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HISTORY OF VEGETATION AND CLIMATE IN THE KATHMANDU VALLEY

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Palynological studies were undertaken on the samples from fluvio-lacustrine Lukundol, Gokarna, Thimi and Patan Formations which cover from Early Pliocene to the Last Glacial Age. It is suggested that climate had been cooler in the past than the present in the Kathmandu Valley. Seven climatic oscillations had occurred during the period of older stage deposits. The steppe had expanded with the growth of *Abies* and *Picea* in the hill in Pollen Zone LK-9 after the Olduvai Subchron. The climate had started to deteriorate from Pollen Zone LK-7 and recovered after Pollen Zone LK-9. *Cedrus deodara* had been distributed intermittently in or near the Kathmandu Valley since Early Pliocene to the Last Glacial Age.

In the period of the younger stage deposits, the climate had been deteriorated during Pollen Zone GK-3. The coldest and drier climate had prevailed and the steppe had expanded during the period of Patan Formation. The time of lower Gokarna and Thimi Formations could be interstadial.

Key Words : Vegetation; Pollen; Kathmandu Valley; Glacial

INTRODUCTION

THE Kathmandu Valley is a big intermontane basin, 1,300–1,500m in elevation, covering an area of 340km^2 in the Lesser Himalayan Range of Central Nepal. The valley is filled by the thick sequence of lacustrine and fluvial deposits, ranging from Neogene to Quaternary. The palynological investigations in the Kathmandu valley were undertaken by Yoshida and Igarashi[1] and Vishnu-Mittre and Sharma.[2] However, the details yet remain unexplored.

The authors undertook more detailed geological and magnetostratigraphic research and collected pollen samples based on the stratigraphy. We discussed vegetation and climatic changes in the valley during the period from Neogene to Early Quaternary and the Last Glacial Age.

Stratigraphy and Age of the Sediments

The basin-filling deposits were divided into three stratigraphic categories : older stage deposits (Lukundol Formation), middle stage deposits (Pyanggaon, Chapagaon and Boregaon Terrace Deposits) and younger stage deposits (Gokarna, Thimi and Patan Formations) in ascending order[1]. The older and middle stage deposits crop out only in the southern area of the valley. On the other hand, the younger stage deposits are mainly distributed in the northern area (Fig.1).

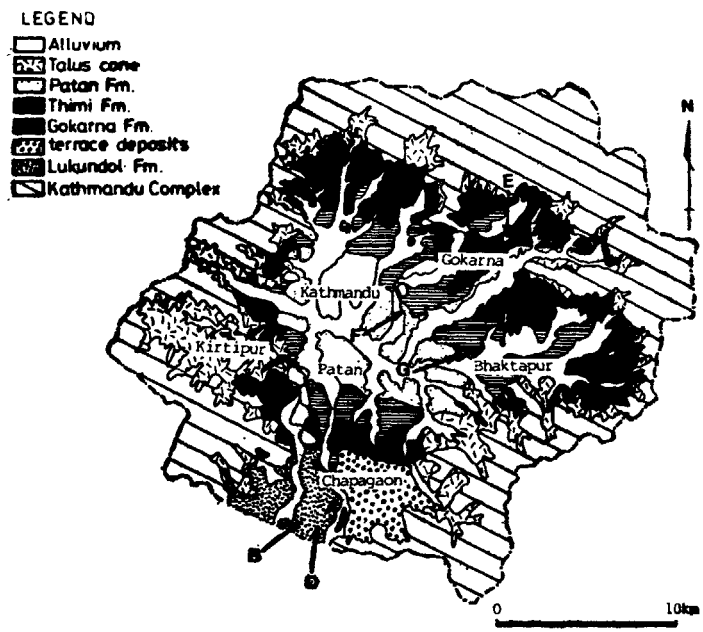

FIG 1 Geologic sketch map and sampling localities in the Kathmandu Valley (modified after Yoshida and Gautam, 1987).

The Lukundol Formation can be subdivided into seven members : Member I to VII in ascending order, according to their lithologic characters. Each member presents a single upward-fining sedimentary sequence. A large number of vertebrate fossils were recovered from the lower part of the formation (Member II to IV). This assemblage is referred to as an equivalent of Pinjore Fauna.[3] The deposition of the Lukundol Formation is estimated to have occurred from Gauss Chron to early (?) Brunhes Chron on the basis of the palaeomagnetic chronology. Therefore, the formation corresponds to the age of Late Pliocene to early Middle Pleistocene.[4]

The middle stage deposits may be correlated with Middle Pleistocene, though the definite conclusion is awaited.

The fluvial and lacustrine deposits of the younger stage were dated to the Last Glacial Age by the radiocarbon method. The Gokarna Formation was

dated to about 25,000 to 30,000yr. B.P. and the Patan Formation to 11,000 to 19,000yr B.P.[1,5-7] A radiocarbon age (45,300 $^{+6,000}_{-3,400}$ yr. B.P. KSU—1120) of the Thimi Formation is added in this paper, but it might be too old probably due to the wooden sample having derived from the older formation. The stratigraphic framework of these sediments is shown in Fig. 4.

Material and Analytical Method

Seventy samples obtained from the fluvio-lacustrine sediments of the Lukundol, Gokarna, Thimi and Patan Formations were analyzed. Twelve samples out of these were found barren.

All samples were prepared with HF, acetolysis solution and separated with $ZnCl_2$ heavy liquid treatment.

At least 200 arboreal pollen (AP) grains were identified in each sample except for several samples. Non-arboreal pollen (NAP) grains and fern spores were counted at the same time. Percentages of AP were calculated based on the total AP number, while those of NAP and fern spores were calculated in terms of sum total of pollen and spores. Undeterminable taxa were included in NAP count.

Results and Discussion

Each formation was divided into 2–14 pollen zones according to the characteristics of pollen assemblage. The pollen assemblage of each zone was compared with the present flora and vegetation in Central Midland of Nepal[8,9] and the climate was inferred from the characteristics of pollen assemblage and the ecology of some key genera included in the pollen assemblage on the asssumption that Pliocene and Pleistocene plants had climatic requirements similar to those of the modern ones. *Pinus* occurring from sub-tropical to cool temperate and *Quercus* occurring from warm temperate to timber line were subordinate key genera to infer the past climate. *Abies* was one of the key genera to show cold climate and *Picea* was a key genus to show cold and drier climate. Entomophilous *Castanopsis* was of considerable importance to show warm temperate climate when it occurred with the other temperate plant groups, even though the presence was in trace. It needs to be noted, for a correct reconstruction of the past vegetation, that entomophilous plants such as *Castanopsis* and *Schima* were not well represented in pollen assemblage even under their forests in Kathmandu.[2] Cool temperate broad-leaved trees and shrubs such as *Juglans*, *Corylus* and *Carpinus* growing in more or less restricted habitats were also subordinate key genera. The coexistence of subordinate key genera and richness of flora are important as the characteristics of the pollen assemblage to reconstruct the past vegetation and climate. Aquatics indicated the existence of marshes and/or open water. The high frequency of fern spores inferred humid climate, though fern growth might have been affected by local conditions. The presence of *Cedrus* and *Larix* which prefer drier condi-

tions and are not found in Kathmandu valley today except cultivated trees was as an important evidence of drier climate in the region.

Lukundol Formation

Fourteen pollen zones, LK-1 to LK-14 in ascending order, and four barren zones were discriminated (Fig. 2, Table I).

LK-1 Zone (*Pinus-Quercus*-Gramineae-Pteridophyte *Assemblage*) : Pine forests occurred with oak woods. *Castanopsis* might have made considerable contribution

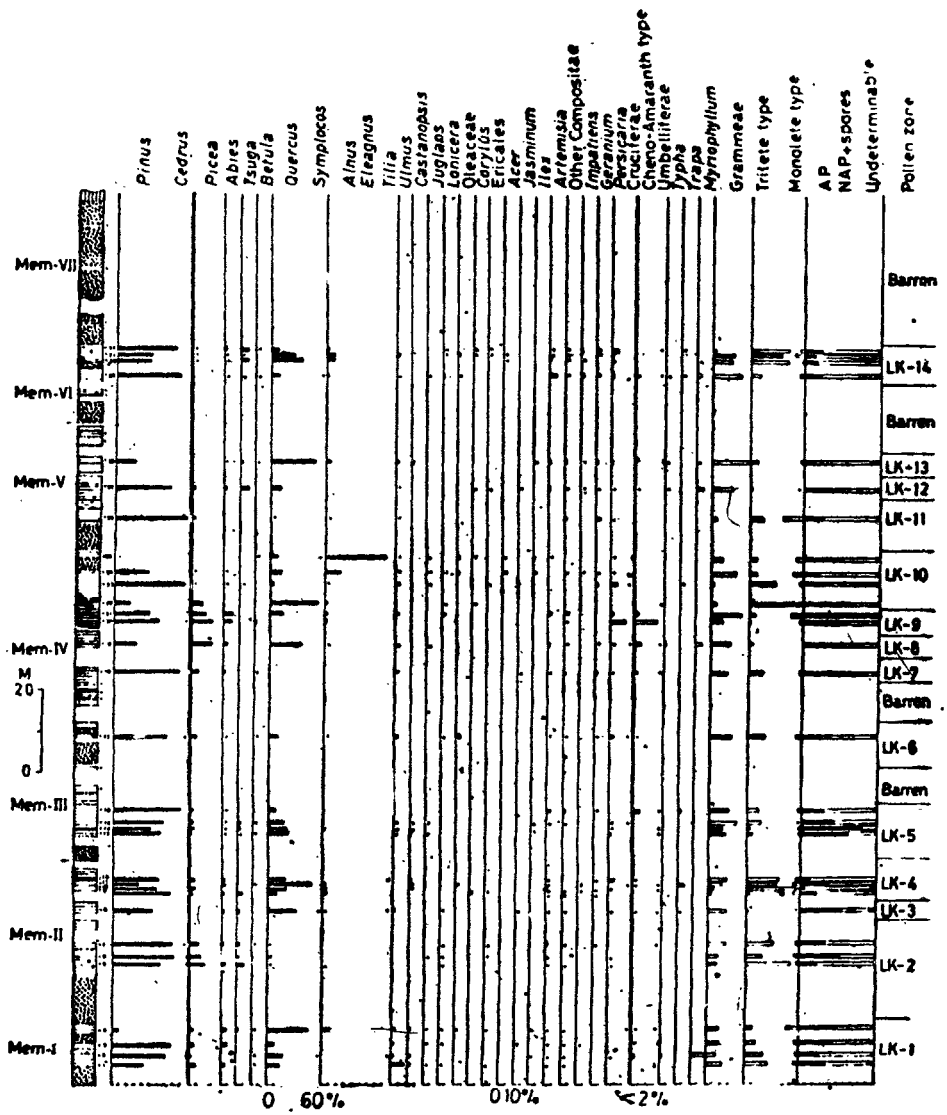

FIG 2 Pollen diagram from Lukundol Formation.

TABLE I

Supplementary list of pollen fossils from Lukundol formation

Sample number	*Celtis*	*Fraxinus*	Araliaceae	*Rhus*	*Prunus*	*Salix*	Caryophillaceae	Verbenaceae	*Dicliptera*	*Justicia*	Euphorbiaceae	Ranunculaceae	*Thalictum*	Labiatae	Campanulaceae
32									0.5	0.5					
31							0.5				0.3				0.3
30							0.5		1.0						
29							0.4			0.4		1.6			
28						0.7	0.6		0.3	0.3		1.6	0.3		
27							0.9								
26									0.2						
25						0.4								0.9	
24			0.9	0.9	0.9		0.4		0.4	0.2					
23	0.7														
22							0.8								
21							1.4		0.3			1.1			
20													1.2		
19							0.8					0.4			
18							2.9								
17											0.2	1.5			
16							0.7	0.7	0.3						
15							0.4		0.4			0.4			
14			0.4				0.4	0.8				0.4			
13									0.3						
12	0.3						1.2		0.3			0.3			
11							0.2		0.2			0.2			
10							0.3		0.3	0.3					
9							1.1								
8			0.3				0.2					0.3	0.3	0.3	
7									0.6						
6															
5							0.2				0.2				
4		0.2					0.2		0.2						
3							1.0		0.2			0.4	1.0		
2	0.5										0 2		0.2		
1							1.8	0.5	0.5						

to the vegetation. Species diversity was high, containing cool and warm temperate plants. *Cedrus* was observed slightly in the middle of the zone.

LK-2 Zone (*Pinus-Picea*-Gramineae-Pteridophyte *Assemblage*): Apparent drop in species diversity indicating climatic deterioration was observed with predominancy of *Pinus*. *Picea* increased slightly and *Cedrus* was also detected.

LK-3 Zone (*Pinus-Quercus*-Gramineae *Assemblage*): *Quercus* recovered in importance. Ferns were poorly found.

TABLE I (*Contd. . .*)

Pachysandra	*Scabiosa*	*Epilobium*	*Rumex*	Legumin-osae	*Humulus*	*Utricularia*	*Menyanthes*	*Sparganium*	*Nymphoides*	*Nuphar*	Liliaceae	Cyperaceae	Tricolpate type	Tricolparate type	Triporate type
				0.1								4.4		2.8	0.3
		0.3												0.8	
												1.0	6.5	1.0	
												2.9		0.8	
				0.6								3.4		9.4	2.2
			0.6									0.3		1.8	
				0.2								0.2		0.4	0.2
0.4					9.7									4.5	1.5
0.4					2.2							0.2	0.4		
													1.7		
												0.4		1.2	
												2.5		0.7	3.9
												1.2			
							0.2	2.2	0.4			0.6		2.6	
												2.1		4.2	0.4
												0.4	0.3		5.5
						0.3								0.3	2.1
														0.8	
			0.3									1.8		1.2	0.9
					0.3										
														1.5	
													0.3		
														1.6	1.6
	0.3			0.3						0.6		1.9		7.2	0.3
	0.6											1.2		0.6	
		0.2										0.7		1.2	
				0.2							0.2	1.4		2.3	0.5
	0.2	0.2	0.4			0.2						2.0		5.9	0.4
						0.2						1.2		3.6	
												0.5		0.5	3.1

LK-4 Zone (*Pinus-Quercus*-Pteridophyte-Gramineae *Assemblage*: *Pinus* occurred with *Quercus* and grasses. *Castanopsis* was recorded.

LK-5 Zone (*Pinus-Quercus*-Gramineae-Pteridophyte *Assemblage*): The floral composition seemed to be similar to LK-4, though NAP grains decreased.

LK-6 Zone (*Pinus-Picea*-Gramineae-Pteridophyte *Assemblage*): *Pinus* was predominated in the forest. *Picea* started to increase upward.

LK-7 Zone (*Pinus-Picea*-Gramineae-Pteridophyte *Assemblage*): Vegetation

seemed to be simple with coniferous forests predominated by *Pinus* and grassland. *Abies* had a tendency to increase toward upper horizons. *Quercus* was not detected. Species diversity decreased.

LK-8 Zone (*Pinus-Picea-Quercus*-Gramineae *Assemblage*) : Oak woods expanded and ferns decreased.

LK-9 Zone (*Pinus-Picea-Abies-Quercus-Persicaria*-Cheno/Ams/Gramineae *Assemblage*) : Steppe with Cheno/Ams, *Persicaria* and compositae expanded and it might have been succeeded towards hills by coniferous forests with oak woods. *Abies* increased compared to the lower zone. *Cedrus* was also found. The vegetation was poor in floristic composition.

LK-10 Zone (*Pinus-Quercus-Alnus*-Gramineae-Pteridophyte *Assemblage*) : *Quercus* increased at the bottom of the zone. *Pinus* replaced *Quercus* and *Pediastrum* occurred in the middle and upper zones. *Alnus*, then, was predominated in AP probably due to local environmental changes such as formation of marshes at the site and *Pediastrum* was found plentifully. Vegetation of this zone was rather rich in species or plant groups being characterized by the decrease of *Abies* and *Picea*.

LK-11 Zone (*Pinus*-Pteridophyte *Assemblage*) : *Pinus* was dominant, though no clear evidence of remarkable climatic change was found. Probably local disturbances caused the simplification of the vegetation.

LK-12 Zone (*Pinus-Tsuga-Quercus*-Gramineae *Assemblage*) : Pine forests expanded with decrease of ferns. *Abies* and *Picea* increased slightly.

LK-13 Zone (Gramineae-*Pinus-Assemblage*) : Grassland expanded. *Castanopsis* occurred somewhere in the catchment area of the Kathmandu Valley, though the floristic diversity of the vegetation was not high.

LK-14 Zone (*Pinus-Tsuga-Quercus*-Pteridophyte-Gramineae *Assemblage*) : The vegetation was rich floristically with temperate species, though AP grains were relatively not much in number.

Gokarna Formation

Three pollen zones, GK-1 to GK-3 in ascending order, were discriminated (Fig. 3, Table II).

GK-1 Zone (*Pinus*-Pteridophyte *Assemblage*) : Pine forests predominated with poor existence of ferns. *Quercus* was very poorly present. *Cedrus* was distributed in the vicinity of the Kathmandu Valley to some extent.

GK-2 Zone (*Quercus*-Pteridophyte *Assemblage*) : Oak forests expanded with rather rich fern flora and *Pinus* declined drastically. Temperature species increased in number in comparison to the lower horizon (GK-1).

GK-3 Zone (*Pinus-Picea*-Pteridophyte *Assemblage*) : *Picea* and *Abies* increased and *Quercus* dwindled with increase of *Pinus*. Grassland expanded and species diversity decreased.

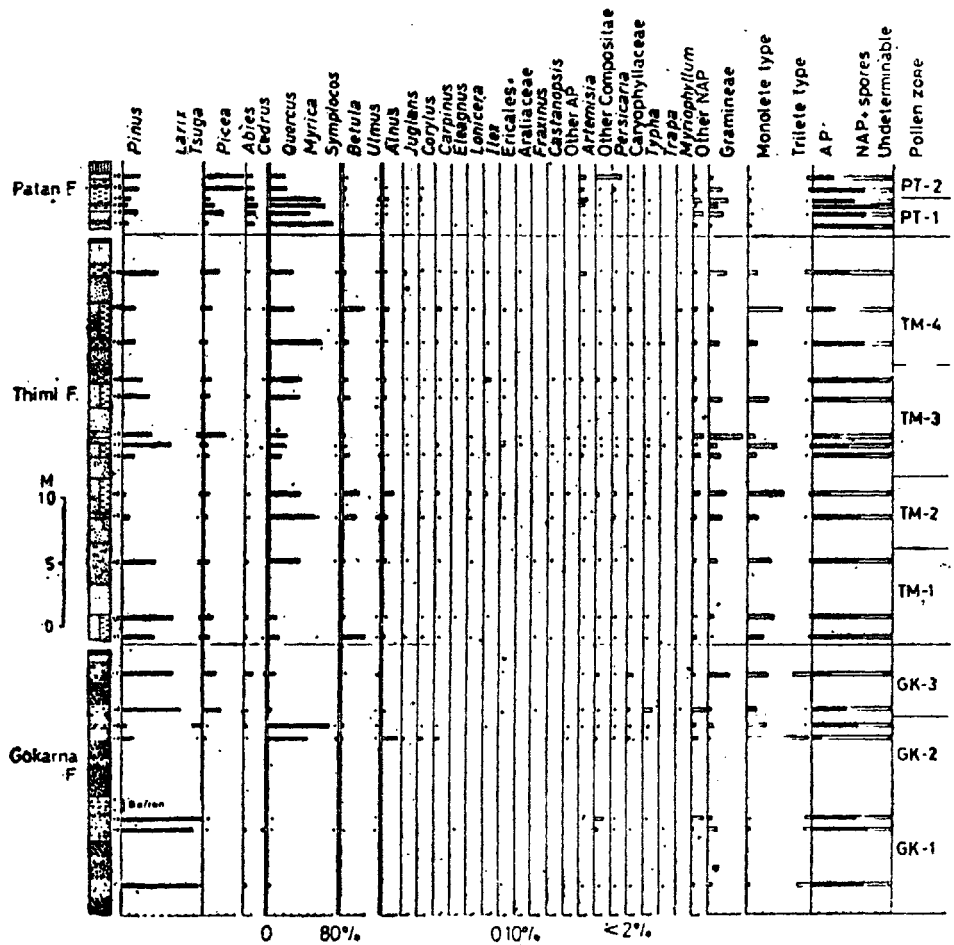

FIG 3 Pollen diagram from Gokarna, Thimi and Patan Formations.

Thimi Formation

Four pollen zones, TM-1 to TM-4 in ascending order, were discriminated. Pine and oak forests prevailed and warm temperate *Castanopsis* occurred upto TM-3 without significant fluctuation of *Picea* (Fig. 3, Table III).

TM-1 Zone (*Pinus-Quercus*-Pteridophyte *Assemblage*) : Pine forests prevailed with the occurrence of *Picea*, *Abies* and *Quercus*. Species diversity increased very much in comparison with the preceding age (Gokarna Formation).

TM-2 Zone (*Quercus*-Gramineae-Pteridophyte *Assemblage*) : *Quercus* was dominated in the pollen assemblage with remarkable decrease of *Pinus*.

TM-3 Zone (*Pinus-Quercus*-Gramineae-Pteridophyte *Assemblage*) : Floristic composition was richest in younger stage deposits, though the occurrence of

TABLE II

Supplementary list of pollen fossils from Gokarna Formation

Sample number	*Celtis*	*Acer*	Cheno-Amaranth type	*Geranium*	Umbelliferae	*Thalictrum*	Cruciferae	*Impatiens*	*Jasticia*	Leguminosae	Rosaceae	Valerianaceae	*Sparganium*	Cyperaceae	Tricolporate type	Tricolpate type	Triporate type	*Sphagnum*
7				1.6											1.8	4.8	0.3	
6					5.0	0.2							0.8	9.9	1.4	0.2		0.2
5		0.4	2.5		2.7	0.2	0.6	0.2	0.2	0.2	0.2			2.5	1.7	2.2		0.2
4	0.6		0.2					0.2	0.2			1.4		6.8	1.2	4.7		
3					0.9									12.8		1.5		
2			1.0	2.1	0.5	0.5									0.4	0.4		
1			0.4											2.0	0.5	2.5		

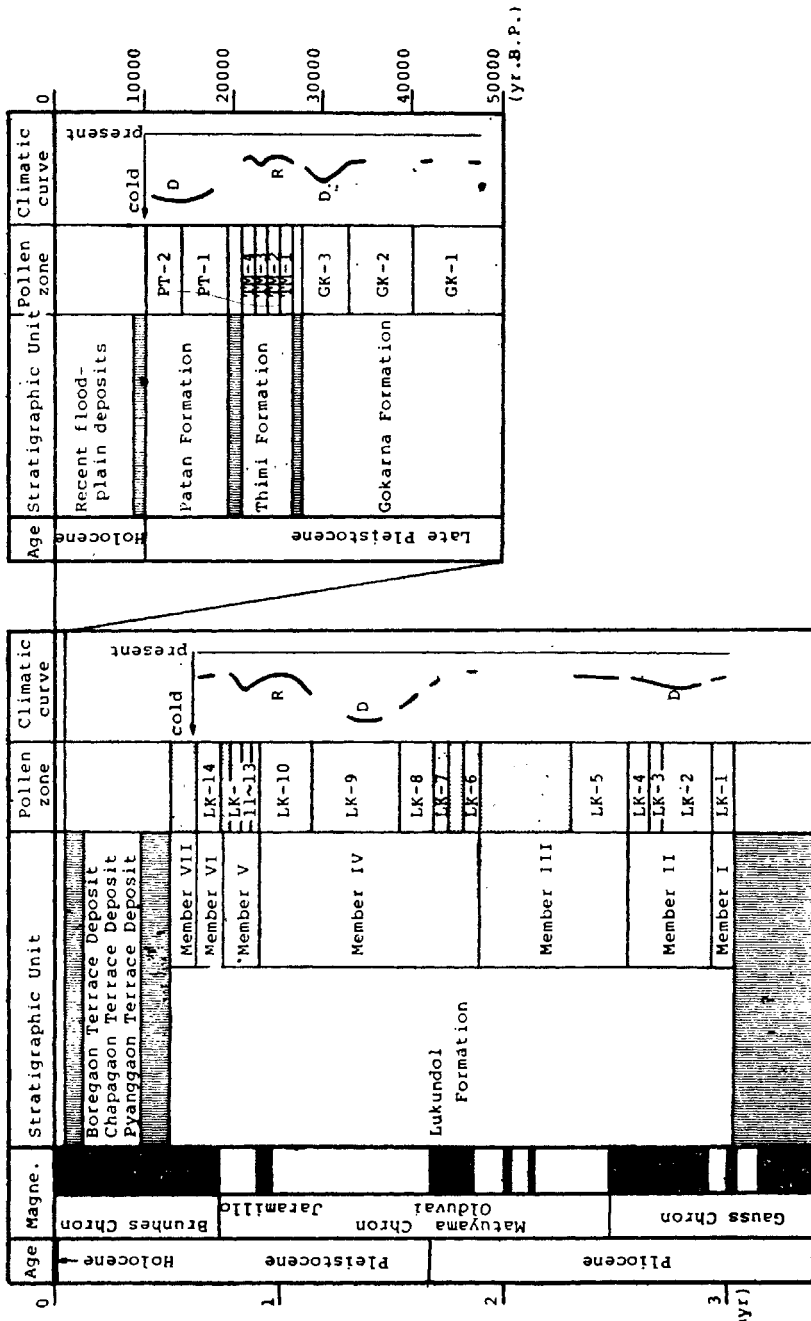

FIG 4 Stratigraphic framework and climatic changes. D: drier climate, R: rich flora.

TABLE III

Supplementary list of pollen fossils from Thimi Formation

Sample number	*Celtis*	*Rhus*	*Ligustrum*	*Prunus*	*Sorbus*	*Jasminum*	*Tilia*	Cheno-Amaranth type	*Geranium*	Umbelliferae	Ranunculaceae	*Thalictrum*	Cruciferae	Labiatae	*Impatiens*	*Justicia*
13								1.4			0.2	0.4				0.2
12								0.4	0.7		1.3		0.2	0.7		0.2
11										0.6			1.5	0.6		
10	0.5	1.0	1.0					0.4		0.8						1.2
9								0.2					0.4		0 4	
8			0.4	0.4				0.3		9.6						
7								0.6					0.2	0.4		
6	0.5		0.3		0.3	0.3		1.0					0.8	2.4	0.2	0.5
5			0.4			1.3	1.3		0.3	1.3			1.5	1.8		
4								0.5	0.3	0.3			0.5	0.5		1.1
3			0.5					0.3					0·3	0.3		0.3
2									0.2	0.2						
1			0.5					0.3	0.3					1.2		0.3

Picea fluctuated. *Picea* and *Abies* increased in the middle part with expansion of grassland. *Castanopsis* was detected from TM-1 to TM-3.

TM-4 Zone (*Quercus-Pinus-Picea Assemblage*) : *Picea* gradually increased upward with dwindling of *Quercus*. Species composition of the vegetation was poorer than TM-3.

Patan Formation

Two pollen zones, PT-1 and PT-2 in ascending order, were recognized though the depositonal environment seemed to be lacustrine and rather stable. Species richness decreased significantly in this formation. PT-1 was dominated by *Quercus* but in the succeeding *Picea* was prominent. Ferns were trifling in importance (Fig. 3, Table IV).

PT-1 Zone (*Quercus-Picea-Abies*-Gramineae *Assemblage*) : Oak forests expanded with an increase of *Abies*. Pine forests relatively shrank.

PT-2 Zone (*Picea-Abies-Quercus* Compositae *Assemblage*) : This zone was characterized by dwindling of *Quercus* concurrent with the expansion of *Picea* forests. *Larix* grew in the vicinity of the Kathmandu Valley. *Artemisia* and the other Compositae (Cichorioideae) showed more than 30 per cent.

The Lukundol Formation seems to be characterized by higher frequency of *Abies* and *Picea*, and lower species diversity, and by the presence of *Castanopsis*, a higher value of *Quercus* and a greater species diversity. Seven climatic oscillations were inferred and the schematic reconstruction of the climate is shown in

TABLE III (*Contd.*)

Urtica	*Galium*	*Dicliptera*	Leguminosae	*Patrinia*	*Plantago*	Rosaceae	*Menyanthes*	*Lysichiton*	*Namphoides*	*Nuphar*	*Sparganium*	Cyperaceae	Tricolporate type	Tricolpate type	Triporate type
												1.9	1.7		0.2
0.4	1.5										0.2	0.4	0.7	3.1	0.7
	1.2	0.3										0.3	0.6	0.9	
	0.8	0.4	0.4										1.2		
		0.2		0.2								2.2	0.9	0.9	0.2
	0.5	0.2		0.2	0.2	0.2	0.3					1.2	2.0		
								0.3	0.3	0.2	0.2	0.2	3.7	1.3	0.2
		0.5										1.9	1.0	0.4	
											0.3	1.3	2.9		1.5
												1.1	1.4		
	1.2											0.3	0.5		0.3
				0.4								0.2	0.4	0.2	
	0.6	1.4		0.9							1.2	0.3	0.3	2.3	0.3

Fig. 4 compared with the present subtropical climate of Kathmandu. The climate had been colder and drier than the present through the time of Lukundol Formation. The horizon which showed climatic deterioration in Member IV (Pollen Zone LK-9) was deposited after the Olduvai Subchron. The precipitation could be less by more than 500mm than the present precipitation in Kathmandu when *Cedrus* occurred in the vicinity of Kathmandu, if we apply the present conditions conducive for the growth of *Cedrus deodara*. The lake area expanded at the time of the upper part of Member IV.

There is no positive evidence to show climatic deterioration in the period of lower Gokarna Formation. The climate was slightly deteriorated during the upper part of the Gokarna Formation, though good samples could only be obtained from limited horizons because of the gravelly nature of deposits. The species composition of vegetation was rich and the climate ameliorated during the period of TM-2 to TM-3 characterized by the presence of *Castanopsis*.

The coldest climate prevailed during the Patan Formation. It was drier than the present as suggested by the growth of *Larix* in the vicinity of the valley (Fig. 4).

Palynological studies in the Kathmandu Valley have just started. Precise dating and extensive and elaborated stratigraphical work are required with pollen analysis.

TABLE IV

Supplementary list of pollen fossils from Patan Formation

Sample number	*Styrax*	*Salix*	Cheno-Amaranth type	*Rumex*	*Geranium*	Umbelliferae	Ranunculaceae	*Thalictrum*	Cruciferae	*Hydrocharis*	Labiatae	*Impatiens*	*Daphne*	*Sparganium*	Cyperaceae	Tricolporate type	Tricolpate type	Triporate type
6		1.8	4.4	0.4	1.8	1.3	0.4									5.8	3.1	
5	0.6		0.4				2.2	0.4	0.4						0.4	3.3		
4			0.6			0.3	0.8			0.3				0.5	0.6	1.3		0.6
3	0.7		3.7			0.5			0.5									
2			7.5		0.4		2.1	0.4	0.4		0.8			0.4		2.5		
1						0.5	0.5		1.0			0.5	0.5		0.5	0.5	2.5	

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