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Late Pleistocene and Holocene large magnitude earthquakes along Himalayan Frontal Thrust in the Central Seismic Gap in NW Himalaya, Kala Amb, India

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ABSTRACT

The Himalayan Frontal Thrust (HFT) forms the southernmost active tectonic mountain front of the Himalaya. To understand the ongoing tectonics further, paleoseismological study has been carried out in the vicinity of the HFT system along the Himalayan Front near Kala Amb, India. The trench excavation survey conducted across an explicit surface exposure of the HFT exhibits two distinct faults considered to be associated with the reactivation of the HFT where the Middle Siwalik rocks (Late Miocene) have repeatedly thrust over the Late Pleistocene and Holocene sediments. Presence of large-sized coseismically induced sand-injection feature and its disposition recognized in the trench also suggest occurrence of large magnitude earthquakes in this region. An uplifted and upwarped strath terrace, 3 to 5 m thick alluvium, resting over the 15 m high Middle Siwaliks, abruptly truncated by the HFT indicates its latest activity. Optically Stimulated Luminescence dating techniques were employed to constrain the chronology of events. The long term slip rate of the abandoned terraces due to the activity of the HFT is estimated to be 3.4 mm/yr or greater since Late Holocene. The paleoseismological investigations have provided unambiguous evidences of at least two large magnitude earthquakes occurred in this region where an earthquake with 12 m or larger surface displacement and magnitude 7.5 or greater hit this region in the period between 29.3 ka and 17 ka in the Late Pleistocene and another great earthquake recurred with 20–22 m or more surface displacement and magnitude of 7.7 or greater between 5.8 ka and 2 ka in the Holocene. The present study is the first time report of multiple large magnitude paleoearthquakes in the northwestern part of the Frontal Himalaya during Late Pleistocene and Holocene. The repeated reactivation of HFT substantiates high seismic potential of the Frontal Himalaya and calls for more extensive study of paleoearthquakes of this vastly populous mountainous region.

1. Introduction

The collision between the Indian and Eurasian plates around 50 Ma along the Indus–Tsangpo Suture Zone (ITSZ) has subsequently resulted to the uplift of the Himalaya, the highest mountain belt of the world. The plate motion models and GPS based measurements indicate that the convergence between the Indian and Eurasian plates is about 40–50 mm/year (Banerjee and Bürgmann, 2002). Of these, ~10 to 20 mm/yr of convergence is accommodated along the entire Himalayan arc and the remaining is accommodated beyond the Himalaya towards the north. The continued convergence of the Indian plate has produced linear zones of deformation, resulting in crustal shortening, especially along the prominent boundary faults of the Himalayan orogenic belt (Gansser, 1964; Lyon-Caen and Molnar, 1983; Seeber and Armbuster, 1984; Valdiya, 2003). These crustal scale major tectonic features identified as the Main Central Thrust (MCT), Main Boundary Thrust (MBT) and Himalayan Frontal Thrust (HFT), have contributed to the present day structural and topographic architecture of the fold and thrust belt of the Himalaya. All the above NW–SE striking south verging thrusts believed to be merging into a common decollement, the Main Himalayan Thrust (MHT) (Brown et al., 1996; Nelson and Project INDEPTH Team, 1998; Seeber and Armbuster, 1984). As a result of ongoing convergence along the Himalayan Front and its influence in the Outer Himalaya, many imbricate structures have also been developed subsequently (Fig. 1). The convergence and shortening have been accommodated along various thrust planes and have eventually resulted in generation of numerous seismogenic active faults along the deforming Himalayan Front.

The historic records of past seismic events in the Himalaya are poorly documented and only a very few site-specific paleoseismological studies have been carried out to recognize causative active faults and the paleoearthquakes. For example, in the Outer Himalaya or the Foot Hills (Fig. 1), lying between the MBT and HFT, so far few active faults have been reported (Kumar et al., 2001, 2006; Malik and Mathew, 2005; Malik and Nakata, 2003; Malik et al., 2003, 2008, 2010; Nakata, 1972, 1989, Philip and Virdi, 2006; Philip et al., 2011 and references therein), which have generated major earthquakes. A trench excavation survey across the HFT near Kala Amb reports evidence of two large magnitude earthquakes during the past 650 years subsequent to

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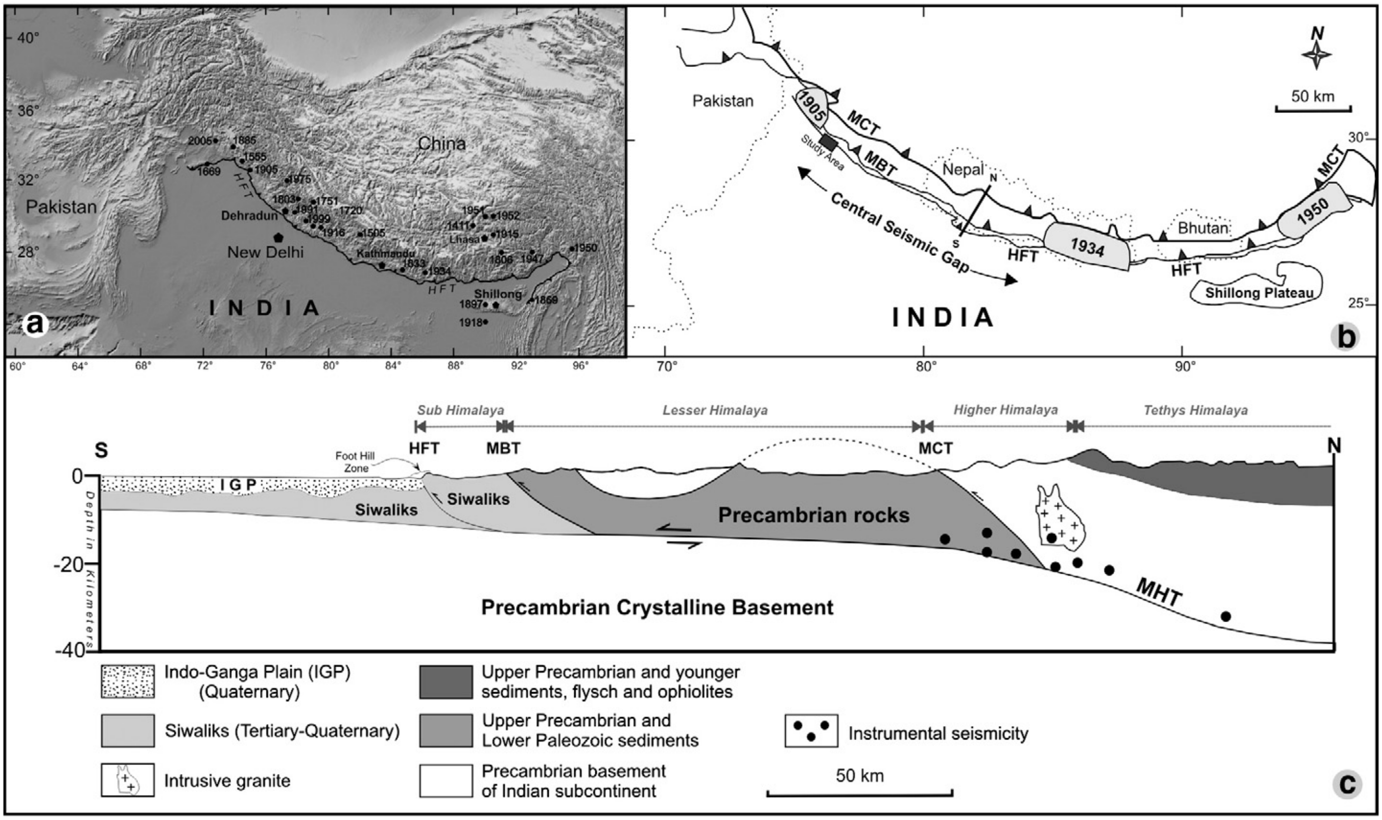

Fig. 1. Regional geological set up and seismicity of the Himalaya. a. Map showing the Himalayan Frontal Thrust (HFT) and the significant earthquakes (Ambraseys and Douglas, 2004; Khattri, 1987; Quittmeyer and Jacob, 1979; Rajendran and Rajendran, 2005). b. Major thrust faults (MHT, MCT, MBT and HFT) and meizoseismal zones (shaded and labeled with year) of major historical earthquakes along the Himalayan arc and location of the study area. c. Generalized NE–SW geologic section (N–S in Fig. b) across the central portion of the Himalayan arc (Seeber and Armbruster, 1981).

1294 A.D. and 1423 A.D., and another possible rupture around 260 A.D. (Kumar et al., 2001). Evidence of two parallel to sub-parallel active-fault traces along the Himalayan Front around Chandigarh has provided additional information on the imbricated faulting pattern that branches out from the HFT system (Malik et al., 2003, 2008). The HFT near Chandigarh (Fig. 2) has repeatedly ruptured in the past as is evident from fault scarps with heights varying from 15 to 38 m. The Optically Stimulated Luminescence (OSL) dates suggest the occurrence of a major earthquake around 1300–1400 A.D. Malik et al. (2010) have carried out trench excavation survey along the northwestern end of the Janauri anticline (Fig. 2) in the foothill zone and have reported occurrence of a large magnitude earthquake around 400 years ago. Data of micro-seismicity from temporary/permanent stations has also shown high percentage of clustering of microearthquakes in some areas of northwestern Himalaya (Kayal, 2001). However, with limited instrumental data and poorly documented historic records of large and moderate earthquakes, it is difficult to reasonably evaluate seismic potential of any region along the ~2500 km east–west stretch of the Himalayan arc.

As per the available information on seismicity and GPS based monitoring of crustal movements, the thickly populated areas of the Ganga plain, Outer and Lesser Himalayan realms are prone to major earthquakes. The area between 1905 Kangra and 1934 Bihar–Nepal earthquakes has been categorized as the Central Seismic Gap (Khattri and Tyagi, 1983) and has a high probability for one or more M>8 Himalayan earthquakes in this century (Bilham et al., 2001). The losses in terms of life and property would be much higher than for the great earthquakes experienced in the past hundred years because of the explosive growth of population and industrial establishments in the Frontal-Outer Himalayan realm in the last half a century.

During the last 600 years, along the whole Himalayan arc, four significant earthquakes occurred which are either instrumentally or historically documented (Quittmeyer and Jacob, 1979). They are the June 12, 1897 Shillong (Mw~8.1); April 4, 1905 Kangra (Mw7.8); January 15, 1934 Bihar–Nepal (M~8.3), and August 15, 1950 Assam (M~8.7). The existing historical records also supplement a few more major earthquakes in the Himalaya which are estimated to be M>7.5. These are the September 1, 1803 Garhwal (M 7.7); August 26, 1833 Kathmandu (M 7.7); August 28, 1916 western Nepal (M 7.3); July 29, 1947 Assam earthquakes (Ambraseys and Jackson, 2003).

Evidence of recurring paleoearthquakes in the northwestern Frontal Himalaya is therefore significantly important for recognizing the earthquake hazard of these zones. Based on paleoseismological investigations, we present here evidences of large magnitude multiple paleoearthquakes that have produced surface rupture along the HFT, in the northwestern Himalayan front, near Kala Amb, Himachal Pradesh, India (Figs. 2 and 3). The earthquakes to occur within a future time span of concern to society will be therefore very important in the highly populous region of the Frontal and Foot Hills of the northwestern Himalaya.

1.1. Data sources and methodology

CORONA satellite photographs taken October 1965, multi-spectral satellite data of IRS-ID-LISS-III and PAN acquired 04 October 2002, CARTOSAT-1 acquired 08 June, 2007 and black and white aerial photographs taken 1988 of the Frontal area constituted the main data source for the present study. The DEM for part of the study area taken from the SRTM data has been useful to map some of the