Geodesy and great earthquakes in the Himalaya

Roger Bilham[1]

[1]CIRES and Department of Geological Sciences University of Colorado, Boulder, CO 80309, U.S.A., bilham@colorado.edu

In the past three decades our knowledge of Himalayan collision processes has been changed radically by the application of GPS measurements across the plate boundary, by the clarification of historical accounts of damaging earthquakes, and most recently by the trench excavations across the frontal thrusts of the Himalaya. The single most important discovery is that the past five centuries of earthquakes include only those that are unrepresentative of the megaearthquakes with rupture lengths exceeding 500 km that permit India's northward advance beneath the Tibetan plateau. This is of particular concern when it is realized that populations in the region south of the Himalaya have increased by an order of magnitude in the past century. Perhaps the most important hitherto unresolved question concerns the mechanism that allows large shallow megathrusts to rupture southward over the descending Indian plate.

Early estimates of the convergence rate across the Himalaya were derived by calculating India/EuroAsian plate velocities from a consideration of global plate motions, and then summing cumulative moment release on the various tectonic features between Mongolia and southern Tibet to reveal the velocity across the Himalaya of 20±5 mm/a. Two alternative direct measures of convergence rate were proposed: an estimate for the rate of advance of sedimentary facies south of the frontal thrusts of the Himalaya, and a summation of seismic moment release for known Himalayan earthquakes. The first of these yielded convergence rates of 21±7 mm/a and the second was known to yield an estimate that was too low since less than 30% of the Himalaya has ruptured in the past two centuries, and earthquakes have yet to be observed to repeatedly rupture the same segment of the Himalaya.

Although precise geodetic measurements were introduced throughout India in the mid 19th century the direct measurement of the convergence velocity across the Himalaya was frustrated by the absence of geodetic triangulation crossing the range. In 1913 a line of triangulation points was measured by the Survey of India through Kashmir along what is now the Karakoram highway to Osh in the Pamir. The line was partially remeasured in 1980 with the inconclusive result that convergence of 2±1 m had occurred in this 76 year interval (26±13 mm/a). The estimate was rendered further uncertain by the unknown contribution from unmeasured segments of the line to the north and south. The 1980 measurements, however, were distinguished by being the first to apply space geodesy to the region using the cumbersome and low-precision TRANSIT satellites (Chen and others, 1984).

The application of GPS to the Indian plate was slowed by suspicions on the part of host countries linked to the complex and still unresolved border disputes between the contiguous nations in the region. The first GPS measurements in the Himalaya were undertaken by an Italian team organized by Ardito Desio in 1984 in connection with confirming the relative heights of Everest and K2. With this precedent established Nepal soon followed with a nationwide series of measurements that permitted the velocity field between southern Tibet and the Indian plate (20±3 mm/a) to be determined, a velocity field that serendipitously lacked complexity as was evident from the simple elastic model that could be proposed to explain its essential features - a gently dipping Indian plate locked beneath the Greater Himalaya at depths shallower than 18 km and creeping steadily beneath the southern Tibet at deeper depths (Bilham and others, 1997). Subsequent GPS measurements confirm that this simple geometry prevails throughout most of the central Himalaya, with one or two caveats. The locking depth appears to follow closely the 3.5 km elevation contour as evidenced by a line of microseismicity that follows the transition from the locked to creeping upper surface of the Indian plate throughout the length of the Himalaya (Bollinger and others, 2004). The significance of the locking line is that it represents the northern edge of great ruptures in the Himalaya, and because the distance between the locking line and the frontal thrusts of the Himalaya varies along the arc, so must the steepness of the rupture zone and possibly also the geometric moment release in great earthquakes. The inferred ruptured width narrows from >100 km in the west to <80 km in the east, and is moreover segmented in numerous places along the arc as delineated by small (5 km) abrupt arc-normal offsets in microseismicity.

The second incremental advance of our understanding of earthquakes in the Himalaya followed the reassessment of intensities and sparse geodetic clues describing 19th and 20th century earthquakes. These studies showed that the rupture areas of earthquakes in 1803, 1833, 1897, 1905 and 1934 were smaller than believed hitherto, thereby implying a much greater of the Himalaya remains recently unruptured. Details of the largest and most recent great earthquake in, the 1950 Mw=8.5 event in eastern Assam remain enigmatic. These studies provide unexpectedly, as yet incompletely realized insights into microzonation in the sedimentary plains south of the Himalaya. A recently published compilation of more than 7700 intensity observations in India promises further refinement of estimates of seismic risk.

Perhaps the most important advance in the past decade has been the discovery that the thrust faults fronting the Himalaya, which have not been associated with surface rupture in any of the past 300 years, ruptured in earthquakes with surface slip of 10-24 m in at least two earthquakes between 1150 and 1505 (Lave and others, 2005, Kumar and others, 2006). The estimated magnitudes of these earthquakes depending on the along-arc rupture lengths range from 8.6<Mw<9.0, releasing 4 to 16 times more energy than the Bihar/Nepal earthquake of 1935. We remain ignorant concerning the recurrence intervals of these megaearthquakes but based on the observed geodetic convergence rate we may infer that they cannot occur more frequently on average than once every 1000-1200 years. The previous occurrence of these megaquakes would have occurred between the time of Buddha (in the eastern Himalaya) and around the time of decline of the Roman Empire (in the central and western Himalaya). Their next recurrence is not anticipated for a few centuries, although megaquakes cannot be excluded from the syntaxial regions where trench studies have yet to find evidence for historical ruptures

GPS geodesy in the western and eastern syntaxis reveals that velocity vectors are not influenced substantially by the curvature of the Himalayan arc. This is unexpected from considerations of the radial mechanisms of moderate and major earthquakes along the arc and requires that slip partitioning occurs near the two syntaxes. This raises an unresolved problem in Kashmir where slip is more than 40° oblique to the range front, and where no active strike-slip fault, other than the Karakoram fault system is known to be seismically active. The low rates of slip on the Karakoram fault are insufficient to accommodate the partitioned sinistral slip deficit in the Pir Pinjal, and it is tempting to conclude that earthquakes rupture obliquely southward beneath the range. The 2005 Kashmir Mw=7.6 earthquake will have advanced a Pir Pinjal earthquake closer to failure. A further unresolved problem in Kashmir concerns the low present rates of oblique convergence across the Pir Pinjal (3-6 mm/yr) and the relatively high rates of convergence (6-12 mm/yr) in the Zanskar ranges of western Ladakh. Although we have no record of historical seismicity in Zanskar the historical record of earthquakes in the Kashmir valley lacks sufficient detail to distinguish between ruptures occurring to its north or to its south. GPS measurements in Zanskar are too sparse as yet to clarify details of the locking line in Zanskar.

References

Bettinelli, P., and others, 2006, Plate motion of India and interseismic strain in the Nepal Himlayan from GPS and DORIS measurements, J. Geod., doi:10.1007/s00190-006-0030-3

Bilham, R., Larson, K., Freymueller, J. and Project Idylhim members, 1997, GPS measurements of present-day convergence across the Nepal Himalaya, Nature, 386, 61-64.

Bollinger, L., Avouac, J. P., Cattin, R. and Pandey, M. R., 2004, Stress buildup in the Himalaya, J. Geophys.Res., 109, doi:10.1029/2003JB002911.

Chen, W.-P. and Molnar, P., 1977, Seismic moments of major earthquakes and the average rate of slip in Central Asia, J. Geophys. Res. 82, 2945-2969.

Chen, J., Crompton, T., Walton, J. and Bilham, R., 1984, survey work of the International Karakorum Project, 1980, International Karakorum Project 1980, 2, Camb. Univ. Press., 124-139.

Kumar, S., and others, 2006, Paleoseismic evidence of great surface rupture earthquakes along the Indian Himalaya, J. Geophys. Res, 111, B03304,

Lave, J., and others, 2005, Evidence for a Great Medieval Earthquake (~1100 A.D.) in the Central Himalayas, Nepal, Science 307, 1302-1305.

Cite as: Bilham, R., 2010, Geodesy and great earthquakes in the Himalaya, *in* Leech, M.L., and others, eds., Proceedings for the 25th Himalaya-Karakoram-Tibet Workshop: U.S. Geological Survey, Open-File Report 2010-1099, 2 p. [http://pubs.usgs.gov/of/2010/1099/bilham/].