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# Implications of fossil valleys and associated epigenetic gorges in parts of Central Himalaya

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**Conventionally, epigenetic gorges in tectonically active orogen are attributed to the bedrock geometry and original valley configuration. Because they are invariably associated with fossil valleys containing appreciable sediment succession, it is argued that the older river course was abandoned due to accelerated sedimentation (landslides or widespread fluvial aggradations) as a result of which rivers were forced to occupy the new course (epigenetic gorge). Thus it can be suggested that fossil valleys and gorges are the outcome of the climate–tectonic interaction. The present study is therefore undertaken in the monsoon-dominated and tectonically active inner Lesser Central Himalaya to understand the role of climate and tectonics in their evolution. Preliminary observations in three river valleys indicate that their locations (epigenetic gorges) are structurally controlled (independent of lithology). However, the abandonment of old river course (fossil valleys) was caused due to the accelerated sedimentation (climatically induced). Chronology of the fill sediment indicates that old river course abandonment occurred during the early Holocene climatic optimum (15–9 ka), whereas the incision leading to the epigenetic gorge formation began after 9 ka.**

**Keywords:** Climate, epigenetic gorges, fossil valleys, incision, tectonics.

IN a tectonically active orogen, where rivers are actively incising, fossil valleys and associated epigenetic gorges are common features. The term 'epigenetic' refers to the secondary nature of the bedrock gorges, which occur after the formation of the original gorge and are the result of lateral shifting of the channel by landslide debris, alluvial fans or widespread fluvial aggradation[1–6]. There are few studies from the northwest and Central Himalaya where their formation mechanism climate–tectonic significance has been discussed[4,6,7]. The formation mechanism of epigenetic gorges and associated fossil valleys relies upon the bedrock geometry and original valley configuration. The bedrock geometry affects the location and lateral mobility of an incising channel, whereas original valley shape determines rates of bedrock incision[8]. The rate of bedrock incision associated with an epigenetic gorge can

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be very high (> 1 cm/year), typically orders of magnitude higher than both short- and long-term landscape denudation rates[8]. Considering that epigenetic gorges are flanked by relict valley fills (fossil valleys), it is suggested that accelerated sedimentation either due to the landslides, debris flow, alluvial fan or widespread fluvial aggradation, is an integral part of epigenetic gorges.

In view of this, it can be suggested that there are two major processes that govern the formation of epigenetic gorges, viz. the high sediment flux which laterally shifts the river course followed by rapid incision of the fill sediment and the bedrock. In an active orogen, on time-scales of the range of $10^5$ years, regional deformation can be considered constant[8]. Thus the only variable could be the temporal changes in the nature of sedimentation, the local channel geometry and geological structure. Therefore, the morphology and sediment characteristics of the epigenetic gorges can help in (i) reconstructing the processes (climate) responsible for the accelerated sedimentation, and (ii) structural and lithological control in their evolution (tectonics). Keeping this in mind, we have studied some of the epigenetic gorges and associated fossil valleys in the monsoon-dominated and tectonically active Central Himalaya with an objective to ascertain the role of climate and tectonics in their evolution.

We studied parts of the Kosi, Pindar and the Alaknanda Rivers. The Kosi River flows perpendicular to the plunging syncline of Almora Nappe having an asymmetrical structure and gently dipping southern limb and steeply inclined northern limb. The northern boundary of the Nappe is called the North Almora Thrust (NAT), whereas the southern boundary is called the South Almora Thrust (SAT)[9].

The Alaknanda and Pindar rivers cut across various Himalayan thrusts and drain through the rocks of the Tethys Sedimentary Sequence (TSS), the Higher Himalayan Crystalline (HHC) and the Lesser Himalayan Metasedimentaries (LHM)[9,10]. The tectonic movement along these thrusts has resulted into the development of various tectonomorphic features such as the knick points across longitudinal rivers; deep narrow incised valleys, widening of river channel and development of terraces[11,12].

Kosi is a monsoon-fed river (mean annual precipitation ~ 800 mm)[13]. In the study area, the river cuts through the SAT zone and comprises *V*-shaped valleys. Morphotectonically, these valleys are located on the hanging wall of the SAT, whereas the wide valleys with fill terraces occur on the footwall block.

In the Kosi Valley, well-developed fill terraces can be seen around Someshwar, Palsiyari, Kakrighat, Mahjera, Khairna and Betalghat. Near Kakrighat (29.543840N, 79.532456E), a valley fills sequence (fossil valley) was observed that lies on the up-thrown block of SAT with a deep gorge flanking it towards the north (Figure 1 *a*). The Kosi River has incised and created a gorge on the quartz–mica schist belonging to the Almora crystallines. The fossil valley which is 560 m long and 40 m wide is dominated by clast-supported, well-rounded and imbricated gravels dominated by quartz–mica schist, 40%, biotite schist, 20%, quartzite, 20%, gneisses, 10% mylonitic rock fragments, 10% sub-ordinate sand lenses, and which are separated from the active channel by a rock spurs (Figure 2). The channel seems to be abandoned (giving rise to a fossil valley) by the landslide-induced debris flow which plugged the channel and forced the Kosi River to migrate ~ 230 m towards the NNE (present course), where it has incised ~ 15 m deep gorge into the quartz–mica schist bedrock (Figure 2).

The Pindar River is fed both by the glacial melt and summer monsoon (~ 1200 mm annual rainfall)[14]. The river originates from Pindari glacier and cuts across the Main Central Thrust (MCT) before meeting the Alaknanda River at Karnaprayag (Figure 1 *b*). Two fossil valleys and associated epigenetic gorges have been identified near Simli and Tharali.

Simli (30.229628N, 79.259517E) is sandwiched between the Berinag and Narayanbagar thrusts[9]. The area comprises of a narrow *V*-shaped valley located on the footwall of Narayanbagar Thrust. At few places such as

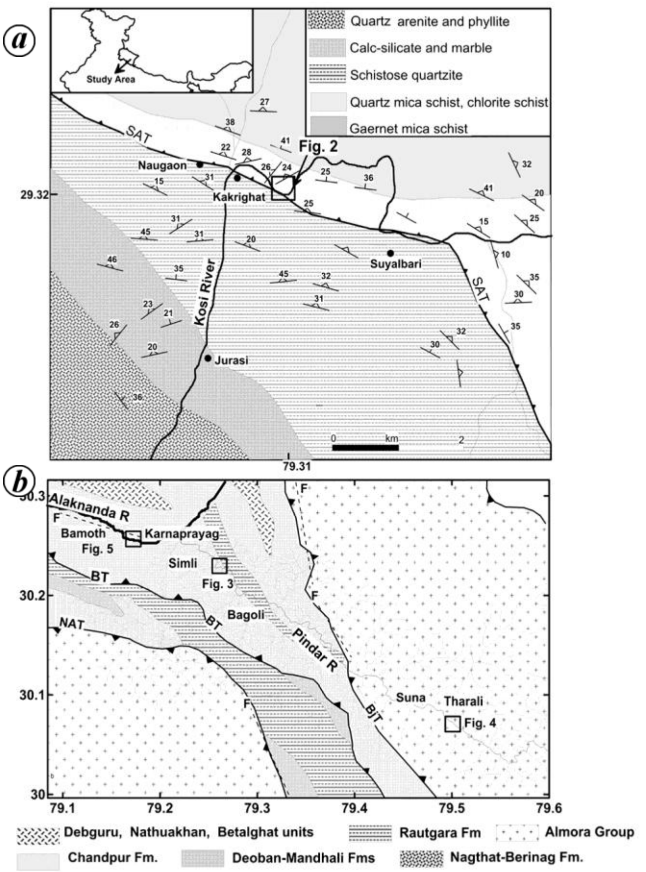


**Figure 1.** Location and generalized geological map of (***a***) Kakrighat area of Kosi Valley (after Joshi[11]) and (***b***) Tharali, Simli and Bamoth area of Pindar–Alaknanda valleys. SAT, South Almora Thrust; NAT, North Almora Thrust; BT, Berinag Thrust; BjT, Baijnath Thrust.

Bagoli and Simli where the valley is wide, the well-developed fill terraces can be observed. An epigenetic gorge and associated fossil valley have been identified on the footwall of Narayanbagar Thrust. The gorge is developed on the phyllite and schist lithology belonging to Berinag Formation of Jaunsar Group. Texturally, the fossil valley is filled with angular to sub-rounded lithoclasts dominated by quartzite (30%), shale (20%) schist (20%), phyllite (20%) and granite (10%). The sediment characteristics of fossil valley suggest that they were locally derived (debris flow) and fluvially modified into terraces. A total of three levels of terraces can be observed in the fossil valley which we ascribed to the pulsating reduction in the hydrological condition before the channel occupied the present course. The fossil valley is ~ 500 m in length, ~ 240 m in width and is separated from ~34 m deep gorge by a rock spur (Figure 3).

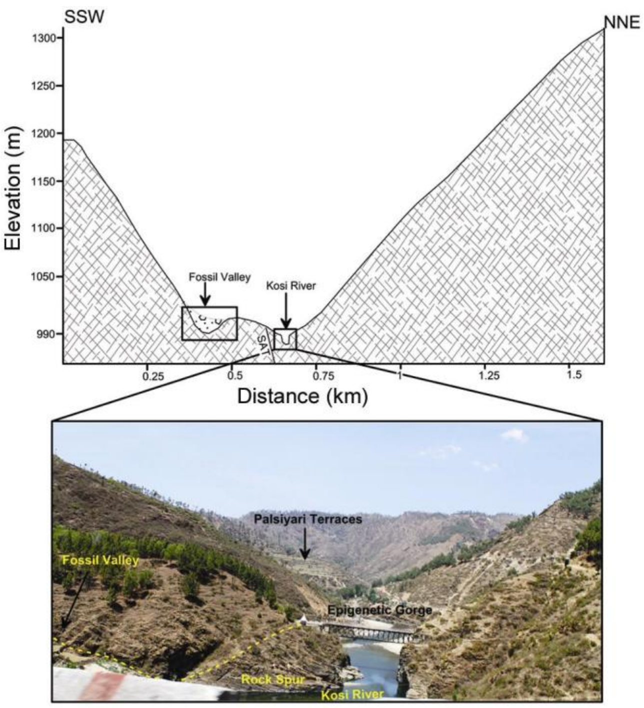


**Figure 2.** Cross-section and field photograph of fossil valley and associate epigenetic gorge at Kakrighat area (Kosi River).

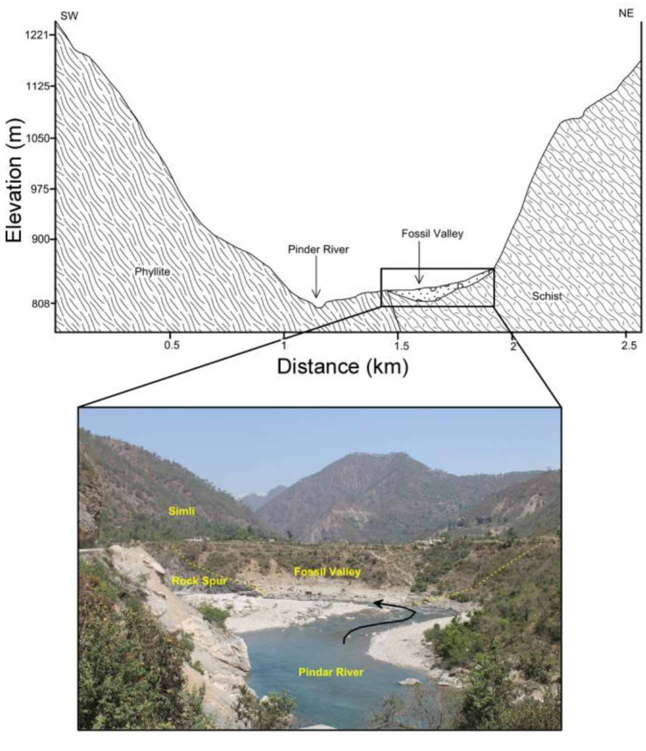


**Figure 3.** Cross-section and field photograph of fossil valley and associate epigenetic gorge at Simli.

Tharali town is located on a folded klippen bounded by the Askot Thrust in the north and Baijnath Thrust in the south[9]. The lithology is dominated by gneissose granetoids of Baijnath crystallines. Around Tharali, Pindar River flows proximal to the plunging synclinal thrust sheets (Figure 1 *b*). The sediment fills in the fossil valley are angular to sub-rounded lithoclasts dominated by granite (60%), schist (20%), quartzite (10%), shale (5%) and dolomite (5%). Textural attributes of the fill sediment indicate that they were locally derived by landslide-induced debris flows. An epigenetic gorge and fossil valley was observed at Tharali (30.074688N, 79.499661E). The fossil valley is ~ 415 m in length and ~245 m in width and is separated by ~ 40 m rock spurs from the present-day river course (Figure 4). The fill sediments have been incised into three levels of terraces, suggesting pulsating reduction in the river discharge before culminating into the present channel course.

Alaknanda River is fed both by the glacial melt and summer monsoon (mean annual rainfall ~ 700 to ~ 1500 mm)[15]. The river flows perpendicular to major thrusts, viz. the Trans Himadri Fault (THF) and MCT. In addition, the river also cuts across the minor structures such as the Alaknanda Fault (AF) (at Karnaprayag) and the North Almora Thrust (at Srinagar). A fossil valley and associated well-developed epigenetic gorge were observed near Bamoth village ~ 3.5 km downstream of Karnaprayag (Figure 1 *b*).

Bamoth village is located on the footwall block of E-W trending AF. The lithology is dominated by Lesser Himalayan quartzite and phyllite. The fossil valley has preserved spectacular sediment succession dominated by well-rounded, imbricated and relatively well-sorted fluvial gravel. These are incised into two distinct fill terraces followed by a well-developed youngest strath terrace (Figure 5). The terrace lithoclast is dominated by quartzite (30%), gneisses (20%), phyllite (20%), schist (15%), shale (10%) and dolomite (5%). The youngest strath terrace is separated by ~ 30 m high sheared phyllite spur from the present-day active channel. The AF runs parallel to the Alaknanda River near Bamoth village, and the fossil valley and epigenetic gorge are located on the footwall of the AF (Figure 5).

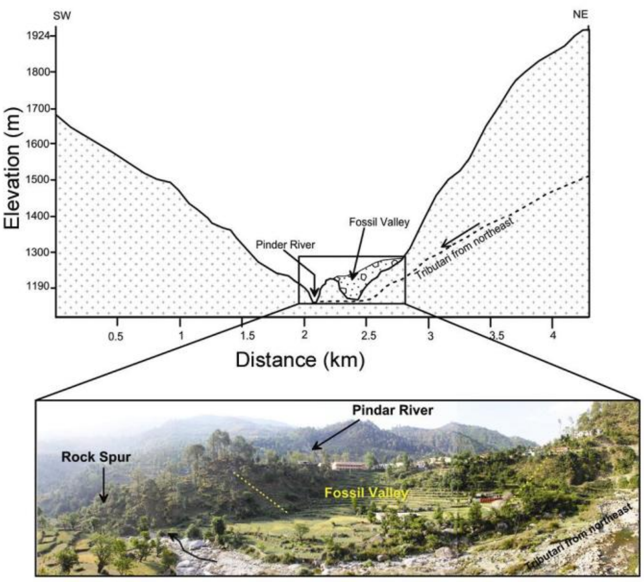


**Figure 4.** Cross-section and field photograph of fossil valley and associate epigenetic gorge at Tharali. Pindar River flows behind the fossil valley.

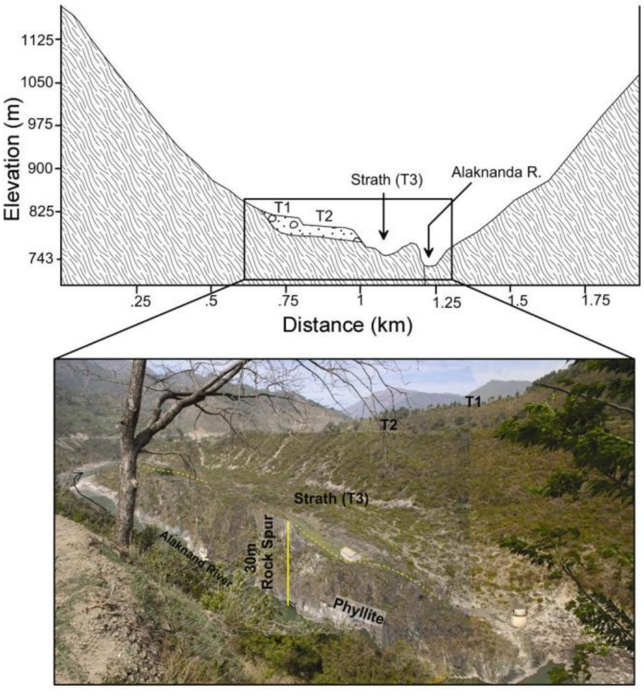


**Figure 5.** Cross-section of fill terraces and strath surface near Bamoth village and associated epigenetic gorge in the Alaknanda valley.

An earlier study on the fossil valleys and epigenetic gorges in the Bhagirathi and Alaknanda River valleys suggested that the fossil valleys are the abandoned original river courses that are now filled up with moraines, landslide debris or later river deposits[2]. According to Pant[2], the epigenetic gorges are structurally or topographically controlled. This seems to be the overriding factor in the formation of fossil valleys and epigenetic gorges as observed in the present study, that the locations where they have been developed are invariably associated with major or minor geological structures. For example, in the Kosi River, the fossil valley and epigenetic gorge are found to be associated with the up-thrown block of SAT. Similarly, in Pindar valley, they are located proximal to the Berinag and Narayanbagar thrusts, whereas at Bamoth in the Alaknanda valley, it is the AF that seems to control the nature and extent of fossil valley and epigenetic gorge below the confluence of Pindar and the Alaknanda rivers (Figure 1 *b*). The relict courses are filled with fluvial or fluvially transported debris flows which in majority of the cases are incised into multiple terraces. The textural attributes of majority of the fluvial deposits plugging the fossil valley indicate that the deposition occurred under persistent flow regime with seasonality. For example, at Bamoth village we observed two fill terraces (T1 and T2) and one strath terrace (T3), which is in accordance with the observations made by Ray and Srivastava[16]. The lower fill terrace (T2) is dated to 15 ka at Bamoth village[16]. Texturally and stratigraphycally identical valley fill terraces (similar to Bamoth village) have been dated at many places along the Alaknanda valley between 12 and 9 ka (ref. 15). The above event of valley-fill aggradation was not only regional in nature, but coincides with the early Holocene climatic optimum when the southwest summer monsoon strengthened. Further, this period also coincidently corresponds to the post-glacial warming that led to the recession of valley glacier in the Alaknanda basin[17] and breaching of the proglacial lakes in the Higher Central Himalaya[18,19]. This would imply that the Central Himalayan rivers were overwhelmed with sediment with the onset of early Holocene climatic optimum.

Fossil valley sediments remain to be dated in the Pindar and Kosi valleys. Therefore, in order to ascertain the age of fossil valley sedimentation, we compared it with the optically dated, stratigraphically and texturally equivalent fill sequences in the Alaknanda valley[15]. Based on the above we suggest that the enhanced sediment flux during the early Holocene intensified monsoon was the major factor responsible for the abandonment of these valleys. It has been suggested that weak monsoon led to a decrease in sediment load and strengthened the ability of the river to incise into the terrace deposits[20]. The terracing of the fossil valley sediments as observed in majority of the cases can be attributed to decreased hydrological condition (low sediment flux).

In terms of processes point of view, (i) prior to valley fill aggradation (in the present-day fossil valleys), the rivers were sediment-limited, and thus the ambient stream power was used to incise the channel. This probably happened prior to 15 ka. (ii) The rivers did not migrate laterally to their present course (epigenetic gorge), as observed in case of landslide-dammed river courses[16].

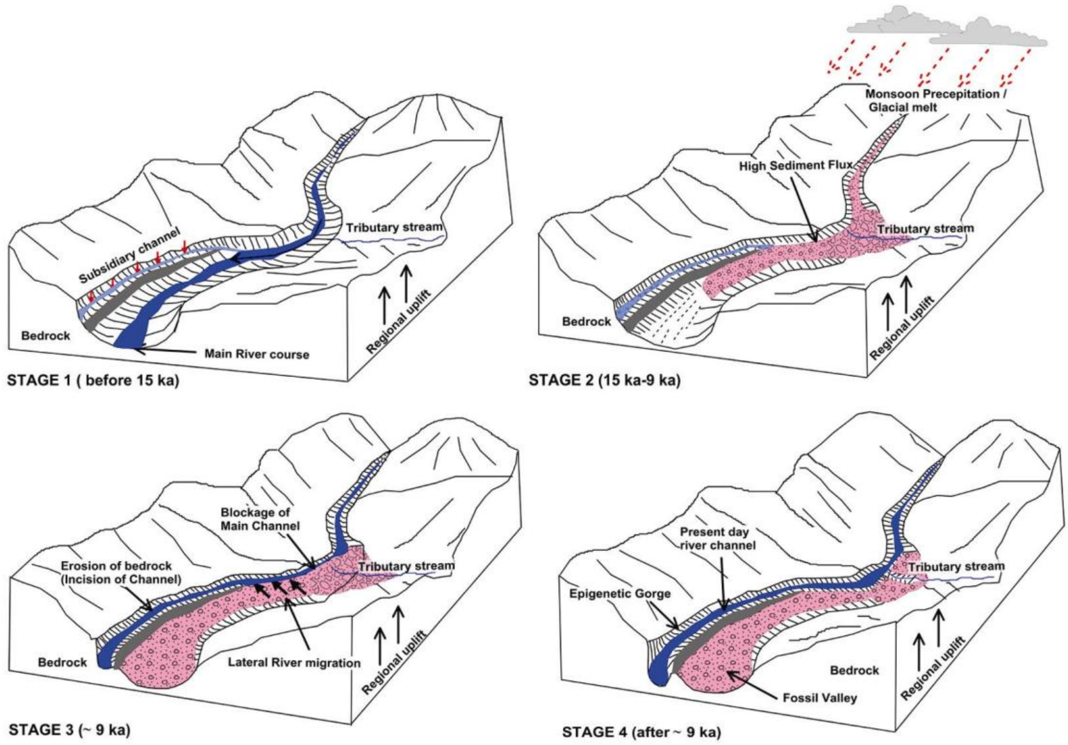


**Figure 6.** Three-dimensional block diagram showing evolutionary stages of fossil valleys and associated gorges in the study area. Stage 1 – Position of river channel before 15 ka. Note the subsidiary channel towards the left bank of the river. Stage 2 – Major valley fill aggradation that occurred during early Holocene climatic optimum (15–9 ka). Stage 3 – Enhanced sedimentation that led to the lateral river migration ~ 9 ka, thus occupying the subsidiary channel. Stage 4 – Present river course flowing through the gorge section.

Had it been the case, the prominent rocky spur flanking the epigenetic gorges would have been eroded away. (iii) We hypothesize that while the present-day fossil valleys were aggraded during 15–9 ka (Figure 6), there existed a subsidiary channel, as the valley began to clog with the sediments, and as the hydrological condition dwindled, the river was forced to occupy the subsidiary channel (least resistance path) from its upstream course after ~ 9 ka, and since then it is continuously incising (Figure 6). The epigenetic gorges are 15–43 m deep and separated by a rocky spur. Assuming that rivers occupied the present course, after ~ 9 ka (discussed above) the estimated incision rate of these gorges is 1.66 mm/a for the monsoon-fed Kosi River. This is significantly low compared to the monsoon-plus-glacial-fed Pindar River (4.77 mm/a) and the Alaknanda River (3.33 mm/a). The higher incision rates accord well with independent estimates obtained from the glacial and monsoon-fed Alaknanda River catchment[21].

Finally, due the fact that epigenetic gorges are invariably associated with the sediment-filled fossil valleys in the study area, it can be suggested that the ability of the river to incise the bedrock was not limited by the strength of the rock. This indicates that the rivers in which these kinds of epigenetic gorges form are transport-limited, as opposed to detachment-limited, where incision into bedrock is regulated by ability of a river to detach and abrade the bedrock channel bed[22,23].

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