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Climatically controlled Late Quaternary terrace staircase development in the fold- and -thrust belt of the Sub Himalaya

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ABSTRACT

The alluviation and incision history of Late Quaternary terrace staircases of Yamuna River and its tributaries in the Sub Himalaya, between the Main Boundary Thrust (MBT) and the Himalayan Frontal Thrust (HFT), were studied to understand interlinkages between tectonics and climate in their genesis. We documented five levels of terraces (T1 to T5), cutting across numerous tectonic plains, ranging in elevation from 65–80, 40–44, 28–30, 8–12 and 3–4 m from the present day river bed, deposited by both glacier-fed perennial and piedmont-fed ephemeral streams. Temporal and spatial distribution of these terraces, coupled with absolute ages based on optically stimulated luminescence (OSL) chronology documents five distinct fluvial accretions separated by incision events spanning between Marine Isotope Stage (MIS) 3 and MIS 1. Two major accretion phases occur in the Late Pleistocene (>37 to 24 ka and >15 to 11 ka) and three minor phases in the mid- to late Holocene (7–4 ka; 3–2 ka; and <2 ka). The Phase-I aggradation is thicker and occurs as alluvial fill in a pre-existing valley, whereas younger accretion sequences are cut-in-fill and rest over remnant deposits. The periods of terrace formation are coeval with the Indian Summer Monsoon (ISM) oscillations, however abrupt termination of T1 to T3 terraces in the Himalayan mountain front reflects tectonic upheaval along HFT after their development. This study outlines the climatic control on the terrace genesis in the tectonically active Himalaya on the scale of 10^3–10^4 years.

1. Introduction

The Late Pleistocene–Holocene river terraces and their genesis are generally correlated either with climate, resulting in sediment supply and/or water discharge (Hancock and Anderson, 2002; Bridgland and Westaway, 2008; Vandenberghe, 2008) or with tectonic deformation (Láve and Avouac, 2000; Hodges et al., 2004). In any tectonically active mountain belt, the relative role of climate perturbations in terrace formation generates interests amongst geoscientists (Starkel, 2003; Bridgland and Westaway, 2008; and references therein). In the orogenic belt of the Himalaya, the studies of Pleistocene–Holocene fluvial deposits have addressed a close relationship between uplift, climatic variations (orographic control on monsoon intensification) and erosion (Láve and Avouac, 2000; Bookhagen et al., 2005; Wobus et al., 2005; Suresh et al., 2007; Srivastava et al., 2008; Sinha et al., 2010). This time interval is also well known for the dynamics of the Indian Summer Monsoon (ISM), resulting purterbations in the Himalayan rivers (Goodbred, 2003; Thiede et al., 2004; Gibling et al., 2005) and glacial maxima (Owen, 2009).

The response of climate and tectonics might be manifested in the duration of alluviation and incision phenomena of fluvial deposits in the thust bounded Sub Himalaya. The Sub Himalaya archives a good repository of alluvial fans and fluvial terraces, mainly deposited in the duns (e.g. Dehra Dun, Pinjaur Dun, Soan Dun) over the last 100 ka, by glacial-fed major rivers (e.g. Satluj, Yamuna and Ganga) and their tributaries (Nakata, 1972; Khan and Dubey, 1981; Singh et al., 2001; Kumar et al., 2007; Suresh et al., 2007; Sinha et al., 2010). At places, these deposits have undergone neo-tectonic deformation (Nakata, 1972; Oatney et al., 2001; Virdi and Philip, 2006; Thakur et al., 2007; Philip et al., 2009; Jayangondaperumal et al., 2010).

The present study aims to understand the intricacy of climate in the tectonically active mountain range of the Sub Himalaya, using geomorphologic features, sedimentologic proxies and well constrained optically stimulated luminescence (OSL) based chronology, and their role in the evolution of terraces along the Yamuna River and its tributaries (Fig. 1A and B). Previous studies in this area have supported two contrasting views for the genesis of terraces, either related to tectonic activity (Singh et al., 2001) or climatic amelioration (Khan and Dubey, 1981). However, these studies have lacked well constrained chronology of valley aggradation and incision. This paper deals with detailed mapping of terraces along with sound chronology for alluviation and incision and discusses how climatic and tectonic variability have affected the genesis of terraces.

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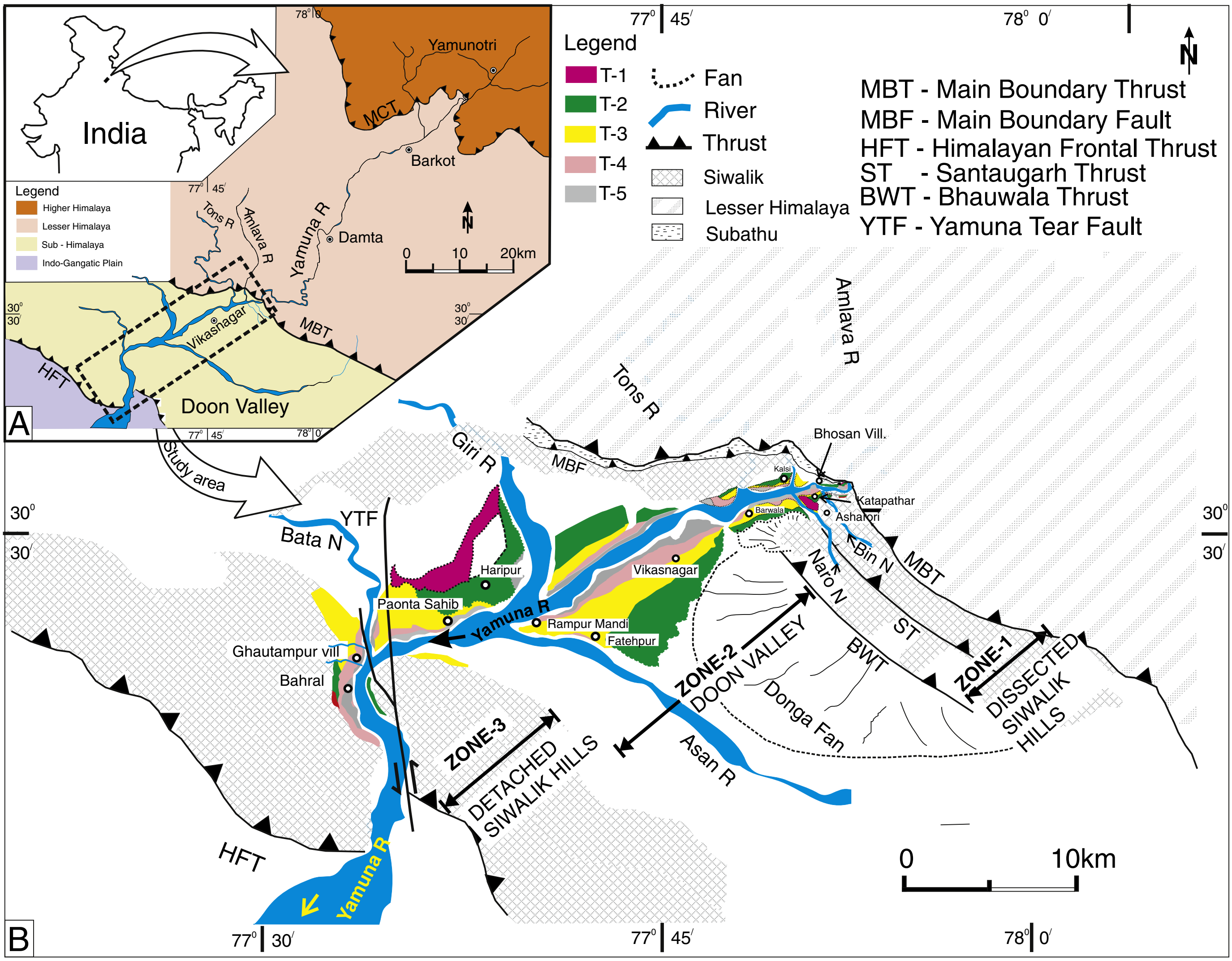

Fig. 1. (A) Regional geological map of Yamuna Valley showing major lithotectonic units of the Himalaya. (B) Tectonic and Geomorphic map of the Yamuna Valley between the Main Boundary Thrust and Himalayan Frontal Thrust showing various landforms and intervening thrusts.

2. Study area: geology, structure and drainage system

The study area, located in the western part of Doon Valley (Dehra Dun), a piggy-back basin in the Sub Himalaya (Fig. 1B), is bordered by the Lesser Himalayan rocks (argillite, limestone and siliciclastics rocks of Proterozoic age) in the north along the Main Boundary Thrust (MBT) and the Indo-Ganga Plain (IGP; Quaternary alluvial deposits) in the south, along the Himalayan Frontal Thrust (HFT). The Sub Himalaya consists of Subathus (marine shale and sandstone deposits of Late Paleocene to Middle Eocene age), Siwaliks (fluvial conglomerate, sandstone and mudstone deposits of Miocene to Pleistocene age) and post-Siwalik sediments (gravel, sand and mud of Late Quaternary). The Subathu Group is exposed between MBT and Main Boundary Fault (MBF). The Siwalik rocks (Fig. 1B) are exposed as dissected (e.g. Santaugarh anticline; ~900 m above mean sea level (amsl)) and detached Siwalik hills (Mohand anticline and Kaleshwar syncline; ~750 m to 450 m amsl) which is separated by a synclinal depression of Doon Valley (~600 to 400 m amsl). The northern part of the Sub Himalaya exhibits a series of imbricate thrusts of MBT (Raiverman, 2002) such as MBF, Santaugarh Thrust (ST) and Bhauwala Thrust (BWT). The detached Siwalik Hills are dislocated along Yamuna Tear Fault (YTF), an N–S trending tear fault.

The Yamuna, a perennial river, originates from the glacier covered Higher Himalaya, drains through the Lesser and Sub Himalaya into Ganga Plain cutting across major tectonic lines such as the Main Central Thrust (MCT), MBT and HFT (Fig. 1A). The Yamuna River is further joined by the glacial-fed Tons and Amlava rivers and piedmont-fed ephemeral streams/rivers (like the Bin, Naro, Asan, Giri and Bata), which carry significant discharge during the southwest (SW) Monsoon (Fig. 1B). The Yamuna River has narrow active channel width (about 30 to 40 m) in the confined gorge regions in the Lesser Himalaya. In the Sub Himalaya, the width is narrow between MBT and BWT (~250 m) and detached (~400 m) Siwalik hills, however, in between, width of the channel-belt increases to several kilometers with active channel of 300–500 m.

3. Materials and methods

The temporal and spatial distribution of terrace staircases, both fluvial and alluvial fan, was mapped for an ~40 km stretch between MBT and HFT and elevation of terraces from present day river bed were documented using Total Station. The river profile is constructed using Survey of India toposheet (1:50,000 scale) at 20 m contour interval and trends of terraces are plotted in the river profile (Fig. 2).