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Evolution and genetic interpretation of the Ghaggar river terraces at Siwalik hill water-gap locale

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Abstract

Terraces of the Ghaggar river have been developed between Panchkula and Dara Kharauni, and the Chandigarh—Kalka highway, which partly lies on the fifth level terrace. The depositional and erosional fluvial terraces mostly exist on Ghaggar River's western bank water-gap locale which indicates the eastward movement of the river. Terrace deposits are entirely fluvial but their occurrence and the proximity to the Himalayan glaciated area, indicate the existence of periglacial conditions. Amongst other factors: local climate- environmental and topographical settings; change in the river course conditions; changes in detritus character and amount; climate change effects on the vegetational cover and variations in the river discharge caused by shift in climates leading to the formation of these terraces. During pauses in down-cutting there occurred deposition and there was rejuvenation of river tributaries and an increased sediment yield from upstream during incision of the main channel. The repetition of the processes resulted in a sequence of fluvio-depositional terraces. The evolution is illustrated through a hypothetical model of six stages which has led to the development of erosional and depositional terraces at the water-gap locale of the Ghaggar River.

Keywords: *Degradation and unilateral shift, entrenchment, genetic interpretation, Ghaggar, river terraces, Siwalik hills, valley incision, water-gap locale.*

Introduction

At the Siwalik foothills from northeast to northwest, many prominent geomorphological features such as the river terraces, alluvial cones and fans had been formed by the Himalayan Rivers at their water-gap locales. These geomorphic features show broad genetic and generic resemblances. The studied terraces of Ghaggar River are located at about fifteen kilometers NE of Chandigarh near Panchkula. Geomorphologically, the depositional terraces are in the Siwalik foothill water-gap locale, on the Ghaggar river's western bank. These terraces merge with the adjoining plains in the south. The absolute location of the studied region lies between 30°40' North to 30°45' North and from 76°49' East to 76°56' East (Behl and Singh, 2016). The terraces are at maximum extent near the water-gap locale and are got in patchy towards interior (Fig. 1).

The geological time of the Ghaggar river terraces spreads from middle Pleistocene to Holocene (Sahni and Khan, 1959). Climate changes and tectonic factors combinedly have influenced the terraces. Topographical expressions show diverse convergence owing to gentle warping and tilting. Two parallel faults between Panchkula and Mansadevi have uplifted the Ghaggar terraces and the distances between the fault varies from 0.25 to 0.3 km (Malik and Nakata, 2003). The objective of the current study is to discover the genetic processes of the terrace formation and to evaluate the role of tectonic and climatic events and their conditions in the evolution of terraces.

Ghaggar river terraces

Terrace formation

The Ghaggar River has carved out a sequence of terraces on its west bank in the Ghaggar water-gap (Fig. 1). The incidence of terraces along the west bank evidently reveals the eastward advance of the river (Mukerji, 1975). The altering of the course channel has given accretional point bars along with back-water pools beside clean washed bottom gravels. In the process, straightening and narrowing of the channel further increased the rates and tendency of the river to shift its course. River terraces through lateral planation cut the bedrock and covered it with fluvial deposits in the due process. Mackin (1937) on the other hand, suggested climate change being alternative potential source for down cutting during the glacial periods. However, there is no explanation for reversing the aggradation during interglacial periods.

Another type of terrace may be distinguished as evolved in previously deposited alluvium by the same stream cutting it down. In a way, aggradation interrupting degradation (Moody, 1907). The resultant degradation taking place either by constant lateral shifting of the channel through down cutting resulting in the formation of transitional terraces depicting an irregular pattern and not matching in height or numbers on both sides of the valley; or by some down cutting usually trailed by slow widening of valley or re-aggradation process (Davis, 1899).

Even though real glacial settings certainly not occurred in the region, the incidence terrace occurrence and vicinity of the foothill zone near Himalayan glaciated region perhaps imply periglacial occurrences (Valdia, 2001). Some pondering need to be specified to local climatic factors and topographical settings; changing environments along stream; changing detritus character and its bulk feeding the river by mass-movement and denudation; climate change effects on vegetation and consequent ground protection vis a vis changing discharge runoff rate. During pluvial phases prevailing at present, the river contained sufficient water to carry some load and to erode at the same time. Down cutting of river's bed, therefore, took place mainly during pluvial phases.

Delcaillau *et al.* (2006) have examined the recent folding and drainage development of the Janauri and Chandigarh anticlines in the Siwalik foothills of the northwestern India and found differential deformations from the northwest to southeast, where fault related folding gets accommodated by transfer fault of Ghaggar. Likewise, Singh and Tandon (2008) while examining the geomorphological and morphotectonic evolution of the Pinjore dun, found the formation of four surfaces due to active tectonics and neo-tectonic activities. However, Behl and Singh (2016) elaborating on Ghaggar river's morphology and stratigraphy at water gap locale have found five terraces formed by Ghaggar river on its western bank (Fig. 1). It will also be relevant here to briefly sketch the climatic responses of the Siwalik Hills to glacial climatic changes in the adjacent

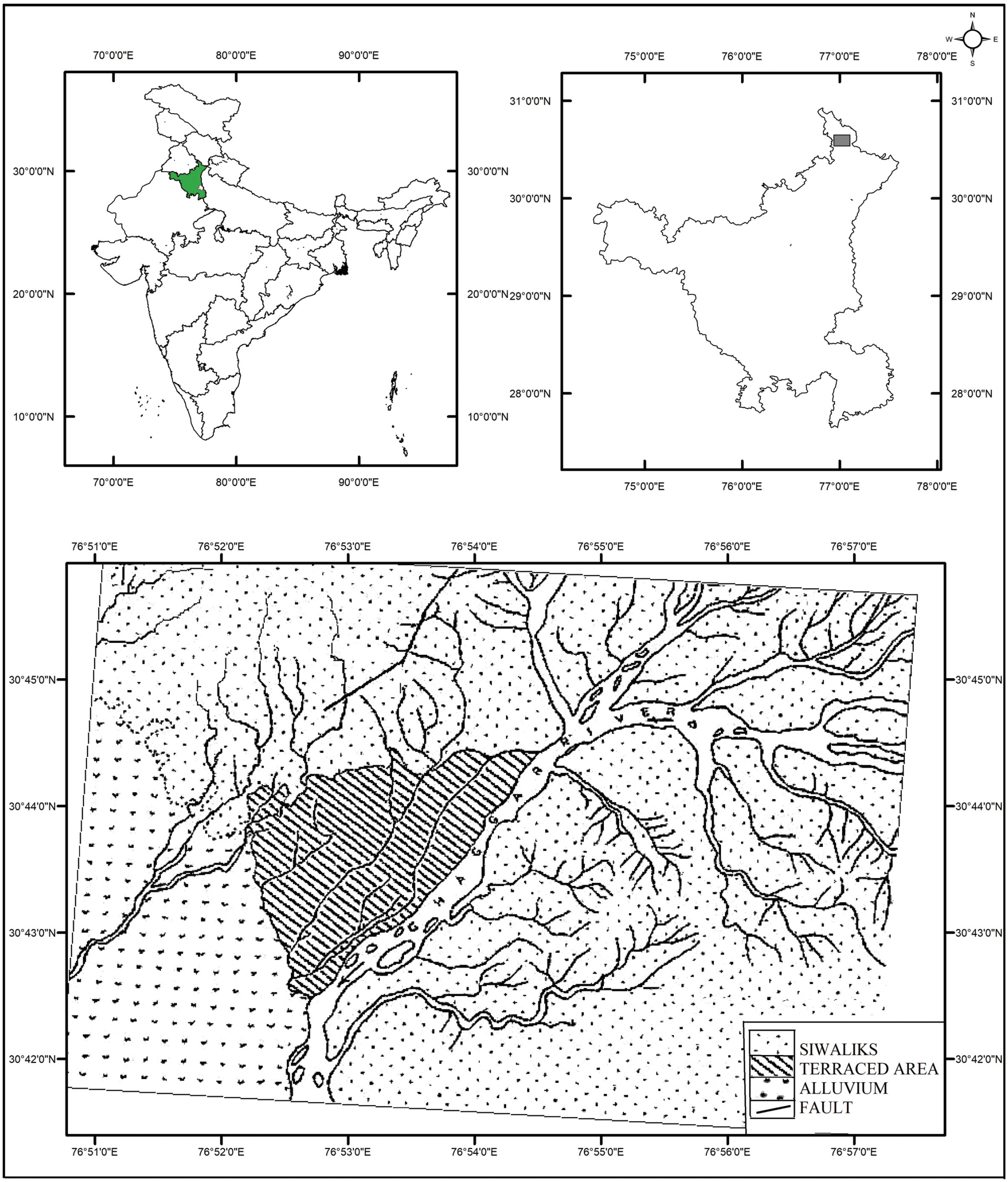

Fig. 1: Ghaggar river terraces mapped from Survey of India sheet no. 53 B/13 and 53 B/14.

Himalayas. The upper Siwaliks indicate the arrival of wetter conditions and additional change making climate noticeably colder towards the end of Tatrot times (Krishnan, 1960). However, during the shorter Riss and Wurm glacials and Riss-Wurm interglacial phase humidity became less pronounced. While definite glacial environments didn't ensue in the area, the existence of river terraces and nearness of this region to the glacial Himalayas almost certainly imply the existence of periglacial environs. In this sense, this fact supports the finding of Mukerji (1975) that this area was never controlled by glacial and proglacial processes, its climatic regime was, to a great extent, influenced by the changes in monsoonal circulations. Sahni and Khan (1959) also emphasized that the conglomerates in this region suggest that pluvial conditions had set in; the paucity of fauna indicates that the climate had become appreciably colder which led to its partial extinction or migration elsewhere.

Although the climate has been periglacial in mode, the river carried immense amounts of rock-waste and accumulated its additional load in terrace form. These terraces are irregular, unpaired and discontinuous which somewhere else have generally been explained through lateral stream shifting across the valley floor, through continuing down cutting. In the Ghaggar valley, nevertheless, down cutting has been intermittent. In fact, during pause in down cutting was deposition. Through incision of mainstream, there has been rejuvenation of tributaries and an increased sedimentation from upstream. The load of sediments was so intense that down cutting ceased, and depositional work started, which continued till it was likely for the stream to incise more and to endure the down cutting further. The repetition of the process resulted in a sequence of fluvio-depositional terraces of Ghaggar river.

Hypothetical model

While explaining the formation of choe terraces, Mukerji (1975) concluded that excavation, lateral shifting, entrenchment, and valley filling were the main causes of terrace emergence in the Chandigarh Shiwaliks. Moving further from this, the hypothetical model (Behl, 1990) being proposed here depict the genesis of the Ghaggar river terraces at Siwalik hill water-gap locale having evolved through its six stages (Fig. 2), which are listed below:

I Degradation and unilateral shift

II Valley incision

III Valley aggradation

IV Unilateral channel shift and entrenchment

V Terrace evolution

VI Unilateral channel shift, entrenchment, aggradation and terrace evolution

In the first stage the river shifted its course a bit due to two conditions: homoclinal dips of the upper Siwalik's beds and topographic slopes created by the accumulation of talus on the up-dip sides of the valley. This unilateral shift was due to less structural causes than to changing factors in fluvial aggradations and degradation (Behl, 1990; Behl and Singh, 2016). In this stage fluvial degradation was more effective than aggradations.

During the second stage the river incised a wide bed-rock valley from the relatively resistant upper Siwalik beds through the process of lateral planation and down-cutting, the former dominating the continuous unilateral shifting of the channel positions (Behl, 1990). This unidirectional shifting of river and down cutting was predominant, and energy was generated by regionally powerful tectonic movements.

In the subsequent stages there was a reduction in rainfall and discharge (Mukerji, 1975). In this phase, aggradation became more important. Hence, the boulders, cobbles, pebbles and other weathered material derived from higher elevations were deposited in the form of second terrace level (T2). Subsequently, with a gradual reduction in rainfall and discharge and increased supply of material developed braiding and frequency of channel shifting was reduced (Fig. 2). In the fourth stage rainfall and discharge were further reduced and this led to wide channel swinging and entrenchment of river and fluvial aggradations led to formation of third terrace level (T3).

During the fifth stage a marked increase in rainfall and discharge throughout the catchment, and local tectonic rise through faulting forced the river to steepen its channel gradient. As a result, it entrenched into one side of the valley fill and the frequency of channel shifting was reduced. In the up-dip side of the valley, unaffected by the lateral planation, the lateral and accumulated part of the fill was left abandoned at a higher elevation relative to lower, narrower plain of channel shifting in the down dip side and emerged as fourth terrace level (T4). Thus, the fourth terrace level evolved through the sequence of deposition and abandonment, not of deposition and erosion (Behl, 1990).

During the last stage, the frequency of lateral swinging was further reduced. The channel continued to shift toward the downdip side, and by lateral planating the fill surface caused a net lowering of its elevation. The repetition of the process of entrenchment, aggradation and climate-tectonic conditions led to the evolution of lowest terrace level (T5).

From the above description of the evolution of various terrace levels, it can be inferred that except for the higher terrace level (T1) the others are depositional. These terraces are indirectly influenced by glacial-climatic changes in the Pleistocene period (Sahni and Khan, 1959). In the beginning of Holocene period, there was sudden increase in rainfall, which brought large number of boulders, cobbles, pebbles, sand and other weathered material downwards from higher altitudes, which resulted in the formation of depositional terraces. The depositional terraces of Ghaggar River are also partially influenced by local tectonic disturbances. The sedimentation sequence in the river can be related to the periodic activities of adjoining basin-margin structural highs in the north (Tandon and Kumar, 1984).

Genetic interpretation

There are two chief categories of fluvial terraces existing on the Ghaggar river's western bank at the water-gap locale: largely erosional and depositional. The former is eroded out of pre-existing formations, and the latter resulted directly from accumulation of river deposition (Behl, 1990, Behl and Singh, 2016). Ghaggar terrace deposits are entirely fluvial but have reference to Pleistocene glacial and interglacial ages. The oldest form of terrace is characterized by the largest gravels. Afterwards, the gravel was altered and again deposited in the younger terraces and new alluvium. There has been appreciable river locational change due to climatic and local tectonic events that resulted in the cross-bedding structure of deposits. In Pleistocene times, the shifting or repeated temporary effacements of the watershed zone were due less to structural causes than to changing factors in fluvial deposition and erosion (Geddes, 1960).

The upper Siwaliks were uplifted and tilted being laid down on the middle Siwaliks subsequent to folding, uplift and denudation;

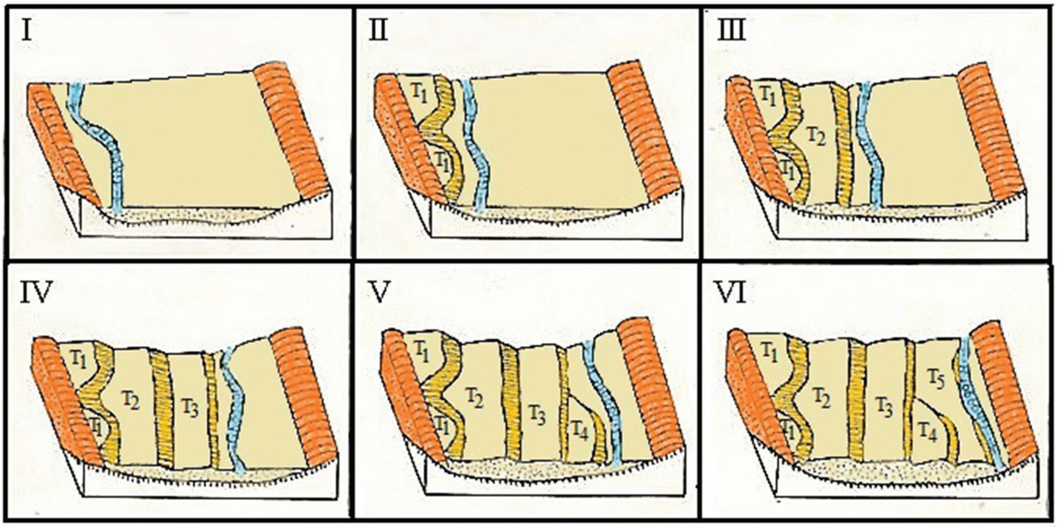

Fig. 2 : Hypothetical model illustrating the sequence of the evolution of five terrace levels on the west bank of the Ghaggar at water-gap locale.

and carved into hogback ridges during the late Mindel Glacial and early Mindel-Riss interglacial period (Tripathi, 1986). The Riss-Wurm interglacial (last interglacial) was estimated to have been three times longer, the Mindel-Riss interglacial (second interglacial) twelve times longer than the post glacial time and permitted the creation of a variety of conditions, operations of several processes and emergence of diverse geomorphic patterns. The relatively rapid uplift and deepening of valley took place in Mindel-Riss interglacial phase (Tripathi, 1986). Increased rainfall and discharge during the Mindel-Riss interglacial helped the river to cut a rather narrow channel at considerable elevations (Joshi, 1970). The absence of vegetation at higher elevations led to rapid down cutting as well. During this phase the highest terrace level (T1) was formed. The lower Paleolithic implements of the pebble chopper typed (Fig. 3) found in terrace T1 by G C Mohapatra (1966) also suggest a middle Pleistocene age for T1. It is clear that the highest terrace level is mostly erosional and belongs to Mindel-Riss interglacial period.

After the carving of the highest terrace level the river experienced a unidirectional shift and entrenched itself very deep, by about 38 meters or so. This was further aided by a combination of local climatic and tectonic events (Mukerji, 1975; Behl, 1990). During this phase gravel supply decreased, deposition ceased, and erosion followed. The river Ghaggar cut its course downwards, giving rise to a valley in the older sediments, and the remnants of which remain in the shape of a terrace (T1). Thickness and size of material also point to the long duration of Mindel-Riss interglacial. Terrace level (T1) is highly dissected and is found in patches.

In this valley thus created another gravel bed might have been laid down during a subsequent glacial stage, the same sequence of processes then being repeated. This type

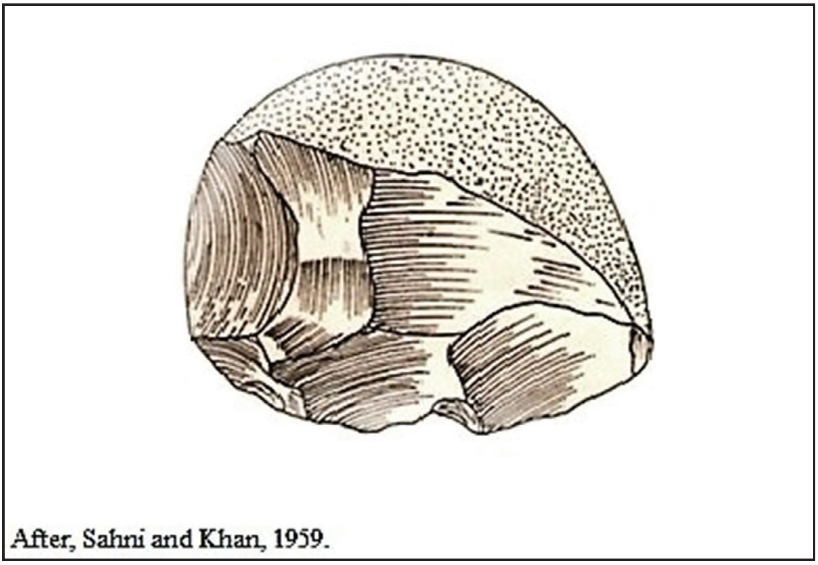

Fig. 3: The lower Paleolithic implement of pebble chopper type found on terrace 1.

of development may be assumed to have recurred several times during the succession of alternating cold and warm events. Owing to a general tendency of land uplifting, throughout the Quaternary time, every new basal gravel bed came to be deposited at a level lower than that of the older ones.

Once the uplift and tilting ceased and entrenchment was gradually replaced entirely by horizontal shifting, during the early humid phase, detrital supply to the stream carrying higher discharge also increased considerably leading to aggradations. With the arrival of the Riss glacial, a rather short period, there was reduction in rainfall (Sahni and Khan, 1959 and Mohapatra, 1973), and hence a change in the texture of stream loads to silty clay. Also, the thickness of the bed laid down during this phase became smaller. The second terrace (T2) is of this age, during which the lateral shifting was further reduced and instead of laterally planation of the river, aggradation got affected. The process of deposition was continuously gaining net elevation everywhere, but it was more proclaimed at the riverbank where slope weathering debris materials were accumulating. The deposition was under the influence of the heavy monsoon rains that followed annual periods of aridity such as still occurring in this region (Mukerji, 1975).

During the Riss-Wurm interglacial, much shorter than the second interglacial but longer than post glacial time, there was increased discharge. The third terrace (T3) is of this age. Increased discharge resulted in the deposition of a thin horizon of pebbles. It is noteworthy that though Riss-Wurm interglacial was a humid pluvial phase, it was less moist than Mindel-Riss interglacial, a fact suggested by the far smaller size of gravel in the horizon (Sahni and Khan, 1959). Also, humidity, by increasing discharge a bit, promoted lateral planation, hence the horizon remained rather thin. The lower part of Pinjore formation is further evidence of their being deposited in warmer interglacial period of Pleistocene (Tiwari and Sharma, 1972). Gaur (1987) found that with a meandering riverine system, low frequency of gravel deposits in the Tatrot deposits, west of Ghaggar probably points towards deposition under low energy conditions in general. The finer characteristics of the third terrace level (T3) reveals relatively low energy conditions. The low energy conditions might have resulted either from low water discharge or due to the low gradient of the river. The deposition took place under shallow water is suggested by the occurrence of cross bedding (Behl, 1992).

During the succeeding phase Wurm glacial and beginning of Holocene aridity and reduction in discharge became characteristic. This resulted in the deposition of a thick band of clay loam. Only, in these deposits the predominant material is fine textured clay and loam and the process of deposition was very slow. Since Wurm comprises Wurm I, interstadial, and Wurm II, the period is obviously long and even with slow deposition the resultant bed has become thick. The final fashioning of fourth terrace (T4) is ascribed to the Wurm glaciation. The deposits of last or Wurm glaciation occupy a superficial position and have been little subjected to destructive processes. Because of decreasing precipitation and increasing warmth, the alluviation was replaced by lateral planation in the temperate latitudes has been suggested by Pitty (1971).

At the end of Wurm glaciation and with the full establishment of Holocene, increased discharge promoted outward shifting and entrenchment, the latter following the former. Entrenchment was also caused by crustal disturbances, particularly strike faults. Terrace formation of Ghaggar river is also provided by trans-current hinge fault. The lowest terrace level (T5) was formed in Holocene period. The formation of T5 was affected through lateral planation which increased discharge when normal monsoonal rainfall regime was re-established during the later Holocene and the river started laterally swinging in a more pronounced manner. There was an additional entrenchment, perhaps for the last time, about 8 meters or so (Mukerji, 1975; Behl, 1990). With this present-day river was established and the lowest terrace (T5) as a topographic level emerged.

Conclusions

The existence of Ghaggar river terraces at water gap locale of Siwalik hills, and vicinity of the region to the glaciated Himalayas perhaps suggests the occurrence of glacial/ periglacial conditions. Enormous quantities of rock-waste and the over-loaded river deposited its surplus load in the shape of terraces, which are irregular, discontinuous that have usually been explained by the lateral shifting of the stream across the valley floor, during progressive down-cutting and depositions. The repetition of the processes resulted in a sequence of fluvio- depositional terraces on the western bank of Ghaggar, clearly indicates the eastward movement of the river. Broadly, Ghaggar terraces are composed of weathered, sub-rounded to rounded ill-sorted sandstone gravel beds.

From the north-east to the north-west at the Siwalik foot-hills or their peers the terraces having water gap locations show broad generic and genetic similarities. The Ghaggar River has carved out a sequence of terraces on its western bank at the water gap locale, which are depositional and are markedly different from the climatic-tectonic terraces of perennial rivers located in Himalayas.

Conclusively, it may be inferred that degradation, unilateral shifting, entrenchment & aggradations; and four repetitions of the sequence of shifting, entrenchment and aggradations caused mainly by glacial and interglacial climatic changes and local tectonic events partially constitute the genetic structure of Ghaggar terraces. These five river terraces are regarded as aggradations during pluvial phases which can be correlated with glaciations. However, the climatic aspect of the Ghaggar terraces in the zone of summer rains and dry season, certainly deserves a close palaeo-climatological and geomorphic study.

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