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Revisiting the earthquake sources in the Himalaya: Perspectives on past seismicity

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ABSTRACT

The ~2500 km-long Himalaya plate boundary experienced three great earthquakes during the past century, but none of them generated any surface rupture. The segments between the 1905–1934 and the 1897–1950 sources, known as the central and Assam seismic gaps respectively, have long been considered holding potential for future great earthquakes. This paper addresses two issues concerning earthquakes along the Himalaya plate boundary. One, the absence of surface rupture associated with the great earthquakes, vis-à-vis the purported large slip observed from paleoseismological investigations and two, the current understanding of the status of the seismic gaps in the Central Himalaya and Assam, in view of the paleoseismological and historical data being gathered. We suggest that the ruptures of earthquakes nucleating on the basal detachment are likely to be restricted by the crustal ramps and thus generate no surface ruptures, whereas those originating on the faults within the wedges promote upward propagation of rupture and displacement, as observed during the 2005 Kashmir earthquake, that showed a peak offset of 7 m. The occasional reactivation of these thrust systems within the duplex zone may also be responsible for the observed temporal and spatial clustering of earthquakes in the Himalaya. Observations presented in this paper suggest that the last major earthquake in the Central Himalaya occurred during AD 1119–1292, rather than in 1505, as suggested in some previous studies and thus the gap in the plate boundary events is real. As for the Northwestern Himalaya, seismically generated sedimentary features identified in the 1950 source region are generally younger than AD 1400 and evidence for older events is sketchy. The 1897 Shillong earthquake is not a décollement event and its predecessor is probably ~1000 years old. Compared to the Central Himalaya, the Assam Gap is a corridor of low seismicity between two tectonically independent seismogenic source zones that cannot be considered as a seismic gap in the conventional sense.

1. Introduction

The Himalaya, one of the most active interplate regions of the world has witnessed four great and many large earthquakes in recent history. Although cultural habitats and the tradition of documentation have existed in India for nearly four thousand years, records of ancient earthquakes are incomplete. The past two centuries have witnessed several significant earthquakes, four of which were of magnitude >8 (Fig. 1). Given such frequency of large/great earthquakes, it is reasonable to assume that the region might have experienced more earthquakes in the past, which are probably not documented. Even for the earthquakes identified from historic records, locations and magnitudes remain uncertain and there have been many recent attempts to reconstruct the earthquake history. For example, Iyengar et al. (1999) have used scriptures and other archival information as evidence for earthquakes in the medieval India, some of them dating to BC 2600–1800. Similarly, in the updated catalog of earthquakes of Northern India and Tibet, Ambraseys and Douglas (2004) have reevaluated the size and locations of earthquakes during the last 200 years; seven earthquakes (M >7) during AD 15–18 century are reported in their catalog.

Interestingly, none of the great earthquakes of the past century has caused any primary surface rupture and thus the slip–magnitude scaling relations have to be inferred primarily from paleoseismological and geodetic data. Trenching excavations in the source zones of the past great earthquakes have exposed paleoliqefaction features, stratigraphic offsets and other evidence for past earthquakes (Kumar et al., 2001, 2006, 2010; Lave et al., 2005; Rajendran et al., 2004; Sukhija et al., 1999a,b, 2002; Wesnousky et al., 1999). Displacements recorded in some trenches on the foothills of the Central Himalaya have been interpreted to be of the order of 16–26 m (Kumar et al., 2006, 2010). Similar displacement (~17 m) has been reported also from trenches excavated near Nepal (Lave et al., 2005).

Gaps of seismicity in time and space have been observed along the ~2500-km-long Himalaya plate boundary. The 500–800-km-long segment of the Himalayan arc between the rupture zones of the great 1934 Bihar–Nepal and 1905 Kangra earthquakes, known as the central seismic gap has been noted for its prolonged quiescence in terms of plate boundary events (Bilham et al., 2001; Khattri, 1987; Rajendran and Rajendran, 2005; Satyabala and Gupta, 1996, for example). Notable

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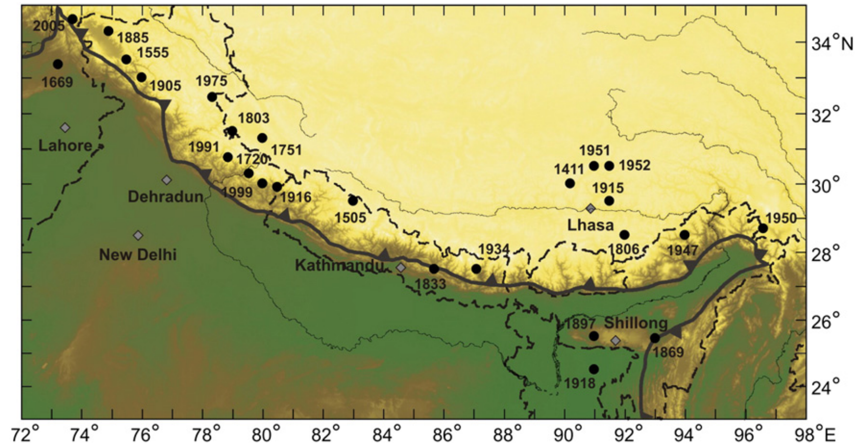

Fig. 1. Map showing the Himalayan Frontal Thrust (HFT) and the significant earthquakes (source of data: Ambraseys and Douglas, 2004; Khattri, 1987; Oldham, 1883; Quittmeyer and Jacob, 1979).

among the large earthquakes in this region are the 1803, Mw ~7.7 and the 1833, Mw ~7.7 events (Ambraseys and Douglas, 2004; Bilham, 1995; Rajendran and Rajendran, 2005). The 1866, Mw ~7.2 and the 1916, Ms 7.1 are the other large earthquakes that occurred in this region during the last 200 years (Szeliga et al., 2010) Pacheco and Sykes, 1992). Earlier studies have indicated that both the 1833 and 1866 earthquakes have ruptured similar locations in the Nepal Himalaya (Khattri, 1987; Oldham, 1883). Study by Szeliga et al. (2010) based on the evaluation of intensity concurs with this and places this earthquake within 80 km of Kathmandu. The 1505 earthquake, with an estimated rupture length of ~600 km and moment magnitude Mw 8.2, is projected as a significant event to have occurred in the gap (Ambraseys and Douglas, 2004; Ambraseys and Jackson, 2003; Feldl and Bilham, 2006); although its status as a plate boundary event in the Central Himalaya is being debated (Rajendran and Rajendran, 2005). Despite these reported events, a Mw >8.0 earthquake is considered imminent in this region, based on plate convergence rates (Feldl and Bilham, 2006; Wallace et al., 2005). These observations call for a critical reevaluation of our current understanding of the past earthquakes in this region.

Ever since the “Assam Seismic Gap” was proposed based on the estimate of rupture extent between the 1950 and 1897 events, it has been debated (Bapat, 1985; Khattri and Wyss, 1978). Both these earthquakes have been well documented and they remain two of the best studied, among the contemporary earthquakes (Ben-Menahem et al., 1974; Oldham, 1899; Rao, 1953). Paleoseismological investigations within their respective regions of strong ground shaking initiated during the last decade provide further understanding on the record of past events in this region (Kumar et al., 2010; Rajendran et al., 2004; Reddy et al., 2009; Sukhija et al., 1999a,b). In this paper we address two important issues concerning the seismicity of the Himalaya. One, we review the status of the central and Assam seismic ‘gaps’ using a variety of data that has already been gathered and two, we try to address the issue of the lack of any surface rupture from known great/large earthquakes of the last century as against the paleoslip observed in the recent trenches excavated in the foot hills of the Himalaya.

2. Tectonics and large earthquakes

The Himalaya, ~2500 km-long and the highest mountain chain on Earth has resulted from the collision between India and Eurasia that started ~50–55 Myr ago with an estimated convergence of ~2000 to 3000 km (Molnar and Tapponier, 1975; Molnar et al., 1977). The collision has produced three major south-verging thrust faults that constitute the most significant tectonic features in the Himalaya, which also accommodate the convergence across the Himalayan arc (Fig. 2A and B). The northern most and the oldest of this thrust system is the Main Central Thrust (MCT), which dips 30°–40° northward and marks the contact between the Higher and the Lesser Himalaya (Gansser, 1964). The age of the youngest deformation in the MCT zone is unknown (Hodges, 2000) and based on the absence of active deformation within the Quaternary deposits, Nakata (1989) argued that this thrust system is inactive. South of the MCT, the north-dipping thrust faults of the Main Boundary Thrust (MBT) separate the predominantly pre-Tertiary Lesser Himalayan sediments from the Tertiary and Quaternary sub-Himalayan sediments. The MBT is clearly expressed as a fault in the bedrock and locally it transports pre-Tertiary to Quaternary Lesser Himalayan and sub-Himalayan sediments over the younger Quaternary deposits (Nakata, 1989; Valdiya, 1992). The southernmost and the youngest of the three thrusts is the Himalayan Frontal Thrust (HFT), which is not as well exposed as the older ones, but occurs as a discontinuous range of scarps that cut the Quaternary fluvial terraces and alluvial fans (Kumar et al., 2001; Nakata, 1989; Valdiya, 1992). All of these south-verging thrusts within the Eurasian plate appear to merge with the Main Himalayan Thrust (MHT), the plane of detachment commonly referred to as the décollement (Hodges, 2000; Seeber and Armbruster, 1981) (Fig. 2B).

Plate motion models and GPS measurements suggest that India–Eurasia convergence continues today at a rate of about 40 to 50 mm/year (Banerjee and Bürgmann, 2002). Thrusting on the HFT takes up about 10 to 20 mm/year of the total 40 to 50 mm/year of the convergence and the remaining motion is absorbed by a combination of thrusting, crustal extension and strike–slip motion within the Eurasian plate (Avouac and Tapponnier, 1993; Lave and Avouac, 2000). The continuing buildup of strain results in occasional great and large earthquakes along the Himalaya. The Himalaya plate boundary witnessed three major earthquakes during the past century and these are the 1905 Kangra (Ms 7.83); 1934 Bihar–Nepal (Ms 8.15), and 1950 Assam (Ms 8.48) earthquakes (magnitudes based on the revised estimates by Ambraseys and Douglas, 2004). The great plate boundary earthquakes are believed to have originated north of the MCT and ruptured the entire basal décollement south of the Higher Himalaya up to the HFT (Seeber and Armbruster, 1981).

The surface geological data imply that the crust above the MHT is composed principally of thrust-imbricated sedimentary and crystalline strata that were detached from the leading edge of Indian plate (Gansser, 1964). Based on the analysis of great detachment earthquakes and focal parameters of medium size earthquakes, it has been suggested that a gently dipping (2–3°) regional detachment underlies the thrust faults at a depth of 15–20 km (Baranowski et al., 1984; Ni and Barazangi, 1984;