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RESEARCH NOTE

The 2015 *M*7.8 Gorkha, Nepal, Earthquake: Possible Implications for Northeastern India

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ABSTRACT

We study the mechanism and pattern of the 25 April, 2015 M7.8 Gorkha, Nepal, earthquake and examine the seismotectonics of the region (including the occurrence of the 28 June, 2015 M5.6 Basugaon earthquake in Assam). We also compare the recent events with historical earthquakes along the Himalayan front, and question whether this present event was typical or if we might expect even larger earthquakes to occur in this region. We conclude that there remains a significant seismic hazard, and that it may be prudent to strengthen close monitoring efforts (focused GPS studies, deployment of state-of-the-art seismic networks and high resolution imaging studies) in anticipation of a future event in Nepal, its surroundings, and northeastern India.

Keywords: Gorkha earthquake, Nepal, Kathmandu Valley, Northeastern India, Thrust faulting, Disaster preparedness

PRESENT STUDY:

The 25 April 2015 Gorkha, Nepal earthquake (M_W 7.8) was a major earthquake for the country of Nepal and surrounding regions Figure 1. A result of thrust faulting along the boundary between the Indian plate with the Eurasian plate (the Main Himalayan Thrust), the quake (and resulting landslides) caused over 9,000 deaths, affected thousands of people, caused the uplift of the Kathmandu Valley by nearly a meter (Lindsey et al., 2015), and inflicted widespread damage (see https://www.rt.com/news/255213-mount-everest-shrinks-quake/; last accessed 2 December, 2015).Though the loss of life was mainly caused by poor construction (Hashash et al., 2015), significant destruction was also caused by more than 4400 earthquake-induced landslides and more than 220 aftershocks (Collins and Jibson, 2015; Kargel et al. 2015; Hashash et al., 2015). Similar (and sometimes larger) earthquakes are known to occur periodically in the Himalayan Arc, and these present a known hazard to the region (Bilham, 1995; Berryman et al., 2014; Martin et al., 2016). There was little evidence for liquefaction or surface rupture from the Gorkha event (Hashash et al., 2015).

There remain many unknowns about the dynamics and ground motions associated with the Gorkha event and these will have implications for the region. As northeastern India is subject to similar tectonic forces as Nepal, these unknowns will be relevant to work being conducted in India as well, and we suggest they be considered with respect to disaster preparedness and post-earthquake relief and recovery measures in select locales identified as earthquake prone zones.

The Main Himalayan Thrust accommodates most of the convergence between India and Eurasia at a rate of between 17 and 21 mm/yr (Galetzka et al. 2015). One of the most curious (and concerning) questions to arise following the Gorkha earthquake, then, is why the damage in the Kathmandu Valley and other parts of Nepal was not more severe? Kathmandu sits in a valley, and is thus subject to amplification effects (Hashash et al., 2015), but despite the high magnitude of the event so near to a population center, the rupture directivity, and the relatively inadequate construction of local structures, the damage was lower than expected, at least at short distances (Martin et al. 2015, Hashash et al., 2015; Showstack, 2015). Indeed, scientists at a special symposium about the Gorkha earthquake at the International Union of Geodesy and Geophysics (IUGG) general assembly in Prague, Czech Republic pointed out that shaking intensity from the Gorkha earthquake was more akin to a Mw 6 or 6.5 earthquake, and that the rupture was confined to a small zone with insufficient energy released to lessen the seismic hazard of the region (Showstack, 2015), suggesting that future large earthquakes in the same area are possible.

Such low shaking intensities might possibly be explained by some noticeable characteristics of the rupture, which produced largest ground motions at a period of ~5 s (Dixit et al., 2015).Tectonic earthquakes typically nucleate at a point on a fault surface, and propagate along that surface. The scale of the nucleation zone is uncertain, as are the mechanics of this process, but it seems likely that the rupture dynamics might lend a clue as to why the shaking intensity was less for this

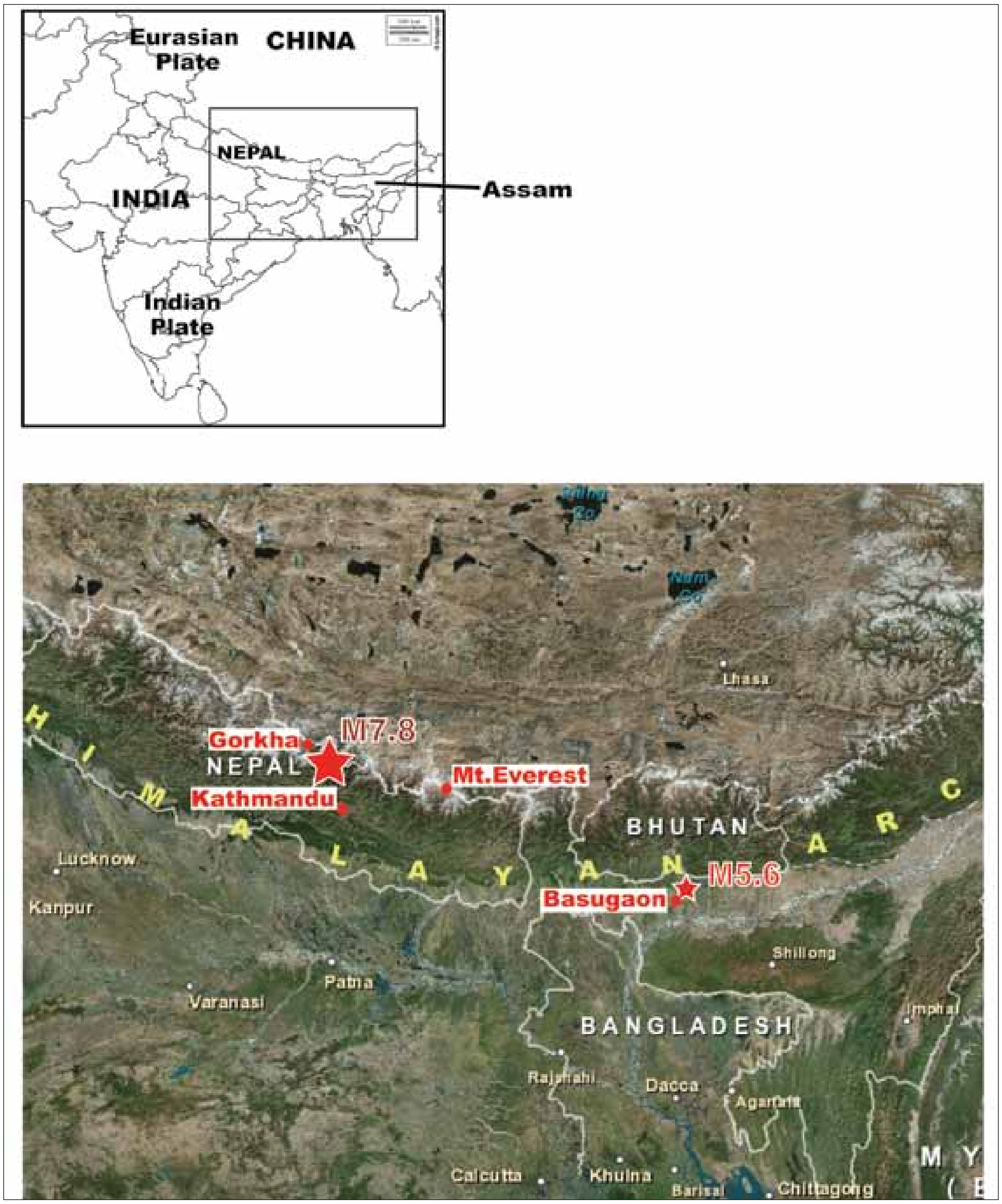

Figure 1. Large star shows the epicenter of a M7.8 earthquake which struck Nepal on 25 April 2015. More than 4400 earthquake-induced landslides and more than 220 aftershocks ($M \geq 3.0$) followed this event which killed more than 9000 people. Despite its size, the rupture was confined to a small zone within sufficient energy released to lessen the overall seismic hazard of the region. The small star shows the epicenter of a M5.6 earthquake that struck ~23km from the Indian city of Basugaon in the northeastern state of Assam on 28 June 2015. The moderate, shallow earthquake was also reportedly felt in neighboring Bhutan, Bangladesh and Nepal.

particular event than might be expected of an earthquake of this magnitude.

In earthquake studies, the amplitude of shaking cannot always be predicted based on the rupture dynamics, regardless of magnitude. Modeling rupture dynamics is typically a complicated process, and each earthquake may look different than others of similar magnitude. Depending on the propagation of the seismic waves, which will be influenced by the local geology and fault characteristics, it is not currently possible to predict how earthquakes will affect a region. Johnston (2015) concedes that fault zone geology, seismology, geodesy, heat flow, and laboratory data all indicate that geometric irregularities in a fault surface exert major controls on the starting and stopping of ruptures. He further states that the initial fault failure nucleation size for damaging earthquakes is minuscule (<10 cm) and does not scale with final moment release. Furthermore, Johnston (2015) notes that observed stress accumulation rates can be uniform over hundreds of kilometers around active faults with no measurable deviations from these rates prior to earthquakes that might indicate the initiation of fault failure. It would seem then that, after nucleation, the eventual size of an earthquake is controlled by poorly known external conditions that may be unrelated to the initial rupture dynamics. More comprehensive simulations of potential earthquakes would therefore be needed before we can effectively mitigate the likely damaging effects from both Himalayan earthquakes and other major events around the world. If the prediction of earthquake size, location, and occurrence time appears inherently impossible, perhaps probabilistic intermediate-term earthquake forecasting based on clustering, repeat times, and other related factors might still be useful (Johnston, 2015). This has implications for continued seismic hazard in the region, especially if there is evidence of consistency in the earthquakes in this part of the Himalaya (e.g. Bilham, 1995).

Bilham (1995) analyzed destruction (and thus apparent shaking intensities) attributed to a Himalayan earthquake that occurred in June, 1255, and stated that the damage seemed to have been confined to the Kathmandu Valley. In addition, Bilham (1995) found that a majority of the 13 large Himalayan earthquakes dating from 1260-1934 occurred in the Kathmandu Valley region. From these past events and the most recent event, it may be possible that relatively weak shaking for a given magnitude is characteristic of this part of the Himalayas. Seismic activity has possibly been following a pattern, with local seismic wave amplification (such as observed in Kathmandu; Hashash et al., 2015) clearly playing a significant role.

The historical record and past earthquakes all indicate that the Himalayan region could expect a larger magnitude event in the future, as the slip potential that has accumulated in the last 300 years has not yet been released by significant earthquakes and the strain continues to build (Bilham, 1995). Segou and Parsons (2016) observed that the 25 April mainshock struck the eastern edge of a 500-km-wide gap between historical earthquakes along the Himalayan front. They calculated the expected redistribution of stress at the central Himalayan front, and developed short-term forecasts, noting that all of their calculations show the Kathmandu Valley to be under a stress increase. The 30-year time dependent probability calculation on the stress-increased areas of the main boundary thrust, west of the mainshock, shows an almost two-fold increase of the probability of a great earthquake occurring west of Kathmandu, reaching 14% vs the pre-Gorkha earthquake value of approximately 8% (Segou and Parsons, 2016).

In addition to the possibility of another large earthquake in the region, two secondary, but no less deadly, hazards should also be noted. These are the abundant earthquake-induced landslides and aftershocks. The Gorkha event produced more than 4400 co-seismic or post-seismic landslides (Kargel et al., 2015). These movements not only destroyed entire villages, but also hampered rescue and relief efforts by covering roads and damming rivers, which delayed access to remote valleys (Collins and Jibson, 2015). The earthquake-related landslides were distributed geographically between the mainshock and its largest (to date) aftershock (Mw 7.3; 12 May 2015, ~150 km ENE of the mainshock; Kargel et al., 2015). Though landslide concentrations were highest near the mainshock, significant concentrations extended about twice as far to the east as they did to the west, likely a result of directivity of the rupture (Collins and Jibson, 2015). Additionally, more than 220 aftershocks (>Mw 3.0 with five of those ≥Mw 6.0) were spawned by the mainshock (Kargel et al., 2015). The aftershock decay followed a typical pattern until a M7.3 aftershock struck on May 12, 2015 and re-energized the aftershock sequence, implying that aftershocks should also be considered as a continuing hazard(in addition to the probability gain of another large event previously mentioned).

On 28 June 2015, a M5.6 earthquake struck a region ~20km north of the Indian city of Basugaon in the state of Assam Figure 1. The moderate, shallow earthquake was also reportedly felt in neighboring Bhutan, Bangladesh and Nepal(see http://earthquake.usgs.gov/earthquakes/eventpage/us10002m67#general_summary and https://www.rt.com/news/270196-earthquake-rocks-india-assam/; last accessed 2 December 2015).This earthquake (focal depth of ~26km), likely was not associated with the Gorkha shock, as it is >500 km east of the Gorkha epicenter. However, due to its proximity to seismically active northeastern India, this moderate shock serves as a reminder that northeastern India may similarly experience strong shaking (P.S: Such a fear was reiterated by the 4th January, 2016 earthquake of 6.7 magnitude in Manipur state of Northeast India, near the border with Myanmar and Bangladesh).

It is well known from the Gutenberg-Richter law (Gutenberg and Richter, 1956) that moderate quakes such as the Basugaon earthquake are often insufficient to dissipate the accumulated tectonic stress, so it may be prudent to strengthen close monitoring efforts (focused GPS studies, deployment of state-of-the-art seismic networks and high resolution imaging studies) in anticipation of a much larger future event. Likewise, decision makers and emergency response officials might heed the warning and work to prepare the region for such an event through initiatives to increase readiness, promote mitigation, and enhance the response and recovery operations that may be needed. If earthquakes truly are impossible to predict, then preparedness is of the utmost importance.

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