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Geomorphology of the Arun Valley, Eastern Nepal

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ABSTRACT

The Arun Valley can be divided into the Upper Arun Periglacial Valley (UAPV) and Lower Arun Fluvial Valley (LAFV). They area separated by the linearly arranged ridges of Jaljale Danda, Harale Danda, and Sichok Danda. The UAPV lies in the north whereas the LAFV occupies the southern territories. The UAPV is further divided into four geomorphic provinces with fifteen distinct Holocene terrace levels, whereas the LAFV is divided into four geomorphic provinces with thirteen Pleistocene terrace levels.

The concept of geomorphic province is introduced to denote distinct geomorphological features formed in a type locality within a given geological time span. The identified geomorphic surfaces are morpho-stratigraphically defined at respective villages and have a wide geographic distribution.

This paper attempts to classify geomorphologically the whole Arun watershed and to compare the position of various terraces in terms of neo-tectonic activities. The main geomorphic features of the watershed and their relationship with the major geological structures are also discussed. The boundaries of the geomorphic province often coincide with the reported thrusts in the area.

INTRODUCTION

The study area lies in the Arun Valley of Eastern Nepal (Fig. 1). The Arun River is one of the largest tributaries of the Sapta Koshi River, which is one of the most important tributaries of the Ganges. The Arun River flows between Mt. Everest in the west and Mt. Kanchenjunga in the east, and contains many deep gorges. The main aim of the study was to reveal the geomorphological evolution of the Arun Valley. For this purpose, the area between Tribeni and Kimathanka was studied in the field and various geomorphic provinces and terraces were demarcated. A comparative study of fluvial and periglacial terraces was also carried out to work out the neotectonic activities in that area.

The Arun River originates from the Yeobkanjial Glacier lying in the north of Mt. Xiabanga (8,016 m), which is the southwestern part of Xizang (Tibet). It extends between latitudes 27° 49' and 29° 05' N, and longitudes 85° 38' and 88° 57' E, and occupies an area of 25,307 sq km (Sino–Nep. Rept. 1988). The Arun River begins at an altitude of 6,706 m and after dropping to about 4,267 m, becomes a braided river flowing eastwards through a valley flanked with terraces of gravel. At an altitude of about 3,962 m, it abruptly turns towards the south, first through the Yo Ri gorge and then through the long gorge lying between Mt. Everest and Kanchenjunga, which carries it down to about 1,219 m (Holmes 1978).

The Arun River enters into the Nepalese territory at the Kimathanka village and makes a deep (about 350 m) gorge (Plate 1) between the ridge of Pisu La and the Chumsur village (Table 1). Within the Nepalese territory, the Arun River extends between latitudes 26° 45' and 27° 30' N, and longitudes 87° and 87° 30' E, where it occupies the drainage area of 34,700 sq km (Dunsmore 1988). The Arun Valley enjoys typical monsoon climate with heavy rains (about 1000 mm) between June and August, and dry winter (about 20 mm) between December and January (Shrestha 1988).

Plate 1: The deepest (330 m) gorge of the Arun River between the Pisu La Ridge and the Chumsur village. It is a good example of transverse erosion. *View towards NE.*

The Arun Valley is one of the rare valleys that accommodate all regions from the high Himalayan peaks to the Siwalik Hills. A short description of geology, geomorphology, and geomorphic evolution of the Arun Valley and its surroundings is given below.

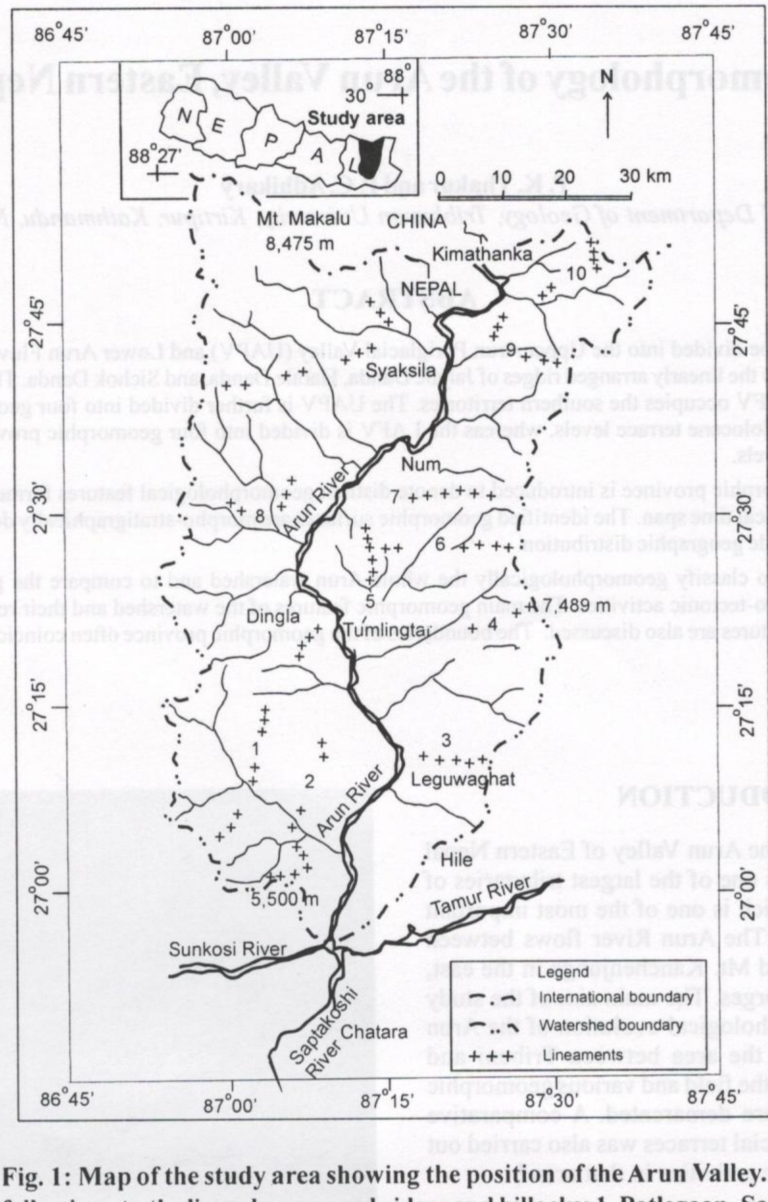

Fig. 1: Map of the study area showing the position of the Arun Valley. The following are the linearly arranged ridges and hillocks: 1. Patlegaon–Salme; 2. Yampang–Habu–Tintole; 3. Pubang–Badle–Mujure Danda; 4. Pipale–Chainpur; 5. Arunthan–Harale Danda; 6. Dandagaon–Chitre; 7. Harale Danda–Gunyang Danda; 8. Shichok Danda–Kulung Danda; 9. Namche–Gyabling; and 10. Chepua–Dukan.

GEOLOGY

On the basis of lithology, grade of metamorphism, and tectonics, Hagen (1969) identified the following three major litho-tectonic groups in the study area: the Nawakot Nappe, Kathmandu Nappe, and the Khumbu Nappe. These nappes are further subdivided into several units. The nappes were formed during the Himalayan orogeny in Early Miocene.

The Nawakot Nappes are the lowermost tectonic units, consisting of sedimentary and low-grade metamorphic rocks (i.e., phyllites, argillaceous quartzites, and limestones). They are exposed in a tectonic window in the centre of the valley between Dingla and Diyale (Table 1).

The Kathmandu Nappe is exposed in the northern part of the Arun Valley, around the Milke Danda as well as in the Barabise–Chainpur region, Ridak–Chepuwa (Table 1) region, and the lower Barun region. The rock types of the Kathmandu Nappe include schists, quartzites and gneisses, and are relatively resistant to weathering and erosion.

Table 1: List of major villages in the study area

Village	Latitude/Longitude	Altitude (m)	Village	Latitude/Longitude	Altitude (m)
Chatara	26°50'/87°10'	150	Kumalgaon	27°18'/87°12'	458
Tribeni	26°55'/87°09'	263	Tarigaon	27°37'/87°19'	2,150
Salme	27°06'/86°55'	2,400	Yamchung	27°28'/87°12'	1,840
Tintole	27°01'/87°09'	1,350	Bungling	27°28'/87°08'	790
Mujure Danda	27°12'/87°25'	2,885	Dandagaon	27°10'/87°20'	1,870
Pubang	27°13'/87°19'	1,475	Dandagaon (Chitre)	27°23'/87°15'	1,100
Yampang	27°14'/87°10'	1,210	Num	27°33'/87°18'	1,150
Pipale	27°17'/87°12'	558	Sima	27°37'/87°21'	1,475
Chainpur	27°17'/87°20'	1,610	Mangkhim	27°39'/87°21'	1,650
Patlegaon	27°19'/87°05'	2100	Syaksila	27°40'/87°22'	1,850
Dandagaon	27°23'/87°15'	1,150	Chyamdang	27°46'/87°27'	2,300
Chitre	27°23'/87°22'	2,100	Namche	27°43'/87°23'	2,030
Arunthan	27°25'/87°11'	1,215	Chepua	27°45'/87°25'	2,250
Kulung	27°27'/87°50'	1,510	Hatiya	27°44'/87°21'	1,650
Sichok	27°27'/86°56'	4,475	Ekua	27°37'/87°19'	2,150
Salleri	27°28'/87°08'	7,875	Chumsur	27°48'/87°25'	2,760
Gogane	27°28'/87°13'	1,872	Chyangrimbu	27°50'/87°25'	2,630
Mempang	27°24'/87°04'	1,350	Ridak	27°48'/87°27'	2,950
Pangma	27°24'/87°11'	1,212	Kimathanka	27°51'/87°25'	2,630
Tumlingtar	27°17'/87°13'	365	Kepu Pokhari	27°49'/87°22'	4,325
Mangmai	27°06'/87°16'	330	Sting Danda	27°48'/87°19'	4,630
Dingla	27°22'/87°08'	1,280	Popti Bhanjyang	27°49'/87°19'	4,625
Salkhani	27°31'/87°14'	1,150	Khade Danda	27°49'/87°22'	4,550

The Khumbu Nappe is the highest tectonic unit, and it is exposed in the eastern and western flanks of the Arun Valley as well as to the east of Ridak and west of Thulo Pokhari. It includes schists, quartzites, migmatites, gneisses, and crystalline limestones. The rocks are massive and resistant.

Akiba et al. (1973) divided the Arun region into various structural units (Fig. 2). They separated the Siwalik Zone, South Marginal Zone, Midland Autochthonous Zone (including the Tumlingtar Window and Dudh Kosi Dome), Midland Zone (containing augen gneiss, phyllite, and crystallines), Basement Gneiss Zone, and Tibetan Zone (containing sedimentary rocks).

Amatya and Jnawali (1994) compiled a geological map of Nepal and showed the Kuncha Group (phyllite and quartzite), Nawakot Group (phyllite, quartzite, calcareous sandstone, dolomite, and slate), Higher Himalayan Crystallines, and Tibetan Sedimentary Zone (Fig. 3). The axis of the Arun Anticline is followed by the Arun River. The Num–Bungling bend of the Arun River is controlled by the presence of the Arun Anticline and Chamlang–Irkhua Synform (Fig. 2). The Tumlingtar–Tamur Anticline with its E–W trend is another important structure of the area (Fig. 2).

Apart from the bedrock, there are also glacial and periglacial deposits of Holocene age, and the fluvial deposit of Pleistocene age, which occupy respectively the northern and southern territories.

GEOMORPHOLOGY

Within the Nepalese territory, the Arun Valley can be divided into the Upper Arun Periglacial Valley (UAPV) and Lower Arun Fluvial Valley (LAFV). The two geomorphic zones are separated by the linearly arranged ridges (Plate 2) of Jaljale Danda, Harale Danda, and Sichok Danda (Fig. 4). The UAPV represents a recently retreated glacial valley with deep stream channels incised into the thick fluvio-glacial sediments. There are also debris flow and landslide deposits mostly triggered by heavy precipitation. The LAFV represents a wide fluvial valley surrounded by undulating and moderately steep hills and mountain ridges with steep incisions and numerous villages of indigenous tribes.

Each geomorphic zone is further subdivided into various geomorphic provinces. The concept of geomorphic province is introduced to denote distinct geomorphological features of a type locality such as topographic distribution pattern, evolutionary trend, and erosion index. These provinces are

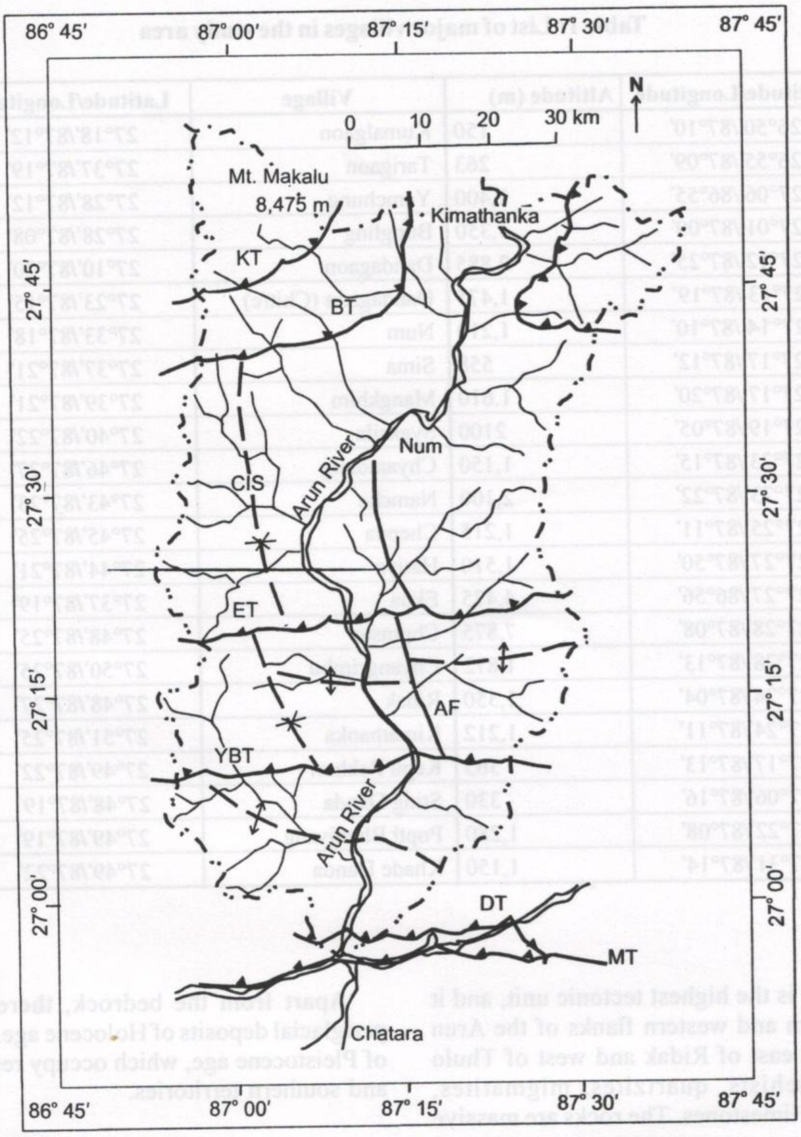

Fig. 2: Tectonic map of the Arun region showing major geological structures. MT: Mulghat Thrust, Dt: Dhankuta Thrust, YBT: Yaku Bilte Thrust, AF: Arun Fault, TTA: Tumlingtar–Tamur Anticline, CIS: Chamlang–Irkhua Synform, BT: Barun Thrust, and KT: Khumbu Thrust (after Akiba et al. 1973)

bounded by the linearly arranged topographic expressions (Fig. 4). In the study area, there are four geomorphic provinces in the LAFV and four in the UAPV. A short description of them is given below.

The following geomorphic provinces are observed in the UAPV, respectively from north to south (Table 2).

Upper Arun Periglacial Valley

The Barun–Chamlang province is well developed around the upper reaches of the Sankhua Khola, Apsua Khola, Irkhua Khola and Barun Khola, and it extends up to the Barun–Chamlang glaciers. It is the uppermost province developed in the Nepalese territory. The province consists of four geomorphic surfaces developed between 15,000 and 20,000 ft, such as the BC4 (15,000–16,000 ft), BC3 (16,000–17,000 ft), BC2 (17,000–18,000 ft and BC1 (18,000–20,000 ft), respectively. The Barun–Chamlang province is separated from the Sursing Khola–Popti Bhanjyang province in the south by the Khumbu Thrust.

The Sursing Khola–Popti Bhanjyang province is developed around Molung Pokhari, Kepu Pokhari, and extends up to the pass of Popti Bhanjyang in the north,

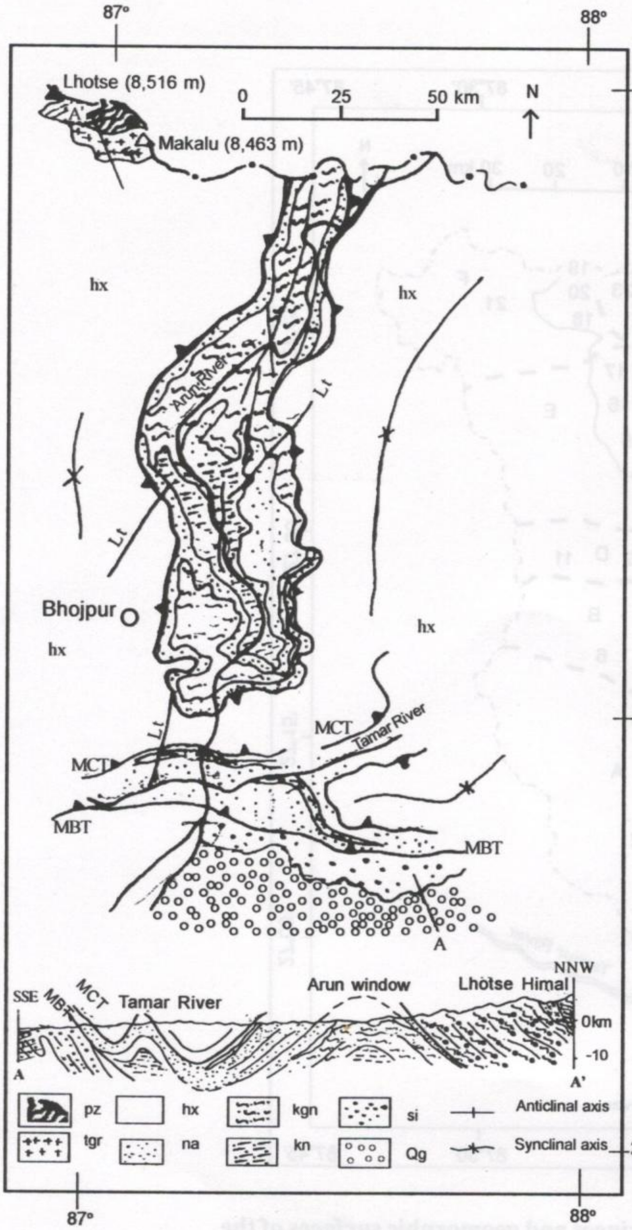

Fig. 3: Geological map of the Arun region (after Amatya and Jnawali 1994). kn: Kuncha Group (metasandstones and phyllites); na: Nawakot Group (slates, dolomites, quartzites, and limestones); hx: Precambrian Himalayan Crystallines; Tgr: Tertiary Himalayan Crystallines; kgn: Augen gneisses (in the Kuncha Group); si: Siwalik Group (conglomerates, sandstones, and shales); Qg: Quaternary alluvial deposits; Lt: Major lineament; MBT: Main Boundary Thrust; MCT: Main Central Thrust

Pholung Pokhari in the east, and the Sting Danda area in the south. The province consists of three geomorphic surfaces developed between 11,000 and 15,000 ft. It includes the Sting Danda (11,000–13,000 ft), Khade Danda (13,000–14,000 ft), and Popti Bhanjyang (14,000–15,000 ft). The Sursing Khola–

Plate 2: Panoramic view of linearly arranged ridges around the Harale Danda and Gunyang Danda. *View towards NE.*

Table 2: Geomorphic provinces and surfaces developed in the Upper Arun Periglacial Valley

Province (altitude range, ft)	Geomorphic surface	Altitude range (ft)
Num–Hatiya (3,500–7,000)	Hatiya–Sankarante	6,000–7,000
	Ekua	5,000–6,000
	Hedangna–Garhi	4,000–5,000
	Num	3,500–4,000
Kimathanka–Ridak (7,000–11,000)	Ridak	10,000–11,000
	West Chumsur	9,000–10,000
	Kimathanka	8,000–9,000
	Chepua–Chyamdang	7,000–8,000
Sursing Khola–Popti Bhanjyang (11,000–15,000)	Popti Bhanjyang	14,000–15,000
	Khade Danda	13,000–14,000
	Sting Danda	11,000–13,000
Barun–Chamlang (15,000–20,000)	BC 1	18,000–20,000
	BC 2	17,000–18,000
	BC 3	16,000–17,000
	BC 4	15,000–16,000

Popti Bhanjyang province is separated in the west from the Barun–Chamlang province by the Khumbu Thrust. In the south, it is separated from the Mempang –Kulung province by the Barun Thrust.

The Kimathanka–Ridak province is developed around the Chepua, Hunghang and Chyamdang areas, and it extends up to Kimathanka (Plate 3), the northern border of Nepal. The province contains four geomorphic surfaces developed between 7,000 and 11,000 ft. They are the Chepua–Chyamdang (7,000–8,000 ft), Kimathanka (8,000–9,000 ft), West Chumsur (9,000–10,000 ft), and Ridak (10,000–11,000 ft). The Kimathanka–Ridak province is separated in the west by the Barun Thrust, and it is separated in the south from the Num–Hatiya province by the linearly arranged ridges of the Namche–Gyabling area.

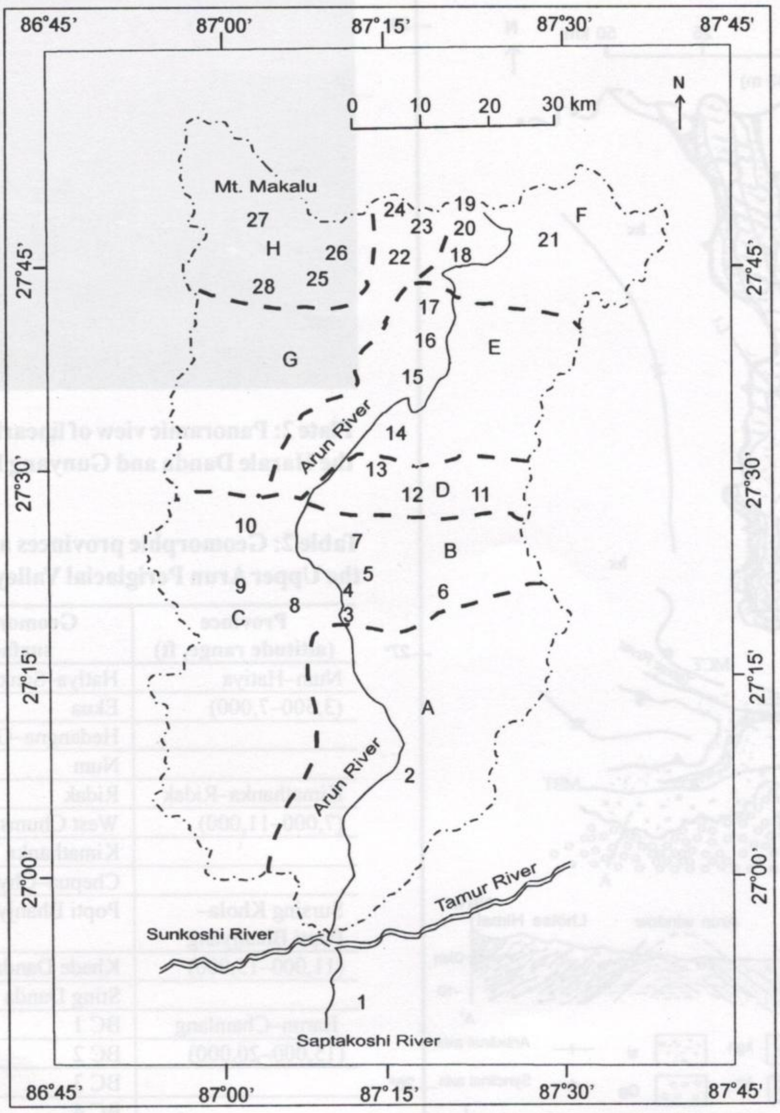

Fig. 4: Map showing the geomorphic provinces and geomorphic surfaces of the Arun Valley. *Geomorphic provinces:* A. Chatara–Mangmai Province; B. Tumlingtar–Pangma Province; C. Mempang–Kulung Province; D. Gogane–Bhotebas Province; E. Num–Hatiya Province; F. Kimathanka–Ridak Province; G. Sursing Khola–Popti Bhanjyang Province; and H. Barun–Chamlang Province. *Geomorphic surfaces:* 1. Chatara; 2. Mangmai; 3. Tumlingtar; 4. Kumalgaon; 5. Hokse; 6. Khandbari; 7. Pangma; 8. Mempang; 9. Dingla; 10. Kulung; 11. Gogane; 12. Yamchung; 13. Bhotebas; 14. Num; 15. Hedangna–Garhi; 16. Ekua; 17. Hatiya–Sankarante; 18. Chepua–Chyamdang; 19. Kimathanka; 20. West Chumsur; 21. Ridak; 22. Sting Danda; 23. Khade Danda; 24. Popti Bhanjyang; 25. Barun–Chamlang geomorphic surface 1 (BC1); 26. Barun–Chamlang geomorphic surface 2 (BC2); 27. Barun–Chamlang geomorphic surface 3 (BC3); and 28. Barun–Chamlang geomorphic surface 4 (BC4).

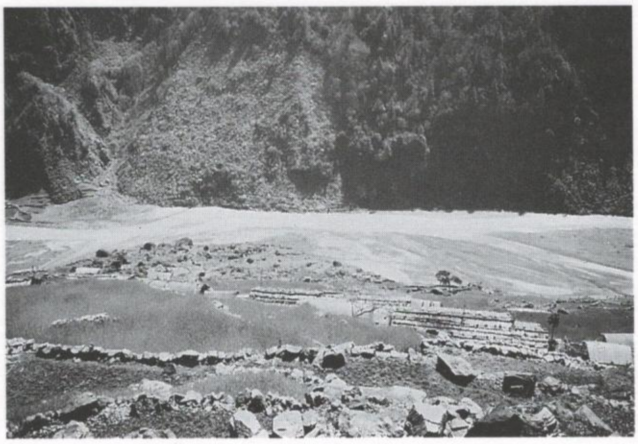

Plate 3: The Kimathanka geomorphic surface is seen at an altitude of 2,630 m and is covered by the cultivated land. The meandering Arun River is flowing about 0.5 m below the surface. *View towards SW.*

The Num–Hatiya province occupies the lowermost level in the UAPV. It is developed around Num (Plate 4), Sedua, and the Hedangna area. It also extends up to Ekua and Hatiya. The province consists of four geomorphic surfaces developed between 3,500 and 7,000 ft. They are the Num (3,500–4,000 ft), Hedangna–Garhi (4,000–5,000 ft), Ekua (5,000–6,000 ft), and the Hatiya–Sankarante (6,000–7,000 ft). The Num–Hatiya province is bordered in the northeast by the linearly arranged ridge of Namche–Gyabling. In the west, the Barun Thrust separates it from the Sursing Khola–Popti Bhanjyang province and it is bordered in the south by the Jaljale Danda, Harale Danda, and Sichok Danda.

Morpho-stratigraphically, the LAFV includes the area between Chatara and Salleri (near the confluence of the Sankhua Khola and the Arun River), i.e., the area lying south of the Jaljale Danda, Harale Danda, and Sichok Danda. It is possible to classify the landscape of the LAFV into the following four provinces with thirteen distinct Pleistocene geomorphic surfaces (Table 3).

The Gogane–Bhotebas province occupies the uppermost level around the Gogane, Patlegaon, Kharpang and Yamchung areas, and it extends up to Ahale, Thalkhark, and Bhotebas. It consists of the following three geomorphic surfaces developed between 5,000 and 6,500 ft: the Gogane (5000–5500 ft), Yamchung (5,500–6,000 ft), and Bhotebas (6,000–6,500 ft). This province is bordered in the north by the ridges of Jaljale Danda, Harale Danda, and Sichok Danda. Similarly, the southern boundary is the Dandagaon–Chitre Ridge.

The Mempang–Kulung province is observed around Mempang, Marse, Dingla (Plate 5), Pubang, Phakse, and Kulung. It is made up of three geomorphic surfaces developed between 3,500 and 5,000 ft. They are the Mempang (3,500–

Table 3: Geomorphic provinces and surfaces developed in the Lower Arun Fluvial Valley

Province (Altitude range, ft)	Geomorphic surface	Altitude range (ft)
Chatara–Mangmai (300–1,000)	Mangmai	500–1,000
	Chatara	300–500
Tumlingtar–Pangma (1,000–3,500)	Pangma	3,000–3,500
	Khandbari	2,500–3,000
	Hokse	2,000–2,500
	Kumalgaon	1,500–2,000
	Tumlingtar	1,000–1,500
Mempang–Kulung (3,500–5,000)	Kulung	4,500–5,000
	Dingla	4,000–4,500
	Mempang	3,500–4,000
Gogane–Bhotebas (5,000–6,500)	Bhotebas	6,000–6,500
	Yamchung	5,500–6,000
	Gogane	5,000–5,500

Plate 4: The agricultural land on the Num geomorphic surface is at an altitude of about 1,150 m. The Arun River is flowing about 275 m below the surface. *View towards SE.*

4,000 ft), Dingla (4,000–4,500 ft), and Kulung (4,500–5,000 ft) surfaces from top to bottom, respectively. The Mempang–Kulung province is bordered in the north by the Shichok–Kulung Ridge and in the east by the Arun River. Similarly, in the south, it is developed up to the lowermost boundary of the Arun watershed and is separated from the Chatara–Mangmai province by the Patlegaon – Salme Ridge.

The Tumlingtar–Pangma province is developed around the Tumlingtar, Hokse, and Khandbari (Plate 6) area and it also extends up to Pangma as well as around Chanwa, Humbang, and Tarigaon. It consists of the following five geomorphic surfaces developed between 1,000 and 3,500 ft: the Tumlingtar (1,000–1,500 ft), Kumalgaon (1,500–2,000 ft), Hokse (2,000–2,500 ft), Khandbari (2,500–3,000 ft), and Pangma (3,000–3,500 ft). The province is bordered by the

Plate 5: The Dingla geomorphic surface (with the village and cultivated land) is developed at an altitude of about 1,280 m. The Arun River is flowing about 500 m below the surface. *View towards NW.*

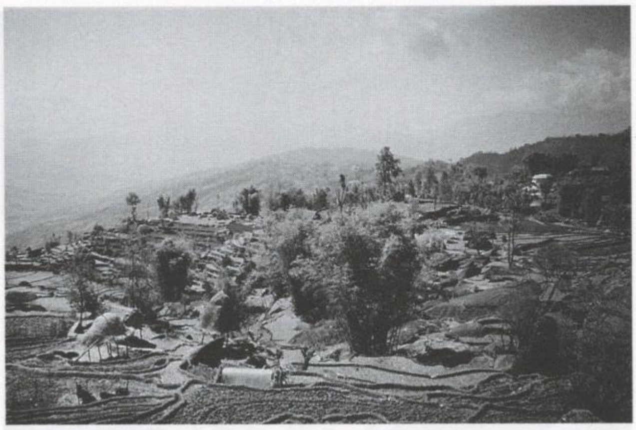

Plate 6: The Khandbari geomorphic surface (with the village and cultivated land) is developed at an altitude of about 900 m. The Arun River is flowing about 350 m below the surface. *View towards NW.*

Dandagaon–Chitre Ridge in the north, and the Piple–Chainpur Ridge in the south.

The Chatara–Mangmai province occupies the lowermost part of the LAFV. It consists of two geomorphic surfaces developed between 300 and 1000 ft. The Chatara (300–500 ft) and Mangmai (500–1,000 ft) surfaces occupy the lower and upper pats of the province, respectively. The province is bordered in the upper region of the Surtibari area by the Piple–Chainpur Ridge and in the west by the Patlegaon–Salme Ridge.

GEOMORPHOLOGICAL EVOLUTION

The UAPV is a recently retreated glacial valley with deep stream channels incised in the thick fluvio-glacial sediments. Throughout the UAPV, the Pleistocene geomorphic surfaces are either buried or completely eroded away. Sporadically, they are preserved as relict surfaces at hilltops (e.g., around the Num–Garhi area).

Geomorphologically, the UAPV is influenced by the glaciers and rivers. Even today, snow covers most of the area above 15,000 ft. There are many glacier lakes, end moraine-dammed lakes, and trough valley lakes. Some lakes occupy the hollow cirques of recently disappeared glaciers. Most probably, these features were formed during the Late Pleistocene neo-glaciation time or Little Ice Age.

From the lower part of the glacial zone, the glacio-fluvial nature of channels (e.g., the Inkhua, Sankhua, Apsua, and Barun Rivers) begins. These rivers cover a vast region, carry heavy sediment load, and are capable of deepening the channel transversely. In this process, they have formed several terraces. On the other hand, the retreating glaciers have left behind a series of moraines. The area is also reshaped by the effect of neo-tectonics, which helped in the formation of terraces as well as their uplifting and subsidence. For instance, the Barun–Chamlang province is considerably elevated in comparison with its surroundings due to the activity of the Khumbu Thrust. Similarly, the Kimathanka–Ridak province is also uplifted giving rise to the formation of the Leksua, Gogan, and Dukan ridges. General glacial episodes and geomorphological evolution of the UAPV are illustrated in Table 4.

The geomorphological evolution of the LAFV can be envisaged as gradual building-up and uplifting of the surfaces, accelerated by the neo-tectonic activities. The rate of incision is high at the upper altitudes, and it decreases gradually and sometimes rapidly in the lower altitudes (Table 5).

At an altitude of about 5,000 ft, the Kulung geomorphic surface represents the upper mountain front. At this level, the incision with respect to the present-day Sapta Koshi river channel is about 4,700 ft. Similarly, another mountain front is represented by the Khandbari geomorphic surface around 3,000 ft, where the incision is 2,700 ft. The youngest mountain front is formed by the MBT, where the incision is 200 ft and it is steadily increasing towards the north. In other words, an interior curvilinear mountain front was formed initially in which the terraces were gradually enclosed and fossilised. After their fossilisation, another mountain front came into existence in front of the previous one, and this process repeated for several times. Consequently, the valley acquired a bead-like structure with alternating narrow and wide zones.

Thus, the Kulung surface is the existing oldest landscape of the LAFV, whereas the Mangmai geomorphic surface is one of the youngest ones that went through the process of enclosing and fossilisation of terraces.

Table 4: Probable ages, depositional/erosional phases, and glacial events in the UAPV

Chronostratigraphy	Depositional Phase	Erosional Phase	Glacial Events
Post Little Ice Age	Sursing Khola–Popti Bhanjyang	Makalu Region	Barun Glacier
Little Ice Age	Kimathanka–Ridak	Hatiya Surface	Kimathanka Glacier
Atlantic Stage		Barun-Chamlang	Barun–Chamlang
Upper Pleistocene	Hatiya	Num	Num Glacier
Lower Pleistocene	Num		Num Glacier

Table 5: Probable ages of the geomorphic surfaces in the Lower Arun Fluvial Valley

Geomorphic surfaces		Probable age
Chatara Mangmai	Yamchung Gogane Bhotebas	Holocene
Tumlingtar Kumalgaon Hokse	Khandbari Pangma	Pleistocene
Mempang Dingla Kulung		Pliocene

Nevertheless, it is complicated to reconstruct the whole sequence of aggradation, uplift, and fossilisation of the individual surfaces in the Arun Valley throughout the Pleistocene.

CONCLUSIONS

The UAPV was influenced by the glacial as well as fluvial processes, particularly in the area above 15000 ft. Even today, the area is partially covered by snow. There are many glacier lakes (such as end moraine-dammed lakes and trough-valley lakes) in the UAPV. Most probably, they were formed during the late Pleistocene Epoch or Little Ice Age. Major part of the region is covered by present-day glacial deposits, whereas glacio-fluvial channels exist below them. Consequently, there are both U- and V-shaped valleys in the upper reaches of the Arun River.

The presence of gravel and sand beds in and around the geomorphic surfaces in the LAFV indicates that they were formed by the fluvial activities. The nature of channel deposits indicates that they were formed either by the Arun River itself or by the other palaeo tributaries.

The Ekulade Thrust was responsible for the aggradation and uplift of terraces between Kulung and Kumalgaon with a relative relief of 200 ft. Similarly, the Tumlingtar surface is interpreted as a tectonic standstill. The major tectonic reactivation south of the MBT resulted in the upheaval of the Chatara surface.

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REFERENCES

Amatya, K. M. and Jnawali, B. M., 1994, Geological map of Nepal. Scale 1:1,000,000. Published by Department of Mines and Geology (DMG), Kathmandu, Nepal.

Akiba, C., Amma, S., and Ohta, Y., 1973, Arun River Region. In: Yoshihide Ohta and Chikara Akiba (eds.), *Geology of the Nepal Himalaya.* Saikon Publishing Co. Ltd., Sapporo, Japan, pp. 13–33.

Dunsmore, J. R., 1988, Mountain Environmental Management in the Arun River Basin of Nepal. ICIMOD Occasional Paper No. 9, International Centre for Integrated Mountain Development, Kathmandu, Nepal, 66 p.

Hagen, T., 1969, Report on the geological survey of Nepal. Preliminary reconnaissance. Denkschr. Schweiz. Neff. Geo. LXXXVI / 1, 185 p.

Holmes, A., 1978, *Principles of Physical Geology*. Thomas Nelson and Sons Ltd., U. K., 730 p.

JICA, 1987, *Final Report of feasibility study on Arun III hydroelectric power development project*. Unpubl. report. Japan International Cooperation Agency/HMG Nepal Electricity Authority, A–19 p.

Shrestha, T. B., 1988, *Development Ecology of the Arun River Basin*. ICIMOD, 134 p.

Sino–Nep. Rept., 1988. *Sino–Nepalese Investigation of Glacier Lake Outburst Floods in the Himalayas*. Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Science; Water and Energy Commission Secretariat, Nepal; Nepal Electricity Authority, 1988, 192 p.