Geohazards

Earthquakes in Nepal (*January 2016*)

The magnitude 7.8 Gorkha earthquake hit much of the Himalayan state of Nepal on 25 April 2015, to be followed by one of magnitude 7.3 150 km to the east 18 days later. As would have happened in any high-relief area both events triggered a huge number of landslides as well as toppling buildings, killing almost 9000 people and leaving 22 000 injured in the capital Kathmandu and about 30 rural administrative districts. Relief and reconstruction remain hindered 9 months on in many of the smaller villages because they are accessible only by footpaths. Nepal had remained free of devastating earthquakes for almost 6 centuries, highlighting the perils of long quiescence in active plate-boundary areas.

Damage in Kathmandu, Nepal, after the Gorkha earthquake in May 2015 (Credit: CNN)

The International Charter: Space and Major Disasters consortium of many national space agencies was activated, resulting in one of the largest ever volumes of satellite images ranging from 30 to 1 m resolution to be captured and made freely available for relief direction, analysis and documentation. This allowed more than 7500 volunteers to engage in 'crowd mapping' coordinated by the Humanitarian OpenStreetMap Team (HOT) to provide logistic support to the Nepal government, UN Agencies and other international organizations who were swiftly responding with humanitarian relief. Most important was the location of damaged areas using 'before-after' analysis and assessing possible routes to remote areas. The US NASA and British Geological Survey with Durham University coordinated a multinational effort by geoscientists to document the geological, geophysical and geomorphological factors behind the mass movement of debris in landslides etc that was triggered by the earthquakes, results from which have just appeared (Kargel, J.S. and 63 others 2016. Geomorphic and geological controls of geohazards induced by Nepal's 2015 Gorkha earthquake. *Science*, v. **351**, p. 140; DOI: 10.1126/science.aac8353).

The large team mapped 4312 new landslides and inspected almost 500 glacial lakes for damage, only 9 had visible damage but none of them showing signs of outbursts. As any civil engineer might have predicted, landslides were concentrated in areas with slopes exceeding

30° coincided with high ground acceleration due to the shaking effect of earthquakes. Ground acceleration can only be assessed from the actual seismogram records of the earthquakes, though slope angle is easily mapped using existing digital elevation data (e.g. SRTM). It should be possible to model landslide susceptibility to some extent over large areas by simulation of ground shaking based on various combinations of seismic magnitude and epicenter depth modulated by maps of bedrock and colluvium on valley sides as well as from after-the-event surveys. The main control over distribution of landslides seems to have been the actual fault mechanism involved in the earthquake, assessed from satellite radar interferometry, with the greatest number and density being on the downthrow side (up to 0.82 m surface drop): the uplifted area (up to 1.13 m) had barely any debris movements. Damage lies above deep zones where brittle deformation probably takes place leading to sudden discrete faults, but is less widespread above deep zones of plastic deformation.

The geoscientific information gleaned from the Gorkha earthquake's effects will no doubt help in assessing risky areas elsewhere in the Himalayan region. Yet so too will steady lithological and structural mapping of this still poorly understood and largely remote area. As regards the number of lives saved, one has to bear in mind that few people buried by landslides and collapsed buildings survive longer than a few days. It seems that rapid response by geospatial data analysts to the logistics of relief and escape has more chance of positive humanitarian outcomes.

In the same issue of *Science* appears another article on Nepalese seismicity, but events of the 12th to 14th centuries CE (Schwanghart, W. and 10 others 2016. Repeated catastrophic valley infill following medieval earthquakes in the Nepal Himalaya. *Science*, v. **351**, p. 147-150; DOI: 10.1126/science.aac9865). As the title suggests, this relates to recent geology beneath a valley floor in which Nepal's second city Pokhara is located. It lies immediately to the south of the 8000 m Annapurna massif, about 50 km west of the Gorkha epicentre. Sections through the upper valley sediments reveal successive debris accumulations on scales that dwarf those moved in the 2015 landslides. Dating (^{14}C) of interlayered organic materials match three recorded earthquakes in 1100, 1255 and 1344 CE, each estimated to have been of magnitude 8 or above. The debris is dominated by carbonate rocks that probably came from the Annapurna massif some 60 km distant. They contain evidence of extreme pulverisation and occur in a series of interbeds some fine others dominated by clasts. The likelihood is that these are evidence of mass movement of a more extreme category than landslides and rockfalls: catastrophic debris flows or rock-ice avalanches involving, in total, 4 to 5 km^3 of material.

China's legendary great flood did happen (*August 2016*)

The Biblical Flood is one of several legendary catastrophes that over the millennia have made their way into popular mythology. Indeed, Baron Georges Cuvier explained his stratigraphy of the Paris Basin and fossil evidence for extinctions of animals as the results of repeated inundations. His opinions and those of other scientists of the catastrophist school reflect the philosophical transition that began with the Enlightenment of the 18th century: curiosity and observation set against medieval dogma. It seems that transition is incomplete as there are still people who seek remains of Noah's Ark and propose alien beings as the constructors of the huge geoglyphs of the Nazka Desert in Peru. On the other hand, Walter Pitman – one of the pioneers of plate tectonics – and his colleague William Ryan sought a rational explanation for the Flood, based in part on a more detailed description of a flodd in the Near East in one of the oldest written documents, the *Epic of Gilgamesh* (~2150-1400 BCE). In 1996 they published a hypothesis that such flood legends may have arisen from oral accounts of the flooding of the previously cut-off Black Sea basin through the Bosphorus as global sea level rose about 7600 years ago.

Chinese mythology too contains graphic descriptions of catastrophic flooding in the legend of Emperor Yu, first written down at the start of the first millennium BCE. Rather than being a victim or a survivor of catastrophe, Yu is credited with relieving the aftermath of the supposed flood by instigating ingenious systems of dredging and rechanneling the responsible river, and instigating the start of Chinese civilisation and the Xia Dynasty. Such detail conveys a greater air of veracity than a substantial boat containing male and female representatives of all animal species ending up on top of a mountain once Flood waters subsided! Recent research by Quinglong Wu of the School of Archeology at Peking University, together with other Chinese and US colleagues along the Yellow River has nailed the truth of the legend to events in the headwaters of the Yellow River (Wu, Q. and 15 others 2016. Outburst flood at 1920 BCE supports historicity of China's Great Flood and the Xia dynasty. *Science*, v. **353**, p. 579-582; DOI: 10.1126/science.aaf0842).

Map of the Yellow River from the Qing Dynasty. (Photo credit: Wikipedia)

The team discovered evidence for a huge landslide in a terrace of the Yellow River where it flows through the Jishi Gorge. Probably dislodged by an earthquake, the slide blocked the gorge so that a large lake formed above it. The lake also left sedimentary evidence on the flanks of the gorge, which suggest that it may have been as much as 200 m deep and impounded 12 to 17 km^3 of water. Downstream of the gorge sediments of the Guanting Basin contain chaotic sediments characteristic of outburst floods, probably deposited once the landslide dam was breached. ^{14}C dates of charcoal from the outburst flood sediments give a likely age for the massive event of 1922±28 BCE. Astonishingly, remains of three children from a cave near the Yellow River are buried in the flood deposits and provided an age within error of that of the flood: they were victims. Sediments extending to the coast in the North China Plain are the repositories of much of the archaeological evidence for the evolution of Chinese culture along with signs of rates of sedimentation. The definite signs of a catastrophic flood upstream coincides with the transition from Neolithic to Bronze Age artefacts in the Yellow River flood plain.