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Status Report

River Systems of Himalaya: Archive of Past Climate and Tectonics

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River systems in Himalaya evolve interacting with climatic changes and neotectonic adjustments that take place in this mountainous region. The resulting landscape thus becomes an important archive to understand the past climato-tectonic conditions. This article reviews the published peer reviewed literature dealing with river systems draining the Himalaya and its foreland between 2007-11. The rivers in Himalaya from NW-NE preserve morphostratigraphic records suggesting their in-phase oscillation with climate. Aggradation takes place in the climatic transition from drier to wetter and the incision during the enhanced monsoon phases. Geomorphic configuration of the terraces indicate that the mountain front is deforming at higher rates but there are zones of deformation occurring within the Himalayan prism as well. The geochemical proxies indicate the increased erosion from lesser Himalaya during the weaker monsoon phases and from Higher Himalaya during the wetter phases.

Key Words: River; Himalaya; Climate Change; Tectonics; Optical Dating

Introduction

Interaction of river systems with ongoing tectonic evolution of Himalaya and past climatic perturbations result into a complex array of landform and deposits. Fluvial landforms in an active mountain like Himalaya are thus, often used to decipher factors and time scales that control river aggradation and incision and related tectono-climatic forcings. The researches suggest that the valley scale aggradations may represent the climatic impact while the fluvial incision into the bedrock equals the long-term uplift rate and thus the local rise of the incision rate can be interpreted as an effect of vertical motion along the active tectonic discontinuities and/or increased hydraulic efficiency. Several river systems like the Ganga, the Gandak, the Teesta, the Brahmaputra are governed by single climatic forcing viz., Indian Summer Monsoon (ISM), originate in the higher Himalaya, cut through the tectonic discontinuities of the orogen and traverse the E-W trending foreland before finally debouching into the Bay of Bengal. Researches in India during the last five years have focused on (1) Basin wide aggradation and incision pattern of the rivers, (2) river landscape and tectonic evolution of Himalaya, and (3) sediment sources and identification of hot spot of erosion in Himalaya.

Aggradation and Incision of Rivers in Himalaya

The process of aggradation and incision in Spiti (drier northwest Himalaya), Ganga and Brahmaputra (NE Himalaya) rivers has been studied in detail. The studies incorporated geomorphic configuration of terraces, sedimentary facies analysis and chronology using optically stimulated dating technique. The results indicated river valley aggradation and subsequent formation of terrace is a result of varying sediment supply and/or hydrology induced by climatic perturbations. The Alaknanda-Ganga river system in such that, NW Himalaya, largely responded to global climatic changes and local glaciation-deglaciation conditions and evolution of the valley fills took place (1) Glaciation-deglaciation processes in the upper catchment that produced huge amount of sediment during ~63-12 ka, (2) Glacially produced sediment was transferred to lower valley via several cycles of erosion and deposition, (3) The period incorporating a drier LGM and moderately wet MIS-3 was characterized with lower discharge accompanied with high sediment load, lead to extensive valley aggradation in Himalaya, and (4) The climatic amelioration after the LGM at ~12 ka and completion of deglaciation process lead to increased fluvial discharge and decreased sediment supply, a condition conducive for incision of alluvial fills (Srivastava *et al*., 2008; Ray and Srivastava, 2010; Juyal *et al*., 2010). Sinha *et al*. (2010) identified two younger phases of river aggradation at Ganga river exit at 9.7 ka and 6.9 ka. Similar studies on Tista, Brahmaputra, Kameng, Kale and Siyom rivers, NE and E Himalaya indicated river incision in response to the monsoon strengthening during the Early Holocene (Meetei *et al*., 2007; Mukul *et al*., 2007; Srivastava and Misra, 2008; Srivastava *et al*., 2009a,b).

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However Spiti River that lies in the arid rain shadow zone of NW Himalaya indicated that aggradation continued till 6 ka and suggested that valley filling processes is mainly assisted by mass wasting and subsequent channel damming during the wetter climatic phases of MIS-3 and 1 (Phartiyal *et al*., 2009a,b). An investigation using landslide dammed lakes along Alaknanda and Spiti River suggested that the phases of active landsliding coincide with the periods of strengthened monsoon where the dammed lake sediments are used to reconstruct Late Pleistocene-Holocene climatic variability (Sundriyal *et al*., 2007; Phartiyal *et al*., 2009a; Juyal *et al*., 2009). The studies from Dun valleys indicated two phases of fan progradation from 97-84 ka and 45-20 ka. The incision of the older fans sequence was controlled enhanced monsoon whereas younger incision phase was said to be controlled more by tectonics (Suresh *et al*., 2007).

Fluvial Records as Evidences of Tectonics

Rivers while responding to active deformation in Himalaya leave morphotectonic imprints that are being studied by several workers. The focus was mainly to understand the style of tectonic evolution of the mountain whether it was in-sequence (where the focus is deformation is the mountain front) or was out-of-sequence deformation also occurred. Study on the piedmont zone sediments and associated geomorphology in conjunction with the OSL chronology suggested an active uplift along the front of Himalaya (Thakur *et al*., 2007). Active faulting and deformation of colluvial deposits NW Sub-Himalaya and active uplift zone along Alaknanda river were reported (Pant *et al*., 2007; Kothyari *et al*., 2010; Tyagi *et al*., 2009). Subsequently Yeats and Thakur (2008) examined the landscape south of Himalayan Frontal Thrust (HFT) and implicated an active faulting and establishment of a new plate boundary. Similarly in the NE Himalaya study along the Brahmaputra River indicated active uplift along the HFT during the Holocene (Luirei and Bhakuni, 2008; Srivastava *et al*., 2009a). Kmaeng River showed three phases of uplift resulting into 95 m of bedrock incision between 14-6 ka that indicated active deformation of frontal Himalayan belt of Siwalik (Srivastava and Misra, 2008). Studies along Tista river in the frontal part of Eastern Himalaya suggested an out-of-sequence, surface-breaking faults in the Himalaya indicating partial accommodation of active convergence within the Himalayan wedge (Mukul *et al*., 2007). Likewise, geomorphic evidences of active uplift along several tributaries of Brahmaputra river are presented in several studies (Devi, 2008a,b; Agarwal *et al*., 2009; Luirei and Bhakuni, 2009; Misra and Srivastava, 2009). In the north of Main Central Thrust in Himalaya in the Spiti valley evidences of neotectonic rejuvenation in Kaurik-Chango normal Fault are presented (Joshi *et al*., 2010) and this zone of Himalaya is deforming under extensional tectonic regime.

The frontal belt of Himalaya is characterized by several Duns and geomorphic evidences of tectonically controlled tilting of alluvial fans, development of drainage divides, channel following the lineaments in Pinjaur, Dehra and Kota Duns has been reported (Goswami, 2007; Philip and Virdi, 2007; Philip *et al*., 2009; Singh and Tandon, 2007; 2010; Singh *et al*., 2008a).

Sediment Generation and Erosion Hotspots

Lately, fluvial erosion and tectonic evolution of Himalaya have been linked. The zone of high erosion rate is known to have higher exhumation and uplift rates and induces out-of-sequence deformation if such an area lies in the hinterland. Thus during the last five years focus has been on the identification of erosion hotspots of Himalaya. A study on temporal variations in Sr and its $^{87}Sr/^{86}Sr$ in Brahmaputra River indicated that most weathering within the Himalaya takes place during the monsoon and this ratio can be used as tracer to track the origin of flash floods in this river (Rai and Singh, 2007). Nd isotopic measurements on the bedload of the Alaknanda River suggested that most of the modern bedload of this river is derived from Higher Himalaya and thus implicating the natural causes as compared to anthropogenic play overriding role in enhancing hill slope erosions (Wasson *et al*., 2008). Srivastava et al (2008) while studying the sedimentary fill of a Alaknanda river suggested that focus of erosion varied with the past monsoon conditions. Lesser Himalayan zone was eroded more during week monsoon phase of Last Glacial Maximum (LGM). This possibly happened because during LGM the monsoon front was located at lower heights within the Lesser Himalayan zone of more sediment. Combined study using Sr and Nd isotopes in the Ganga river sediments from Gangotri to Rajmahal indicated that besides eastern (Brahmaputra) and western syntaxis (Indus) the Gandak River is another erosional hotspot that can potentially influence regional tectonics of Himalaya (Singh *et al*., 2008b). Major, trace and REE composition of modern bedload of the upper Ganga catchment indicated that the silicate weathering in not a dominant weathering process in Himalaya and the most fraction of sediment is derived from Higher Himalayan Crystallines (HHCs). The contribution from Lesser Himalayan Sedimentaries and Siwalik is minimal (Singh, 2009).

The published literature during the last five years (2007-11) suggested that

1. The Sermentation imasion patterns of rivers in Himalaya change with climate. Aggradation takes place in the climatic transition from drier to wetter and the incision occurs during the enhanced monsoon phases.

2. The mountain front is deforming at higher rates but

some zones of deformation occurr within the Himalayan prism as well.

3. The Late Pleistocene-Holocene signatures of mountain front deformation are spread all along the arc from NW to NE Himalaya.

4. Therefore the Himalaya is depicting both in-sequence and out-of-sequence deformation pattern of the taper wedge.

The geochemical studies emphasized that the higher Himalayan crystallnes are eroding faster than any other lithotectonic unit of Himalaya and thus has potential to deform at higher rates.

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