Morphotectonic Development of the Western Part of the Trijuga Dun , Nepal Sub-Himalaya

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Kazuo KIMURA*

Abstract The Trijuga Dun, the easternmost longitudinal valley in the Sub-Himalaya, consists of the following five geomorphological units; the Bokse 1 Terrace formed in Middle Pleistocene age, the Bokse 2 Terrace emerged in the age around 10 ka, the Bokse 3 Terrace and the Gaighat Terrace of the Holocene, and the present floodplain. The Bokse 1 Terrace Deposit is conformably underlain by the Upper Siwalik Formation, which is the molassic sediment formed since Plio-Pleistocene age. Even on the north-dipping sedimentary surface, the Bokse 1 Terrace Deposit shows southward current. Therefore the Bokse 1 Terrace was formed as piedmont alluvial fans developed on the foot wall of the Central Churia Thrust (CCT). On the other hand, the Bokse 2 Terrace Deposits and the later sediments are valley fills. The fact displays that the Trijuga Dun was established as an intermontanein in the stage between the Bokse 1 and 2 terraces. The counter-dipping Bokse 1 Terrace Deposit is distributed on the thrust ramp of the Himalaya Frontal Fault (HFF), along which the Siwaliks are in fault contact with the Gangetic Alluvium. Therefore, the Trijuga Dun is a piggyback basin developed with the growth of the thrust ramp of the HFF. Ages of the valley fills show that the Trijuga Dun is the youngest among the Sub-Himalayan piggyback basins. The valley fills distributed along the left bank of the Trijuga River were uplifted to higher place than those of the right bank. This geomorphic feature suggests that the CCT is still active beneath the valley floor in Holocene age.

Key words: Late Quaternary, Siwalik Belt, terrace, palaeogeography, neotectonics, piggyback basin

1 Introduction

The Trijuga River, a tributary of the Sapt Kosi River, forms a longitudinal valley situated in the eastern part of the Nepal Sub-Himalaya (the Churia Range or the Siwalik Hills). The Sub-Himalaya is known as foothills of the Himalayas and a zone of active tectonics (*e.g.*, Kizaki, 1988). Therefore, the geomorphic feature of the Sub-Himalayan longitudinal valleys must be reflecting the recent crustal movement related

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to the growth of the foreland fold-thrust wedge. The author aims to clarify the geomorphic development of the Trijuga Dun, which is the easternmost longitudinal valley in the Sub-Himalaya. The application of morphostratigraphic classification, palaeogeographic reconstruction and their chronology make it possible to explain the tectonic story of the Himalayas and their surroundings. The results may provide important basis for understanding the thin-skinned tectonics of the active foreland of the Himalayas.

2 Overview

2.1. Physical features

The Sub-Himalaya is the Himalayan Front consisting of the Churia (Siwalik) Range and longitudinal valleys (dun). The Trijuga Dun is situated in the eastern part of Nepal (Figs 1, 2). It extends about 30 km along the Trijuga River, and its width is less than 8 km. The surveyed area is the western half of the dun. The valley floor ranges from 130 to 200 m above sea-level. The Trijuga Dun is surrounded by the Churia Range with its hogbag features. The Churia Range is subdivided into the Inner Churia Range (the Mandrebhir Danda) in the north and the Outer Churia Range in the south. The former stands 600-800 m above sea-level, while the latter is about 400 m in height.

The Siwalik Group, the Himalayan molasses accumulated during the period from the Miocene to the Early Pleistocene, predominates the Churia Range (Fig. 3). Litho-stratigraphically, the Siwaliks distributed in the area around the Trijuga Dun are divided into the following three units, the Lower Siwalik Formation composed chiefly of siltstone, the Middle Siwalik Formation consisting of sandstone and the Upper

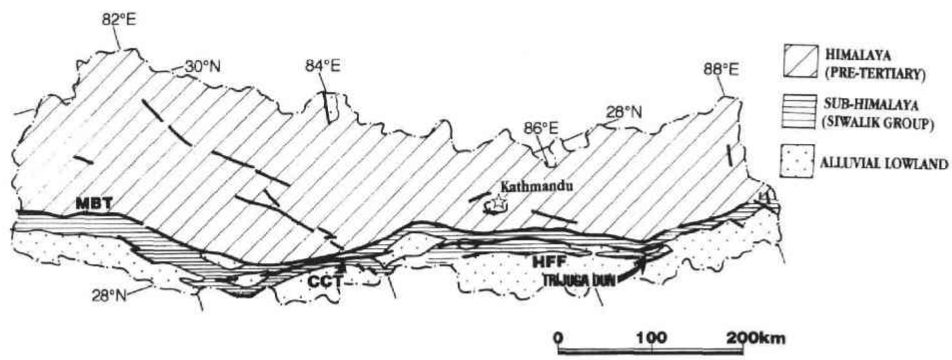


Fig. 1 Simplified geological map of Nepal
The Sub-Himalaya, composed of the Mio-Pleistocene molassic sediment called the Siwalik Group, is bounded by the Main Boundary Thrust (MBT) in the north and the Himalaya Frontal Fault (HFF) in the south.

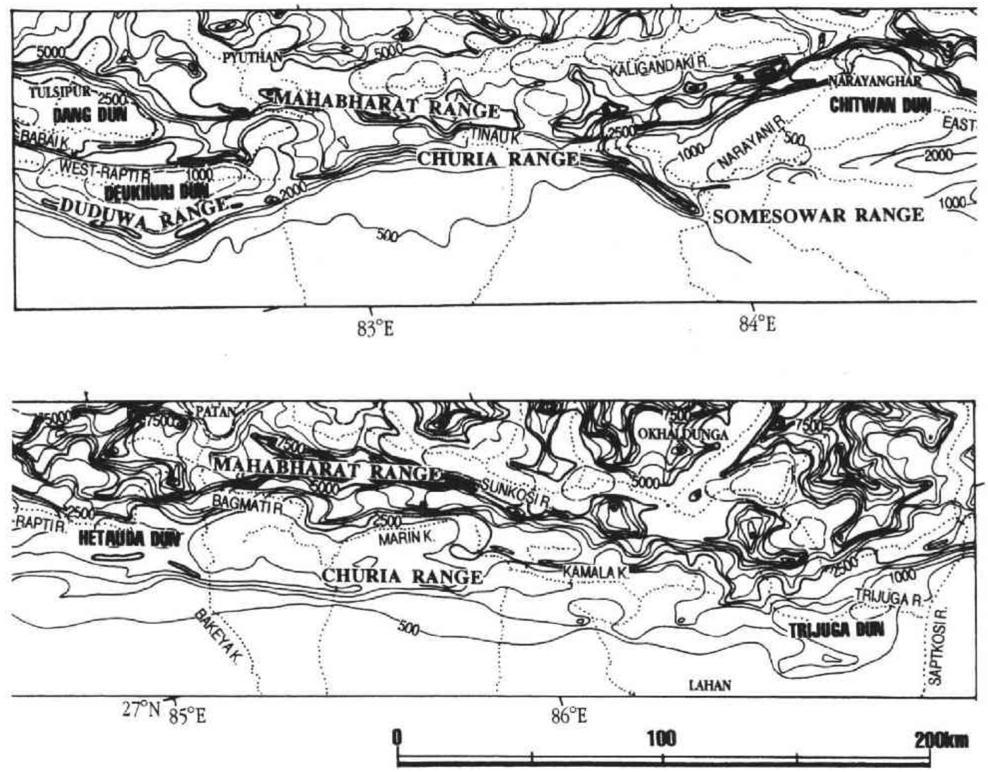


Fig. 2 Summit level map of the Nepal Sub-Himalaya (contour interval: 500 feet)
The Nepal Sub-Himalaya is topographically called the Churia Range, which stands about 1,000 m (3,000 feet) above sea-level. Longitudinal depressions in the Sub-Himalaya are celled the dun valleys.

Siwalik Formation composed of semi-consolidated sand and gravel (Itihara *et al.*, 1972). In the basin, younger unconsolidated deposits unconformably off-lap the Siwaliks. These coarse deposits are generally termed as the Dun Gravels (*e.g.*, Sharma 1990).

Three major fault systems, which are north-dipping reverse faults, are paralleled with the valley (Fig. 3). Itihara *et al.* (1972) illustrate the Main Boundary Thrust (MBT), which runs 4-6 km north of the valley with WNW-ESE direction. The Lower Siwalik Formation is overthrusted by the Lesser Himalayan Metasediments along the MBT. As Nakata (1982, 84, 88) points out, the MBT located along the north of the Trijuga Dun (Udaypur Fault) is the north-dipping normal fault in morphological aspects. Itihara *et al.* (1972) also mapped a thrust along the Mandrebhir Danda and the Trijuga River that is NW-SE strike. The thrust is called the Mandrebhir Fault in this paper. It is a boundary between the Lower and the Middle-Upper Siwaliks.

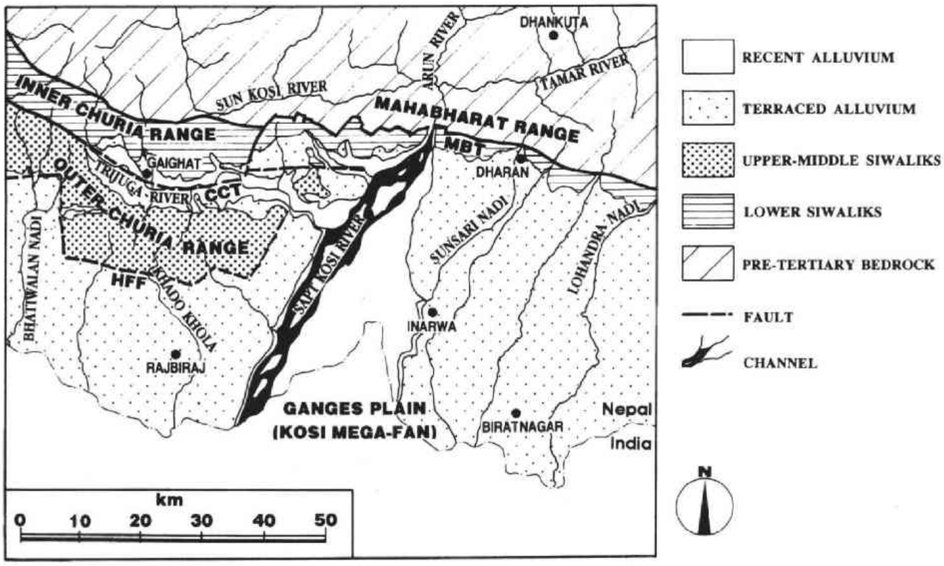


Fig. 3 Geological map of the area around the Trijuga Dun (modified after Itihara *et al.* (1972), Delcaillau *et al.* (1987) and Schelling (1992))
The Trijuga Dun is the easternmost intermontane basin in the Sub-Himalaya. To the east of the Sapt Kosi River, the Sub-Himalaya is pinched, and is solely composed of the Inner Churia Range (the north belt of the Siwaliks) without duns and the Outer Churia Range.

This structural relation shows that the thrust is equivalent to the Churia Central Thrust (CCT ; Tokuoka *et al.*, 1986) or the Main Dun Thrust (MDT ; Delcaillau *et al.*, 1987). The CCT is considered as a boundary fault between the mountainous zone and the foreland basin in the Upper Siwalik stage. In addition, the CCT morphologically divides the Siwalik Group into two parts, the north belt (Inner Churia Range) and the south belt (Outer Churia Range). The CCT, however, cannot be traced in the Trijuga Dun. The third reverse fault, showing scarplets and pressure ridges of EW orientation, runs intermittently along the south foot of the Outer Churia Range. It is named as the Pansewar Fault in this paper. The thrust is the present boundary dividing the "rising" Himalaya from the Gangetic Foredeep, thus, it is equivalent to the Himalayan Frontal Fault (HFF ; Nakata, 1982), the Main Siwalik Thrust (MST ; Delcaillau *et al.*, 1987) or the Main Frontal Thrust (MFT ; Schelling, 1992).

Schelling (1992) synthesized the geology of Eastern Nepal. He applied balanced cross-section analysis to estimate the crustal shortening of the Himalayan region in 25-15 Ma. In his study, the Sub-Himalaya in Eastern Nepal is clarified as a system of imbricated thrusts showing piggyback sequence, and it has been shotened about 24 km in Neogene Period.

Chalaron *et al.* (1995) examined tectonic conditions in the Nepal Sub-Himalaya by the technique of numerical modelling. As describing them, the Main Frontal Thrust (MFT = Pansewar Fault) fringing the Trijuga Dun is segmented to tear faults of NS-oriented in the east and the west, and EW-striking thrust in the south (Fig. 3).

2.2. Previous studies

First geomorphic research in the area around the Trijuga Dun was carried out by Itihara *et al.* (1972). They recognised three levels of river terraces, which consist of gravels several to 10 m in thickness, in eastern Nepal. They report that the terraces cut the Siwaliks and their deposits are several to 10 m thick. In the Trijuga Dun, however, detailed research was not completed.

Delcaillau *et al.* (1987) describe the morphostructures of the Siwalik Hills in eastern Nepal. Three levels of fluvial terraces (T3-T1) are mapped in the area including the Trijuga Dun. They illustrate a Sub-Himalayan longitudinal valley like a piggyback basin developed under NNE-SSW compression with the modification of WNW-ESE tensile tectonics. However, the Quaternary tectonic history in the area around the Trijuga Dun is not mentioned in detail.

Bashayal *et al.* (1989) discuss the Sub-Himalayan neotectonics through the physiographic aspect reported by Delcaillau *et al.* (1987). In their study, the morphostructural organization in the Himalayan Front is characterized by two types of relief ; the escarped front and the smooth front according to dip of thrust. They also present a schematic image of succession of longitudinal basins corresponding to the thrust front migration from the MBT to the MST (HFF). Their idea leads to the result that the basin formation behind the MST (HFF) began in the age around 0.2 Ma, though its data source is not presented.

Those studies are mainly focused on the analysis of the Siwalik Group and the tectonics in the Siwalik Stage in macro-scale, or description of fault landforms in micro-scale. Therefore and regrettably, the discussions of the post-Siwalikan tectonics in meso-scale seem to be built on some imaginations without reasonable evidence.

3 Morphostratigraphic Units

Pre-recent geomorphic surfaces would be classified into the following four terraces ; the Bokse 1 Terrace (T3 in Delcaillau *et al.*, 1987), the Bokse 2 Terrace (T1), the Bokse 3 Terrace (T1) and the Gaighat Terrace, in consideration of continuity, litho-facies, lithological composition of terrace deposits and soil development on terrace surfaces (Fig. 4).

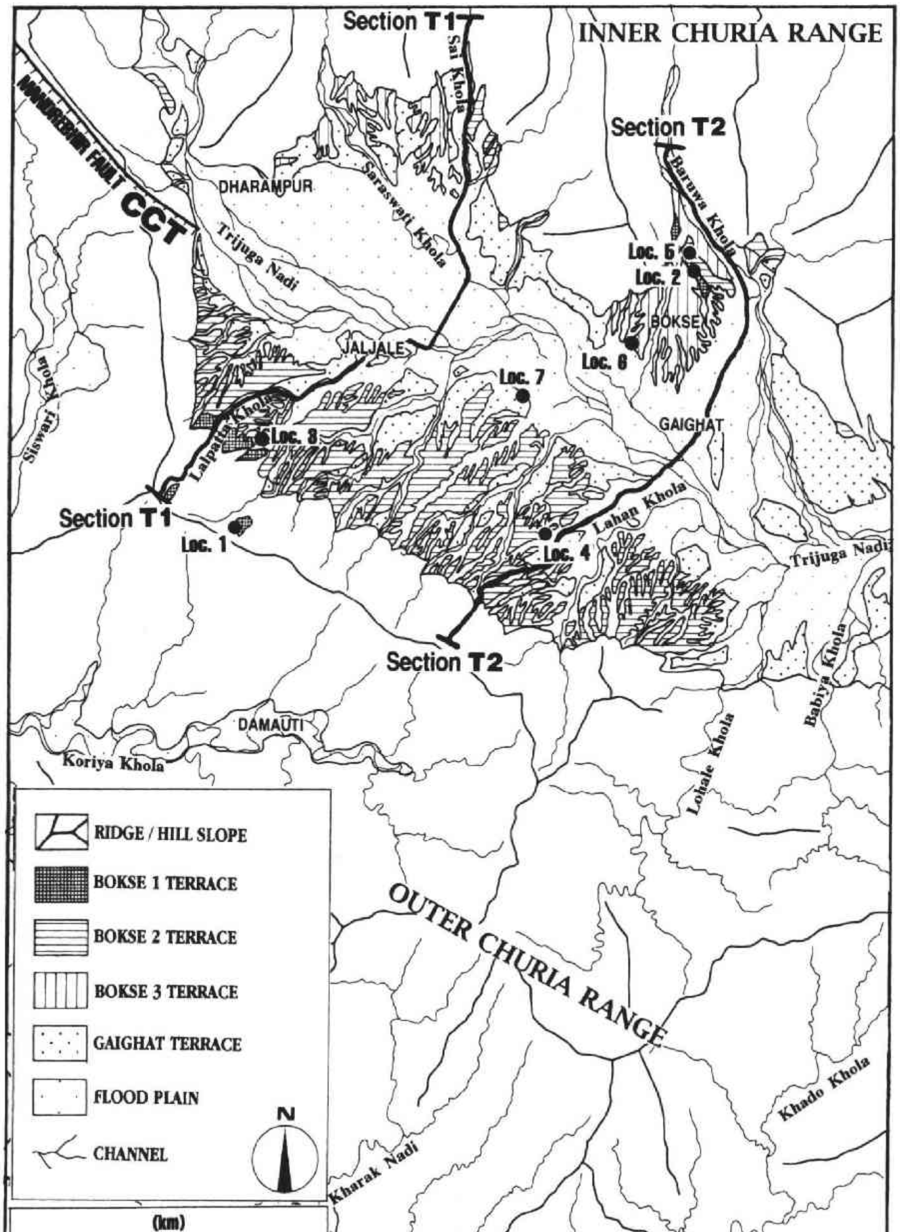


Fig. 4 Geomorphological map of the western part of the Trijuga Dun (Locs. 1~8 are index for Fig. 5. Sections T1 and T2 are index for Fig. 9)

3.1. The Bokse 1 Terrace

The Bokse 1 Terrace, which is characterised by its dissected and red-weathered surface, is chiefly distributed in the southern part of the Trijuga Dun. Along the right bank of the Baruwa Khola, the terrace is exceptionally developed in the northern part of the valley. The relative height of the terrace scarps reaches 28 metres along the Baruwa Khola. The surfaces are underlain by alternating beds of thick medium-sorted gravel and thin silty sand (Fig. 5). The deposit is conformably underlain by the Upper Siwalik Formation, which was accumulated in the age from the late Pliocene to the Early Pleistocene. The gravel in the Bokse 1 Terrace Deposit has imbricated structure showing southward current even in the southern part of the study area (Fig. 6). Those features demonstrate that the Bokse 1 Terrace had been formed as alluvial fans, developed along the foot of the Lesser Himalaya and the Inner Churia Range. The fan was directly faced to the ancient foreland basin, because the Outer Churia Range, the present dividing ridge between the dun and the Ganges Plain, is covered with the fan deposit. The fill-top surface of the Bokse 1 Terrace is deeply oxidised and changes to red clay. The weathering crust develops 3 to 10 m thick, and its rubification is ranging from 10R 6/8 to 5YR 6/8. The deep red-weathered surface is

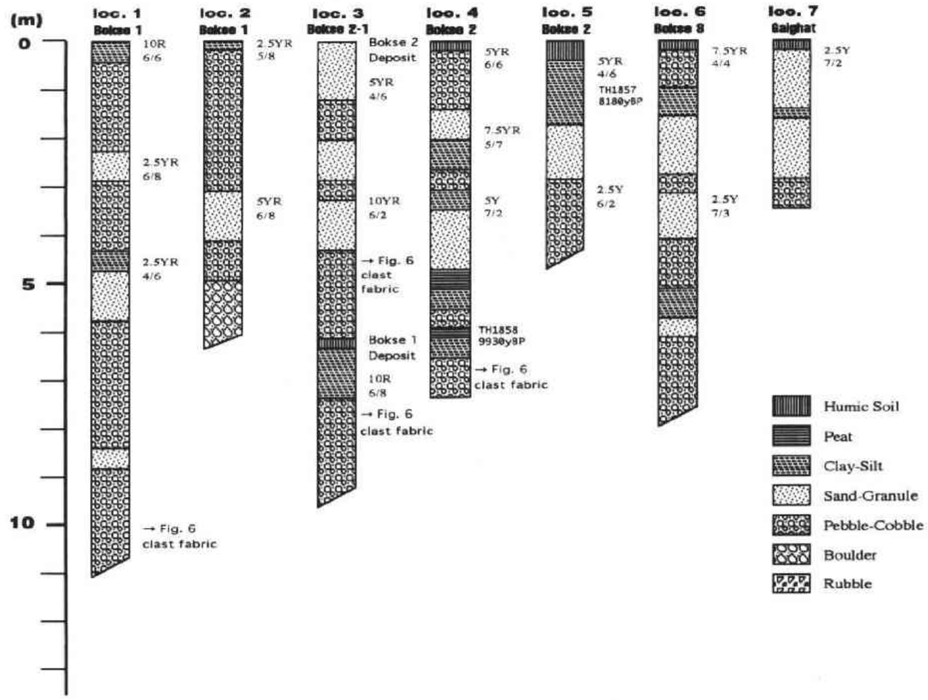


Fig. 5 Geological columns of the terraced deposits in the study area

correlated to the Higher Terrace (*ca* 120-200 ka) in Central Nepal (Iwata and Nakata, 1985) or the Gorbathan Surface (*ca* 140 ka) in Eastern Nepal Front (Nakata, 1984). Thus, the Bokse 1 Terrace was a piedmont alluvial fan formed in late-Middle Pleistocene time.

3.2. The Bokse 2 Terrace

The Bokse 2 Terrace, being several to 20 m above the present flood plain, is well developed in the southern part of the dun, and is narrowly distributed along the tributaries from the Inner Churia Range. The terrace deposit is characterized by interfingered beds of gravel and silty sand (Fig. 5). Their gravelly beds consist of metamorphic and carbonate rocks derived from the Lesser Himalaya, and sandstone and siltstone from the Lower Siwaliks. Clast fabric of them is similar to that of the present floodplain deposits. The Bokse 2 Deposit is in abutting with the Bokse 1 Deposit, and its distribution is limited in the dun. These sedimentological characters show that the Bokse 2 Deposit is the oldest basin fill of the Trijuga Dun. Total thickness of the deposit increases from north (less than 10 m) to south (over 20 m). It has orange-coloured weathering crust (around 5YR6/6-7.5YR4/4). Two radiocarbon ages, indicating 8180 ± 50 ^{14}C yrs B.P. (TH-1857) and 9930 ± 60 ^{14}C yrs B.P. (TH-1858), are obtained from the upper part of the deposit (Fig. 5). These data suggest that the Bokse 2 Deposit had been mostly accumulated in Late Pleistocene age, and the fill-top surface was emerged in the age around the Pleisto-Holocene boundary.

3.3. The Bokse 3 Terrace

The Bokse 3 Terrace, standing about 17 m above the stream (along the Baruwa Khola), is wide and flat fill-top surface developed along some tributaries from the Inner Churia Range. The terrace surface is dissected by gullies, and is weathered as same as that of the Bokse 2 Terrace. Its deposit, more than 15 m thick, embodies of alternating beds of silt, sand and gravel (Fig. 5). The filltop surface of the terrace is slightly weathered showing yellowish colour (5YR4/4-10YR7/4). Judging from the soil development and morphostratigraphic position, the Bokse 3 Terrace was formed in early Holocene time without long time-lag from the emergence of the Bokse 2 Terrace.

3.4. The Gaighat Terrace

The Gaighat Terrace, being less than 5 m above the flood plain, is distributed in front of the Bokse 2 and 3 Terraces. It is slightly-dissected alluvial fans formed by the tributaries of the Trijuga River. The terrace deposit is composed of alternating beds of sand and pebble. The base level of the deposit is commonly below the river beds. (Fig. 5). Weathering crust is immature on the surface, and its topsoil colour ranges

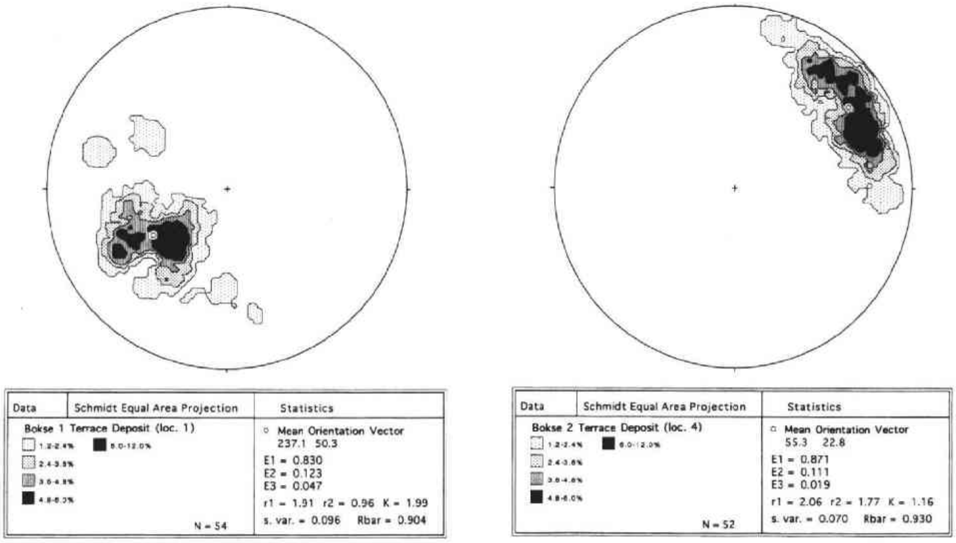


Fig. 6a

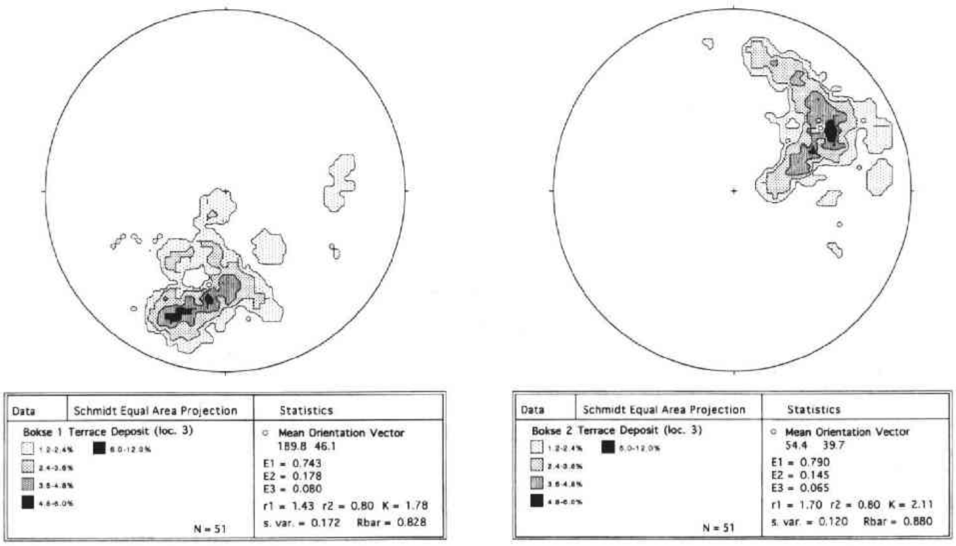


Fig. 6b

Fig. 6 Clast fabric of the terraced alluvium in the study area

The density plots are poles of a-b plane of cobbles to lower hemisphere of Schmidt net. The plots clearly displays that the palaeocurrent along the Outer Churia Range was changed from south to north in the stage between the Bokse 1 Terrace and the Bokse 2 Terrace. This palaeogeographic change, that is to say the upheaval of the Outer Churia Range, formed the Trijuga Dun as an intermontane basin in the Sub-Himalaya.

from 10YR3/4 to 2.5Y5/5. These features show that the Gaighat Terrace was developed in the latest Holocene.

4 Discussion

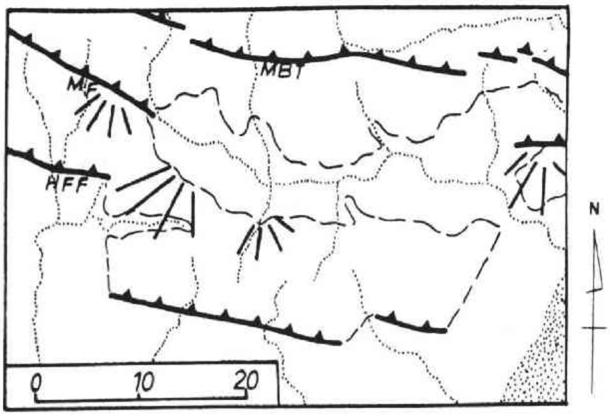
4.1. Formation of the dun

The Bokse 1 Terrace deposit, conformably overlapping the Upper Siwalik Group, was formed as piedmont alluvial fans in Middle Pleistocene age (*ca* 120–200 ka). The ancient fans were mainly distributed on the foot wall of the CCT except along the Baruwa Khola (Fig. 7A–B). The fan-deposits showing southward current were spread across the present divide between the dun and the Ganges Plain. This palaeogeography is similar to the pre-dun phase in the area around the Hetauda Dun (Kimura, 1994). In the pre-dun phase, the fans were developed along the foot of the Inner Churia Range (the thrust ramp of the CCT), and the Outer Churia Range was not situated as a barrier separating the dun from the Gangetic Foredeep.

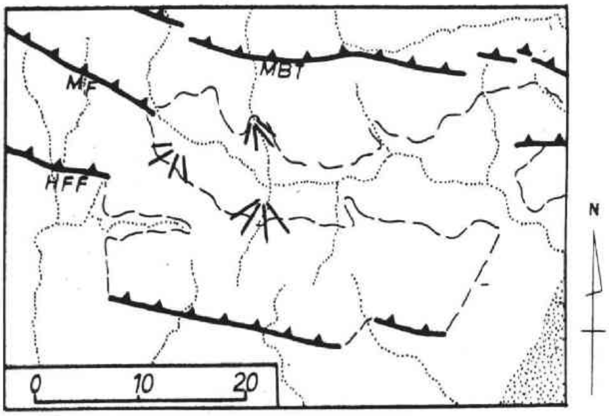
Unlike the pre-dun sediments, the current directions of the Bokse 2 Terrace Deposit and the younger sediments are in accord with that of the present drainage system (Fig. 7C). They are distributed "within" the dun valley. Therefore, the Bokse 2 Terrace and the later deposits were formed as basin fills (dun-phase deposits). The palaeogeographic change occurred in the stage between the Bokse 1 and the Bokse 2 terraces (Fig. 7B–C). Although the age of the base of the Bokse 2 Deposit is unknown, radiocarbon dates (8–10 ka) were obtained from the upper part of the deposit. Comparing with accumulation rate of the Upper Siwaliks, which is estimated about 1–4 mm/y (*e.g.*, Tokuoka *et al.*, 1986), it is considered to have taken thousands of years to complete the 20 metres'-thick Bokse 2 Deposit. Therefore, beginning of the sedimentation of the Bokse 2 Deposit is back to the Late Pleistocene. In other words, the Outer Chruia Range uplifted as a dividing ridge between the Trijuga Dun and the Ganges Plain by Late Pleistocene age.

Figure 8 is a schematic diagram showing the cross-strike development of the Trijuga Dun. From the Upper Siwaliks Stage to the Bokse 1 Terrace Stage, the study area was in the pre-dun phase (Fig. 8a). Generally, the Outer Churia Range is illustrated as a thrust ramp of the HFF (*e.g.*, Tokuoka *et al.*, 1994). In the study area, the HFF-equivalent thrust (MST or MFT) is delineated along the south foot of the Outer Churia Range (Delcaillau *et al.*, 1987 ; Schelling, 1992). Thus, the Outer Chruia Range was uplifted by the vertical displacement of the HFF in Middle-Late Pleistocene time (Fig. 8b). After that, younger sediments began to be trapped in the dun (Fig. 8c), and dissected (Fig. 8d).

A) Upper Siwalik Stage (Early Pleistocene)



B) Bokse 1 Terrace Stage (Middle Pleistocene)



C) Bokse 2 Terrace Stage - (Late Pleistocene -)

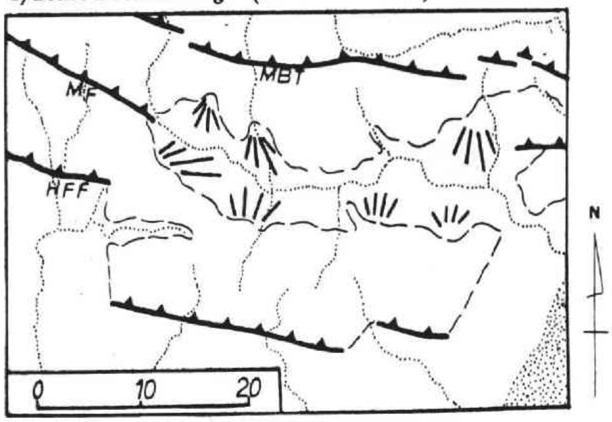


Fig. 7 Palaeogeographic reconstruction around the Trijuga Dun
scale: kilometres, dot line: present channel, broken line: outline of the distribution of Upper Quaternary sediments, radial lines: outlets of foothill fans

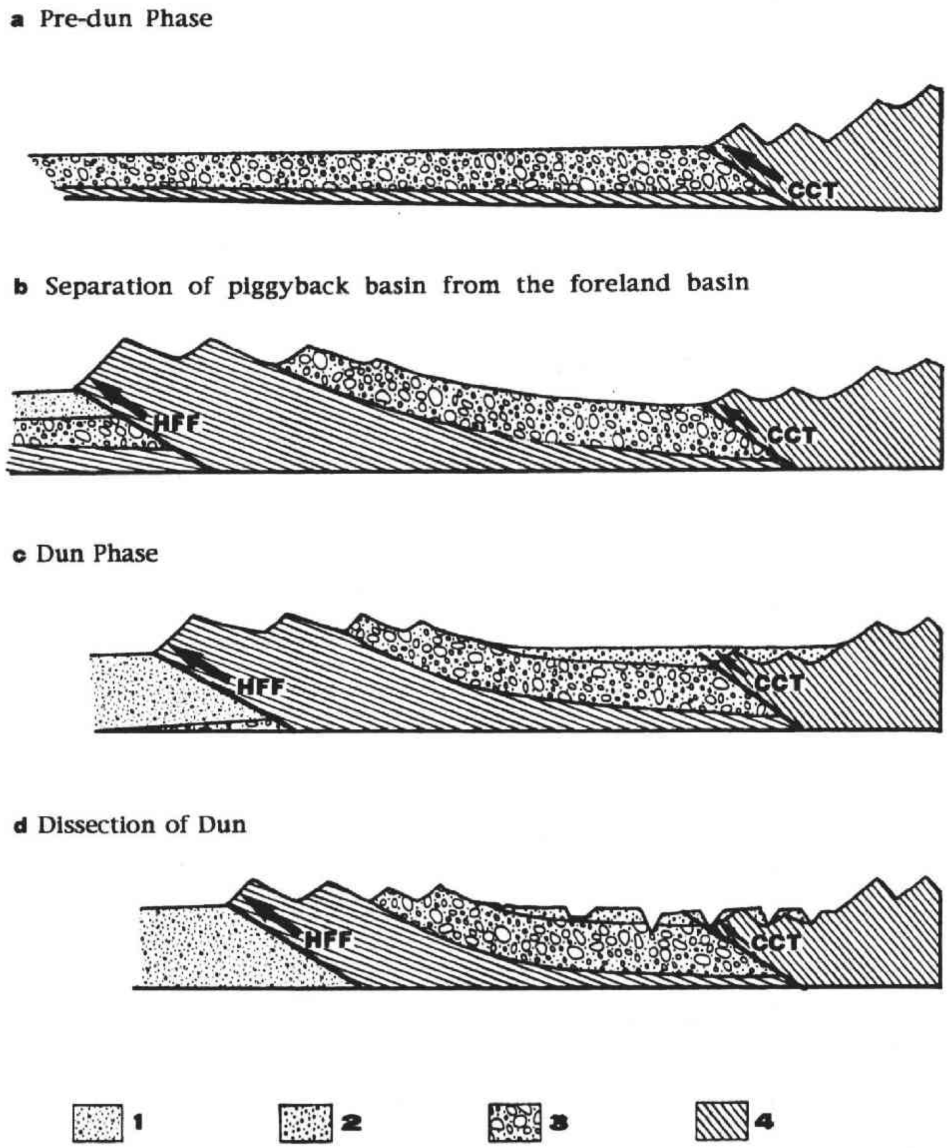


Fig. 8 Morphotectonic evolution of a dun valley
1 : Ganges Alluvium, 2 : Dun fills, 3 : Pre-dun fan deposits (Upper Siwaliks and a part of terraced alluvium), 4 : Middle-Lower Siwaliks

4.2. The easternmost and the youngest dun

The Trijuga Dun is the easternmost dun valley. To the east of the Trijuga Dun, the Sub-Himalaya is pinched, and is composed of the Inner Churia Range without duns and the Outer Churia Range (Fig. 3).

Along the Himalayan Front from Panjab to Eastern Nepal, dun valleys were developed with interesting pattern. Morphologically, dun-like landforms are not developed in the Panjab front, which is the westernmost Sub-Himalaya. Geologically, however, a piggyback basin was formed in the age around 1 Ma in the Panjab front (Pivnic and Khan, 1996). In the Garhwal front (mid-western Sub-Himalaya), most of the dun valleys were developed since the Middle Pleistocene (Nakata, 1972). In the Nepal front (mid-eastern Sub-Himalaya), the Hetauda Dun was established by Late Pleistocene age (Kimura, 1994). Likewise, the timing of the evolution of the dun valleys seems to be shifted from west to east. The oldest valley fill of the Hetauda Dun is more-weathered, including older-dated deposit, than that of the Trijuga Dun. Therefore, the Trijuga Dun is probably the youngest dun.

The diachronous evolution of the dun valleys suggests that the morphogenesis due to the trusting of the HFF propagated eastwards. Lack of duns and the Outer Churia Range in the eastern Sub-Himalaya is considered to mean that the active front of the HFF has not yet reached to the eastern Himalayan front. That is to say the area around the Trijuga Dun is the active front of the HFF, both in strike-slip and thrusting tectonics, since Late Pleistocene age.

4.3. Deformation of the valley floor

Most of the tributaries of the Trijuga River flow across the dun floor in N-S section. Therefore, the longitudinal profiles of the channels and their terraces evince the history of base level changes of the Trijuga Dun (Fig. 9). First of all, numbers of terraces are unequal between the right and the left banks of the Trijuga River. The left bank, the northern part of the dun, consists of the Bokse 2 Terrace, the Bokse 3 Terrace and the Gaighat Terrace. In contrast, the Bokse 3 Terrace is not developed on the right bank. The distribution level of the terraces is different across the river, and definitely, the Bokse 3 Terrace on the left bank is higher than the Bokse 2 Terrace on the right bank. Furthermore, the Bokse 2 and 3 terraces developed in the northern part of the dun are less-slanted towards the downstream than the present river bed. Particularly, the Bokse 3 Terrace along the Sai Khola is almost flat-lying. These topographic anomalies suggest that the elevated fans have been deformed tectonically since their formation. Though the fault is not observed on the earth's surface, these facts suggest that the Mandrebhir Fault is still active as a thrust beneath the flood plain of the Trijuga Dun. In other words, the deformations of the valley floor are caused by the vertical displacement of the CCT during Holocene time.

5 Concluding Remarks

Geomorphic surfaces in the Trijuga Dun are divided into the following five

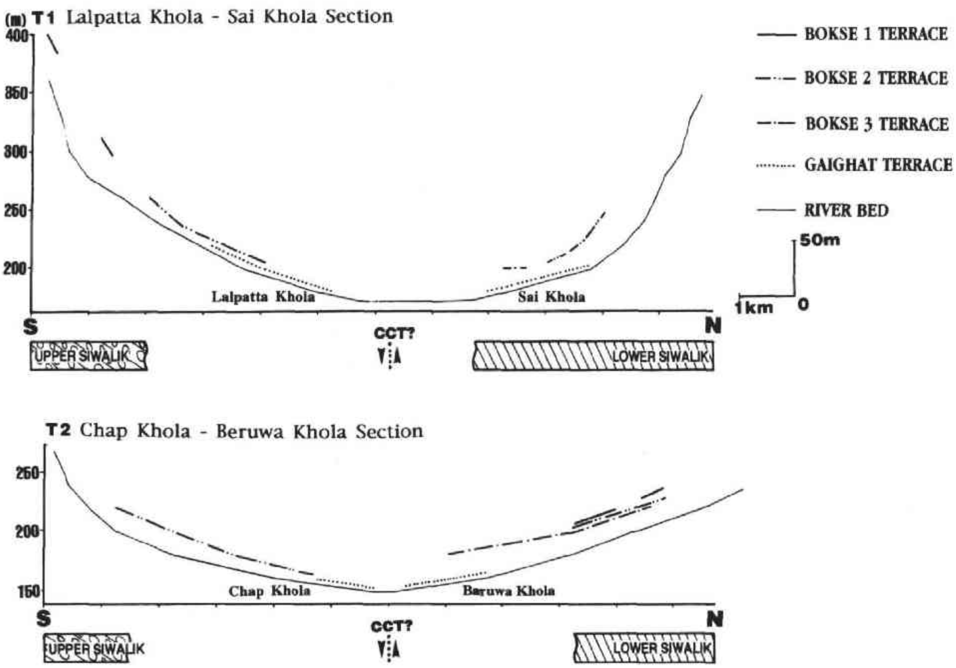


Fig. 9 Cross-sections of the Trijuga Dun
Section T1 : Geomorphic profiles along the Lalpatta Khola and the Sai Khola
Section T2 : Geomorphic profiles along the Chap Khola and the Baruwa Khola
To compare the Bokse 2 Terrace distributed in the northern part and southern part, the fill-top surface in the northern part is higher than that in southern part. The northern part of the dun is underlain by the Lower Siwaliks and the southern part is underlain by the Upper Siwaliks. This geostructure suggests that the northern part of the dun is a hanging wall of the CCT. The gap in the Bokse 2 Terrace implies the vertical displacement of the CCT in Holocene time.

stratigraphic units ; the Bokse 1, the Bokse 2, the Bokse 3 and the Gaighat terraces, and the recent flood plain. Radiometric ages are obtained solely from the upper part of the Bokse 2 Terrace Deposit (8-10 ka). Detailed chronology is remained as a problem to be solved, though, the tentative history of the Trijuga Dun is resulting from morphostratigraphic observation and palaeogeographic reconstruction.

1) Pre-Dun Phase : The Bokse 1 Terrace, piedmont alluvial fans along the foot of the Lesser Himalaya and the Inner Churia Range, had been formed by Middle Pleistocene age. In those days, the study area was a part of the Gangetic Foredeep, and the CCT was the boundary between the Himalayan fold-thrust wedge and the basin.

2) Piggyback-basin formation : The dun was separated from the foredeep in the stage between the Bokse 1 Terrace and the Bokse 2 Terrace. This palaeogeographic

change, which was outlined by Late Pleistocene time, was caused by the growth of the thrust ramp of the HFF. Thus, the Trijuga Dun is the youngest piggyback basin in the Sub-Himalaya.

3) Dun Phase: Intermontane basin environment was established by Late Pleistocene age. Under this condition, the Bokse 2 Terrace, the Bokse 3 Terrace, and the Gaighat Terrace were emerged. After the shifting of the deformation front from the CCT to the HFF, however, the CCT is still active as a blind thrust. As a result, unpaired terraces are developed in the dun, and terraced valley fills in the northern part are distributed on higher level than those in the southern part.

It is noteworthy that the Trijuga Dun is the youngest-and-easternmost piggyback basin in the Sub-Himalaya. Previous studies show that the piggyback-basin formation in the Himalayan front is shifting from west to east in late Quaternary time. This suggests that the morphogenesis of the HFF propagates eastwards. The HFF is generally regarded as a reverse fault, along which the Gangetic Alluvium is overthrusted by the Siwaliks. These facts imply that the HFF is a reverse fault with strike-slip sense.

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