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The Kathmandu Basin: an archive of Himalayan uplift and past monsoon climate

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ABSTRACT

The basin-fill sediment of the Kathmandu Valley is one of the best archives of both Himalayan uplift and past monsoon climate. Thick lacustrine sediments, manily comprised of black clay, locally called as Kalimati clay, are the deposits of the Paleo-Kathmandu Lake during the last 2.5 million years, and the underlying fluvial sediments represent the deposits by the Proto-Bagmati River of the valley. The clay-predominant Kalimati Formation is rich in proxies of paleoclimate, such as fossil pollen and diatom as well as vertebrate and invertebrate fossils. In addition, crystallinity, chemical composition and stable isotope of clay minerals have a potential to provide a continuous paleoclimatic and paleoenvironmental records in the Central Himalaya. The sedimentological study of the fluvial and deltaic deposits that rest on the Kalimati Formation would reveal recent changes of tectonic and depositional environments in the Central Himalaya.

INTRODUCTION

For nearly five decades, the Himalaya remained an attractive field for geologists to study the problems on orogeny. Many geologists have undertaken exploration and research project to find out an answer for the question how the highest and biggest mountain range in the world was formed. The plate tectonics theory provided the concept of collision orogeny (Dewey and Bird 1970; Dewey and Burke 1973; Le Fort 1975), and the Himalayan Range became the focus of study from the viewpoints that the range is a natural laboratory where the continent-continent collision is presently going on. Over the years, a large number of research projects were carried out in the Himalaya aiming to understand the process and mechanism of collision-type orogeny and regarded it as the best available model (e.g. Coward and Rise 1986; Treloar and Searle 1993; Le Fort and Upreti 1999).

During the last decade of the 20th century, the Himalayan mountain range also attracted a much wider group of Earth Scientists, including atmospheric scientists and oceanographers. An attractive hypothesis was put forward, according to which the uplift of the Himalaya and Tibetan Plateau gave rise to monsoon climate in Asia and resulted into the global cooling in late Cenozoic (Hahn and Manabe 1975; Raymo et al. 1988; Ruddiman and Kutzbach 1989; Raymo and Ruddiman 1992). The linkage between the uplift of the Himalaya and monsoon climate has become a very attractive topic, and many research projects have been undertaken on land and under the sea. For example, Chinese Scientists have carried out intensive studies in the Tibetan Plateau and its adjacent areas (Li et al. 1995; Fang and Nettleton 1999). On the other hand, several scientific legs were carried out in the Indian Ocean, and deep-sea drilling was done in offshore areas of Bengal Bay and Oman (Prell et al. 1992). As the results, continuous records of palaeo-monsoon climate are obtained both from the eastern Tibet and Arabian Sea, and their linkages to uplift of the Himalaya are vigorously discussed, even though both areas are far from the Himalayan range. However, the continuous record of monsoon climate in the Himalaya, which is in the strong SW Indian monsoon, has not been clarified yet.

With this background, we focused on the sediments of the Kathmandu Valley, which lies within the heart of the Central Himalaya and falls under the heavy monsoon climate zone. We collected sediments from drillings carried out for the investigation of ground water in the Kathmandu Valley, and analysed the fossil pollen in order to examine the potential of the basin-fill sediments of the Kathmandu Valley with regard to the records of climate change. As the results, we have succeeded to obtain a fairly continuous climatic record during the last 2.5 million years (Fujii and Sakai 2001, 2002). If we could carry out the academic drilling and get continuous cores, we would be able to obtain continuous and precise climatic records and provide linkage to the uplift of the Himalaya. In addition, the drill-core will provide valuable information about the engineering properties of subsurface sediments beneath the capital of Nepal, which is essential for mitigation of earthquake disaster.

In this paper, I briefly review the topography, climate, vegetation and geologic structure of the Kathmandu Valley and discuss the advantage and potential of the valley as an archive of the past monsoon climate record.

TOPOGRAPHY

The Kathmandu Basin is an intermontane basin located in the Central Himalaya and surrounded by mountains of 2,500 to 3,000 m above sea level. The basin is in the Midland of the Lesser Himalaya, and bounded by the Mahabharat Lekh to the south and Shivapuri Lekh to the north (Fig. 1 and 2). Deep valleys of the Likhu Khola and Shindu Khola (600 to 1,300 m above sea level) separate the Shivapuri Lekh from the Great Himalaya. In the eastern and western ends, the hills are lower than the sourrounding areas with an altitude of only about 1,500 m. An average elevation of the valley floor is about 1,340 m and the lowest elevation is 1,220 m at the southern end of the valley.

The Kathmandu Valley has a diameter of about 30 km in E-W and 25 km in N-S directions, and covers an area of about 650 km^2. Only one river, called the Bagmati River, cuts the Mahabharat Lekh in the south and drains the river water to the Gangetic Plain. The catchment area of the river is limited to the inside slope of the Kathmandu Valley (Fig. 1). It means that the basin-fill sediments are supplied only from the mountains sourrounding the valley.

In the southern piedmont of the Shivapuri Lekh, remarkable alluvial fans are formed. Several terraces of alluvial fan are distributed on the northern slope of the Mahabharat Lekh (Fig. 2 and 3): the geomorphic surface of Pyangaon (1,500~1,450 m), Chapagaon (1,450~1,400 m), and Baregaon (1,400~1,370 m) (Yoshida and Igarashi 1984). Two distinct lacustrine terraces are extensively distributed in the central part of the valley and its northern hill area (Fig. 1 and 3): Gokarna surface (1,386~1,340 m) and Thimi surface (1,340~1,320 m). The Kathmandu and Patan cities essentially spread over the Patan geomorphic surface with an altitude around 1,310 m. The Patan geomorphic surface is considered to have been formed in the last glacial stage (Yoshida and Igarashi 1984).

CLIMATE AND VEGETATION

Nepal is located at the boundary between wet southeast Asia in strong influence of monsoon and the dry southwest Asia under the influence of the prevailing westerlies. The vegetation is characterized by mixed facies of Japan-Shino elements and Mediterranean elements, and the

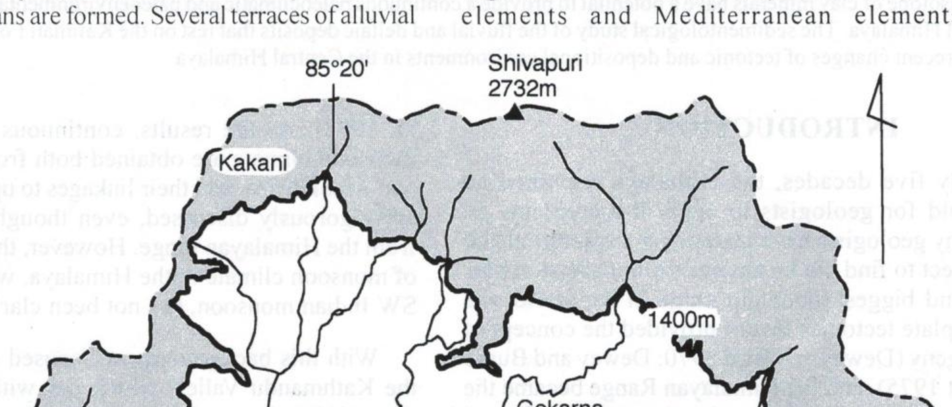

Fig. 1: Physiographic map of the Kathmandu Valley sourrounded by mountains ranging in altitude from 2,400 to 2,800 m. The separation of the valley floor from the valley-side slope (shaded) is shown by a dark line following the 1,400 m contour. A solid circle shows the drilling site of JW-3 at Sundarighat near Balkhu.

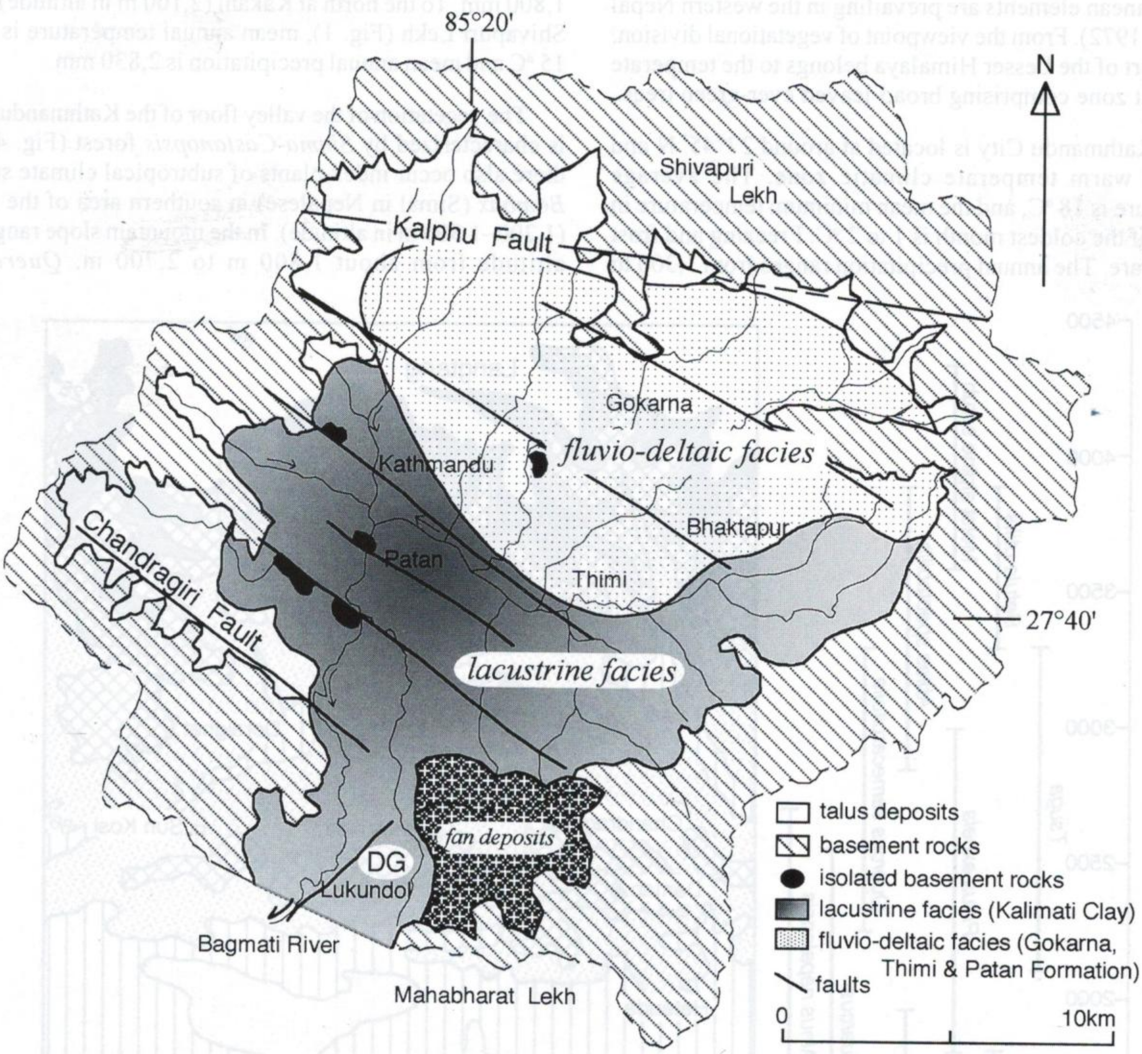

Fig. 2: Simplified facies distribution map of the Kathmandu Basin sediments and basement rocks. DG: Danuwargaun Fault (modified from Fujii and Sakai 2002).

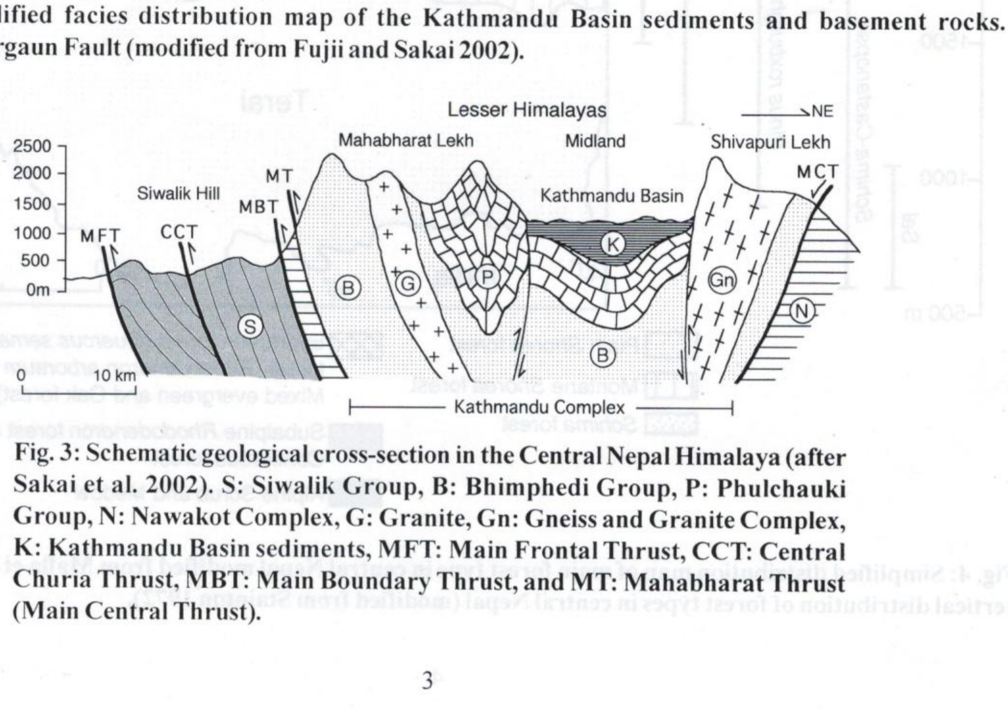

Fig. 3: Schematic geological cross-section in the Central Nepal Himalaya (after Sakai et al. 2002). S: Siwalik Group, B: Bhimphedi Group, P: Phulchauki Group, N: Nawakot Complex, G: Granite, Gn: Gneiss and Granite Complex, K: Kathmandu Basin sediments, MFT: Main Frontal Thrust, CCT: Central Churia Thrust, MBT: Main Boundary Thrust, and MT: Mahabharat Thrust (Main Central Thrust).

Mediterranean elements are prevailing in the western Nepal (Stainton 1972). From the viewpoint of vegetational division, a large part of the Lesser Himalaya belongs to the temperate tree forest zone comprising broad-leaved ever-green trees.

The Kathmandu City is located at around 27° 45' N and lies in a warm temperate climatic zone. The average temperature is 18 °C, and the mean minimum temperature in January of the coldest month is 1 to 2 °C. Freezing and frost are very rare. The annual precipitation ranges from 1,300 to 1,800 mm. To the north at Kakani (2,100 m in altitude) in the Shivapuri Lekh (Fig. 1), mean annual temperature is about 15 °C and mean annual precipitation is 2,830 mm.

The vegetation of the valley floor of the Kathmandu Basin is characterized by *Shima-Castanopsis* forest (Fig. 4), but there also occur index plants of subtropical climate such as *Bombax* (Simal in Nepalese) in southern area of the valley (1,200~1,300 m in altitude). In the mountain slope ranging in altitude from about 1,800 m to 2,700 m, *Quercus* is

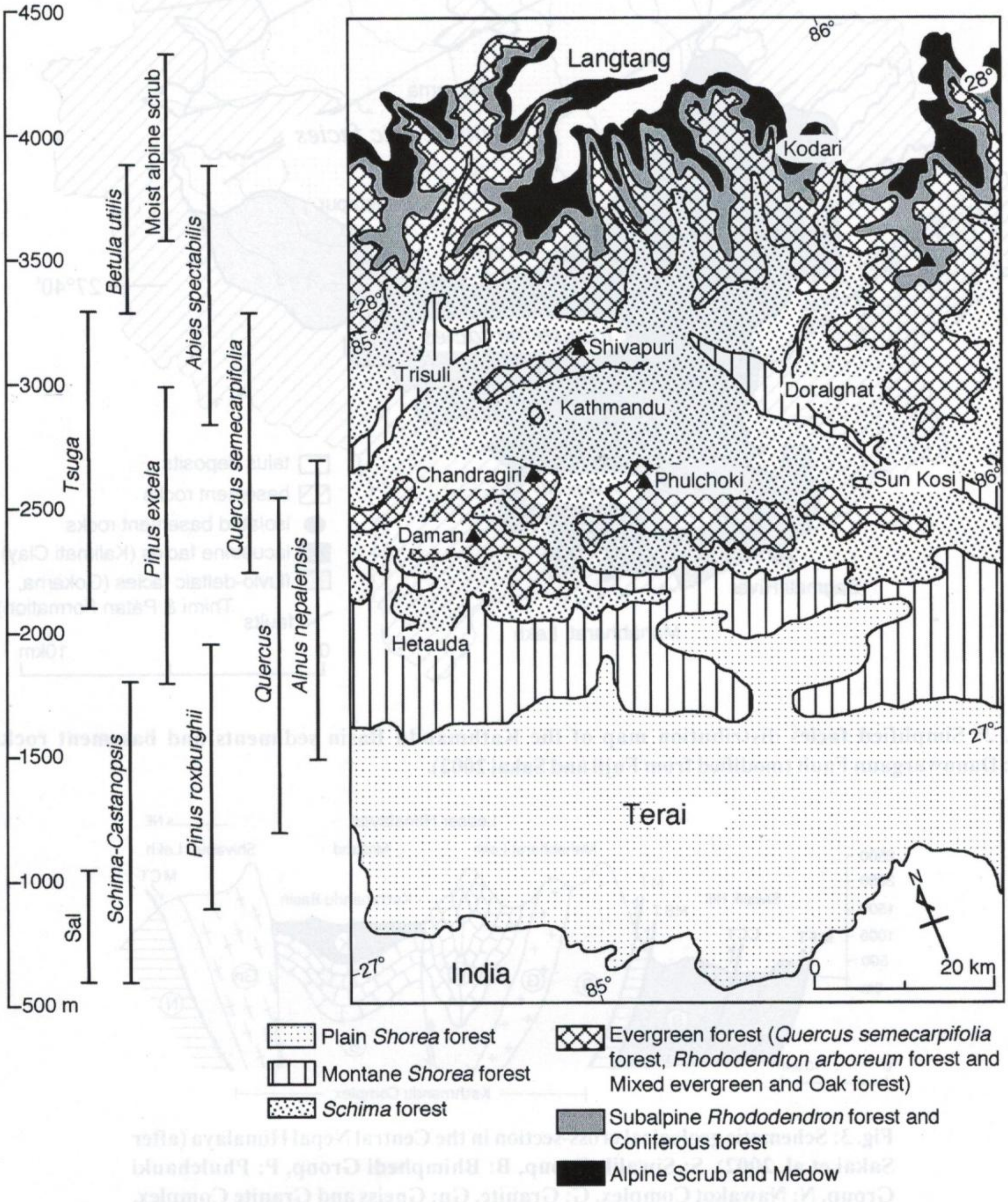

Fig. 4: Simplified distribution map of main forest type in central Nepal modified from Malla et al. (1976) and vertical distribution of forest types in central Nepal (modified from Stainton 1972).

predominant (Fig. 4; Stainton 1972; Malla et al. 1976). Around the summit area, coniferous trees, such as *Abies*, *Tsuga* and *Picea* are rarely distributed. In Nepal, two types of pine tree occur: *Pinus roxburghii* grows in relatively low altitude area from 900 to 2,100 m and *Pinus wallichiana* in high altitude area from 1,800 to 3,200 m (Stainton 1972).

GEOLOGY AND STRUCTURE

Geologically, the Kathmandu Basin lies on the Kathmandu Nappe which consists of metamorphic nappe and the overlying fossiliferous Tethyan sediments, both belonging to the Kathmandu Complex (Fig. 5; Stöcklin 1980; Stöcklin and Bhattarai 1981). The Kathmandu Nappe is composed of the Shivapuri gneiss and granite injection complex and schistose rocks and marbles of the Bhimphedi Group. The early Paleozoic Tethyan rocks, named as the Phulchauki Group, overlie the Bhimphedi Group. Total thickness of both groups attains 13 km. The northern slope of the Kathmandu Valley is mainly composed of gneiss, schist and granite, but the other slopes and the central part of the valley consist of weakly metamorphosed Phulchauki Group. The Bhimphedi Group and Paleozoic granite bodies are exposed to the south, outside of the watershed of the Kathmandu Valley. Therefore, the source rocks of the basin-fill sediments are limited to the Phulchauki Group and the Shivapuri injection complex (Fig. 5).

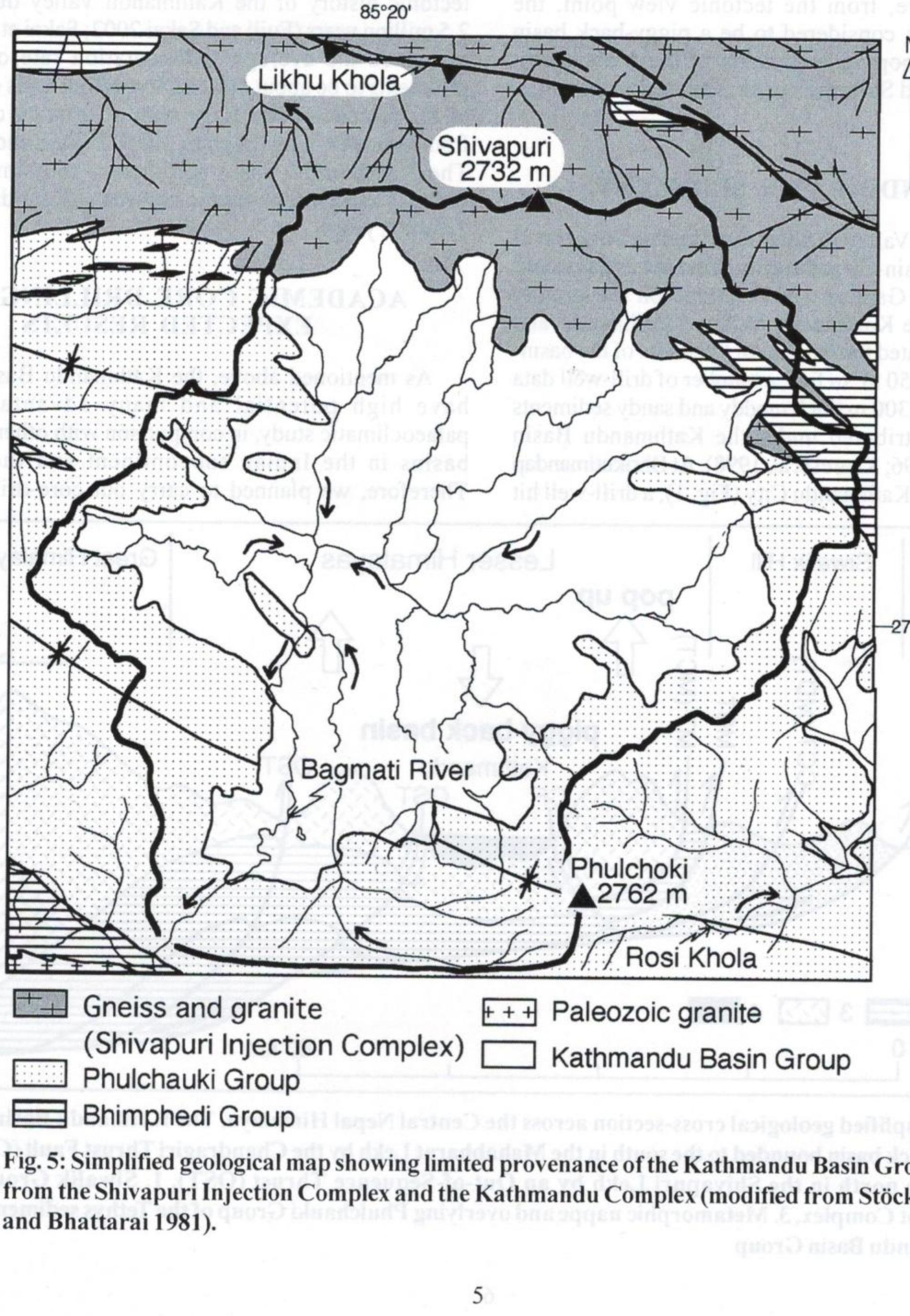

Fig. 5: Simplified geological map showing limited provenance of the Kathmandu Basin Group from the Shivapuri Injection Complex and the Kathmandu Complex (modified from Stöcklin and Bhattarai 1981).

The Kathmandu Complex occupies the core of the synclinorium, the axes of which trends WNW-ESE directions. The main fold axis lies on a line connecting peaks of Phulchauki (2,765 m) and Chandragiri (2,550 m). Many longitudinal faults run parallel to the fold axes, and the northern and southern margins of the basin are bounded by the Kalphu-Dhanr Khola Fault and Chandragiri Fault, respectively (Fig. 2). Both are active faults cutting the late Pleistocene sediments. The Chandragiri Fault is a thrust along which the rocks of the Mahabharat Lekh override the Quaternary sediments of the Kathmandu Basin (Nakata 1984; Saijo et al. 1995). The Shivapuri Lekh is on the ramp formed by fault-bend folding in the hanging wall of the out-of-sequence thrust (Fig. 6; Arita and Ganzawa 1997; Pandey et al. 1999). Therefore, from the tectonic view point, the Kathmandu Basin is considered to be a piggy-back basin lying between the pop-up mountains of the Mahabharat Lekh to the south and Shivapuri Lekh, situated on the ramp, to the north (Fig. 6).

KATHMANDU BASIN SEDIMENTS

The Kathmandu Valley is filled with the late Pliocene to Pleistocene thick basin-fill sediments (Yoshida and Igarashi 1984; Yoshida and Gautam 1988). Based on the gravity measurements in the Kathmandu Valley, Moribayashi and Maruo (1980) estimated the maximum thickness of the basin-fill sediments to be 650 m. In fact, a number of drill-well data prove that more than 300 m thick muddy and sandy sediments are extensively distributed under the Kathmandu Basin (Fig. 3; Katel et al. 1996; Kharel et al. 1998). At Bhrikutimandap in the central part of Kathmandu City (Fig. 1), a drill-well hit the basement rocks at a depth of about 550 m. The drilling data at Harisiddhi, in the southern part of the valley, show that the sediments are more than 457 m thick (Fig. 1; Katel et al. 1996). Fence diagrams of subsurface structure of the Kathmandu Basin compiled by Katel et al. (1996) indicate extensive distribution of black clayey sediments of lacustrine origin (Fig. 7). The clay exposed on the present surface, locally called the Kalimatil Clay, is rich in organic matter. Occurrence of natural gas in the valley suggests that the clayey sediments beneath the surface also contain abundant organic matter (Natori et al. 1980a, b). Sedimentological and palynological studies of a series of slimes taken from a drill-well of 284 m at Sundarighat near Balkhu (Fig. 1) demonstrate that the organic clay has well preserved palaeoclimatic and tectonic history of the Kathmandu Valley during the last 2.5 million years (Fujii and Sakai 2002; Sakai et al. 2001). We estimated the average sedimentation rate of the clayey sediments to be about 104 mm/kyr on the basis of correlation of the palaeoclimatic curve with a variation curve of $\delta^{18}O$ from Ocean Drilling Program, site 722 (Fujii and Sakai 2002). The Kathmandu Basin sediments, thus must preserve tectonic and palaeoclimatic records at least during the last 3 million years.

ACADEMIC CORE DRILLING AND EXPECTED RESULTS

As mentioned above, the Kathmandu Basin sediments have high potential and many advantages for the palaeoclimatic study, in comparison with other sedimentary basins in the Indian subcontinent and the Himalaya. Therefore, we planned to carry out core-drilling and the

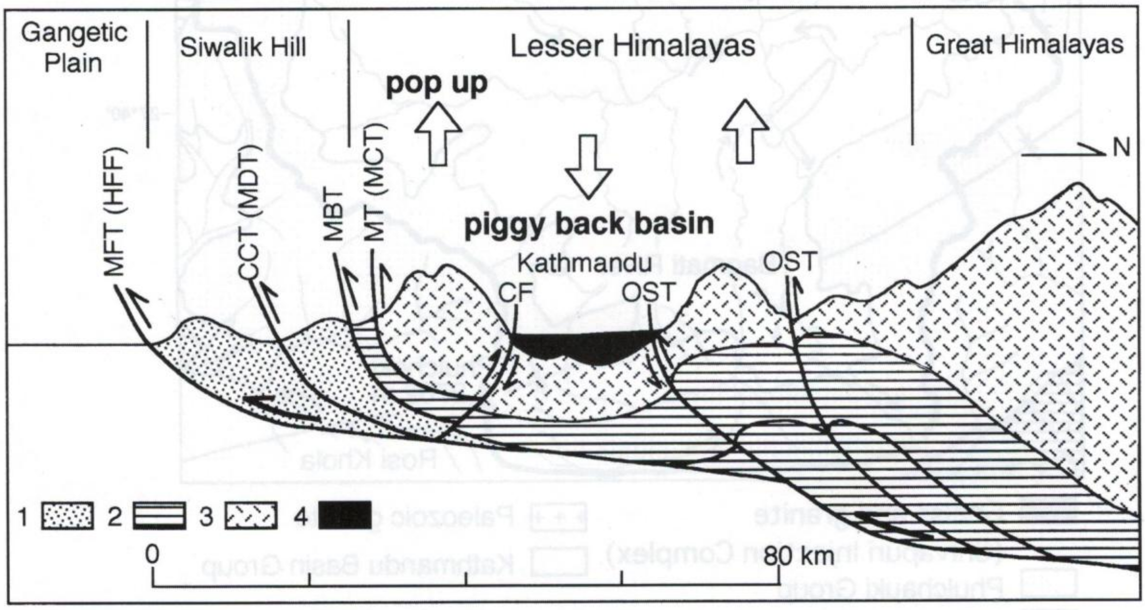

Fig. 6: Simplified geological cross-section across the Central Nepal Himalaya. The Katmandu Basin is a piggy-back basin bounded to the south in the Mahabharat Lekh by the Chandragiri Thrust Fault (CF) and to the north in the Shivapuri Lekh by an Out-of-Sequence Thrust (OST). 1. Siwalik Group, 2. Nawakot Complex, 3. Metamorphic nappe and overlying Phulchauki Group of the Tethys sediments, 4. Kathmandu Basin Group

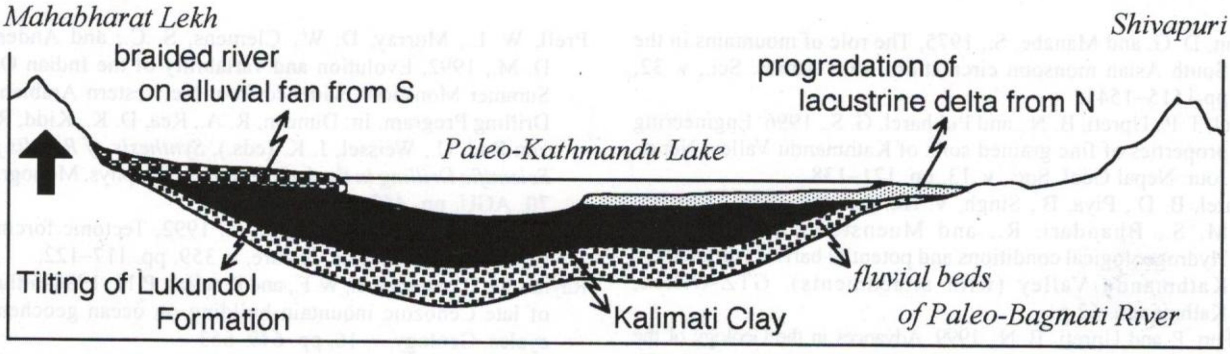

Fig. 7: Schematic geological cross-section showing the stratigraphic framework and depositional environments of the Kathmandu Basin sediments during the late Pleistocene (modified from Sakai et al. 2002).

following laboratory works: sedimentological study, palynological study, palaeomagnetic study, chemical analysis, isotopic study, ^{14}C dating, clay mineralogical study, micro-palaeontological study, measurement of physical properties and so on. After these laboratory works on drill-cores and additional surface geological survey of the Kathmandu Basin sediments, we expect to obtain the following results.

1. We can establish continuous magnetostratigraphy and lithostratigraphy of the Kathmandu Basin sediments, deposited during the last 3 million years.
2. Palynological study provides continuous pollen diagram which shows changes of vegetation and climate during the last 2.5 to 3 million years.
3. Organic and inorganic chemical analyses of the sediments will bear valuable data on environmental changes of the lake and vegetation on land and under the water.
4. Mineralogical study on clay reveals the long-term and annual environmental changes such as climatic changes and expansion or shrink of lake-water.
5. Systematic ^{14}C dating of organic material in the upper part of cores gives their ages and sedimentation rate during the last 40 kyr.
6. Stable isotopic study of organic matter in clayey sediments provides valuable information about changes of vegetation during the last 3 million years.
7. We will be able to reveal when and why the Palaeo-Kathmandu Lake was born and when and why lake-water discharged.
8. Analysis of geologic data of cores in several sites will provide important information on the subsurface geologic structure of the most populated area in Kathmandu City.
9. Both geologic and geophysical data of cores provide valuable fundamental information for mitigation of natural disaster, urban development, underground development and groundwater management.
10. Synthesizing of the whole data listed above will provide the basis for deciphering the inter-relationship between tectonics of the Himalayan uplift and its induced environmental changes.

Recently, we have carried out academic drillings at three sites to bring out the continuous cores in the Kathmandu Basin sediments, under the project entitled "Paleo-Kathmandu Lake Project", in collaboration with the Department of Geology, Tribhuvan University, Nepal. We have already started to analyse the cores. After the completion of this project, we expect to obtain precise palaeoclimatic records during the last 2.5 million years and throw light on the linkage between the climatic changes and uplift of the Central Himalaya.

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