD] medieval earthquake was a giant event with a 800 km rupture length" and thus "validate(s) that the Himalayan continental subduction zone is capable of producing giant earthquakes approaching M_w 9.0" (Figure 1 and *Mishra et al.* [2016]). The suggestion that the Himalayan Frontal Thrust (HFT) might produce megaearthquakes with magnitudes approaching 9 or greater is not new [e.g., *Kumar et al.*, 2006]. However, the idea is new that there exist sufficient observations to conclusively show that such an earthquake ruptured the specific 800 km section of the Himalayan frontal thrust that extends westward from Harmutti, India to Sir Khola, Nepal. We here reanalyze the data on which *Mishra et al.* [2016] rest their conclusions. Our analysis shows that both the new paleoseismic data presented in their paper and their reanalysis of radiocarbon ages reported in paleoseismic studies of other investigators used to put forth this conclusion is characterized by numerous and fundamental flaws in both methodology and observation. Recognition of these flaws shows their conclusions to have no basis.

2. Reevaluation

The year 1255 A.D. corresponds to an historical earthquake that produced significant damage and claimed one third of Kathmandu's population [*Pant*, 2002]. The extent of the Himalaya Frontal Thrust interpreted by *Mishra et al.* [2016] to have ruptured in 1255 A.D. is reproduced in Figure 1. Their conclusion is based largely on the analysis of five sites, each shown in Figure 1. Each is reexamined here.

2.1. Panijhora

We begin with their analysis of a trench exposure at Panijhora that was excavated ~2 km from and along the same scarp of the Himalayan Frontal Thrust previously trenched by *Kumar et al.* [2010]. The log of the trench shown in their Figure 3 (and reproduced as Figure S1 in the supporting information) shows soil has been overthrust by a fluvial gravel. The authors extracted six samples for radiocarbon dating. Five of the samples are clearly overthrust, or at the upper contact of the gravel that is overthrust, and each shows ages prior to 0 A.D. A single sample (P10) sits ~3 m outboard the toe of the thrust (referred to as the plough zone by the authors) and within a >2 m thick massive dark organic-rich soil horizon with abundant roots, their unit 3. The age of P10 is reported at 989–1152 A.D. The authors state that the "position of P10… and its location just beneath fault *F* "confirms" that the most recent paleoearthquake occurred subsequent to its emplacement." Yet there is no evidence of a shear zone within their unit 3 nor reasoning given for their exact placement of the shear zone. It is thus not clear whether the deposit was emplaced prior to or following the faulting event. It seems that the authors have extended the fault southward from the plough zone some 3 m through the massive unit 3 to conveniently sit a few centimeters above their sample P10 and in so doing "confirm" that the age of displacement occurred after A.D. 980–1152, in 1255 A.D. The interpretation is disingenuous. There is no information in unit 3 to, as the authors say, confirm that the sample P10 was emplaced before or after the displacement that produced the plough zone. In this regard, evidence of a 1255 A.D. event recorded in

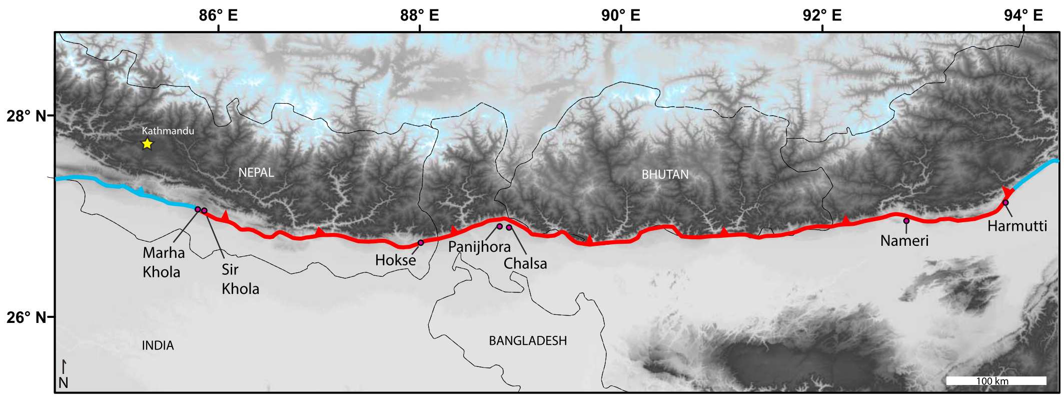

Figure 1. Trench sites used by *Mishra et al.* [2016] as evidence for an 800 km long rupture in 1255 A.D. of the HFT (red: interpreted by Mishra et al. to be the 1255 rupture; blue: unruptured in 1255) in Eastern Nepal and India. Problems with using paleoearthquake observations at Harmutti, Nameri, Chalsa, Panijhora, Sir Khola, and Marha Khola as evidence of this 1255 A.D. earthquake are discussed in this text.

the trench is inconclusive or simply incorrect. Even if one accepts the interpretation that the deposit hosting P10 is faulted, the P10 sample age allows one to only limit displacement to any time after ~ A.D. 989, which certainly is not sufficient to conclude the displacement occurred during 1255 A.D.

The authors' reinterpretations of prior paleoseismic studies along the Himalayan arc are equally unsupportive of simultaneous rupture in 1255 A.D. We address each separately here. The sites are organized from east to west, and locations are shown in Figure 1.

2.2. Harmutti

At Harmutti, *Mishra et al.* [2016] apply Oxcal [*Bronk*, 2009] to radiocarbon ages reported in the trench log provided as Figure 11 in *Kumar et al.* [2010] (provided as Figure S2 in the supporting information). They conclude that displacement in a trench exposure occurred between 1155 and 1378 (mean = 1266). Here they reinterpret that radiocarbon samples from unit 1 of the faulted hanging wall were emplaced subsequent to fault displacement and thus place a capping age on the timing of fault displacement. This is simply wrong. A correct interpretation of the trench log, as provided and described in *Kumar et al.* [2010], shows that all radiocarbon samples were taken from faulted unit 1 and predate the timing of displacement. In this regard, *Kumar et al.*'s [2010] original interpretation that displacement occurred any time after 1271 A.D. (or 1286 A.D. if reanalyzed more formally with Oxcal) remains correct. The observations here provide no basis to place an upper capping age on the possible timing of displacement. In sum, without additional observational constraint, the data are sufficient only to say that displacement occurred subsequent to 1155 A.D. and the idea that the timing of displacement may be limited to 1155–1378, closely bracketing the year 1255 A.D. is misleading and incorrect.

2.3. Nameri

About 100 km west of Harmutti, *Mishra et al.* [2016] again apply Oxcal [*Bronk*, 2009] in reinterpreting the radiocarbon ages reported in log of a trench exposure across the Himalayan Frontal Thrust at Nameri. The trench log is reported in Figure 9 of *Kumar et al.* [2010] (and provided as Figure S3 in the supporting information). They conclude that displacement at Nameri occurred between A.D. 1062 and 1530 (mean = 1245). Here the three radiocarbon samples N7, N10, and N21 extracted from the upper post faulting horizon 9 are older and thus stratigraphically inverted with the age of samples in the underlying and faulted units 5 and 6. The section exposed in the trench is thus contaminated with reworked detrital charcoal, and the three radiocarbon samples do not provide a capping age on the timing of displacement. The three samples could have been deposited at any time after the youngest of radiocarbon samples (N22) taken from a faulted unit. Thus, with respect to the timing of the displacement observed in the trench, it is only possible to say that displacement occurred subsequent to the youngest radiocarbon, N22, in the faulted unit 6, for which the age reported by *Kumar et al.* [2010] is 1025 to 1224 A.D. The upper bound on the Oxcal event horizon 1530 A.D. (quoted by *Mishra et al.* [2016]) is the result or artifact of the use of the “End” function in Oxcal. The function assumes that the likelihood of their interpreted event horizon is not equally distributed between the age of the youngest displaced radiocarbon age and todays ground surface. Because no radiocarbon ages in unfaulted deposits are used (or other constraints cited), there is in this instance no support for use of the End function. *Mishra et al.* [2016] use and interpretation of the output of Oxcal is flawed, and their quoting of an upper bound on their age estimate of the last displacement is incorrect and misleading. It suggests a greater certainty in the timing of displacement than exists. In sum, the observations show that displacement at Nameri occurred any time after 1025 to 1224 A.D. This hardly serves to "confirm" that rupture occurred in 1255 A.D.

2.4. Chalsa

Another ~400 km to the west, *Kumar et al.* [2010] placed a trench across the Himalayan Frontal Thrust near Chalsa. The log of the trench is reported in their Figure 5 (and provided as Figure S4 in the supporting information). The site is along the same trace of the Himalayan Frontal Thrust and ~ 4 km from the previously discussed Panijhora site. *Mishra et al.* [2016]'s effort to use Oxcal failed to refine *Kumar et al.'s* [2010] estimate of the age of displacement for the same reasons that their own analysis of the Panijhora trench failed: due to the massive nature of the deposit in which the youngest radiocarbon samples are situated, it is unclear whether they are in faulted or unfaulted sediment. The observations at Chalsa may only be confidently viewed to indicate that the last earthquake occurred subsequent to 544 A.D. or perhaps after 1059 A.D. or 1315 A.D.

Kumar et al.'s [2010] statement that the broad range of ages allowed that the last earthquake occurred ~1100 A.D. is some contrast to *Mishra et al.* [2016]'s conclusion that the observations serve to confirm that rupture occurred in 1255 A.D.

2.5. Sir Khola and Marha Khola

The western limit of *Mishra et al.* [2016]'s interpreted 800 km megaquake rupture is located at Sir Khola. There, *Sapkota et al.* [2013] used reports of severe shaking and damage in Kathmandu during 1255 A.D. as a priori (Bayesian) input to Oxcal analysis of radiocarbon and stratigraphic relationships in their trench. With the a priori input, they interpreted their trench to display offset associated with the 1255 A.D. event. Without this Bayesian bias, examination of all of their radiocarbon ages shows them to also be consistent with the displacement occurring at a time prior to 1255 A.D. Only 7 km away and to the west at Marha Khola, *Lave et al.* [2005] exposures across the HFT show a well defined stratigraphic sequence, structural relationships, and radiocarbon to support an interpretation that 17 m of offset occurred on the HFT around 1100 A.D., well before 1255 A.D. *Mishra et al.* [2016]'s reanalysis of the Marha Khola data with Oxcal similarly confirms that offset at Marha Khola occurred significantly before 1255 A.D. However, *Mishra et al.* [2016] do not entertain the possibility that the Sir Khola displacement may have occurred simultaneously with the ~1100 A.D. displacement at Marha Khola. Rather, they remain biased as do *Sapkota et al.* [2013] that because there was large earthquake shaking and damage in Kathmandu in 1255 A.D., the displacement on the HFT at Sir Khola must be from that same earthquake. In this regard, the very basis in which *Mishra et al.* [2016] assume the 1255 A.D. earthquake produced surface rupture along the HFT may also be questioned. In this same context, it may be observed that radiocarbon ages at the trench sites we have reexamined here are equally consistent with a hypothesis that displacements occurred ~1100 A.D.

3. Conclusion

It is our view that the *Mishra et al.* [2016] paper is an example of investigators seeing what they believe rather than objectively interpreting the observations. None of the sites, when taken singly or together, provide a basis to conclude that an earthquake in 1255 A.D. ruptured the 800 km section of the Himalayan Frontal thrust that extends from Sir Khola, Nepal, in the west to Harmutti, India, in the east (Figure 1). We encourage readers to take a serious look at it before citing it as support or reference in context of their own studies in this region.

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