Tectonically Controlled Fluvial Landforms on the Yaluzangbu River and Their Implications for the Evolution of the River

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Tectonically Controlled Fluvial Landforms on the Yaluzangbu River and Their Implications for the Evolution of the River

The Yaluzangbu River, the largest river on the Tibetan Plateau, becomes the Brahmaputra when it flows into India. New fieldwork and map analysis show that the fluvial landforms and landform evolution of the river are controlled by the tectonic structures of the southern plateau. The history of the Yaluzangbu River since the Eocene is established here based on geomorphological and tectonic studies. It includes the formation of the main course along the suture before the Miocene and establishment of downstream course and major tributaries along strike-slip faulting in the Miocene. Also noted are the formation of alternations of wide sections and gorges, gentle and steep hydraulic gradient intervals, and deposition and erosion channel stretches along the river by normal faulting and grabens since the Pliocene.

Keywords: *Yaluzangbu River; fluvial landforms; tectonics; Tibet.*

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Introduction

The Yaluzangbu River is known by many names in the literature and on different maps; among these names are Tsangpo, Sangpo, Yarlutsangpo, or the upstream section of the Brahmaputra. The river originates at the Jimayangzhong Glacier on the northern slope of the Himalayas and runs eastward, then turns suddenly southward at 95°E to become the Brahmaputra (Figure 1). It flows through a whole range of different river channel types and valley forms. Braided, freely meandering, and anastomosing channels with wide valleys are interrupted by single straight and deeply entrenched meandering channels with gorges in the upstream and middle stretches of the river. Downstream, the river consists of single straight channels with very deep gorges. The long profile of the main course also is unusual, with relatively gentle profiles on the upstream and middle reaches and a steep profile downstream.

There are still many unexplained phenomena related to the evolution of the Yaluzangbu River on the largest and highest plateau in the world as well as unsolved research problems because of a challenging environment, inaccessibility, and political sensitivity. In the early decades of this century, a few famous geographers (Burrard and Hayden 1907; Hedin 1917; Ward 1934; Pranavanada 1939) explored the river, but their exploration was limited by difficult accessibility. Many geomorphologists from Chinese research institutions and universities have studied the Yaluzangbu River and its tributaries since the 1950s, but their achievements were limited because of insufficient geological evidence and the restricting influence of traditional geological theories. A series of international geological expeditions to Tibet have been undertaken since the 1980s, and great advances have been made in knowledge about plateau tectonics. Generalizing from findings in Tibet, it is possible to establish an order for Tibetan tectonic history since the Eocene. First, compression from the Indian subcontinent created east–west thrusts, reverse faults, and folds. Second, shear force occurring in the Miocene produced a large number of strike-slip faults on the plateau. Finally, the east–west extension of the plateau and formation of normal faults and grabens occurred after the strike-slip faulting period. This was accompanied by the reactivation of some strike-slip faults and rapid uplift of the plateau, as the normal faults cut across the strike-slip faults (Figure 2). There are many arguments about the timing of the initial stage of the last phase in this tectonic history (eg, Powell 1986/1987; Dewey et al 1987; Windley

FIGURE 1 Topographic map of southern Tibet and the western part of the Indian Continent.

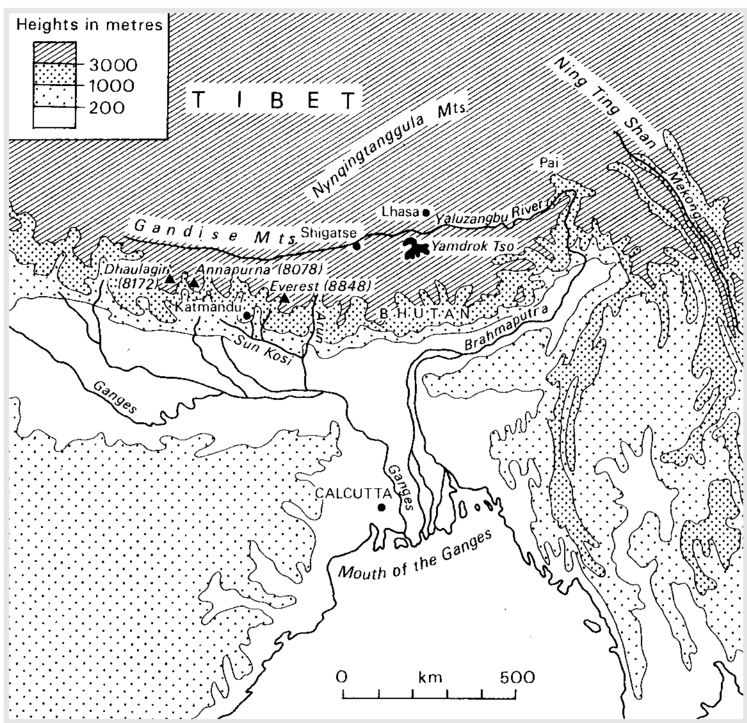
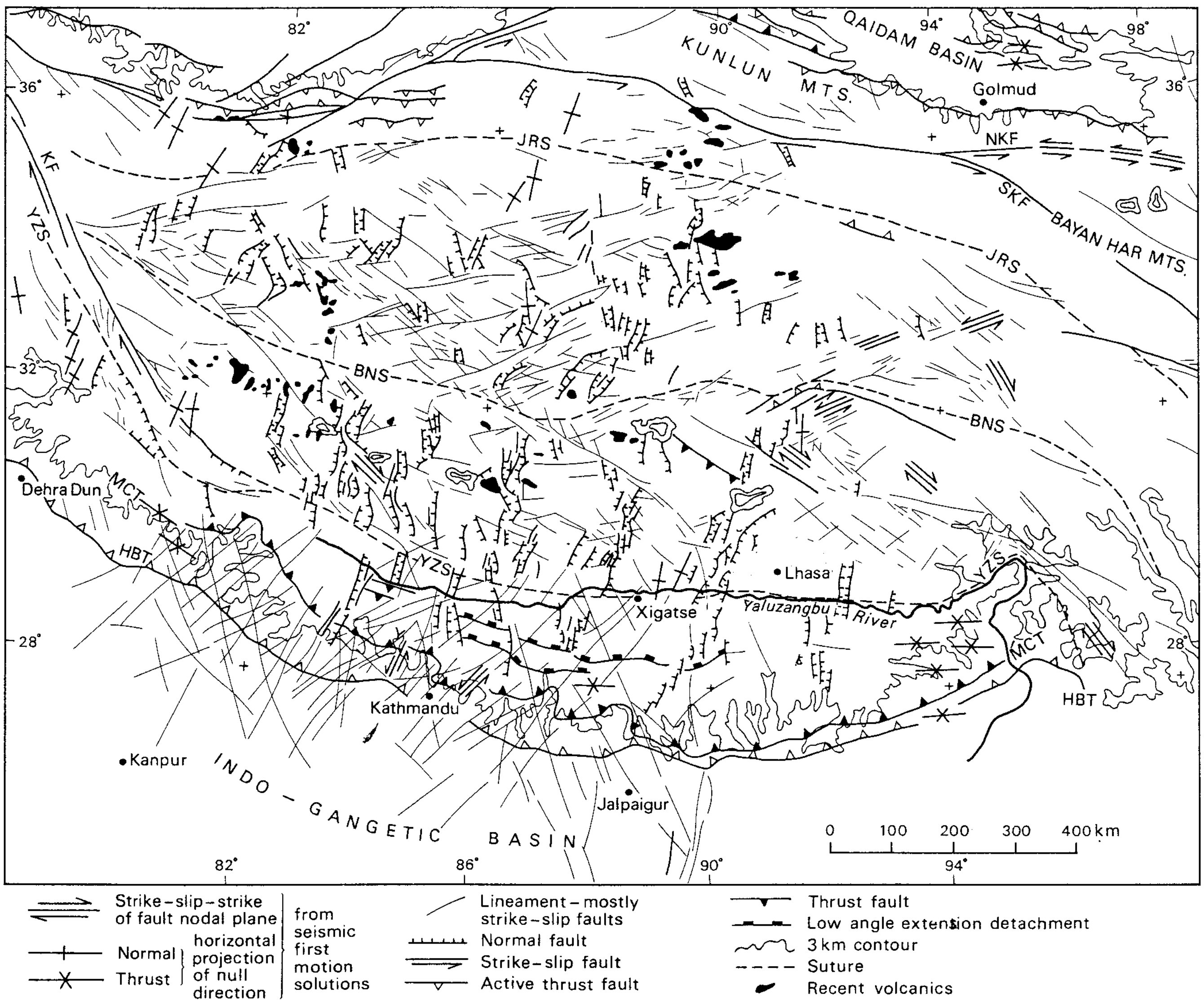


FIGURE 2 Map showing the principal neotectonic features of the Tibetan Plateau and adjacent regions. BNS, Banggong-Nujing Suture; HBT, Himalayan Boundary Thrust; JRS, Jinsha River Suture; KF, Karakorum Fault; MCT, Main Central Thrust; NKF, North Kulun Fault; SKF, South Kulun Fault; YZS, Indus–Tsangbo Suture (after Dewey et al 1987; Zhou et al 1984).



1988; Harrison et al 1992; Molnar et al 1993; Searle 1995; Li 1996; Fielding 1996), ranging from 3 Ma (Li and Fang 1998) to 14 Ma (Coleman and Hodges 1995). However, most authors agree with the above historical order of tectonic events. Evidence for the timing of the last phase can be obtained from the present geomorphological study.

This paper examines the relationships between neotectonic structures and fluvial landforms and evaluates how the tectonic movements in the plateau influenced the development of the river. The research included geological and geomorphological field investigations, reviews of papers, map analysis, and some laboratory measurements.

Fluvial landforms and tectonic structures

Fluvial landforms associated with the suture and strike-slip faults

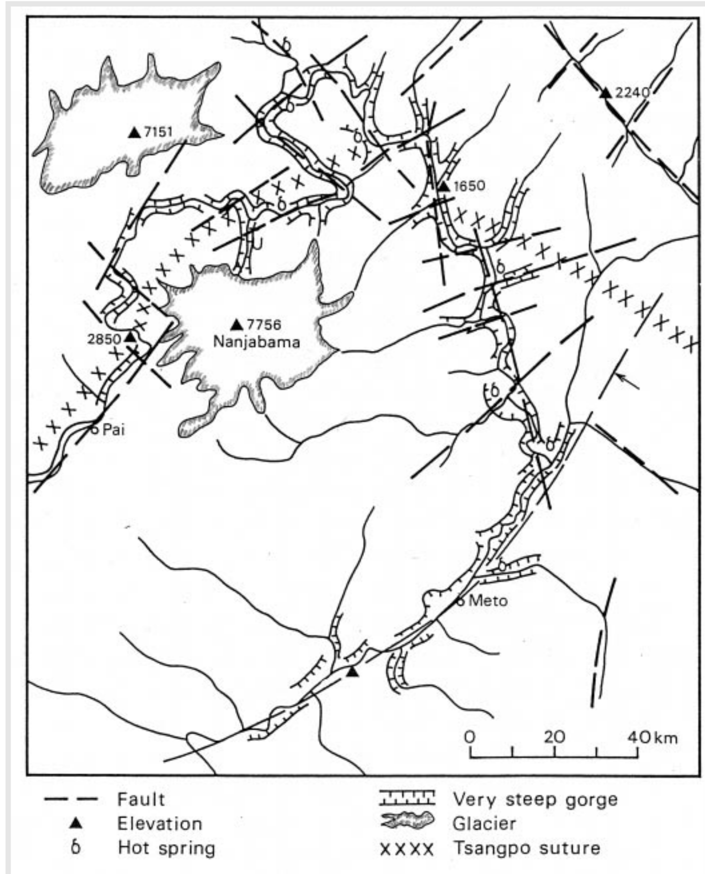
The simplest observation is that the main course of the Yaluzangbu River basically follows the suture and strike-slip faults. The orientation of the upper and middle river valley develops along the Indus–Tsangpo suture along a west–east alignment (Figure 2). The valley makes a U-turn downstream at Pai and cuts into the Himalayas, then flows along the strike-slip faults southward to India. This sudden change in the river flow direction has been called the Great Bend. Some parts of this gorge, which was explored for the first time in 1999, are more than 4000 m deep, making it the deepest in the world. There are many hypotheses about this abnormal change in river orientation (TETCAS 1983). However, it is clear that the Great Bend actually consists of many smaller bends (Figure 3) and that these bends developed along a group of strike-slip faults in various directions, mainly southwest–northeast and northwest–southeast. These faults are still active, as is clear from the many earthquakes that have occurred here in recent years (Xiao 1988) and the hot springs that have been appearing everywhere at the bottom of the gorge. The faults were initially produced in the Miocene and reactivated in the latest tectonic movement.

Some of the orientations of the larger tributaries, such as the Lhasa River, Nian Chu, and Palong Tsangpo, also follow the direction of strike-slip faults. The Lhasa River, which has a rectangular type of drainage, developed along a group of strike-slip faults in the area.

Landforms associated with normal faults

Long profile of the river and valley forms: The whole main course of the Yaluzangbu consists of sections with gentle and steep gradients that accompany the reaches with wide valleys and gorges (Figure 4, Sections 1–8). The changes in the long profile were explained by TETCAS (1983) as the erosion knickpoints of the river. The steep gradients at Pai, Jiacha, and Sago were considered to be 3 erosion knickpoints caused by the 3 stages in the Himalayan Movements during the early, middle, and late Quaternary. However, the 3 stages in the plateau uplift cannot be identified according to the latest geological evidence. The changes in valley forms have also been said to be related to lithological changes, with igneous rocks often forming gorges (TETCAS 1983). But the same igneous rocks are also exposed in wide valley sections, and gorges do not occur in these areas. The author's survey found that the knick points are related to the active normal faults in the internal plateau and the reactivated strike-slip faults in the downstream gorge. The normal faults are the results of east–west extension, and the strike-slip faults downstream are related to the rapid Himalayan uplift, both of which were very active in recent tectonic movements. Many hot springs can be seen at these fault locations, and earthquakes frequently occur. These active faults mark the boundaries of wide valleys and gorges. Thick river sediments were deposited in the wide valleys upstream of these gorges (Figure 5). Therefore, a division can be established that reflects the major characteristics of fluvial landforms in each section and is separated by major active faults across the river valley (Figure 4). However, no active fault is found at the boundary between Sections 3 and 4. Further geological investigation is required at this location. It must be pointed out that short, narrow valleys may exist within the gorge sections, and short gorges may appear in wide valley sections due to the influence of some small, active faults.

FIGURE 3 Tectonic structures and river channel direction in the Great Bend area (fault source from TETCAS 1983; Zhou et al 1984).



Alternations between wide valleys and gorges are also reflected in the width of the river valley. The width of the river valley was measured at 10-km intervals along the main course. The results show that changes in river valley width are controlled by the faults and correspond with the river divisions (Figure 6). The wide valleys have gentle slopes and gentle hydraulic gradients, and the mountain summits on the two sides of the river are generally below 5500 m. However, the gorge sections have steep slopes and hydraulic gradients, and their mountain summits are generally above 6000 m and are covered by glaciers. This indicates that relative movements occurred at the faulting positions. Seeber and Armbruster (1983) also found that high gradients on the profiles of 16 rivers along the Himalayan arc correlate with the Main Central Thrust that is responsible for the Himalayan uplift in the last phase, not with different rock resistance. Hence, the changes in long profile gradient and valley forms are likely to have been caused by the active faults.

River channel forms: In the upstream part of Section 1, the river channel takes the form of a free meandering channel on a wide, flat glacio-fluvial plain with swamps

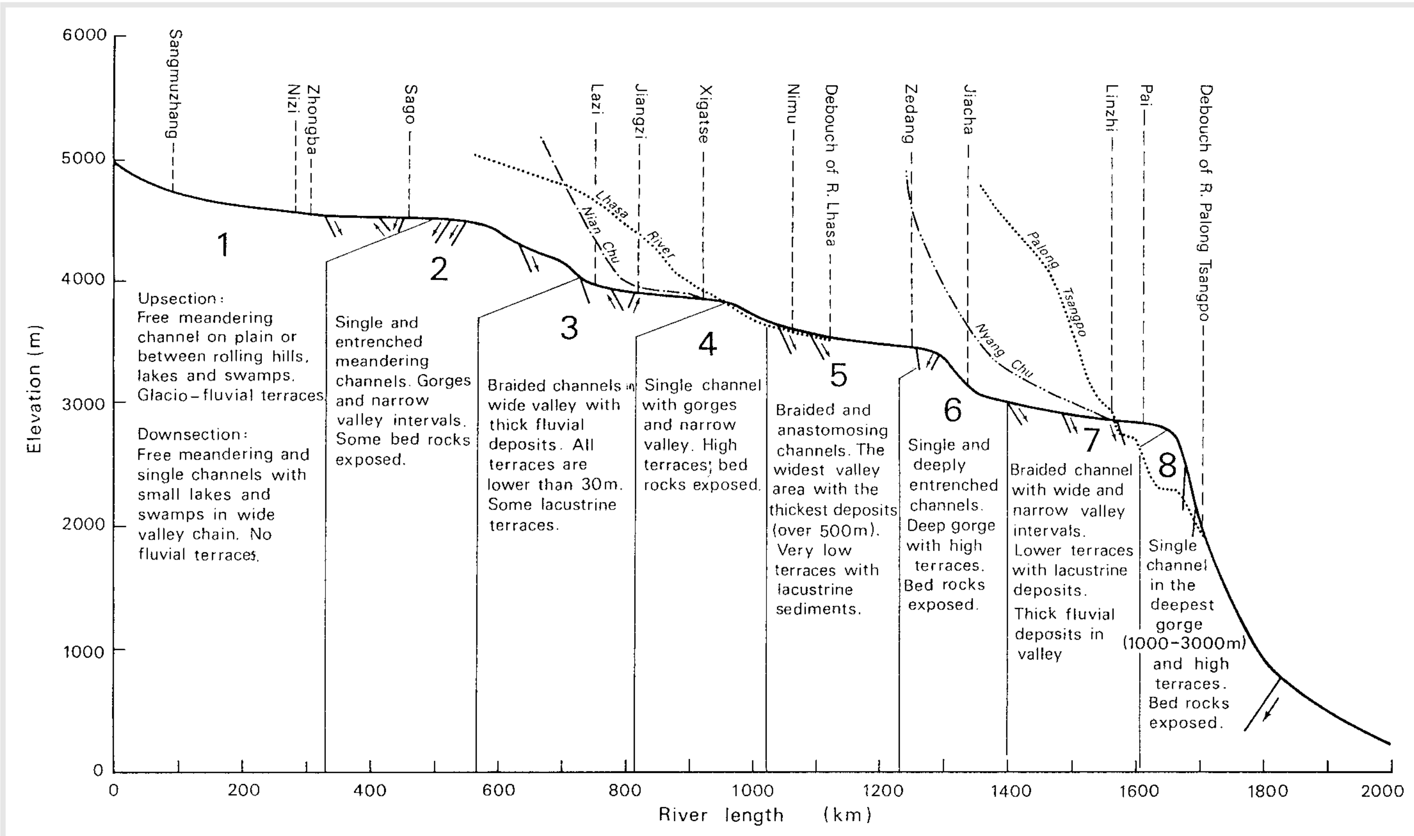


FIGURE 4 Longitudinal profile and the river sections with related fluvial landforms of the Yaluzangbu River (Zhang 1998).

and lakes. The plain has quite a few rolling hills, which TETCAS (1983) considers to be remnants of the Tertiary erosion surface. In the downstream part of Section 1, the channel consists of a braided channel, an anastomosing channel, and a single channel within a 1.5–7-km wide valley. The boundary between Sections 1 and 2 is a normal fault. The upper part of Section 1 can be considered as an area unaffected by base level change, which is often caused by active faulting. Thus, this reach of the river is still at the stage of erosion surface formation. The section downstream has been affected by backward erosion caused by the boundary fault. The formation of the single channel part is due to the invasion of alluvial fans from small tributaries beside the valley. In the middle stream and downstream areas of the river (Sections 2–8), single straight channels are a common channel form in the gorge sections because of their steeper hydraulic gradients and channel incision. The boundaries of single channels and braided channels are also active faults. Deep entrenched meandering channels were also found in gorge Sections 2 and 6, especially Section 6, in which the deep entrenched meandering channel occupies over half of the section length. These deep channels indicate that the original channels here were free, meandering channels, and fast uplift of blocks defined by active normal faults in these places caused deep incision. All the channels in the gorges were cut into bedrock. Widely developed braided and anastomosing channels in the wide valleys are well developed between these gorges. Therefore, channel forms, like long profile gradients and valley forms, are controlled by active faulting.

Terraces and their sediments: Distribution of terraces in the valley of the Yaluzangbu River is scattered and variable in terms of relative heights and sediment between the different sections. Distribution was very confusing prior to the detailed analysis of the sections. Many hypotheses have been suggested to explain the great differences in height and lacustrine sediment problems. These hypotheses suggest that diluvial fans, river regime, glacio-fluvial deposits, or rockfalls may have been responsible for the different heights and sediments. In the author's view, none of these hypotheses can explain the great differences between terrace elevations (a 100-m minimum difference for terraces of the same age) or resolve the questions of terrace height comparison and lack of lacustrine deposits in gorge sections. But if the section divisions are incorporated into the distribution of terraces and their relative heights

FIGURE 5 Wide valley with thick fluvial deposits and braided channels in Section 3 of the Yaluzangbu River. (Photo by author)

with respect to river level, the questions can be resolved (Figure 7). The wave-shaped distribution of the terraces can be explained by the erosion and deposition process changes that are caused by block movements across the valley. There is no terrace at all in the wide valley of Section 1 because it is located on an erosion surface and the local base level has not been changed by active faults. In other wide valleys, the terraces are low and closer together. Due to the burying of the river valley, old terraces are covered by fluvial sediments and/or remain at low levels. By contrast, the terraces in the gorges are higher, scattered, and distributed at greater height intervals. Relative terrace height generally tends to increase downstream (Figure 7). The rapidly uplifted blocks were cut into by the river, and their original terraces were elevated to higher positions in the newly formed gorges (Figure 8). The relative movements of terraces on both sides of normal faults were identified by sediment ^{14}C dating (Zhang 1998). Moreover, strath terraces can only be found in the gorge sections.

Lacustrine deposits on terraces are a common phenomenon in the wide valleys of the middle stream (Sections 3, 5, and 7), especially downstream. This is the result of rapid uplift of the elevating blocks impeding river flow so as to form large lakes behind the uplifted blocks, such as most of the big lakes in present-day Tibet (TETCAS 1983). Even Sven Hedin at the beginning of this century realized the role of active faults in the formation of lakes and established that Pangongcho Lake was formed by blockage of an uplifted fault block (Hedin 1922). The disappearance of these palaeolakes may indicate that rates of river incision have already overtaken the rates of uplift, so that the river cut into the lacustrine deposits and lacustrine terraces were left in the wide valleys. The overall trend of relative terrace elevation increases downstream in wide valleys (Figure 7). This reflects the latest headward erosion process of the river, which has cut down from the edge of the plateau since the plateau uplifted. Within individual sections, the relative elevations of terraces also exhibit the same trend and indicate headward erosion starting from their local base level, with sedimentation causing blockage downstream.

Assessment of the evolution of the Yaluzangbu

Initial phase of the river

Suggested periods for the initial formation of the river vary from the middle Tertiary (TETCAS 1983) to the middle Pleistocene (Fong 1957). The latter hypothesis can be ignored because terraces have been found that predate the middle Pleistocene and the widely disseminated middle Pleistocene lacustrine terraces are not the highest river terraces. The collision of India and Asia created an orogenic belt along the Indus–Tsangpo suture, which is the Gangdise island arc-type volcanic-

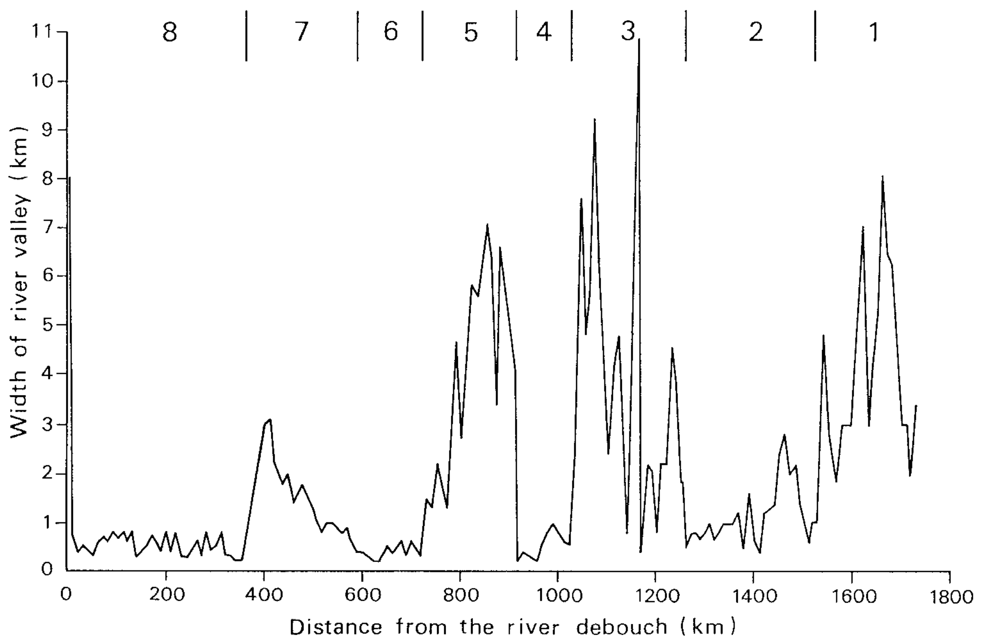


FIGURE 6 Changes in river valley width along the Yaluzangbu main course (based on the Chinese Military Ordnance Map).

plutonic rock mountain belt on the north side of the suture. The orogenic belt is known as the Gangdise Mountain Range (Figure 1). In the lower part of the range, 2 molasse belts were formed after the collision (Yin et al 1988). This implies that the suture was a lower place that received deposits from the uprising Gangdise. Along the middle course, the lower part of the molasse belt consists of a series of colorful conglomerates and sandstone scattered at high elevations on the northern valley slopes. The gravel and sand in the rocks are well sorted and rounded or subrounded in shape. Large-scale cross-bedding and diagonal bedding can be seen in the sandstones, which may be of fluvial facies. TETCAS (1983) argued that this is a large-scale depression deposit along the Tsangpo suture. However, this suggests that some fluvial activity occurred in several cases along the section of the suture at the time.

The river prior to the latest uplift and normal faulting

The strike-slip faults in the Miocene changed the orientation of some tributaries and formed new river channels in the present-day Yaluzangbu drainage system, such as the Lhasa, Nian, and Palong Tsangpo rivers (Figure 4). The downstream river channel—the Great Bend—also follows the direction of strike-slip faults that cut across the suture. However, spurs that represent wide Pliocene valleys have been found on the valley slopes along the main course and along these big tributaries. This suggests that the changed river channels exited in the Pliocene, when they developed following the formation of these faults.

The river after the uplift and normal faulting

Normal faults cut across the river in the last phase, forming a series of new local base levels along the river channel. At the uplifted parts, the river channel cut deeply into rocks and formed gorges while thick river deposits on the descending blocks buried the original channels.

As the uplift rates in uplifted blocks were faster than the downcutting rates of the river, the river was blocked in various places and large lakes formed in Sections 1, 3, and 5. The palaeolake in Section 7 was caused by the rapid uplift of the Himalayas. The relative differences in altitude (200–1000 m) between the Pliocene wide valley and present-day riverbed in the middle stream indicate that normal faulting might have occurred after the formation of the wide valley. Section boundaries very close to normal faults also imply that the normal faults are not very old. The disappearance of the palaeolakes in Sections 3 and 5 may have occurred in the late Pleistocene, according to the sediment dating in lacustrine deposits. At that time, headward erosion reached the palaeolakes because the rising rates of the uplifted blocks were generally lower than the downcutting rates of the headward erosion and top lacustrine sediments isolated to form terraces. Deep gorges with straight channels and deeply entrenched meandering channels formed in uplifted blocks as a result of normal fault movements. Braided and anastomosing channels formed on thick deposits on the wide valley floors.

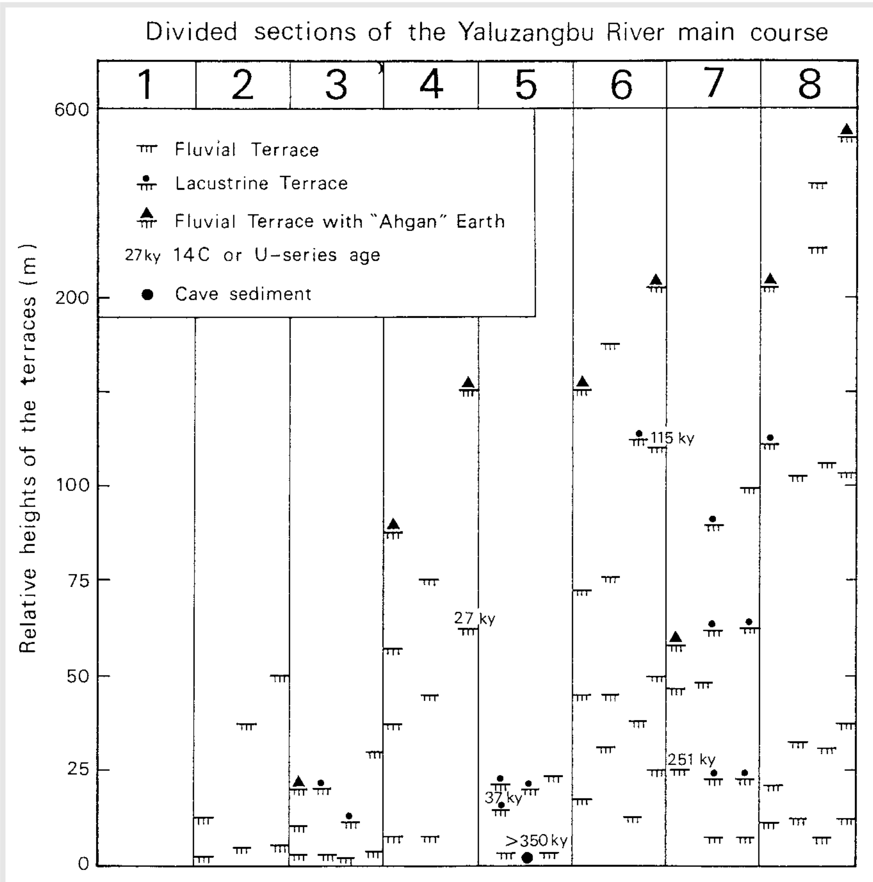


FIGURE 7 Terrace relative heights in the different sections of the Yaluzangbu River (Zhang 1998).

Conclusion

The fluvial landforms along the Yaluzangbu River are controlled by tectonic movement; they are the best examples of landforms changed by tectonic movements. An accurate date for initial formation of the Yaluzangbu River cannot be determined because the whole lower part of the erosion surface has been destroyed by erosion. However, the original river might have formed in the Oligocene-Miocene period. The formation of strike-slip faults changed the river channel directions of some tributaries and created a fault zone in the eastern Himalayas in which the Great Bend developed. Since the Pliocene, the river has been flowing toward the east, with a major bend following the Indus-Tsangpo suture. The latest uplift of the plateau, whose amplitude is about 2500 m, caused the headward erosion to cut deeper into the Himalayas and formed the deepest gorge in the world. The fact that the world's deepest gorge (Section 8) was formed on the edge of the plateau (the Himalayas) challenges Coleman and Hodges' (1995) hypothesis, which suggests that the plateau reached its maximum height in the mid-Miocene. The gorge section is less than 50 km from the Main Central Thrust (MCT), a tectonic boundary of the uplifted Tibetan and Indian Plain. If such an uplift occurred in the Miocene, the headward erosion rate suggests that the deepest gorge should have formed in the middle reach of the current riverbed of the Yaluzangbu. The deep gorges of other rivers flowing out of Tibet along the Himalayas are closer to the MCT because they have less discharge. Meanwhile, normal faults induced by east–west extension in the internal plateau cut across the river and formed a series of new local base levels. Deposition occurred on downthrown sides and strong erosion was produced in uplifted blocks. Therefore, the 3 knickpoints cannot represent the 3 stages of the Quaternary tectonic movements nor does alternation of wide valleys and gorges indicate difference in rock resistance. These were induced by local base level changes caused by block movements in the normal faulting period. The actual dates for the formation of palaeolakes, normal faulting, and most of the terraces require further study. This will improve our knowledge of the latest phase of tectonic movements as well as our understanding of the palaeo-environmental and river processes of the Tibetan Plateau.

FIGURE 8 Deep gorge with terraces (Section 6) on the Yaluzangbu River. (Photo by author)

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