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TERRACE LANDFORM AND QUATERNARY DEPOSIT AROUND POKHARA VALLEY, CENTRAL NEPAL

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ABSTRACT

The Pokhara Valley, a typical intramontane basin in the Nepal Himalayas, is spread around the midstream of the Seti Khola. It is filled with a large volume of gravelly deposits brought mostly from the Annapurna Himal, and splendid river terraces are present. Thus the Pokhara Valley is endowed with excellent conditions for the Quaternary chronological study of the Himalayas.

Quaternary deposits in the valley are divided into nine stratigraphic units. Among them, the Ghachok and Pokhara Formations are most prominent, forming conspicuous accumulation terraces named the Pokhara and Ghachok Terraces. So far these accumulations were considered to have taken place during the glacial ages. In this study,however, the Pokhara Formation was dated by radiocarbon method to prove that the accumulation occurred in the late Holocene.

Hagen (1969) considered that the Pokhara Valley, as well as the Kathmandu Valley, was once occupied by a single huge lake, and his hypothesis has many followers in spite of Gurung (1970)'s refutation. According to the present study, however, only marginal lakes were formed due to damming of tributaries, and the possibility of the existence of a single huge lake in the Pokhara Valley is ruled out.

INTRODUCTION

The Pokhara Valley is considered to be the most important region for the study of Quaternary chronology of the Nepal Himalayas, because Quaternary deposits and terrace topography are widely distributed around there (Hormann, 1974).

Present Study

The present investigations are aimed at illustrating the division, stratigraphy, distribution and lithofacies of Quaternary deposits of the Pokhara Valley, and clarifying the classification, correlation, distribution and geomorphological characteristics of river terraces around the valley.Determination of absolute ages of deposits and terraces along with the study of tectonic movement of the region and origin of lakes are also planned to work out the geological and geomorphological history of the valley.

Method of Investigation

At first the authors prepared a tentative map showing the classification and distribution of terraces, based on the interpretation of air-photographs presented by the Department of Forest, His Majesty's Government of Nepal. Then they carried out a series of field observation to investigate the Quaternary

Table 1. Summary of previous works on the Quaternary geology and geomorphology of the Pokhara Valley.

Topics	Hagen(1969)	Gurung(1970)	Hormann(1974)
Cause of formation of Pokhara Basin itself	Rise of Mahabharat Range and subsidence of basin itself	Uplift of southern hills	Tectonic subsidence of basin itself
Huge "Paleo-Pokhara Lake" filling whole Pokhara Basin	Existed	Not existed	Not existed
Cause of formation of existing lakes	Remaining of former huge lake	Damming of tributaries by sediments of Seti Khola	Damming of tributaries
Quaternary deposit			
Geologic map	No	No	No
Description of deposit	Shortly described	Shortly described	Described
Subdivision of deposit	No	No	Yes [three valley-fill deposits attributed to different glacial stages]
Origin of deposit	Secondary deposit of moraine material	Fluvioglacial	Not mentioned
Cause of deposition	Catastrophic supply of morainic material from Annapurna Range by rivers	Uplift of southern hills	Tectonic subsidence of basin and glacial advance in Great Himalayas
Terrace landform			
Terrace classification map	No	Yes	No
Number of terrace levels	Not mentioned	Three	Three filltop terraces and many fillstrath terraces
Figure indicating longitudinal profiles of terraces	No	No	Yes
Figure indicating cross-sections of terraces	No	No	Yes
Description of terrace topography	Not described	Detailed	Detailed
Cause of terracing	Not mentioned	Not mentioned	Not mentioned
Geohistory of Pokhara Valley	Very shortly mentioned	Not mentioned	Not mentioned
Tectonic movement around Pokhara Valley	Not directly mentioned	Not mentioned	Mentioned

C.K.Sharma(1975)	T.Sharma *et al.* (1978)	Akiba(1980)
Faulting along southern margin during Miocene	Deepening of pre-existing depression (tectonic hollow) by glacier	Not mentioned
Existed	Existed	Existed
Damming of tributaries	Division and reduction of former huge lake	Unknown
No	No	No
Detailed	Detailed	Shortly described
Yes	Yes [Lowest lacustrine deposit and overlying gravelly deposit]	Yes
Mainly glacial and fluvioglacial, partly lacustrine	Mainly glacial or fluvioglacial, partly lacustrine	Lacustrine
Not mentioned	Rise of Mahabharat Range	Not mentioned
No	Yes	No
Four at Gagan-gaunda	Five	Many (nine or more)
No	No	No
Yes	No	Yes
Shortly described	Described	Roughly described
Tectonic uplift of basin and climatic change	Tectonic uplift of basin	Drainage of former huge lake and its reduction
Not mentioned	Mentioned	Not mentioned
Shortly mentioned	Mentioned	Not mentioned

deposits and terrace landform and to examine the tentative geomorphological map. Measurement of relative height of terraces above the river bed was made by means of an American Paulin type altimeter at as many locations as possible, in order to clarify the longitudinal profiles of terraces. Samples were collected at some localities for paleomagnetic measurement, radiocarbon dating and pollen analyses. Paleomagnetic measurement was carried out by M. Yoshida, and radiocarbon dating by H. Yamanaka.

Geological and Geomorphological Outlines

The Pokhara Valley is located in the Midland region, lying between the Great Himalayas and the Mahabharat Range. The valley has unique basin landscape, and it is surrounded by hills made up of the Midland Meta-sediment Group. The Midland Meta-sediment Group is composed mostly of meta-sandstone, quartzite, chlorite-sericite schist and crystalline schist. Its structure in the Pokhara Block (Hashimoto, 1973) has NW-SE strike with gentle folding. The Seti Khola*, which runs through the Pokhara Valley, originates in the Annapurna Himal**. The Annapurna Himal is built up of the Himalayan Gneiss and Tibetan Tethys Group. The latter consists of Paleozoic and Mesozoic sedimentary rocks containing much limestone (Fig. 1).

The Pokhara Valley is an anticlinal valley with a NW-SE running anticlinal axis (C.K.Sharma, 1975). As for the outline of the valley, the northeastern margin is much indented. On the contrary, the

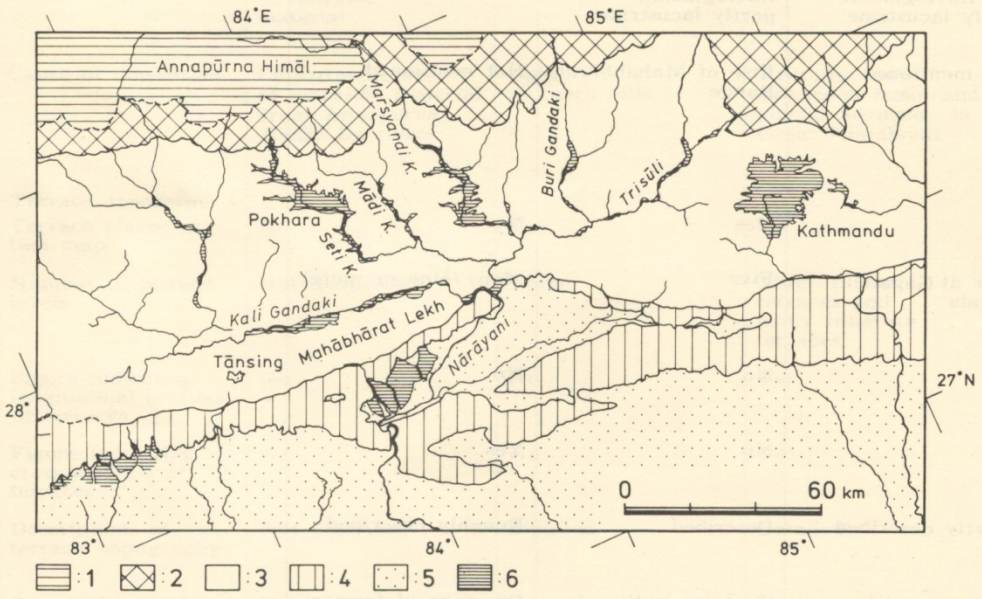


Fig.1. Geology of Central Nepal.
1: Tibetan Tethys Group 2: Himalayan Gneiss 3: Midland Meta-sediment Group, Kathmandu Group and granite 4: Siwalik Series 5: Alluvial plain deposits(Quaternary) 6: Terraced deposits(Pleistocene and Holocene)
The distribution of the former three are based on Hashimoto (1973), and the latter three on Hashimoto (1973), Hormann (1974) and the authors' own photogrammetric survey of 1/50,000 scale air-photographs and 1/750,000 scale Landsat images.

In Nepali:

* "Khola" means river.

** "Himal" means high mountains with snow and glacier.

southwestern margin is comparatively straight, and runs parallel with the anticlinal axis and the Main Central Thrust zone, which is situated between the Midland Meta-sediments zone and Himalayan Gneiss zone and is one of the major tectonic lines in the Himalayas. These topographical features suggest the possibility that the Pokhara Valley may be a fault-angle basin formed by faulting along the southwestern margin (C.K.Sharma, 1975). The zigzag shaped course of the Seti Khola and the arrangement of surrounding hills are also considered to be controlled by the geological structure.

The river terraces formed by the Seti Khola are distributed from Bharbhari upstream to Bhimad downstream. They are widely spread especially between Pokhara town and Gagangaunda.

Previous Works

Some previous works have been published on the geology and/or geomorphology of the Pokhara Valley (Gurung, 1970; Hormann, 1974; C.K. Sharma, 1975; T.Sharma *et al.*, 1978; Akiba, 1980). Hagen (1969), dealing with the structural geology of the Nepal Himalayas, also touched upon the Pokhara Valley. These works are summarized and listed in Table 1. It is obvious that some problems still remain unsolved. One of the most important problems is the existence of the so-called "Paleo-Pokhara Lake" filling up the whole Pokhara Valley (positive - Hagen, 1969; T.Sharma *et al.*, 1978; Akiba, 1980; negative - Gurung, 1970; Hormann, 1974). The division of Quaternary deposits and terraces have been hardly studied substantially except Hormann (1974). In his excellent study, Hormann (1974) distinguished three valley-fill deposits, and recognized three accumulation terraces built up of them and many fillstrath terraces. However, his paper carries regrettably no map showing the distribution of those terraces. Other workers, such as Gurung (1970), classified terraces not based on their origins and ages, but on their relative heights above the river bed. This kind of classification is not proper to study the geomorphic chronology. No radiometric ages of deposits and terraces have been obtained so far. Thus the Quaternary chronology of the Pokhara Valley has not yet been studied in sufficient detail, and much work remains to be done before one is able to understand the geologic history of the Pokhara Valley.

QUATERNARY DEPOSITS

Thick Quaternary deposits, which overlie the Midland Meta-sediments unconformably, are widely distributed around the Pokhara Valley, and some of them have formed river terraces. The Quaternary deposits are divided into nine stratigraphic units: Begnas, Siswa, Tallakot, Ghachok, Phewa, Pokhara and Rupakot Formations, gravel veneers on the fillstrath terraces carved in the Pokhara Terrace and recent flood plain deposit (Table 2 and Fig. 2). This division is based on unconformities and their lithofacies, and all the formations are newly defined or re-defined by the authors.

Begnas Formation

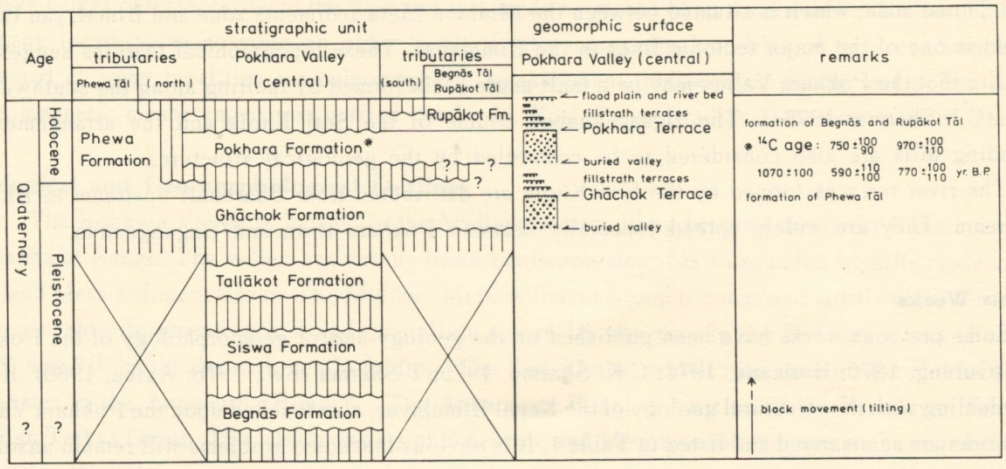
Type Locality; hill to the southeast of the Begnas Tal* (Loc.1).

Thickness; 80m + at the type locality.

The Begnas Formation is fragmentarily distributed on the ridges to the southeast of the Begnas Tal. As briefly described by Gurung (1970), it is a conglomerate bed composed of ill sorted, angular to sub-angular gravels, which consist of shale, sandstone and quartzite probably derived from the upper or middle part of the Tibetan Tethys Group. The Begnas Formation is considered to be talus or slope deposit in origin. It appears to have been deposited during the initial stage of basin formation of the

* "Tal" means lake in Nepali.

Table 2. Stratigraphy of the Quaternary deposits around the Pokhara Valley



Pokhara Valley, and is estimated to be the oldest Quaternary deposit around the valley.

Siswa Formation

Type Locality; hill to the east of Siswa village (Loc.2)

Thickness; 30m + at the type locality.

The Siswa Formation is a heavily red-weathered loose conglomerate bed distributed on the hills around Siswa and Khaireni. It consists of pebble to cobble sized, sub-rounded fluvial gravels. The gravels are mostly meta-sandstone, phyllite and chlorite-sericite schist derived from the Midland Meta-sediments. Hence, it is obvious that the Siswa Formation was deposited by small streams around the Pokhara Valley. The Siswa Formation has lost its depositional surface, and bears hilly landform. Laterite cap, which might be generated during interglacial epochs, is characteristically observed on the hills.

The stratigraphic relation between the Siswa Formation and the Tallakot Formation described below is not yet certain.

Tallakot Formation

Type Locality; south of Tallakot village (Loc. 3)

Thickness; 200m + on the ridge northeast of the Phewa Tal.

The Tallakot Formation is a highly consolidated calcareous conglomerate bed, roughly correlated with the old "Kalkbrekzien" of Hormann (1974). It is distributed around Tallakot in the upper Seti Khola, on an isolated hill near the junction of the Prithivi Highway and the road to the Begnas Tal (Hormann,1974; C.K.Sharma, 1975), and on the ridge northeast of the Phewa Tal. The same conglomerate in lithofacies is found also on the low divide* between the Bijaypur Khola and the Madi Khola. The Tallakot Formation is mostly composed of sub-rounded limestone gravels derived from the Tibetan Tethys Group. The gravels are of granule, pebble and cobble size, and cemented by light brown calcareous substance. They are ill sorted and indistinctly bedded, but the intercalation of sandstone layers is observed near the Phewa Tal.

The conglomerates of the above four localities, however, are not exactly correlated with one

* Another type of unnamed conglomerate composed of gneiss or schist gravels is also found on the top of the divide. The stratigraphic relation between the two conglomerates is yet unknown.

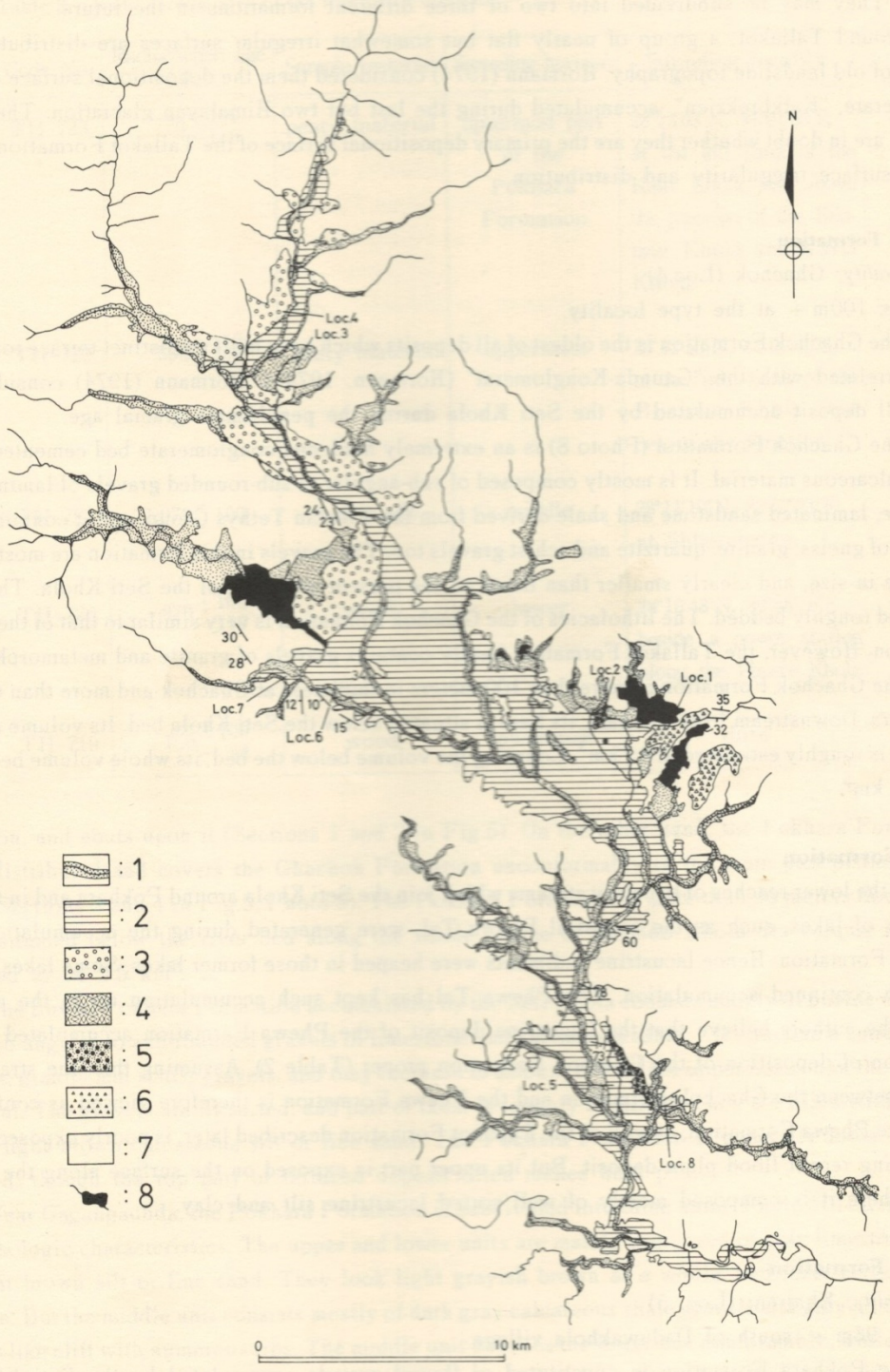


Fig.2. Quaternary geologic map of the Pokhara Valley.
1: Recent flood plain deposit, Rupakot Formation and Phewa Formation 2: Pokhara Formation 3: Ghachok Formation 4: Tallakot Formation 5: Siswa Formation 6: Begnas Formation 7: Basement rocks 8: Lake
Gravel veneers on fillstrath terraces are not indicated.

another. They may be subdivided into two or three different formations in the future.

Around Tallakot, a group of nearly flat but somewhat irregular surfaces are distributed at the bottoms of old landslide topography. Hormann (1974) considered them the depositional surface of the old conglomerate, "Kalkbrekzien", accumulated during the last but two Himalayan glaciation. The authors, however, are in doubt whether they are the primary depositional surface of the Tallakot Formation, because of their surface irregularity and distribution.

Ghachok Formation

Type Locality; Ghachok (Loc.4)

Thickness; 100m + at the type locality.

The Ghachok Formation is the oldest of all deposits which have built up distinct terrace topography. It is correlated with the "Gaunda-Konglomerat" (Hormann, 1974). Hormann (1974) considered it a valley-fill deposit accumulated by the Seti Khola during the penultimate glacial age.

The Ghachok Formation (Photo 8) is an extremely hardened conglomerate bed cemented by light brown calcareous material. It is mostly composed of sub-angular to sub-rounded gravels of laminated gray limestone, laminated sandstone and shale derived from the Tibetan Tethys Group, and it contains a small quantity of gneiss, granite, quartzite and schist gravels too. The gravels in this formation are mostly pebble to cobble in size, and clearly smaller than those on the present river bed of the Seti Khola. They are ill sorted and roughly bedded. The lithofacies of the Ghachok Formation is very similar to that of the Tallakot Formation. However, the Tallakot Formation hardly contains gravels of granite and metamorphic rocks.

The Ghachok Formation is more than 100 meters in thickness at Ghachok and more than 67 meters at Pokhara. Downstream from Pokhara, its base is situated below the Seti Khola bed. Its volume above the river bed is roughly estimated at 8.7 km^3. Counting the volume below the bed, its whole volume becomes far over 8.7 km^3.

Phewa Formation

In the lower reaches of tributary streams which join the Seti Khola around Pokhara and in the north, a number of lakes, such as the ancestral Phewa Tal, were generated during the accumulation of the Ghachok Formation. Hence lacustrine sediments were heaped in those former lakes. Some lakes survived long with continued accumulation. The Phewa Tal has kept such accumulation up to the present.

The authors believe that the lacustrine deposit of the Phewa Formation accumulated after the completion of deposition of the Ghachok Formation proper (Table 2). Assuming this, the stratigraphic relation between the Ghachok Formation and the Phewa Formation is therefore viewed as conformable.

The Phewa Formation, as well as the Rupakot Formation described later, is poorly exposed because of overlying recent flood plain deposit. But its upper part is exposed on the surface along the Yangadi Khola, where it is composed mostly of well sorted lacustrine silt and clay.

Pokhara Formation

Type Locality; Khaireni (Loc. 5)

Thickness; 96m + south of Daduwakhola village.

The Pokhara Formation is constituted of fluvial gravels accumulated by the Seti Khola and lacustrine deposit interfingering with the gravels. The former occupies the major part of this formation, and coincides with the "Pokhara-Schotter" (Hormann, 1974). It was regarded as fluvioglacial deposit in origin (e.g. Gurung, 1970; T. Sharma *et al.*, 1978).

Upstream from Pokhara town, the Pokhara Formation fills the valley sharply cutting the Ghachok

Table 3. Radiocarbon ages of the Pokhara Formation

Code No.	Radiocarbon age (y.B.P.)	Sample material	Sampling horizon	Sampling locality
TH-723	770^{+100}_{-110}	peaty material	uppermost part of the Pokhara Formation	28°13'03"N, 84°01'53"E. at the left bank of the Kalti Khola just above the junction of the Bijaipur Khola and Kalti Khola.
TH-722	590^{+110}_{-100}	peaty material	uppermost	28°12'55"N, 84°01'49"E. at the right bank of the Bijaipur Khola just below the junction.
TH-721	$1{,}070 \pm 100$	humic silt	middle	28°11'10"N, 83°57'21"E. at Shharepatan.
TH-720	970^{+100}_{-110}	wood	lower	28°10'48"N, 83°58'16"E. beside a power station along the Phusre Khola.
TH-719	750^{+100}_{-90}	wood	lowermost	ditto

Formation, and abuts upon it (Sections 1 and 2 in Fig.5). On the other hand, the Pokhara Formation is widely distributed and covers the Ghachok Formation unconformably in the main part of the Pokhara Valley (Sections 3 and 4 in Fig.5; Photo 9). The Pokhara Formation is more than 96 meters thick, and its base is situated below the river bed along the whole course of the Seti Khola. Its volume is roughly calculated to be 5.5 km^3.

The fluvial Pokhara Formation accumulated by the Seti Khola consists mainly of pebble and cobble sized, sub-angular to sub-rounded gravels of limestone and calcareous shale. It contains a small quantity of gneiss, granite and schist gravels, and they increase in amount toward the upper horizon of the formation in general. The gravels are ill sorted, and part of them is roughly stratified. They are filled with matrix of gray or light brown calcareous silt or fine sand. The Pokhara Formation is generally loose or weakly cemented, though the top part of terraced deposit often makes hard pan.

Near Gagangaunda, the Pokhara Formation is subdivided into three units (Photo 10) on the basis of their lithologic characteristics. The upper and lower units are mainly composed of gray limestone gravels and light brown silt or fine sand. They look light grayish brown as a whole, and form vertical cliff at riverside. But the middle unit consists mostly of dark gray calcareous shale gravels and gray silt, and forms badland-like cliff with numerous ribs. The middle unit overlies the lower one conformably, while the upper unit covers the middle one disconformably. These three units and the disconformity is traceable along the lower course below Gagangaunda. The disconformity surface is slightly undulating; the thickness of the middle unit therefore varies from place to place.

Along the Phusre Khola, Medhi Khola and other tributaries, lacustrine deposits are observed (Photo 6). The lacustrine deposit distributed along the Phusre Khola attains about 80 meters in total thickness. It

consists of laminated fine sand, silt and clay, gray or light brown in color. It sometimes intercalates fluvial gravel beds. Rarely very thin humic layers and plant fossils are present.

The accumulation of the Pokhara Formation has hitherto been considered to have taken place during the last glacial age (Hormann, 1974). However, the age of the Pokhara Formation was dated between 1,070 y.B.P. (TH-721) and 590 y.B.P. (TH-722) by radiocarbon method (Table 3), and it was thus revealed that the Pokhara Formation belongs to the Holocene, namely the post-glacial age. The details of the radiocarbon dating will be reported in another paper (Yamanaka, 1982, in press) .

Rupakot Formation

The earlier tributaries had, it is believed, formed many lakes on the northeastern side of the main Pokhara Valley during the accumulation period of the Pokhara Formation, and brought lacustrine sediments that were deposited contemporaneously with fluvial sediments of the Pokhara Formation. But the accumulation of lacustrine sediments continued as long as those former lakes existed, well beyond the end of accumulation of the Pokhara Formation by the Seti Khola. Therefore the Rupakot Formation is newly identified as a lacustrine deposit strictly of post-Pokhara-Formation stage (Table 2). Although the accumulation of the Rupakot Formation ceased much earlier in some extinct lakes, for example the former lake around Shharepatan, it has continued up to the present in the existing lakes, such as the Begnas and Rupakot Tal.

The Rupakot Formation lies conformably over the Pokhara Formation. At Shharepatan along the Phusre Khola and other localities, the uppermost part of lacustrine deposit is considered to correspond to the Rupakot Formation. However, it is practically difficult to distinguish the Rupakot Formation from the lacustrine-facies of the Pokhara Formation, because both deposits consist of laminated clay, silt and fine sand and assume the same facies.

Gravel Veneers on the Fillstrath Terraces carved in the Pokhara Terrace

These veneers are fluvial gravel beds two to three meters thick, and they make up the fillstrath terrace surfaces carved in the Pokhara Terrace described later. They are easily distinguished from the Pokhara Formation, a valley-fill, because of the differences of their facies as follows: (a) The veneer gravels are mainly cobble to boulder in size, and larger than those of the Pokhara Formation. (b) The veneer gravels are mostly sub-rounded, but those of the Pokhara Formation are sub-angular to sub-rounded. (c) The veneers have unsorted sandy matrix, while the Pokhara Formation has well sorted silty or fine sandy matrix. (d) The veneers contain more gravels of gneiss, granite ,quartzite and schist than the Pokhara Formation.

Recent Flood Plain Deposit

The recent fluvial deposit along the Seti Khola channel is mostly composed of cobble to boulder sized, rounded to sub-rounded gravels of limestone, gneiss, quartzite and others; the portion of gneiss gravels being much more compared to the Pokhara Formation. The recent flood plain deposit is widely distributed along tributary streams also.

The above-mentioned stratigraphic division and distribution of formations are closely related with the geomorphic classification described in the following chapter.

GEOMORPHIC SURFACES

The geomorphic surfaces around the Pokhara Valley are classified into five groups on the basis of their origin, age and continuity: two filltop terraces, namely the Ghachok and Pokhara Terraces, two groups of fillstrath terraces and recent flood plain (Table 2 and Fig.3).

Ghachok Terrace

The Ghachok Terrace is a filltop terrace made up of the Ghachok Formation. It coincides with the depositional surface of the "Gaunda-Konglomerat" (Hormann, 1974), and with the Terrace I (T. Sharma *et al.*, 1978). The original topography of the Ghachok Terrace is well preserved and its terrace cliff is left nearly vertical at most localities (Photos 2 and 3), although at Ghachok it is covered with a considerable volume of alluvial cone deposit.

The relative height between the Ghachok Terrace and Pokhara Terrace is larger upstream of the Seti Khola, and rapidly decreases downstream. Finally the Ghachok Terrace is crossed by the Pokhara Terrace just below Pokhara (Fig.4),though Hormann (1974) thought that the place of crossing is just above Pokhara. In the main part of the Pokhara Valley, the Ghachok Terrace is buried under the Pokhara Terrace (Section 4 in Fig.5).

The Ghachok Terrace assumes distinct fan shape around Lachok, Hengjabesi (Photo 4), Balichaur and Pokhara, where the fan-like Ghachok Terrace extends into tributary streams, such as the Yangadi and Kali Khola, and the terrace surface is inclined upstream of the tributaries. The strange inclination of the terrace can be recognized by the flowing direction of irrigation channels. These phenomena suggest that the Seti Khola accumulated the Ghachok Formation so rapidly that it intruded into the tributaries.

Fillstrath Terraces carved in the Ghachok Terrace

These terraces can be identified at three or more levels. They usually have no gravel veneers on the terraces, and often expose the erosional surfaces of the Ghachok Formation.

Pokhara Terrace

The Pokhara Terrace is an accumulation terrace built up of the Pokhara Formation. It corresponds to the "Pokhara-Fläche" (Hormann, 1974) and to the Terrace II (T. Sharma *et al.*, 1978). The Pokhara Terrace is named after the "Pokhara Valley", not after "Pokhara town", because Pokhara town is located on the Ghachok Terrace (Fig.3).

Upstream from Pokhara, the Pokhara Terrace is rather restricted in distribution and scattered in the valley cutting the Ghachok Terrace (Sections 1 and 2 in Fig.5; Photos 1, 2, 3 and 4). But it is widely spread in the main part of the Pokhara Valley (Fig.3; Photo 7). Its relative height above the present Seti Khola bed is rather constant as compared with that of the Ghachok Terrace (Fig.4), and measures between 52 and 96 meters.

Like the Ghachok Terrace, the Pokhara Terrace also extends into tributaries at some places, e.g. near the Begnas Tal. In the main part of the valley, the Pokhara Terrace swells slightly along the central axis of the valley, being similar to the river terrace caused by recurred mudflows reported by Machida (1959). Therefore, it is indicated that the Pokhara Formation accumulated rapidly with catastrophic events like mudflows.

The Pokhara Terrace completed its formation at about 600 y.B.P.according to the radiocarbon dating (Table 3).

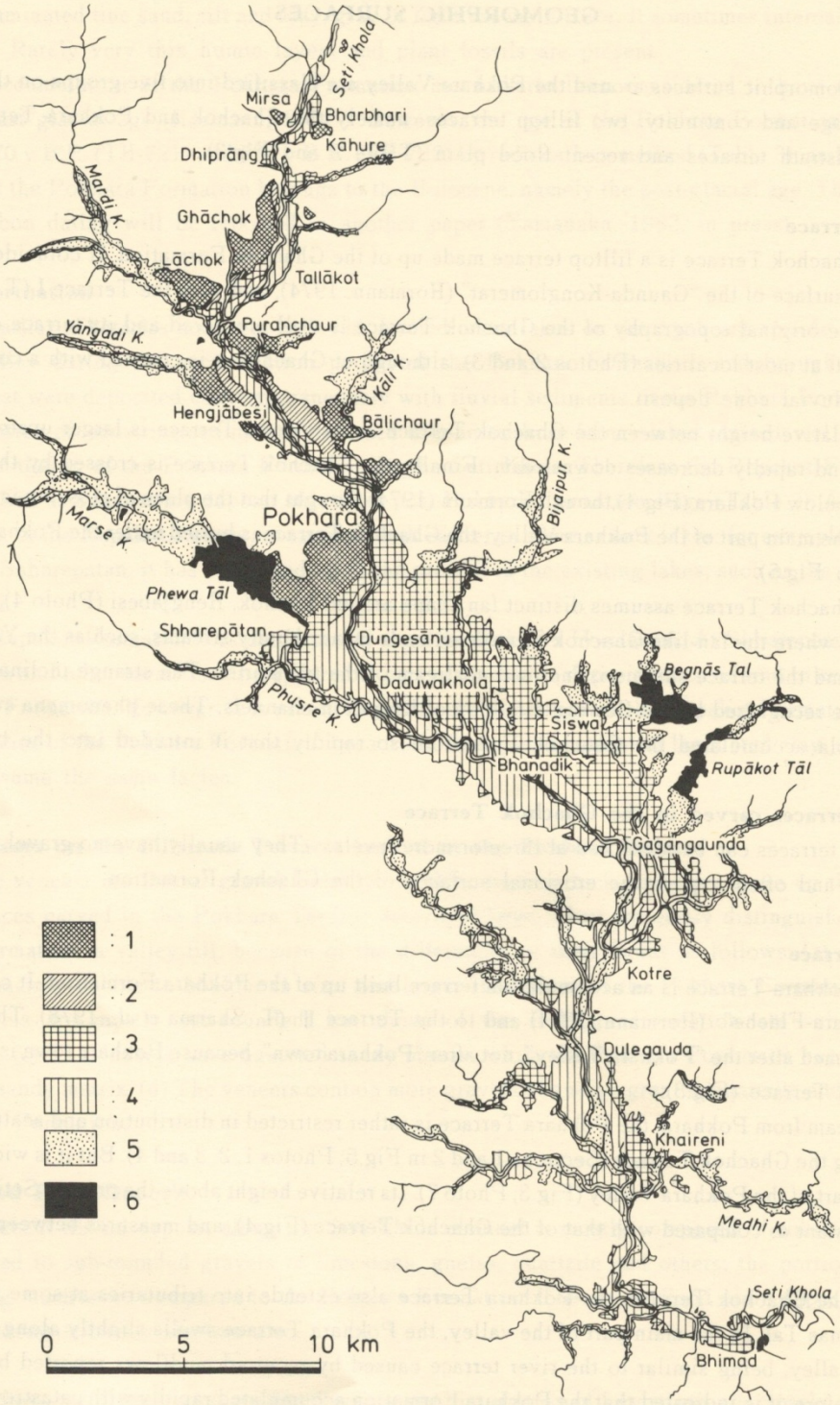


Fig.3. Distribution of river terraces around the Pokhara Valley.
1: Ghachok Terrace 2: Fillstrath terraces carved in the Ghachok Terrace 3: Pokhara Terrace 4: Fillstrath terraces carved in the Pokhara Terrace 5: Recent flood plain and depositional surfaces of the Phewa and Rupakot Formations 6: Lake

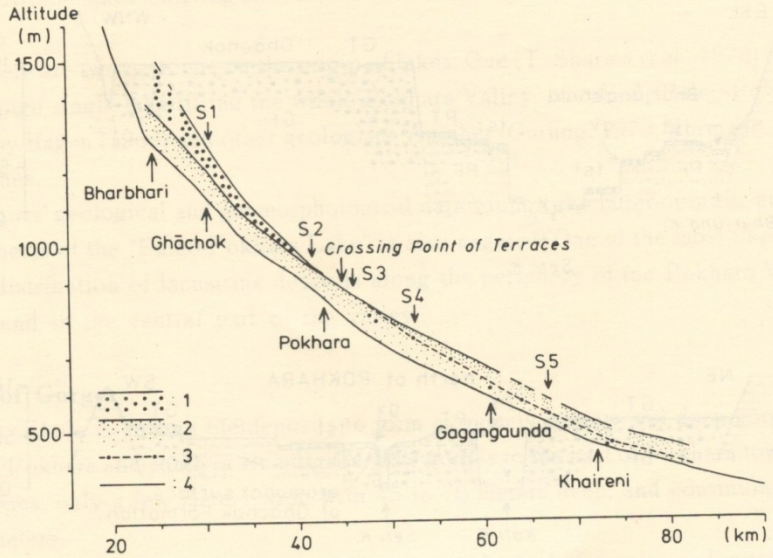


Fig.4. Longitudinal profile of the Ghachok and Pokhara Terraces along the Seti Khola.
1: Ghachok Terrace 2: Pokhara Terrace 3: Confirmed uppermost level (dot) of the Ghachok Formation and the presumed Ghachok Terrace surface (broken line) covered with the Pokhara Formation 4: Present river bed of the Seti Khola

Terraces are projected to a general zigzag course of the Seti Khola. Fillstrath terraces are not indicated. The 0 km point in horizontal distance is situated on the top of Mt. Annapurna Ⅲ (7,555m).

Note the crossing of the Ghachok and Pokhara Terraces just below Pokhara town.

S1～S5 indicate the localities of cross-sections in Fig.5.

Fillstrath Terraces carved in the Pokhara Terrace

These terraces are distributed in the narrow zone along the present river course of the Seti Khola (Fig.3). They are easily subdivided into multi-levels for their well preserved landforms (Photo 7), but it is very difficult or almost impossible to correlate them one another. These terraces have been shown as a group of terraces in Fig.3.

The surfaces of these terraces are extremely flat and horizontal with vertical cliffs, though they are built up of loose or weakly cemented gravels, i.e. the Pokhara Formation and overlying gravel veneers. At some places, fresh traces of braided streams and braid bars are observed on the terrace surfaces,where soil is hardly developed.

Recent Flood Plain

The recent flood plains are distributed along the present Seti Khola channel and along the tributaries, such as the Marse and Bijaypur Khola, at the periphery of the valley.

SOME GEOMORPHOLOGICAL PHENOMENA

Origin of Lakes

The Pokhara Valley has a number of lakes: Phewa,Begnas, Rupakot Tal and a few other small lakes. Some extinct lakes, e.g. "Paleo-Phusre Lake" and "Paleo-Bijaypur Lake", are also known from genuine lacustrine deposits, from which the samples for the radiocarbon dating and paleomagnetic measurement

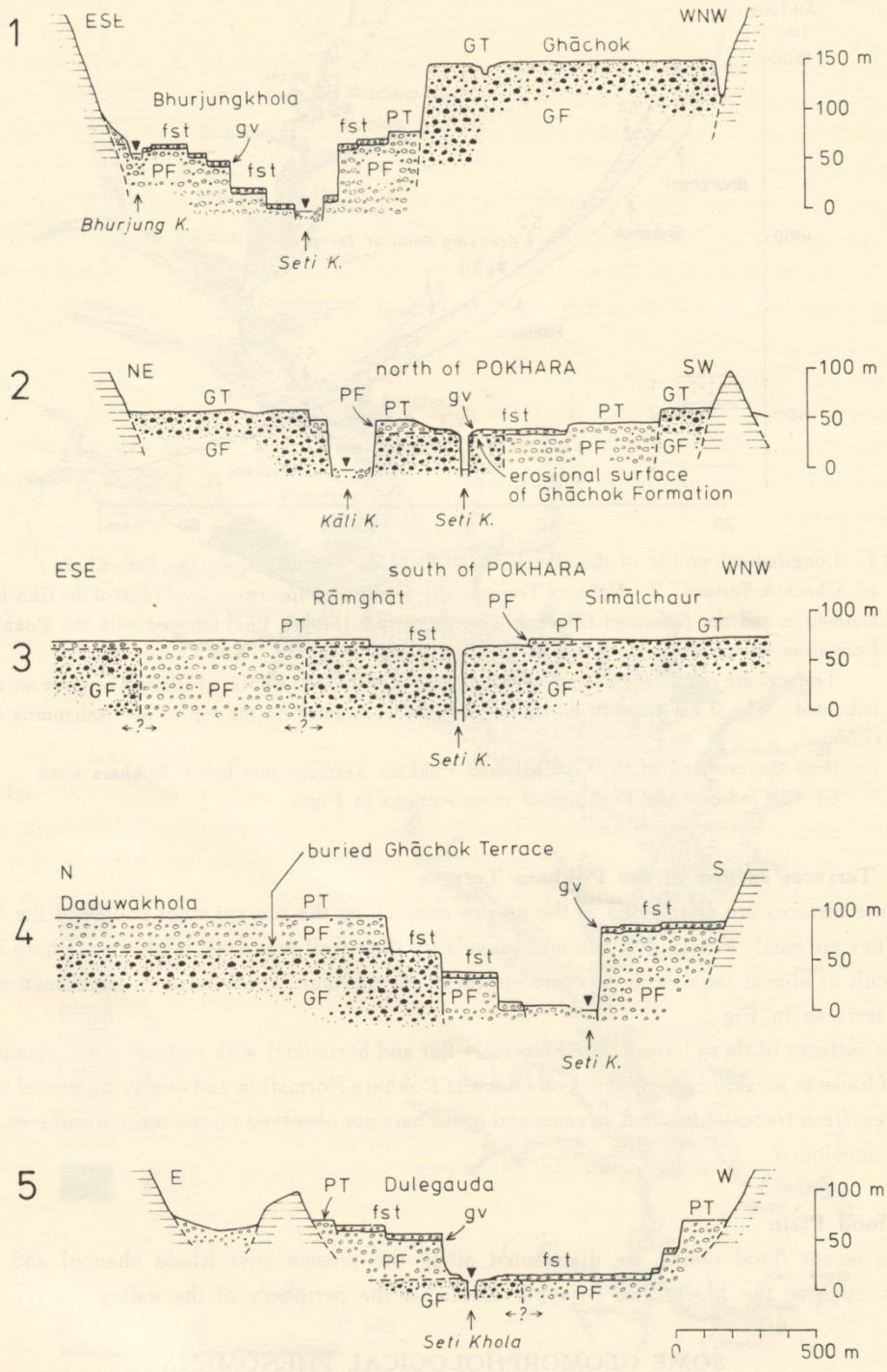


Fig.5. Cross-sections of terraces across the Seti Khola.
Terraces – GT : Ghachok Terrace, PT : Pokhara Terrace, fst : Fillstrath terraces carved in the Pokhara Terrace, Deposits – GF : Ghachok Formation, PF : Pokhara Formation, gv : Gravel veneers on fillstrath terraces. The localities of cross-sections are indicated in Fig.4.

were collected. All the lakes, existing and extinct, are situated just behind the mouths of tributaries into the Pokhara Valley.

So far there are two opinions on the origin of lakes. One (T. Sharma *et al.*, 1978) is that the lakes are remnants of a huge single lake filling the whole Pokhara Valley, so-called "Paleo-Pokhara Lake", which was imagined by Hagen (1969) and other geologists. Another (Gurung, 1970; Hormann, 1974) is that lakes are dammed ones.

The authors' geological and geomorphological data support the latter opinion, and deny the former. Hagen's hypothesis of the "Paleo-Pokhara Lake" is also negated. One of the most important evidences is the restricted distribution of lacustrine deposits along the periphery of the Pokhara Valley; only fluvial gravels are found in the central part of the valley.

Distribution of Gorges

The Seti Khola is cutting the deposits to form extremely narrow and deep gorges at some places; such as east of Pokhara and south of Kumdigaon. The gorges to the east of Pokhara town (Photo 5) are the most typical ones, only a few meters wide with 45 to 70 meters deep, and continuing intermittently for about 7 kilometers.

The distribution of gorges, if examined from the geological viewpoint, is limited to areas where the Seti Khola cuts the extremely hardened Ghachok Formation. On the contrary, where the Seti Khola cuts the Pokhara Formation, this loose or weakly cemented deposit is easily eroded and a gorge is not formed; then the bottom is wide and appears as a recent flood plain.

Some Consideration on Tectonic Movement

The Ghachok Terrace and Pokhara Terrace cross each other just below Pokhara. Hormann (1974) presumed that the crossing of terraces was caused by a tectonic movement of this region. The present authors also agree with his presumption. The following fact further supports this presumption; The lithofacies of the Ghachok and Pokhara Formations are not so different except for degree of cementation. Hence the gradient and other conditions of the former Seti Khola which accumulated these formations and formed the Ghachok and Pokhara Terraces were possibly almost the same.

Furthermore, the authors consider that the tilting, roughly speaking, to the south has lasted since the formation of the Ghachok Terrace, and that the Great Himalayas have upheaved while the Pokhara Valley has comparatively subsided.

The average gradients of the Ghachok and Pokhara Terraces at the present are 3.1 % and 2.4 % respectively along the upper Seti Khola between Bharbhari and Pokhara. Assuming the initial gradients of terraces to have been equal, the amount of tilting between the formative periods of both terraces measures 0.7 % or 7 m/km. If the age of the Ghachok Terrace was known, the rate of tilting between Bharbhari and Pokhara could be calculated.Moreover, if the tilting rate could be equally applied to the whole region up to the main range of the Great Himalayas, and assuming a standing point somewhere, the uplifting rate of the Great Himalayas could be estimated.

PALEOMAGNETIC MEASUREMENT

The earth's magnetic field was reversed frequently in the past, and the polarity changes are well known for the last five million years (Cox *et al.*, 1964; Mankinen and Dalrymple, 1979). In recent years, many reversed polarity events or excursions have been found in the Brunhes Normal Epoch. In the late Quaternary two events occurred: the Laschamp event (Bonhommet and Zahringer, 1969) and the Blake

Table 4.

a Results of paleomagnetic measurements Power Station (PS) section (Loc.6)

Sample	N	Dec.	Inc.	Intensity	α95	K	VGP(lat.)	VGP(long.)	Demagnetization
PS11	4	322	-1	8.00E-7	18	14	43	205	200oeA.F.D.
PS10	4	307	11	7.65E-7	18	14	35	188	200oeA.F.D.
PS09	4	53	8	8.12E-7	12	32	34	188	200oeA.F.D.
PS08	4	353	6	3.57E-6	25	7	64	248	200oeA.F.D.
PS07	4	12	-2	7.10E-7	26	6	58	239	200oeA.F.D.
PS06	4	43	26	1.06E-5	55	1	46	183	200oeA.F.D.
PS05	3	12	18	1.50E-6	8	98	68	228	200oeA.F.D.
PS04	4	8	14	1.18E-5	8	61	67	240	200oeA.F.D.
PS03	4	18	7	6.30E-6	8	74	59	224	200oeA.F.D.
PS02	4	11	32	2.53E-6	7	108	74	214	200oeA.F.D.
PS01	4	15	22	4.47E-6	17	16	67	218	200oeA.F.D.
		(°)	(°)	(emu/cc)	(°)		(°)	(°)	(400Hz)

b Shharepatan (PA) section (Loc.7)

Sample	N	Dec.	Inc.	Intensity	α95	K	VGP(lat.)	VGP(long.)	Demagnetization
PA05	4	44	19	7.85E-7	54	1	44	188	200oeA.F.D.
PA04	3	0	14	7.33E-7	33	5	69	261	200oeA.F.D.
PA02	4	29	-1	8.40E-7	27	6	50	213	200oeA.F.D.
PA01	4	325	32	1.27E-6	8	62	56	184	200oeA.F.D.
		(°)	(°)	(emu/cc)	(°)		(°)	(°)	

c Medhi Khola (KO) section (Loc.8)

Sample	N	Dec.	Inc.	Intensity	α95	K	VGP(lat.)	VGP(long.)	Demagnetization
KO06	4	281	5	8.50E-7	54	1	11	176	200oeA.F.D.
KO02	4	310	15	9.07E-7	21	10	39	187	200oeA.F.D.
KO01	4	301	7	7.62E-7	27	6	29	186	200oeA.F.D.
		(°)	(°)	(emu/cc)	(°)		(°)	(°)	

event (Smith and Foster, 1969).

For the purpose of paleomagnetic measurement, oriented core samples were collected from the lower to upper part of the Pokhara Formation and a part of the Rupakot Formation at Locs.6, 7 and 8. Oriented cores, 3.2 cm in diameter, were covered with non-magnetic acryle tubes. Four cores at 100 to 150 cm intervals in each site were collected, amounting to 96 samples. The remanent magnetization was measured using an automatic astatic magnetometer (Fujiwara and Yoshida, 1981). The stability of remanence was assessed by stepwise demagnetization in a 400 Hz alternating field without specimen rotation (Creer, 1959; Snape, 1967). Mostly the remanences of samples are very stable and weak. In most cases, soft components can be removed by partial demagnetization in a field of 200 to 300 Oe (Figs.6 and 7). A field of 200 Oe was chosen for magnetic cleaning. The intensity of remanent magnetization after cleaning at 200 Oe ranges from 10^{-6} to 10^{-7} emu/cc.

The directions of magnetization before and after A.F. demagnetization treatment are summarized in

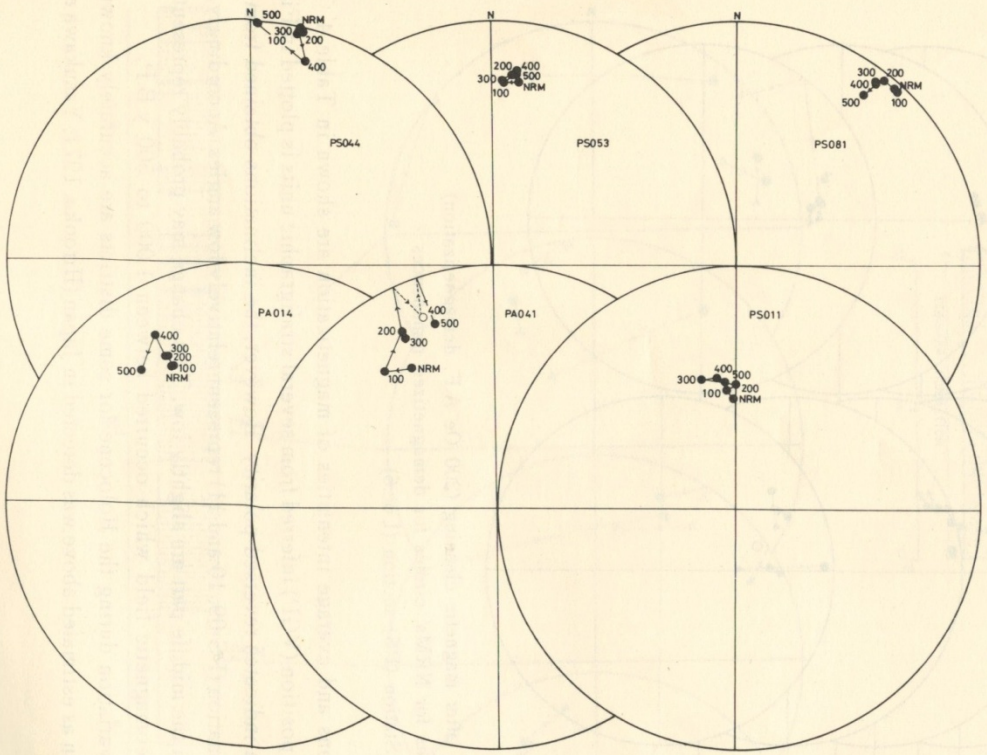


Fig.6. Examples of the change of direction of remanent magnetization by progressive A.F. demagnetization.
Projection is stereographic. Open circles indicate upward inclinations, closed circles downward inclinations.

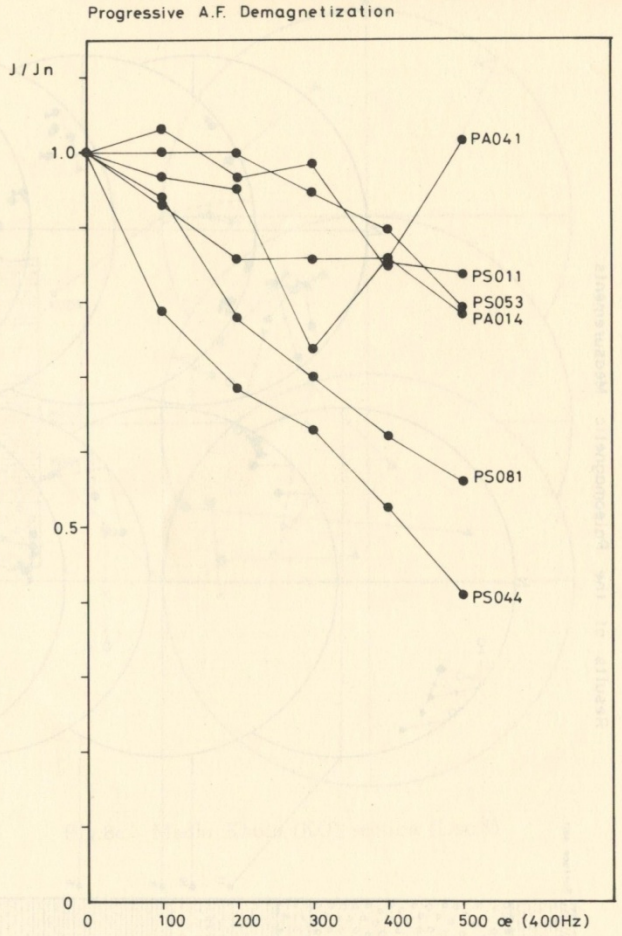


Fig.7. Change of intensity by 400 Hz alternating field demagnetization.

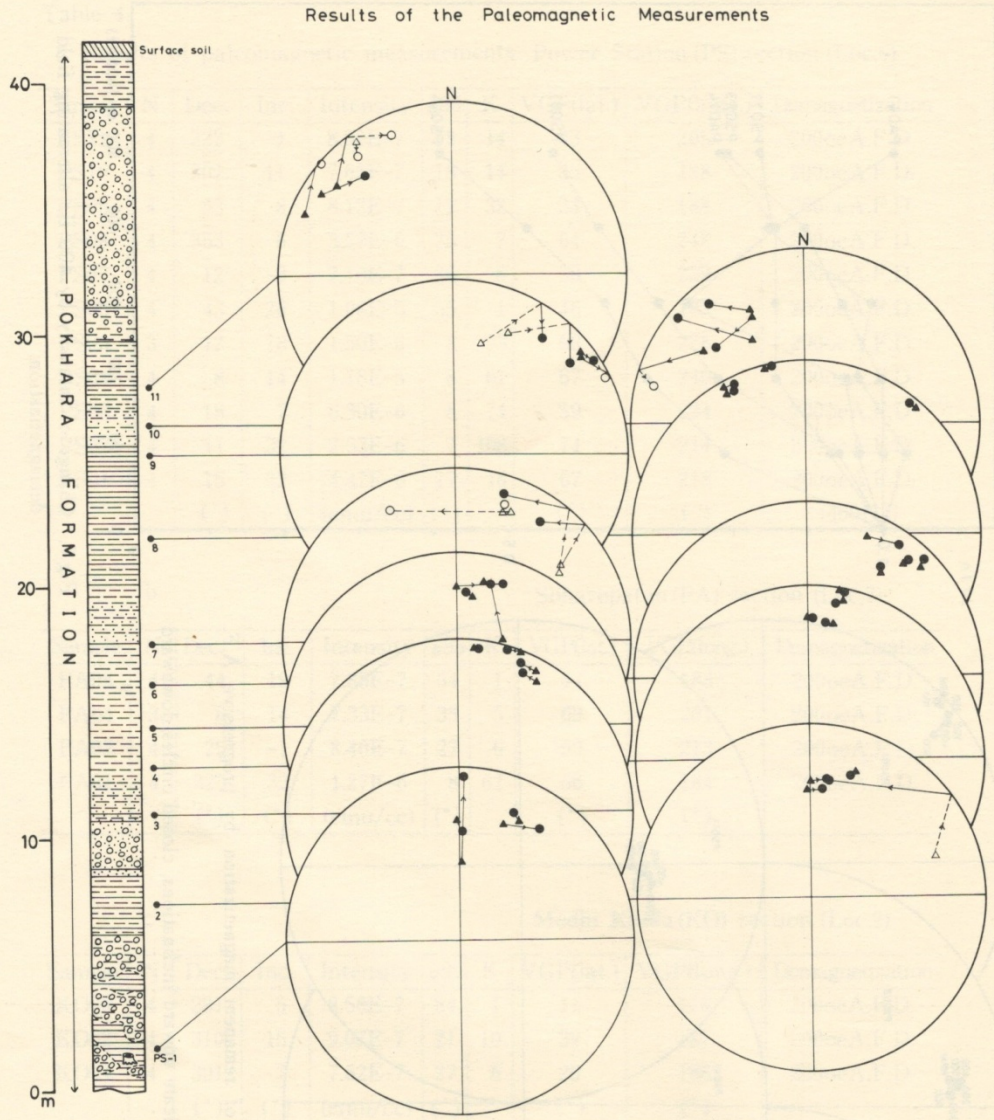


Fig.8a. Change after magnetic cleaning (200 Oe A.F. demagnetization). Triangles for NRMs, circles for demagnetized remanences. Power Station (PS) section (Loc.6)

Fig.8. The sites, mean directions and average intensities of magnetization are shown in Table 4. The change of virtual magnetic pole position (VGP) inferred from several stratigraphic units is plotted in Fig.9. It is clear that none of the data indicates reversed polarity. However, the inclinations obtained from the middle part of the Pokhara Formation (PS-09, 10 and 11) represent relatively low angles. Accordingly, the latitudes of VGPs inferred from the middle part are slightly low. This change may probably represent the ancient secular variation of geomagnetic field which occurred between 1,000 to 500 y.B.P.

The records of secular variation during the Holocene for some districts are accurately known. A similar trend of secular variation as estimated above was detected in Japan (Hirooka, 1971; Yasukawa *et al.*, 1973).

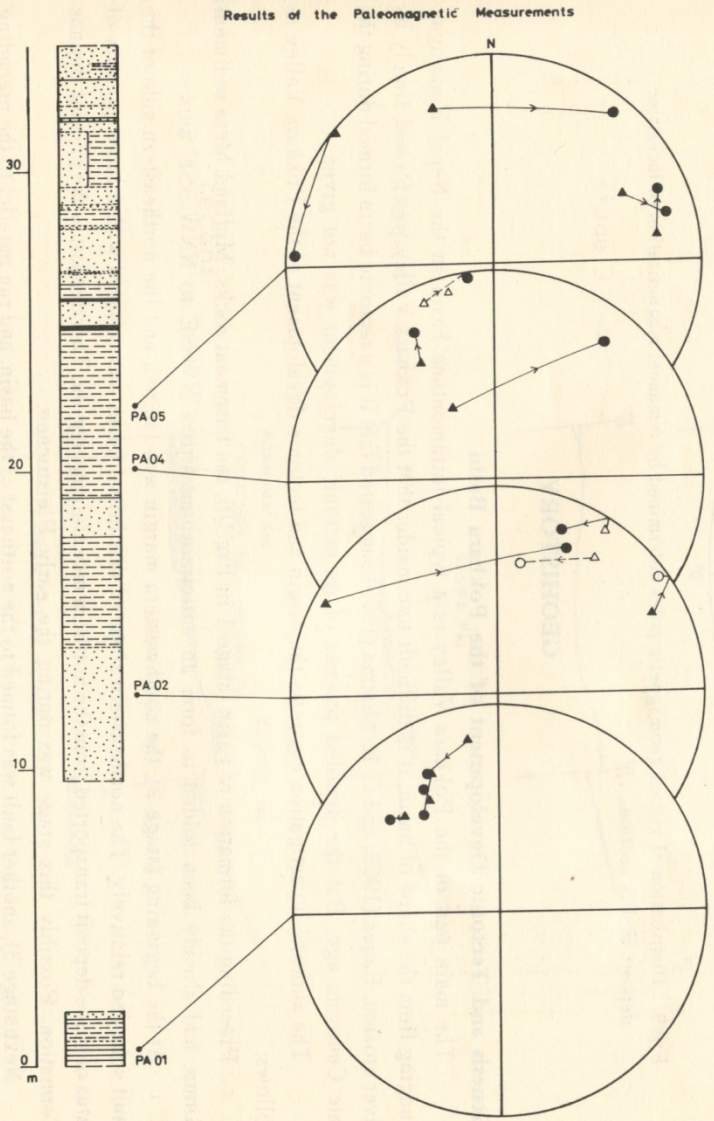


Fig.8b. Shharepatan (PA) section (Loc.7)

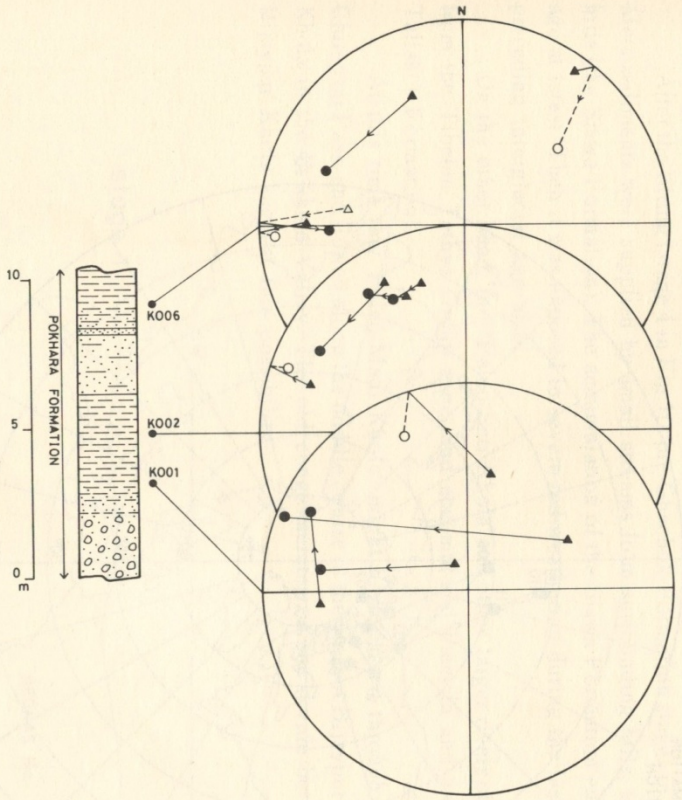


Fig.8c. Medhi Khola (KO) section (Loc.8)

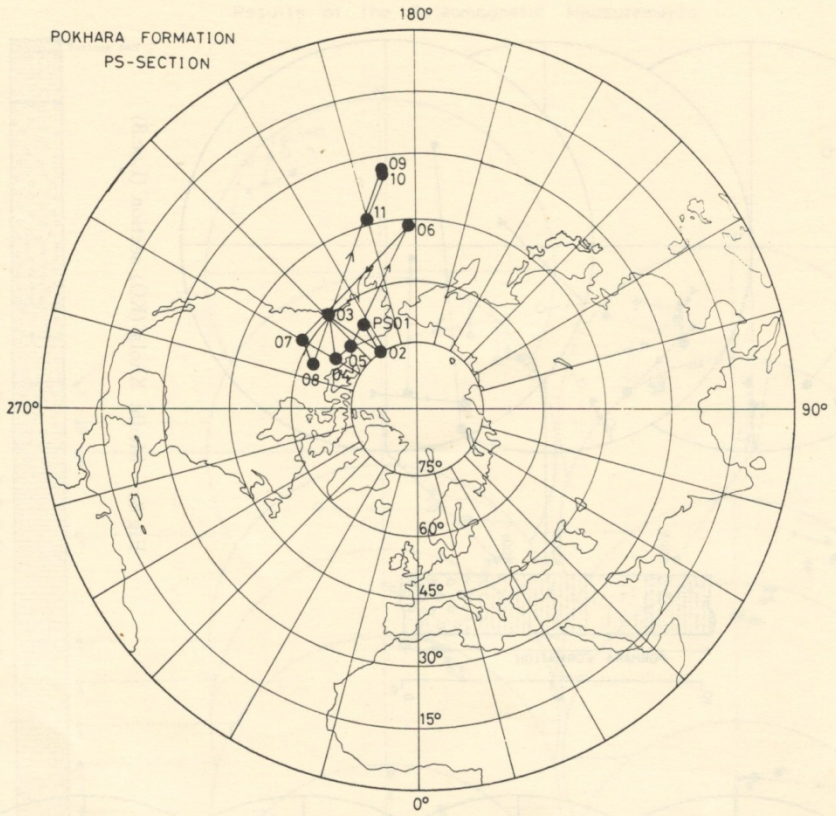


Fig.9. Distribution of virtual geomagnetic poles determined by remanent magnetization of lacustrine deposit at PS section.

GEOHISTORY

Genesis and Tectonic Development of the Pokhara Basin

The main part of the Pokhara Valley is a typical intramontane basin in the Nepal Himalayas. Judging from the shape of basin, it is difficult to consider that the Pokhara Valley was formed simply by river erosion. Hagen (1969) and C. K. Sharma (1975) suggested that it is a tectonic basin formed during the late Cenozoic age. But the detailed process of its tectonic development was not given.

The authors' investigation suggests the origin and tectonic development of the Pokhara Valley as follows;

Preceding the formation of basin (stage 1 in Fig.10), the basement rocks, Midland Meta-sediment Group, had already been folded to form an anticlinorium with a NW-SE to NNW-SSE axis.

At the beginning (stage 2), the southwestern margin was faulted, and the northeastern side of the fault subsided relatively. The northeastern slope of this initial basin was covered with a large quantity of talus or slope deposit transported from the northern mountainous region. This deposit is the present Begnas Formation. Possibly this stage was during the early Pleistocene.

Next(stage 3), another fault was formed to the northeast of the basin, and ran parallel to the preceding fault. Consequently, a large fault block, the Pokhara Block,was born. This fault block tilted down southwestwards; The northeastern part was elevated and the southwestern subsided. Thus the Pokhara Basin was completed as a fault-angle basin.

Accumulation of Older Deposits

After the tilting (stage 4 in Fig.10; pre-Ghachok-Formation stages in Fig.11), gravels of the Midland Meta-sediments were supplied by small streams from surrounding hills, and deposited along the foot of hills (the Siswa Formation). The accumulation of the Siswa Formation ended before the last interglacial age at latest. Then it was exposed to severe red-weathering during the last interglacial age or during the preceding interglacial age also.

On the other hand, the "Paleo-Seti Khola"and other larger rivers of those days transported gravels from the Tibetan Tethys Group zone, and accumulated them in and around the Pokhara Valley (the Tallakot Formation).

At this time the "Paleo-Madi Khola" might have passed through the present divide around the Chitepani Pass, and flowed along the middle course of the present Bijaypur Khola, and then joined the Seti Khola in the Pokhara Valley. The old conglomerates on the divide between the Madi Khola and the Bijaypur Khola suggest this possibility.

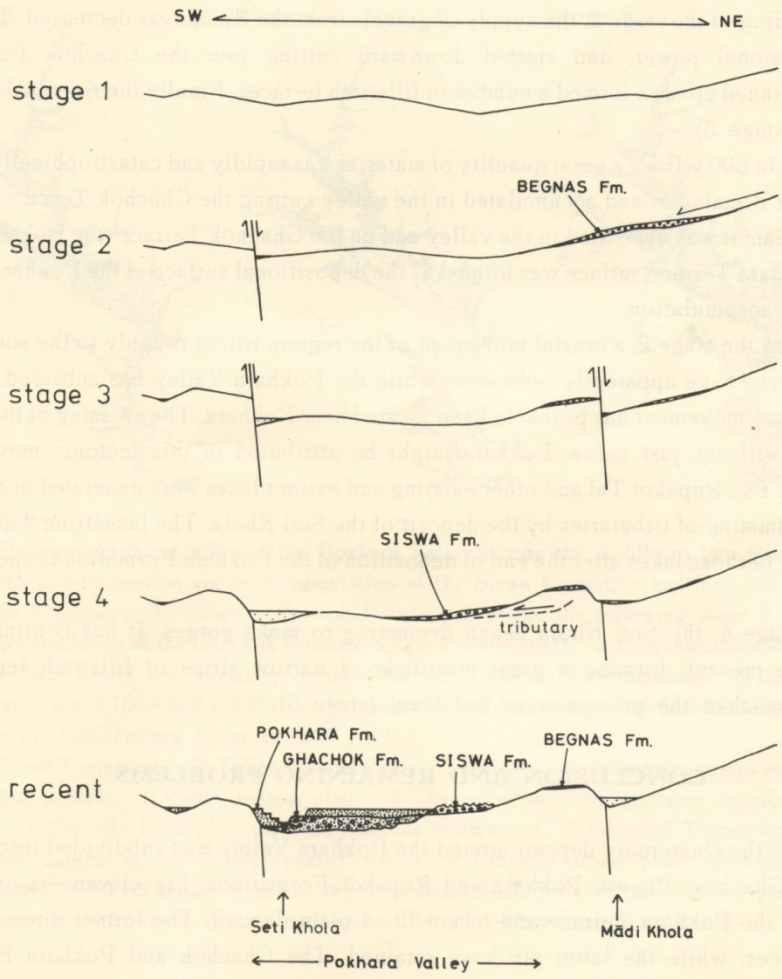


Fig.10. Schematic cross-sections on the genesis and tectonic development of the Pokhara Valley. Stage 1: Before the formation of the Pokhara Basin, 2: Beginning of tectonic movement and deposition of the Begnas Formation, Tilting southwestwards (early to middle Pleistocene?), 4: Deposition of the Siswa Formation (before the last interglacial epoch?).

There are no evidences which indicate the former existence of the so-called "Paleo-Pokhara Lake".

Accumulation of Younger Deposits and Formation of Terraces

1) Later on, the Seti Khola and its main tributaries settled their courses almost in the same localities as the present. These rivers made comparatively wide and deep valleys by erosion (stage 1 in Fig.11).

2) A vast volume of gravels were transported by the Seti Khola from the Annapurna Range to fill up the valley (the Ghachok Formation) (stage 2). And the Ghachok Terrace surface was formed as a filltop one at the final stage of accumulation. Probably this stage was during the late Pleistocene, but its absolute age is not known at all.

In consequence of the rapid accumulation by the Seti Khola, many tributaries, e.g. the Yangadi, Kali and Marse Khola, were blocked up at the mouths into the Pokhara Valley. Hence a number of lakes were formed just behind the barriers. It was during this stage that the antecedent of the Phewa Tal was formed.

Some of those dammed lakes survived after the end of accumulation of the Ghachok Formation, and the lacustrine deposit continued to be heaped in them (the Phewa Formation).

3) With the ending of the stage 2, the supply of gravels from the Himalayas decreased. The Seti Khola recovered its erosional power, and started downward cutting into the Ghachok Formation. The intermittently continued erosion formed a number of fillstrath terraces. Finally the river bed reached below the present level(stage 3).

4) About 1,100 to 600 y.B.P., a great quantity of material was rapidly and catastrophically brought from the glaciated Great Himalayas, and accumulated in the valley cutting the Ghachok Terrace upstream from Pokhara. Downstream it was deposited in the valley and on the Ghachok Terrace (the Pokhara Formation) (stage 4). The Pokhara Terrace surface was formed as the depositional surface of the Pokhara Formation at the final stage of accumulation.

At least since the stage 2, a crustal movement of the region, tilting roughly to the south, has lasted. The Great Himalayas have apparently upheaved, while the Pokhara Valley has subsided. The standing point for this tectonic movement has probably been located near Pokhara. The crossing of the Ghachok and Pokhara Terrace surfaces just below Pokhara might be attributed to this tectonic movement.

The Begnas Tal, Rupakot Tal and other existing and extinct lakes were generated or re-generated as the result of the damming of tributaries by the deposit of the Seti Khola. The lacustrine deposit continued to be piled in some of those lakes after the end of deposition of the Pokhara Formation proper (the Rupakot Formation).

5) After the stage 4, the Seti Khola began deepening to make gorges. It has continued downward erosion up to the present, forming a great multitude of narrow strips of fillstrath terraces, and its downcutting has reached the present river bed level (stage 5).

CONCLUSION AND REMAINING PROBLEMS

In this study the Quaternary deposit around the Pokhara Valley was subdivided into nine: Begnas, Siswa, Tallakot, Ghachok, Phewa, Pokhara and Rupakot Formations, gravel veneers on the fillstrath terraces carved in the Pokhara Terrace and recent flood plain deposit. The former three have lost their depositional surfaces, while the latter six have retained. The Ghachok and Pokhara Formations are prominent valley-fill deposits in the Pokhara Valley. The Pokhara Formation was accumulated about 1,100 to 600 y.B.P. in the Holocene.

The river terraces formed by the Seti Khola were classified into two filltop terraces,namely the Ghachok and Pokhara Terraces, and two groups of fillstrath terraces that were carved in the Ghachok

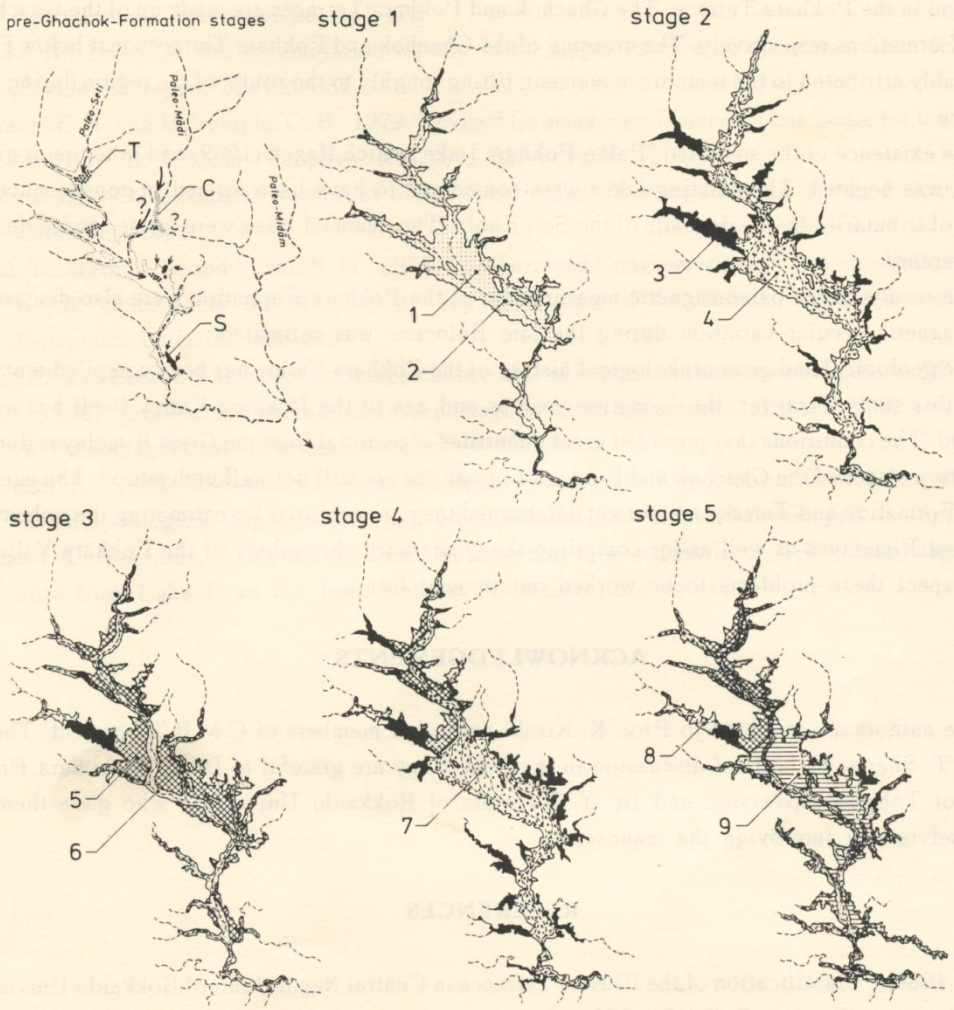


Fig.11. Paleogeographical maps of the Pokhara Valley during the middle to late Quaternary.
Pre-Ghachok-Formation stages: Accumulation of the Siswa Formation and Tallakot Formation (middle Pleistocene?), Stage 1: Erosional stage just before the following stage 2
2: Accumulation of the Ghachok Formation (late Pleistocene?), 3: Rejuvenation and deepening of the Seti Khola and terracing of the Ghachok Terrace, 4: Accumulation of the Pokhara Formation (ca. 1,100～600 y.B.P.), 5: Rejuvenation and deepening of the Seti Khola and terracing of the Pokhara Terrace (since ca. 600 y.B.P.).
S: Siswa Formation, T: Tallakot Formation, C: Unnamed conglomerate composed of gneiss or schist gravels, 1: Valley bottom plain, 2: Channel of the Seti Khola or its tributaries, 3: Lake, 4: Gravelly flood plain (gravels: Ghachok Formation), 5: Ghachok Terrace and fillstrath terraces carved in it, 6: Rejuvenated valley, 7: Gravelly flood plain (gravels: Pokhara Formation), 8: Recent flood plain and depositional surfaces of the Phewa and Rupakot Formations, 9: Pokhara Terrace and upper fillstrath terraces carved in it.

Terrace and in the Pokhara Terrace. The Ghachok and Pokhara Terraces are made up of the Ghachok and Pokhara Formations respectively. The crossing of the Ghachok and Pokhara Terraces just below Pokhara is presumably attributed to the tectonic movement, tilting roughly to the south, of the region during the late Quaternary.

The existence of the so-called "Paleo-Pokhara Lake",which Hagen (1969) and other geologists had imagined, was negated. The existing lakes were considered to have been formed in consequence of the damming of tributaries by the deposits of the Seti Khola. The dammed lakes were formed twice during the late Quaternary.

The results of the paleomagnetic measurement of the Pokhara Formation were also discussed,and the geomagnetic secular variation during the late Holocene was estimated.

The geological and geomorphological history of the Pokhara Valley has been compiled tentatively.

In this study, however, the formative process and age of the Pokhara Valley itself has not been established. The conditions that provided great quantities of material from the Great Himalayas during the accumulation stages of the Ghachok and Pokhara Formations are still not well understood. The ages of the Ghachok Formation and Terrace are not yet determined;they are essential for estimating the upheaval rate of the Great Himalayas as well as for compiling the Quaternary chronology of the Pokhara Valley. The authors expect these problems to be worked out in near future.

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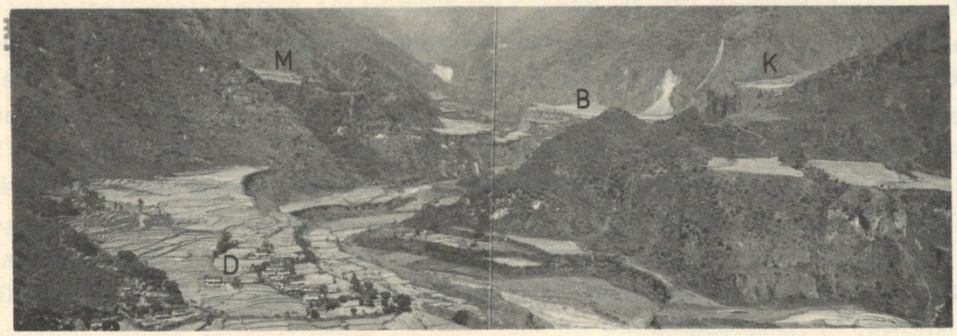

Photo 1. View of the upper Seti Khola and terraces to the north (upstream). The villages of Mirsa (M) and Kahure (K) are situated on the Ghachok Terrace, and Bharbhari (B) and Dhiprang (D) on the Pokhara Terrace. The Ghachok Terrace rises about 230 meters above the river bed of the Seti Khola, and the Pokhara Terrace about 85 meters.

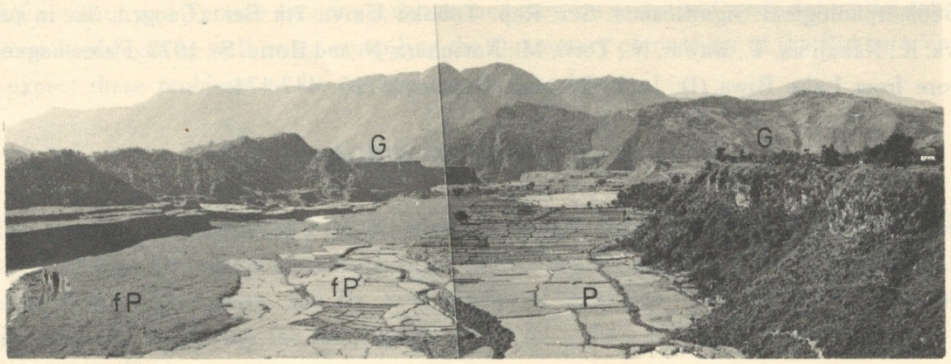

Photo 2. Ghachok Terrace (G) and Pokhara Terrace (P) at Ghachok, looking downstream. The Ghachok Terrace rises about 150 meters above the Siti Khola bed, and the Pokhara Terrace 80 meters. Many levels of fillstrath terraces (fP) have been formed in the Pokhara Terrace.

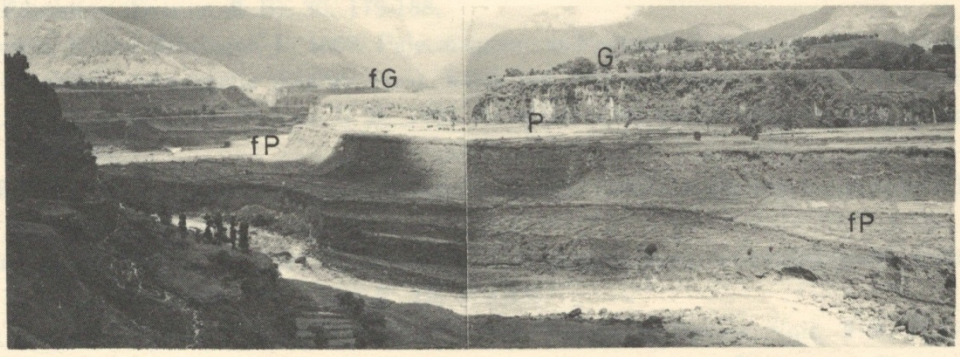

Photo 3. Ghachok Terrace (G) and Pokhara Terrace (P) around Puranchaur. "fG" and "fP" are the fillstrath terraces carved in the Ghachok and Pokhara Terraces respectively.

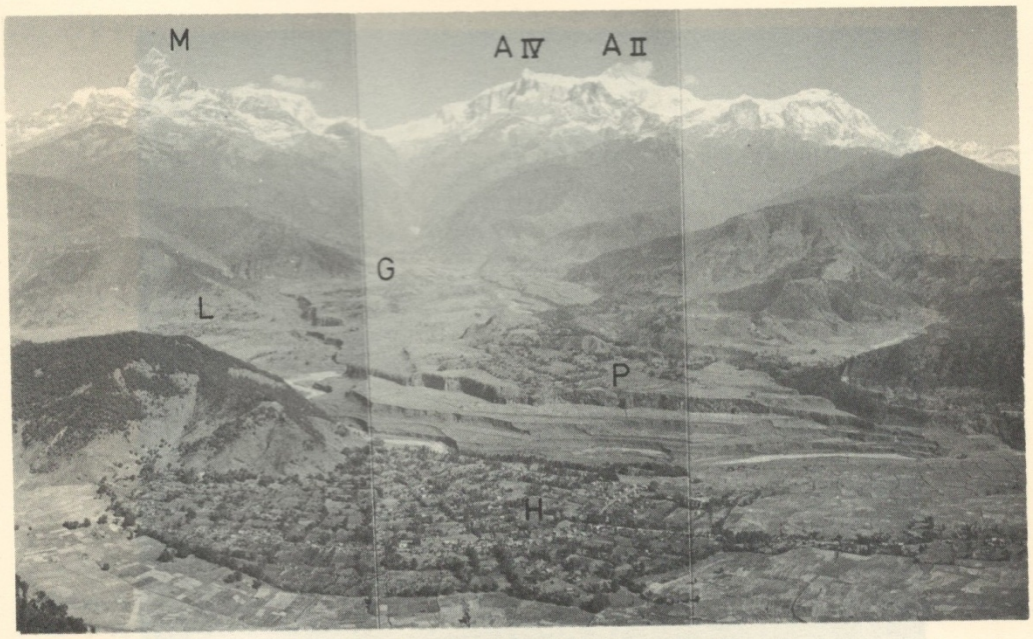

Photo 4. View of the upper Seti Khola valley from on the Sarangkot Ridge. The fan-shaped Ghachok Terrace in the foreground has intruded into the tributary Yangadi Khola and blocked up it. The villages of Ghachok (G), Lachok (L), Puranchaur (P) and Hengjabesi (H) are all situated on the Ghachok Terrace. Along the upper Seti Khola, the Pokhara Terrace is inserted into the valley cutting the Ghachok Terrace. Mt. Machhapuchhare (M, 6,993m), Annapurna Ⅱ (AⅡ, 7,937m) and Annapurna Ⅳ(AⅣ,7,525m) rise in the background.

Photo 5. Entrance of a gorge of the Seti Khola at the north of Pokhara town. The gorge is formed in the consolidated Ghachok Formation. It is only a few meters wide, but about 45 meters deep at the entrance.

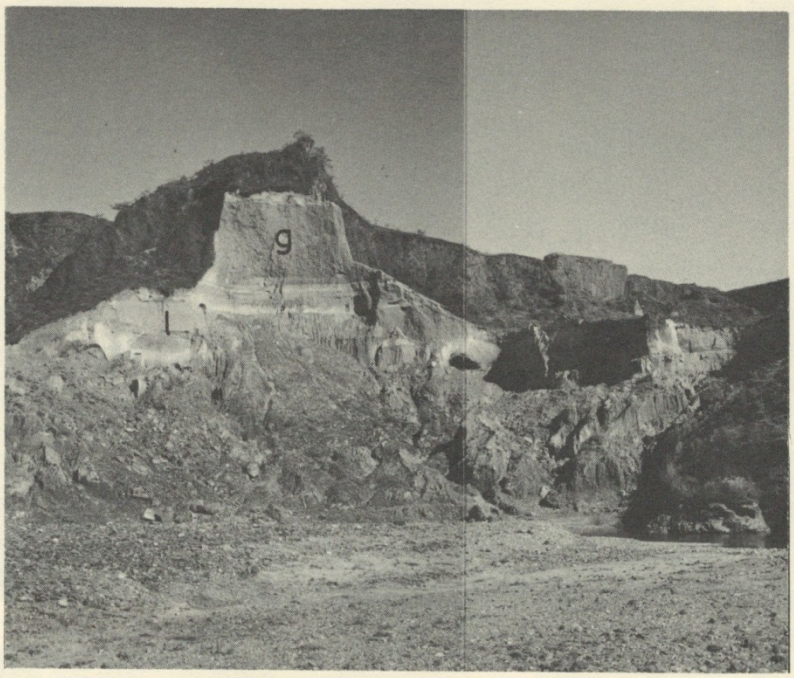

Photo 6. Large outcrop of lacustrine facies of the Pokhara Formation, beside a power station along the Phusre Khola. The lacustrine deposit (l) intercalates a fluvial gravel bed (g). Two samples (TH-719 and TH-720) for radiocarbon dating and the PS section samples for paleomagnetic measurement were collected at this outcrop.

Photo 7. Pokhara Terrace (uppermost level) and fillstrath terraces (lower levels) carved in it, looking north from the south of the junction of the Seti and Phusre Khola. Downstream from Pokhara town, the Ghachok Terrace is buried under the Pokhara Terrace, so the Pokhara Terrace makes the uppermost terrace level. The relative height between the Pokhara Terrace and the Seti Khola bed is about 80 meters.

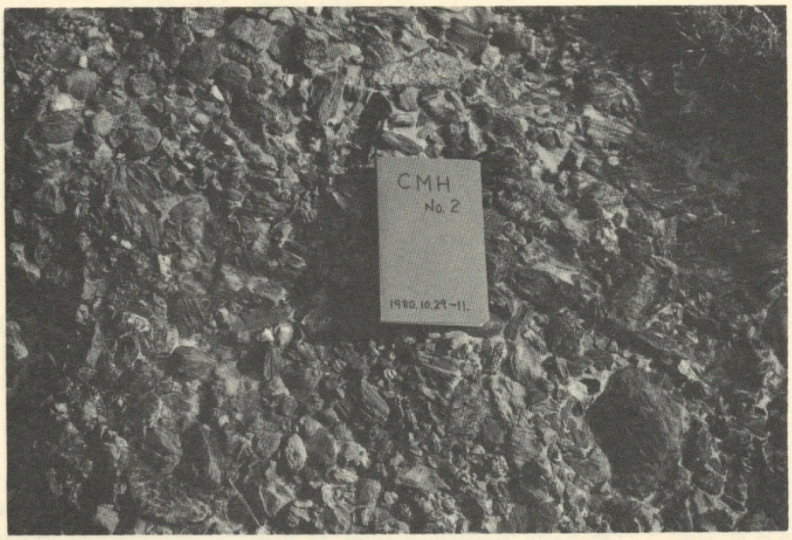

Photo 8. Lithofacies of the strongly consolidated Ghachok Formation, a block washed by the river, on the Seti Khola bed near the junction of the Seti and Phusre Khola.

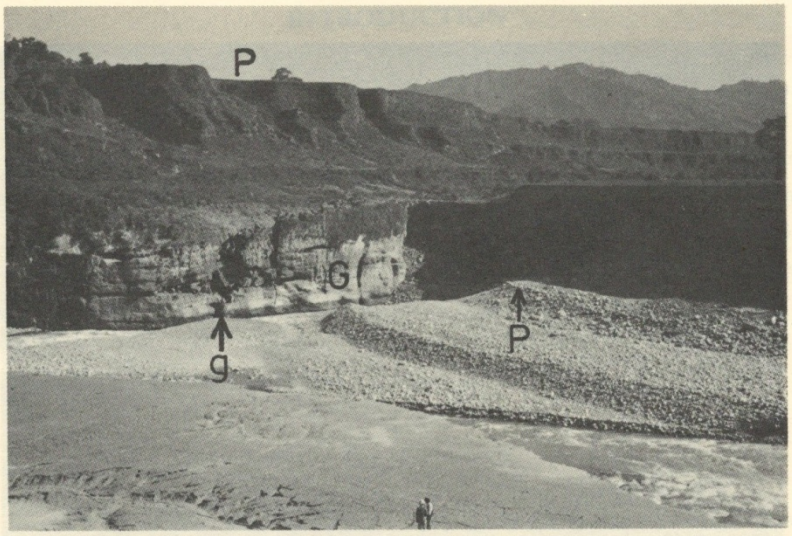

Photo 9. Good example of outcrop showing the relation between the Ghachok and Pokhara Formations at Gagangaunda. The Pokhara Formation (P) fills the former valley (shaded middle right), and covers the Ghachok Formation (G). The present Seti Khola cuts the Ghachok Formation to form an extremely narrow gorge (g).

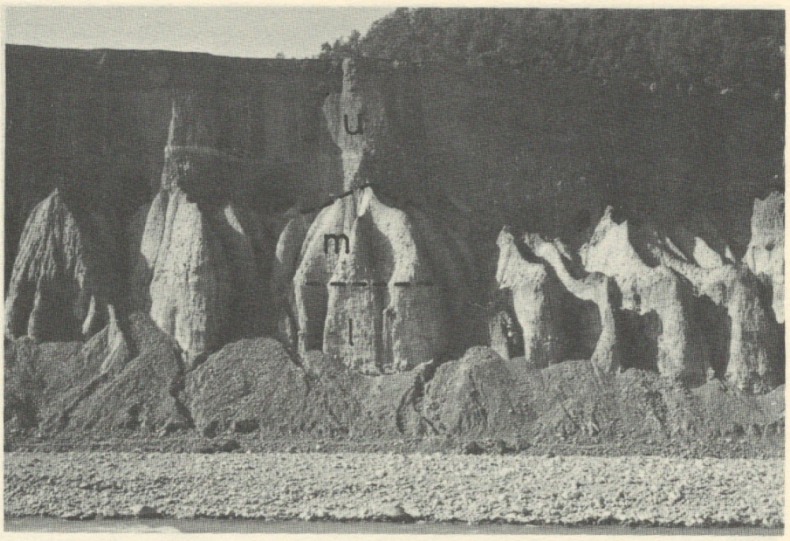

Photo 10. Riverside cliff of the Pokhara Formation near Kotre. Downstream from Gagangaunda, the Pokhara Formation is subdivided into three units: the lower (l), middle (m) and upper unit (u). The middle unit covers the lower conformably, but it is disconformably overlain by the upper.

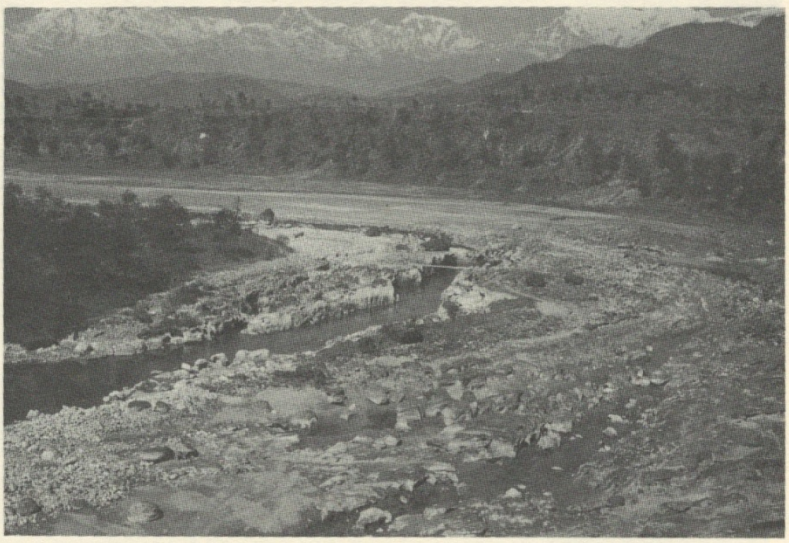

Photo 11. Ghachok Formation exposed on the river bed of the Seti Khola at Khaireni. The Ghachok Formation was once covered with the thick (ca.50 m) Pokhara Formation, and re-exposed recently by river erosion.