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Nepal at Risk: Interdisciplinary Lessons Learned from the April 2015 Nepal (Gorkha) Earthquake and Future Concerns

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INTRODUCTION

In response to the devastation caused by the April 25, 2015 M_w 7.9 Nepal (Gorkha) earthquake and its aftershocks, GSA convened an interdisciplinary session at the 2015 Annual Meeting in Baltimore. The forum allowed researchers from diverse disciplines to exchange information and develop meaningful paths toward reducing societal impacts of future large earthquakes in the Himalayan region. Major seismic hazards exist near Kathmandu and along the Himalayan front due to incomplete rupture of the Main Himalayan Thrust (MHT) (Avouac et al., 2015; Bendick et al., 2015; Elliott et al., 2015; Lay, 2015) and thousands of co-seismic landslides (Andermann et al., 2015; Gallen et al., 2015; Ohja and DeCelles, 2015; Poudel, 2015). Surprisingly, the 2015 event ruptured a limited region. Given shortening rates and interseismic geodetic indications that the MHT is almost uniformly locked along strike, larger earthquakes may occur along the collision zone.

GEOLOGY

The 2015 Gorkha earthquake occurred within the India-Eurasia convergent plate boundary, defined by the >2500-km-long Himalayan orogenic system that involves laterally continuous rock types and structures. Major Himalayan faults sole into the MHT, a pervasive decollement that separates the down-going Indian plate from the Himalayan orogenic wedge (Brown et. al. 2015). The above the MHT, the Lesser Himalayan Duplex is the locus of a ~50-km-wide seismogenic zone of predominately moderate earthquakes, up-dip of which the MHT has low background activity but intermittent large slip events.

The challenge of the rugged and steep terrain of the Himalayas, coupled with its large size have resulted in an incomplete understanding of its paleoseismicity and tectonic history. Unknowns include the northward extent of the Indian craton prior to collision (Lippert et al., 2015) and the role of previously unrecognized or under-appreciated fault systems that accommodated convergence in historical times (Taylor and Murphy, 2015). Segmentation of the MHT is also unclear. The paleoseismic record is limited to ground-rupturing events (Wesnousky et al., 2015); the Gorkha earthquake left little surface record that would have been identified by conventional trenching. Models of the Himalayan seismic cycle based on only mapped surface ruptures lead to misfits between geodetic rates and estimated recurrence intervals.

Space-geodetic measurements of present-day strain accumulation across active fault systems provide direct tests of structural geological models. Earthquakes help to illuminate detailed fault geometry, but event observables must be interpreted in context. In the past, verification of geometric and kinematic relationships depended on rare earthquake occurrences on a fault. Space-geodetic and 3-D fault-geometric data will need to be integrated and made available to earth scientists prior to an earthquake. Novel integration techniques may result in quicker and better hazard estimation.

EVENT INFORMATION FROM SEISMOLOGY AND GEODESY

The Gorkha earthquake occurred on Saturday, April 25, 2015 at 11:56 NST with an epicenter ~75 km WNW of Kathmandu (e.g., Avouac et al., 2015; Lay, 2015). The 2015 event started along the eastern side of a millennial-scale seismic gap and ruptured eastward to the 1934 Bihar-Nepal earthquake zone. It did not break to the surface as in 1934, which leads to the concern of limited paleoseismic recognition of past events (Bendick et al., 2015; Wesnousky et al., 2015; Upreti, 2015).

How interseismic strain will be transferred to the sub-Himalaya could proceed via post-seismic creep along the un-ruptured portions of the MHT, or a large earthquake could occur along the shallower portion of the MHT, feeding slip to the surface (Wesnousky et al., 2015). Another major earthquake is expected near Kathmandu because the Gorkha event ruptured only a portion of the MHT and the up-dip region of the MHT remains locked with minor afterslip occurring south of Kathmandu (Avouac et al., 2015; Bendick et al., 2015; Elliott et al., 2015). Rupture of shallower, highly strained portion of the MHT may involve higher stress drop failure and possibly stronger ground shaking as a result. 3-D visualization links framework- and event-analysis by visualizing seismic, geodetic and structural data (Carena and Verdecchia, 2015). The approach indicates that initial seismological data failed to constrain the geometry of the source fault and the reported uncertainties are unrealistic (Carena and Verdecchia, 2015).

Among the large unknowns are the details of the subsurface structure in Nepal. A systematic program of reflection seismic profiling and targeted 3-D reflection imaging that spans past and potential future rupture zones would help assess continuing hazard (Brown et al., 2015). This should include partnerships with Nepal (Upreti, 2015) and build upon both existing resources, including dense portable seismic recording systems that reduce costs. The focus should be on fault-system geometry and structures that may control rupture segmentation and for time-lapse imaging for rupture zone reflectivity.

DAMAGE

The Gorkha earthquake caused ~9,000 deaths and ~25,000 injuries (Gallen et al., 2015; Poudel, 2015). The destruction was extensive for larger structures in Kathmandu (Acharya et al., 2015; Poudel, 2015; Wang et al., 2015), but moderate ground motions limited urban impact. Thousands of landslides occurred, and destabilized hillslopes and weakened soil horizons present an ongoing threat (Andermann et al., 2015; Gallen et al., 2015; Ojha and DeCelles, 2015). More than 60% of the villages in central Nepal located on near-threshold or threshold dip slopes are at high risk (Ojha and DeCelles, 2015). The main industry affected by the earthquake is agriculture, the primary occupation of rural communities, even along steep Himalayan slopes (Poudel, 2015). More than 6,000 schools collapsed, but because the earthquake occurred on a Saturday, vulnerability of most Nepali schools remains under-appreciated (Acharya et al., 2015).

Nepali national capacity is building in scientific research and disaster management (Upreti, 2015). Acharya et al. (2015) discussed the Kathmandu Valley Earthquake Risk Management Project, initiated in 1995 by the National Society for Earthquake Technology-Nepal and GeoHazards International to train local masons to retrofit 300 schools. Ninety percent of these schools are in areas affected by the Gorkha earthquake and all survived without significant damage. Nepal plans to repair collapsed schools at a rate of 1,200/year, a massive economic and social challenge as time pressure is at odds with construction training and standards. Overcoming local apprehension of retrofitting and building confidence in Nepali communities regarding geosciences education requires major effort. Stone masonry houses are common throughout the Himalayas, which can collapse instantaneously even during moderate earthquakes. Research in inexpensive ways to retrofit and design these homes will save lives. A GIS-based inventory of natural resources and crop production practices in the region affected by the earthquake was proposed as a first-step in rebuilding rural Nepal (Poudel, 2015). Extending these approaches in Nepal along strike is needed; the convergence zone poses a trans-national hazard, and opportunities exist to use this event as an impetus to mitigate hazards. Investments in earthquake disaster response and recovery compared with preparedness and mitigation are unbalanced, and requires immediate change.

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