Chapter 27
The Pokhara Valley: A Product of a Natural Catastrophe

Monique Fort

Abstract The Pokhara valley in the central part of Nepal is one of the few Himalayan intramontane valleys that permits one to decipher the way the landforms of the world's highest mountain range evolve. The valley is attractive to tourists for the scenic majesty of its glaciated mountains, gorges, caves, and lakes, the formation of which results from a complex yet recent and dramatic evolution of the valley. For a long time, most of the inhabitants believed that the valley originated from the drying up of a huge lake similar to those of the Kathmandu and Kashmir valleys. Careful observations of the sediments filling the basin indicate that the Pokhara valley was affected by a giant, catastrophic debris flow five centuries ago. It is an emblematic site, where the steepness of the still rising front of the very Himalaya ("the abode of snow") is maintained by sporadic collapses of the mountain walls controlled by a combination of both glacial and seismo-tectonic dynamics.

Keywords Debris flows • glaciation • Himalaya • mountain building

27.1 Introduction

The Pokhara valley at the foot of the Annapurna Himal presents one of the sharpest contrasts in relief in the world. Located in the central part of Nepal, it stands out as a distinctive feature of the Himalayan landscape. It is an abnormally broad plain with an area of ~125 km^2, and confined by hills ranging from 1,200 to 3,000 m in elevation. Towering above it to the north is the Annapurna Himal (8,091 m), only 35 km as the crow flies from Pokhara town (800 m a.s.l.). It is drained by the Seti Khola (khola meaning "river" in Nepali language) and its tributaries, originating from the glacial cirque of Sabche, surrounded from west to east by the peaks of Macchapuchare (6,993 m), Annapurna III (7,555 m), and Annapurna IV (7,525 m). Well known for the outstanding scenic majesty of these "snowy mountains" ("Himal" in Nepali), the Pokhara valley is also attractive to tourists for its gorges, caves, and lakes, the formation of which results from the complex yet recent and dramatic evolution of the valley.

In fact, for a long time, the formation of the Pokhara valley was a mystery. Inhabitants were struck by the very many large rocks found in the upstream part of the valley, and had their own explanation of these features, referring to legends involving the action of God. Most of them believed that the Pokhara valley originated from the drying up of a huge lake similar to those of the Kathmandu and Kashmir valleys (Hagen 1961). Careful observations of the sediments filling the valley, together with a better understanding of the geomorphological processes in action, have led to new interpretations involving the very recent evolution of the glaciated mountain front of the Annapurna Range. This makes the Pokhara valley one of the few Himalayan basins that permits one to decipher the way the landforms of the world's highest mountain range evolve and explains why this particular part of the Himalaya has been selected for this volume.

27.2 Geographical and Geological Setting

The Pokhara valley is located in the midland region (or Pahar zone) of the Himalayan Range, a low-lying belt, which is sandwiched between the Lesser Himalaya (or Mahabharat Range) in the south and the

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Great (or Higher) Himalaya to the north. It belongs to a series of intermontane basins, the formation of which is closely related to the formation of the Himalayas as a whole.

The Himalayan Arc results from the collision between the Asian and Indian plates, which occurred about 50–45 million years ago. The compressional motion between the two plates has been, and continues to be, accommodated by slip on a suite of major thrust faults, connected at depth along a major detachment plane. The extreme elevations were acquired by stacking of crust units in a continuing continental subduction régime. The Himalayan Range is still rising at a rate estimated to be between several millimeters per year to more than 1 cm/year. The collision process created a series of elongated, more or less parallel and asymmetrical ridges, developed to the north of the Indo-Gangetic plains as a fold-and-thrust belt (Lesser Himalaya), which controls the drainage pattern.

To the north, the steep barrier of the Greater Himalaya reaches more than 8,000 m above sea level (Fig. 27.1). It represents a more than 10 km thick thrust unit made of crystalline, gneissic rocks, bounded at depth by the Main Central Thrust, and overtopped by sedimentary rocks, mostly limestones, that now underlie the Himalayan peaks. It separates two very contrasted terrains: the humid, tropical, monsoon-influenced Indian subcontinent and the cold, arid, and rugged Tibetan and Central Asian High Plateaus. Nowhere in the Himalayan Range is this bioclimatic gradient greater than along the Annapurna Range, north of Pokhara.

The Pahar zone has developed between the Lesser and the Higher Himalayas, and may locally widen in the form of intermontane depressions such as the Pokhara, Kathmandu, or Kashmir valleys. They correspond to large confluences of river valleys and/or to fluvio-lacustrine basins, developed on the back of thrust units of the Lesser Himalaya. They were initiated by tectonic damming as a result of a relatively faster uplift rate in the Lesser Himalaya than along the Pahar, transitional zone.

In contrast to the flat, perched, lacustrine basins of the Kashmir and Kathmandu valleys (Burbank and Raynolds 1984), the Pokhara valley floor is characterized by an extensive, gravel-covered surface, the formation of which has been influenced by a long period of fluvial modeling and dissection, and was the

Fig. 27.1 Northern part of the Pokhara valley, developed at the foot of the High Himalayan Front, dominated by Macchapuchare (6,993 m), Gangapurna (7,454 m), Annapurna III (7,555 m), Annapurna IV (7,524 m), Annapurna II (7,937 m), and Lamjung Himal (6,983 m), from left to right. The Seti Khola, in the foreground, issues from deep gorges cut below the glaciated cirque of Sabche. The river is responsible for the accumulation of the indurated Gaunda conglomerates, which underlie the two highest and very flat terrace levels, for the catastrophic accumulation of Pokhara gravels, deposited about 500 years ago, and for their recent dissection into several (here at least five) strath terraces (Photo M. Fort)

locus for catastrophic events and processes developed in relation to the proximity of the steep Main Central Thrust Front (Fort 1987).

27.3 Landforms and Landform Diversity

Besides magnificent mountain views, the Pokhara basin is characterized by several specific landforms. Firstly, the wide, flat morphology of the Pokhara "plain" is striking, a view reinforced by the sharp contact between the plain and the surrounding hills. The plain slopes to the south; the general longitudinal gradient varies from 32‰ upstream to 9‰ downstream. The plain also slopes laterally from a central axis, a feature that has caused diversions of the tributary streams. The surface of the plain displays a braided-channel morphology (Fig. 27.2). These characteristics are those of a large alluvial outwash fan. In fact, this plain is underlain by the so-called Pokhara gravels (Gurung 1970), excavated by the present Seti Khola River, hence providing numerous sections that permit one to analyze and interpret the nature of the gravels and their mode of deposition.

Another distinctive landform of the Pokhara valley is the dramatic set of terraces shaped by the Seti Khola and its tributaries by both vertical incision and lateral erosion (Fig. 27.1). The number of terraces increases downstream, whereas their relative height above the Seti thalweg increases upstream, from 60 to 50 m in the south to >100 m to the north. Most of the terrace levels are unpaired, a feature distinctive of meandering streams and rapid incision, this last statement being reinforced by the fresh appearance of the topographic surface and the absence of soil developed on terrace surfaces.

The canyons of the Seti Khola and its tributaries are among the most intriguing features of the valley (Fig. 27.3). Interrupting the long sections of terraces, they occur along limited reaches, a few hundred meters to 1 km long, and are deeply (up to 50 m) entrenched into a material made of gravels and boulders, cemented together into a hard conglomeratic bedrock with a rich limestone matrix, locally known as "gaunda" (Hormann 1974). These gorges are locally so narrow that only the sound of water can be heard; in some cases the stream has even disappeared in underground tunnels. One of these canyons is crossed by the Mahendra Pul (bridge), along the main Kathmandu road before entering the old bazaar of the city. These gorges are often associated with potholes and caves, such as the Mahendra and Chamere caves, close to Batulechaur village, the Jogi cave in Balam Hill, or the Gupteshwor and Davis falls caverns in

Fig. 27.2 Surface, braided morphology of the Pokhara gravels, as highlighted by the rice-fields pattern, east of Pokhara airport (Photo M. Fort)

Fig. 27.3 Major terrace levels south of Pokhara valley, underlain by the Pokhara gravels. They have buried the older, indurated "gaunda" conglomerates, which are exhumed by the recent erosion of the Seti River, as observed in the foreground, where potholes and small canyons have developed (Photo M. Fort)

Chorepatan, south of the Phewa lake: there, the Pardi River disappears into a tunnel, 200 m long, with a natural bridge on which the Sidartha highway passes. The development of these karst-like features provides additional evidence for the combined action of water dissolving the limestone and abrading the conglomerates.

The last feature that makes Pokhara famous is the many lakes ("tal" in Nepali) that are found along the edges of the valley (Fig. 27.4). Most of them (Dipang, Maidi, Khalte, Kamalpokhari, and Gunde lakes) have virtually disappeared due to siltation. The lakes Rupa, Begnas, and Phewa are larger, and their sinuous shorelines clearly suggest that they are drowned valleys (Gurung 1970). Close to Pokhara city, the largest of them, the Phewa Tal, is an important tourist attraction, with its waters reflecting the entire Annapurna Himalayan peaks during clear days. The occurrence of these lakes in juxtaposition with the gravelly plain of Pokhara reflects their origin, as a response to the deposition of the Pokhara gravels.

27.4 The Pokhara Gravels

The Pokhara gravels (Gurung 1970; Yamanaka et al. 1982) are the main component of the basin fill: their top layer underlies the geomorphological surface upon which Pokhara town has been built. They extend from Bharabhure at the mouth of the Seti Khola gorge, downstream to Dhoban, at the foot of the Mahabharat Lekh. The total thickness of their accumulation decreases downstream, from an average thickness of over 100 m to about 60 m, although local variations are observed depending on the buried topography. The sections, well visible from along the Prithvi Narayan Road across the Seti valley or its tributaries such as the Bijaypur, reveal the main characteristics of the Pokhara gravels and their modes of deposition.

The Pokhara gravels consist of a rapid succession of beds, decimeters or meters in thickness, with flat basal contacts (Fort and Freytet 1979). The material is mainly composed of layered, sub-angular to sub-rounded, mostly calcareous gravels, centimeters to decimeters in size, embedded in a muddy, calcareous matrix present in variable proportions (Fig. 27.5). Blocks of a meter or more in size – mostly gneisses (Higher Himalaya) or quartzites (Lesser Himalaya) – can also be found randomly within the whole accumulation package. Blocks of exceptional size, such as the Bhimsen Kali Boulder (32 m in diameter) visible on the University campus of Pokhara (Fig. 27.6), are restricted to the top-most layers where they are distributed upon the surface of the Pokhara plain. All these sedimentological characteristics indicate that the Pokhara formation is an alluvial

Fig. 27.4 The Phewa Lake, seen from the west, with the Pokhara valley in the background. This lake is a remnant of a drowned valley dammed downstream by the catastrophic deposition of the Pokhara gravels. This lake, like many others located along the edges of the Pokhara valley, is nowadays subjected to intense siltation by tributary streams (Photo M. Fort)

Fig. 27.5 A 25-m high section of the Pokhara gravels. Noticeable are the flat beds that include random occurrences of big boulders. This accumulation typically exhibits irregular alternations of debris-flow and mud-flow layers (Photo M. Fort)

fan deposit, transported alternately by muddy flows, debris flows, and torrential discharge (Fort 1987). The occurrence of the largest boulders in the final stage of deposition can be explained as a sorting phenomenon distinctive of the dense, debris laden, muddy flow of the Pokhara discharge.

This discharge was first considered to be a product of glacio-fluvial outwash (Gurung 1970; Hormann 1974;

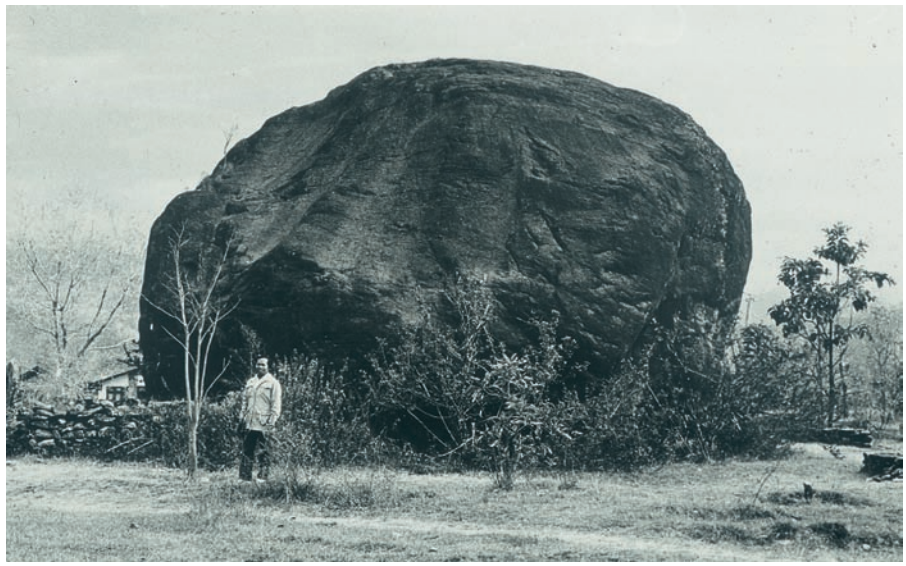

Fig. 27.6 The famous Bhim Kali boulder, 3,000 t large, preserved on the Pokhara University campus. A local legend tells that this rock was thrown down from Machapucchare Peak by the powerful hero Bhim. In fact, it represents the final stage of Pokhara gravels deposition, and was brought by a competent, highly muddy flow nourished by coarse debris detached from the High Himalayan Front. Most of these boulders have nowadays disappeared as they have been quarried (Photo M. Fort)

Fort and Freytet 1979), because most of the clasts are limestones derived from the glaciated cliffs of the Annapurna Range. However, the gneissic nature of the largest boulders indicates that materials derived from the adjacent valley walls located between the glacial cirques and the Pokhara plain were also incorporated by this massive discharge. Moreover, the volume of Pokhara gravels (estimated as >4 km^3; Fort 1987) and their dating between 400 and 1,100 ^{14}C years (Yamanaka et al. 1982; Fort 1987) suggest the occurrence of a short-lasting, historical event that led to the rapid filling of the Pokhara valley by a giant debris flow and to the damming, and hence flooding of the adjacent valleys. The present lakes are the relicts of this exceptional event.

Among the various origins and formation conditions that can explain this sudden, huge supply of both water and debris, it seems that ice and rock avalanches and/or landslide-dammed lake outbursts are capable of liberating the greatest volumes of water and debris simultaneously, in such a catastrophic way. Hence, these processes are the most likely causes of the exceptional Pokhara gravel discharge. The sources of the debris are the very steep slopes of the south face of Annapurna III and IV (Fig. 27.7). The triggering factor of an event of such a magnitude has probably to be related to a tectonic-induced instability, i.e., to an earthquake, the only mechanism capable of bringing instantaneously a slope into disequilibrium and setting into motion so huge a quantity of ice and rock material (Fort 1987).

27.5 Evolutionary History

The Pokhara gravels have buried an irregular topography, which includes the relicts of former stages of Pokhara valley evolution. The evolutionary history of the valley can be summarized as follows.

The formation of the intermontane basin is the result of a long-lasting process. As already pointed out, the basin belongs to the Pahar belt, which is rising at a slower rate than the Mahabharat Lekh (Lesser Himalaya) to the south and the Higher Range to the north. More specifically, it is situated along an anticlinal

Fig. 27.7 Close-up view of the northern part of the Pokhara valley, Seti Khola gorge, and the upper glaciated cirque of Sabche. The terraces developed on the foreground are underlain by the Pokhara gravels. Upstream the Seti gorge, entrenched within the High Himalayan gneisses, is particularly narrow and steep. It channelized the giant, catastrophic debris flow of Pokhara gravels, originated from the southwest face of Annapurna IV (Photo M. Fort)

structure, mostly carved out into schists with intercalations of quartzite and dolomitic limestone bands. The distinctive z-shape of the basin and of the Seti Khola course and its tributaries, together with the arrangement of the surrounding hills, may be interpreted as the superficial expression of deformation – namely fault scarps – induced by the oblique, northward convergence of the Sub-Himalaya underthrusting the Lesser Himalaya.

The present, large-scale morphology of the valley is the result of a complex alternation of aggradational and erosional stages, developed under a tropical, seasonally contrasted climate. In fact, the Pokhara valley has experienced several stages of dissection, separated by brief, yet intense periods of aggradation (Fig. 27.8). A few patches of perched calcareous breccia, like those preserved along the Sarankot ridge, represent early remnants of slope deposits, spread over an aggradational pediment, presently reduced to sharp, karstic ridges modeled into towers by the dissolution of carbonates. After a period of basin dissection to a depth of 50 m or more, perched weathered gravels provide evidence of a previous Seti Khola course. Another period of dissection also followed which, in the central part of the basin, penetrated lower than the present level of the Seti Khola river bed (Fig. 27.9).

This evolution was interrupted by the deposition of the "gaunda" (or "Gachok") conglomerates that are the first extensive deposits in the Pokhara valley. They underlie the prominent terrace benches of the northern part of the valley, near Lachok and Gachok villages (Fig. 27.8). Their well-rounded gravels and sand grains, dominated by limestone, are derived from the south-facing, upper cliffs of the Annapurna Himal. They were until recently considered to be glacio-fluvial outwash deposited by the melting of ice after the last glaciation, but are now explained by similar, catastrophic processes as were involved in the formation of the Pokhara gravels. After their deposition and lithification, these conglomerates were dissected to form a stepped topography of fluvial terraces, well preserved north of the valley, upstream of the Mardi Khola confluence, whereas to the center and south of the valley, they disappear under the Pokhara gravels.

The more recent and rapid deposition of the Pokhara gravels has resulted in burial of the former topography, disorganization of the entire drainage system of the valley, and creation of the peripheral lakes. Soon after, the Seti Khola started incising its bed again to readjust its longitudinal profile to the base level of the Mahabharat Range. In the central part of the valley, the new Seti course, superimposed on the Pokhara gravels, locally cut through the hard "gaunda" conglomerates (present beneath the Pokhara gravels), so that it prevented the river to widen its beds, thus leading to the formation of canyons instead (Fig. 27.4). Elsewhere, the presence of the loose Pokhara gravels favored the shift of the Seti River and the subsequent development of unpaired flights of terraces (Fig. 27.10).

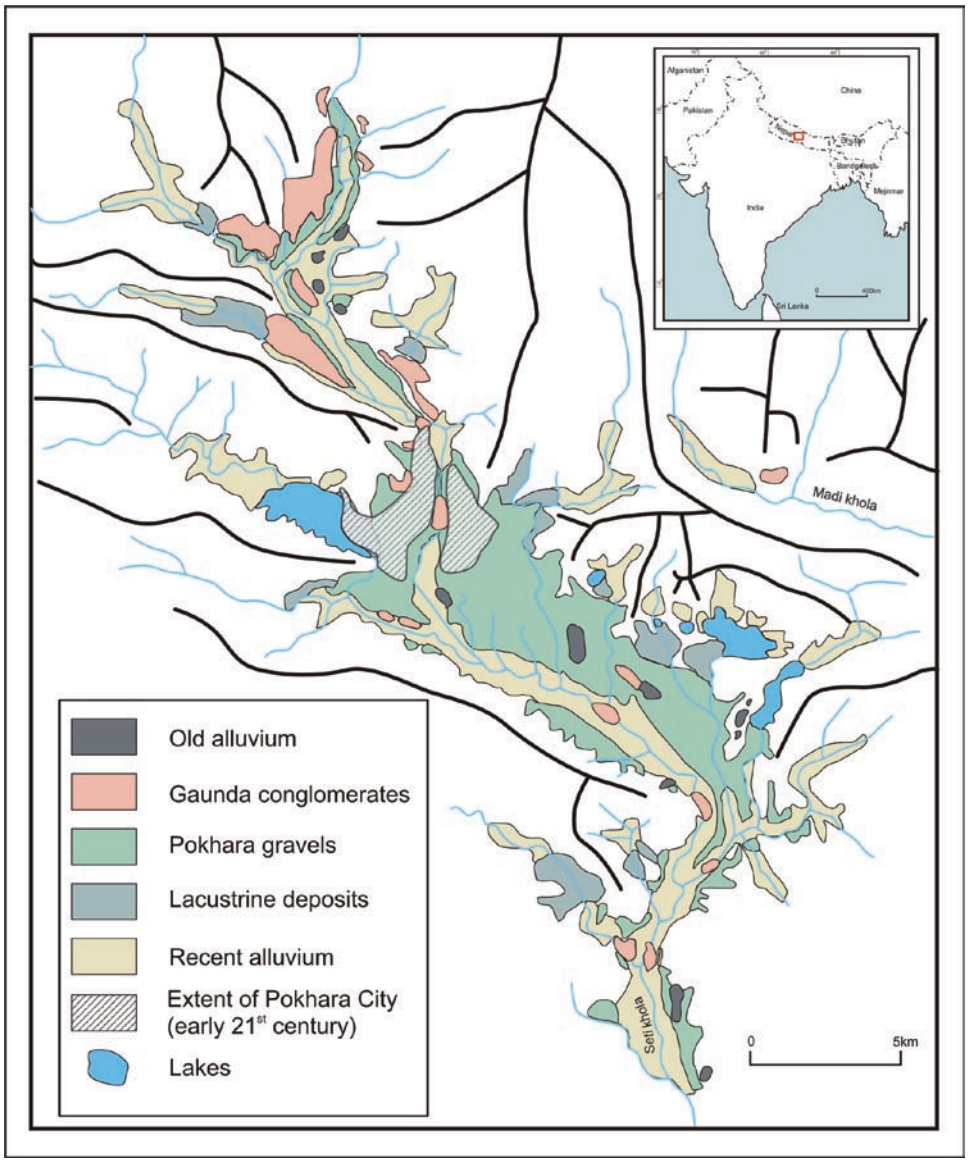

Fig. 27.8 Map of the major deposits of the Pokhara valley. The catastrophic accumulation of the Pokhara gravels buried a dissected topography carved into the older "gaunda" conglomerates. Since the giant debris flow, the Seti River cut through the Pokhara infill, and found locally the "gaunda" conglomerates beneath, so it was forced to incise deep canyons

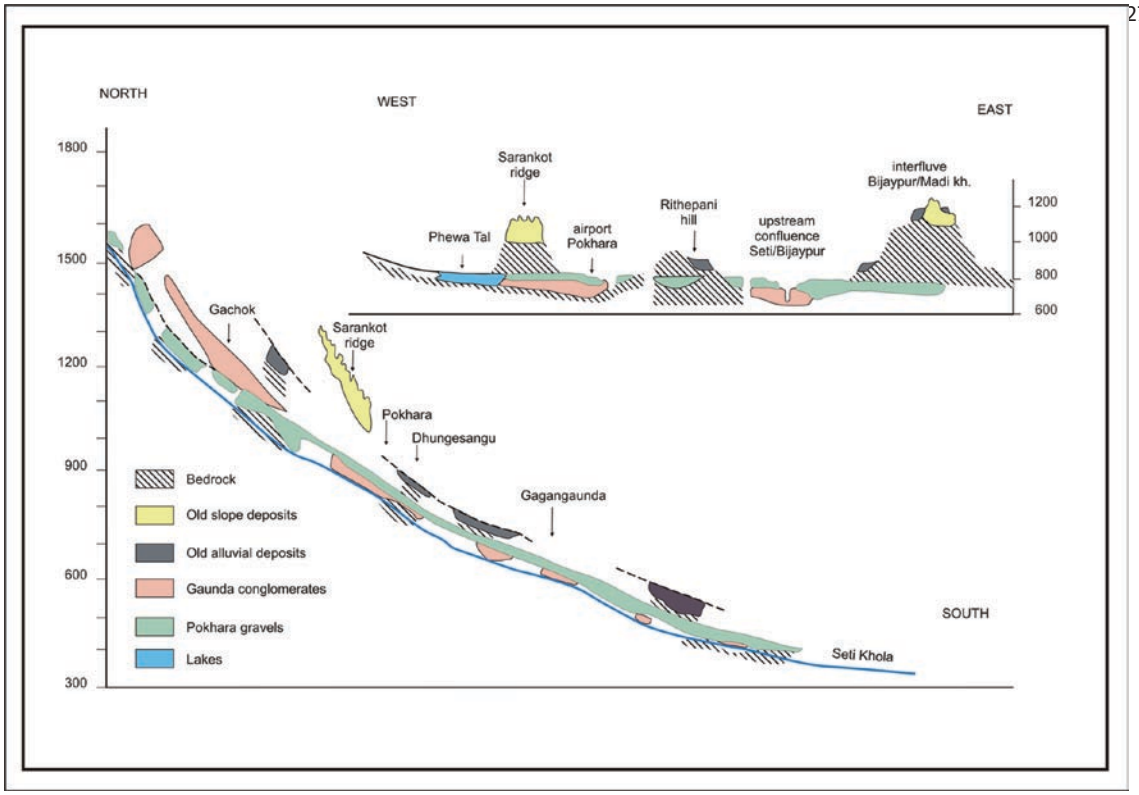

Fig. 27.9 Cross section and altitudinal distribution of the various formations deposited in the Pokhara valley in the last 100,000 years. To the north of the valley, the oldest perched slope deposits (limestone breccia), the old, deeply weathered alluvium and the Gaunda-Gachok formations are stepped above the most recent Pokhara gravels filling, whereas in the center of the valley, the Pokhara gravels have buried the Gaunda-Gachok conglomerates. This particular setting clearly indicates the rising of the High Himalayan Front relative to the basin

Fig. 27.10 Since the deposition of the Pokhara giant debris flow, the Seti Khola started incising its bed again at a rate varying between 20 cm/year upstream and about 10 cm/year downstream of the basin. Locally, the presence of loose Pokhara gravels favored the shift of the Seti River and the development of many, unpaired terraces (Photo M. Fort)

27.6 Conclusions

The catastrophic episode of the Pokhara debris-flow aggradation serves as a model for the geomorphic evolution of the High Himalayan Front (Fort 1987; Fort and Peulvast 1995). It shows how a huge mass of debris almost instantaneously delivered from the front may temporarily be stored in an intramontane basin of the Pahar before transit to the Himalayan foothills. It also demonstrates how the steepness of the still rising front of the very Himalaya ("the abode of snow") is maintained by sporadic processes of collapse of the mountain walls involving a combination of both glacial and seismo-tectonic factors. This makes the basins and the valley trenched across the High Himalayan Front, the areas most prone to unpredictable, catastrophic geomorphological hazards, and creates a permanent, low-recurrence, but significant threat for the growing population living in these valleys.

The Author

Monique Fort is a Professor of Geomorphology and Environmental Sciences, Natural Hazards and Risks, in the Department of Geography of Paris Diderot – Paris 7 University. She worked extensively in various high mountains of the world (Alps, Central Asia, and Himalaya). Her research interests evolved from the relations of landforms with respect to geological structures, then to glacial and climatic fluctuations, and palaeoenvironmental reconstructions. Ongoing field work includes studies on current instabilities and natural hazards (large-scale landslides, catastrophic floods) in the Himalayas and Pamir mountains, floods impacts, and their prevention in various parts of France. She published more than 50 peer-reviewed papers. She was the Vice President of the International Association of Geomorphologists (2005–2009), and member of the Commission on Mountain Response to Global Change of the International Geographical Union (2008–2012).

References

Burbank DW, Raynolds GH (1984) Sequential Late Cenozoic chronologic and stratigraphic development of the Kashmir inter-montane basin, northwestern Himalayan foredeep. Nature 311:114–118

Fort M (1987) Sporadic morphogenesis in a continental subduction setting. Z Geomorph NF, Suppl 63:9–36

Fort M, Freytet P (1979) L'évolution sédimentaire récente du basin intramontagnard de Pokhara (Himalaya, centre-ouest Népal). CR Acad Sci Paris 289(D):1195–1198

Fort M, Peulvast J-P (1995) Catastrophic mass-movement and morphogenesis in the peri-tibetan ranges, examples from West Kunlun, East Pamir and Ladakh. In: Slaymaker O (ed) Steepland geomorphology. Wiley, Chichester, pp 171–198

Gurung HB (1970) Geomorphology of Pokhara Valley. Himalayan Rev 2–3:29–49

Hagen T (1961) Nepal, the Kingdom in the Himalayas. Revised and updated with Deepak Thapa 1999. Himal Books, Kathmandu, Nepal

Hormann K (1974) Die Terrassen an der Seti khola. Ein Beitrag zur Quartären Morphogenese in Zentral Nepal. Erdkunde 28(3):161–176

Yamanaka H, Yoshida M, Arita K (1982) Terrace landforms and Quaternary deposits around the Pokhara valley, central Nepal. J Nepal Geol Soc 2(Sp. Issue):113–142