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Palynological assemblages from the Late Pleistocene sediments of the Patan Formation in Kathmandu Valley and their climatic implications

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ABSTRACT

Palynological investigation of ten samples obtained from a drill core belonging to the Late Pleistocene deposits of the Patan Formation in the Kathmandu Valley revealed 40 plant species belonging to 22 families. The gymnosperms are represented by *Abies, Picea, Pinus* spp. (*P. roxburghii* and *P. wallichiana*) and *Tsuga* sp. The angiosperm tree and shrubs are represented by genera *Quercus* (*Q. semecarpifolia, Q. lanata, Q. leucotricophora* and *Q. lamellosa* and *Q. glauca*), *Castanopsis, Alnus, Betula, Carpinus, Juglans, Myrica, Ulmus, Ilex, Strobilanthes, Elaeagnus* and families Meliaceae, Oleaceae, Ericaceae, Poaceae, Compositae, Caryophyllaceae, Chenopodiaceae, Apiaceae, and Dipsacaceae. Similarly the wetland and aquatic plants are represented by *Polygonun, Myriophyllum* and *Trapa*. The presence of significant number of pteridophytes indicates humid and damp environment at the periphery of the lake and surrounding forest floor. The pollen assemblage suggests that the Patan Formation was deposited under humid subtropical climate except at the middle part which indicates of warm temperate climatic condition. The result obtained from the recent surface samples analysis and its comparison with fossil assemblages show that modern pollen spectra are not different with the fossil assemblages. This justifies that the fossil palynomorphs are local and it denies the influence of exotic pollen.

INTRODUCTION

Kathmandu Valley hosts more than 600 m thick deposits of Plio-Pleistocene lacustrine sediments (Moribayasi and Maruo 1980) providing a unique opportunity to study the climate change based on plant microfossils. Many authors have investigated the soft sediments of this valley and tried to understand the climate change on the basis of palynological assemblages (Franz, and Kral 1975; Kral and Havinga 1979; Yoshida and Igarashi 1984; Igarashi et al. 1988; Vishnu-Mittre and Sharma 1984; Nakagawa et al. 1996; Fujii and Sakai 2001, 2002; Paudayal and Ferguson 2004; Paudayal 2005, 2006; Bhandari and Paudayal 2007). Most of the investigations have been carried out with the samples taken from the surface exposure, cliffs or sand mining pits. Investigation based on drilled core samples was also made by some authors (Fujii and Sakai 2001, 2002). Due to complex sedimentary environment and lack of enough chronological information, understanding the climatic history is becoming difficult for the scientists working in this area. This study is based on the drill core slime obtained from the central part of the basin belonging to the Patan Formation.

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The Kathmandu Valley sediments have been divided into eight different stratigraphic units (Yoshida and Igarashi 1984; Yoshida and Gautam 1988). The oldest is the Lukundol Formation, mostly lacustrine in nature, ranging in age from Upper Pliocene to Lower Pleistocene, followed by intermediate gravel deposits such as Chapagaon, Boregaon and Pyanggaon deposits developed in the course of tilting of the lake due to activation of Main Boundary Thrust (MBT) towards the south margin. Tilting of this lake towards northern direction and further activation of MBT created a new fluvially dominated sedimentary environment. Occasional depositional pause created lacustrine environment periodically within the fluvial cycles. The younger sediments thus deposited in the northern part are the Gokarna Formation, Thimi Formation, Patan Formations and Recent terrace deposits ranging in age

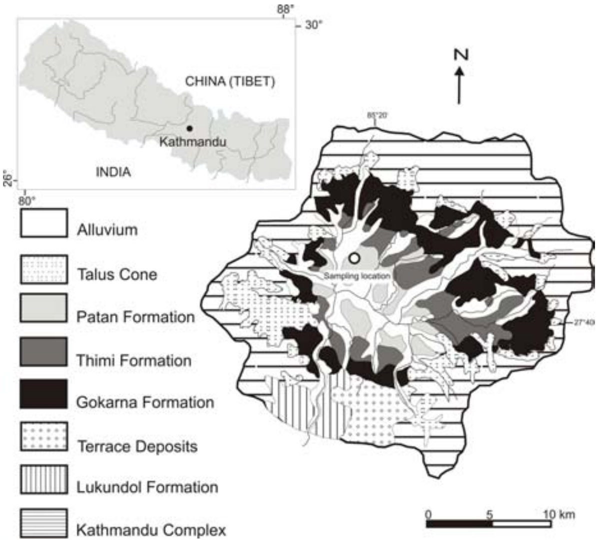

Fig. 1 Geology of the Kathmandu Valley with the location of sampling site. (after Yoshida and Igarashi 1984, Yoshida and Gautam 1988).

from Late Pleistocene to Holocene (Fig. 1). Evaluation and revision of the fluvio-lacustrine sediments from the northern part of the Kathmandu Valley is still in progress on the basis of composite facies analysis, radiometric dating and paleomagnetic polarity data (Sakai et al. 2008). The chronology of the northern part is still not well established because of different sets of radiocarbon dating results obtained from the same sections by different authors (Yoshida and Igarashi 1984; Paudayal and Ferguson 2004; Sakai et al. 2008).

The Patan Formation lies at the core of Kathmandu City. It is composed of alternating fluvio-lacustrine sand, gravel and silt or clay. The lithology of this formation is quite similar to that of the Gokarna Formation showing dominating deltaic environment. The relative height of the Patan Formation is 20 to 50 m above the Bagmati River bed. As the Patan Formation lies in urban area it is therefore difficult to get a surface exposure. Therefore a total of 10 samples collected from 20 m long slime drilled at Bir Hospital compound. The sampling location lies at an altitude of 1304 m at the co-ordinates 27º42'18''N and 85º18'48''E. The detailed litholog of the slime shows an alternation of silt, silty clay and clay mostly dominated by coarse sand deposits (Fig. 2). The radiocarbon age dating made by different authors show that the age of the formation ranges from 14,000 to 19,000 years before present (Table 1).

In order to understand the frequency and distribution of modern pollen that are likely to be deposited in the sediments, 50 surface samples were collected from the northern (Balaju, Sundarijal and Guheshwari) and southern (Godawari) parts of the Kathmandu Valley. These samples were moss bolsters from the forest floor, fine silt and clay sediments from the ditches, swamps and river banks.

METHODOLOGY

The samples were prepared in the laboratory following the methods described by Zetter (1989), and Ferguson at al. (2007). In order to remove any contamination from the recent pollen from the atmosphere the samples were cleaned with scrapper, crushed them to powder and treated with Hydrochloric acid (HCl) to remove any carbonate contain in it. This was followed by the treatment with Hydrofluoric acid

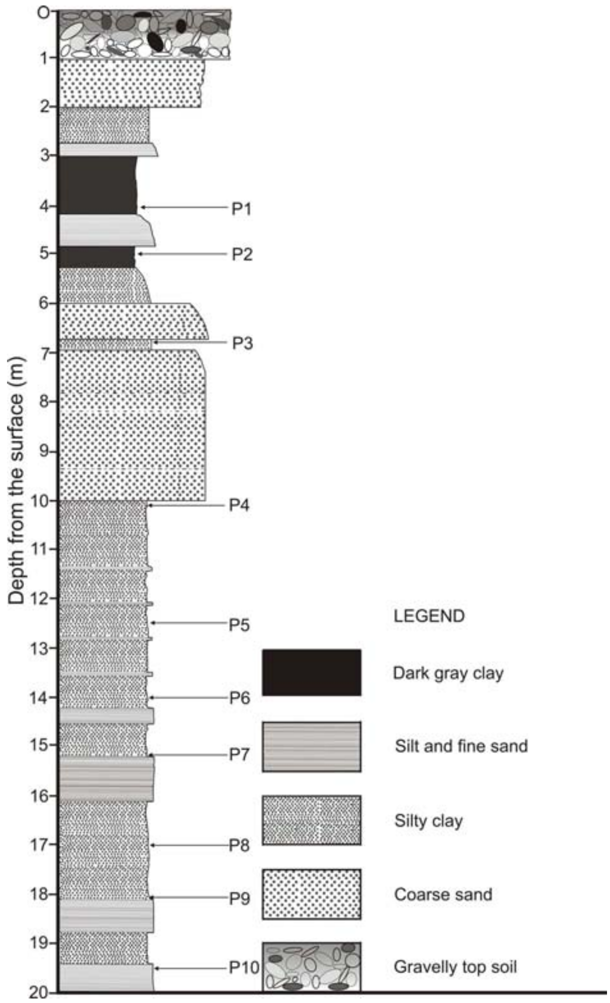

Fig. 2 Lithological details of the Patan Formation.

Table 1: Radiocarbon age of the Patan Formation with the location of the sampling sites.

Radiocarbon age (years BP) and laboratory Codes)	Author and the year of publication	Sample site
14,050 ± 250 (VRI-390)	Franz and Kral (1975)	Airport
17,090 ± 1050 (Gak-6193)	Yonechi (1976)	Teku
14,890 ± 820 (Gak-6194)	Yonechi (1976)	Teku
18,970 ± 1480 (Gak-6195)	Yonechi (1976)	Teku
13,140 ± 380 (Gak-6200)	Yonechi (1976)	Koteswar
11,070 ± 290 (Gak-6201)	Yonechi (1976)	Koteswar
14,579 ± 380/360 (TH-729)	Yoshida and Igarashi (1984)	Pashupati
14,190 ± 110 (JNC-4658)	Sakai et al. (2008)	Sinamangal

(HF) and boiled for half an hour to remove silicate minerals from the samples. The samples were then forwarded to chlorination and acetolysis, then washed with distilled water and glacial acetic acid in each step and centrifuged at the rate of 2000 rpm for 2–3 minutes to remove the finer fraction of the sediments from the sample. Finally the organic material was separated from the inorganic residue using heavy liquid Zinc Chloride ($ZnCl_2$). The residue thus obtained was washed several times with distilled water and mixed with glycerin for microscopic observation.

The modern surface samples (sediments collected from the river banks) were also prepared following the same procedure. The moss samples were washed in water and sieved to separate undesired moss masses. The water with the suspended organic matter was centrifuged at 1500 rpm for 30 seconds and decanted. By repeating this process several times a considerable amount of organic residue was collected in a test tube. The residue was washed with glacial acetic acid and centrifuged three times before preparing for the chlorination and acetylation. It was not necessary to make heavy liquid separation as the residue was devoid of mineral particles. The final residue was washed with water for twice and mixed with glycerin for microscopic examination. In total of 400 pollen and spores were point counted from each sample in a NIKON OPTIPHOT-2 Light Microscope under 10x, 40x or 80x objectives. In order to identify the key climate indicating genera such as *Pinus* and *Quercus*, at least 100 pollen from each sample were examined to their species level. The *Pinus* pollen were identified under Light Microscope (LM) while identification of *Quercus* pollen was made under Jeol JSM 6400 Scanning Electron Microscope (SEM) at 10 kV at different magnifications and orientations.

Interpretation of Quaternary pollen data is mainly based on pollen diagrams. A pollen diagram consists of a series of graphs that are generally prepared on the basis of the percentage of all available (or major) pollen taxa in the total pollen count of an individual sample. The abscissa represents the percentages of all available (or major) pollen types and the ordinate represents the depth of the individual sample from the surface and thus the chronology of the stratigraphic column (Figs. 3 and 4). The graphical representation of pollen data was made by a computer software TILIA version 2.0.b.4.

THE FOSSIL POLLEN ASSEMBLAGES FROM THE PATAN FORMATION

Based on its palynological assemblages, the Patan Formation has been divided into three zones, namely PATAN-I, PATAN-II and PATAN-III in ascending orders (Fig. 3). The composition of the palynomorphs from each zones are described below. The pollen percentage of two key genera *Pinus* and *Quercus* are also used to reconstruct the climate during the deposition of the Patan Formation (Fig. 4).

PATAN-I

This zone is characterized by high percentages of *Quercus* (33-38%) and low values of *Pinus* (5-6%). *Pinus wallichiana* is the predominant pine species. Other Pinaceae (*Abies spectabilis*, *Picea smithiana*, *Tsuga dumosa*) are each represented by less than 1%. *Quercus lamellosa* is the commonest oak, but *Q. lanata* (20-26%) and *Q. leucotrichophora* (14%) are also well represented. Although *Q. semecarpifolia* initially constituted 18% of the oak sum, this value subsequently fell to 2%. *Alnus* (3%), *Betula* (3%), *Carpinus* (1–2%), *Castanopsis* (1–2%), *Ilex* (1%), *Myrica* (1–3%), *Ulmus* (<1%), Meliaceae (<1%) and Oleaceae (1%) are the main constituent of other angiosperm trees and shrubs. The terrestrial herbs are dominated by the Poaceae (16%), *Artemisia* (4%), other Compositae (3%) and the Caryophyllaceae (1%). Aquatic herbs such as *Polygonum* and *Myriophyllum* were represented by less than 2%. Pteridophyte spores are dominating reaching the value by 46–55%.

PATAN-II

The contribution of *Pinus* increases to 11–13% in this zone. Of the two pine species, *P. wallichiana* is the more numerous. The remaining Pinaceae continue

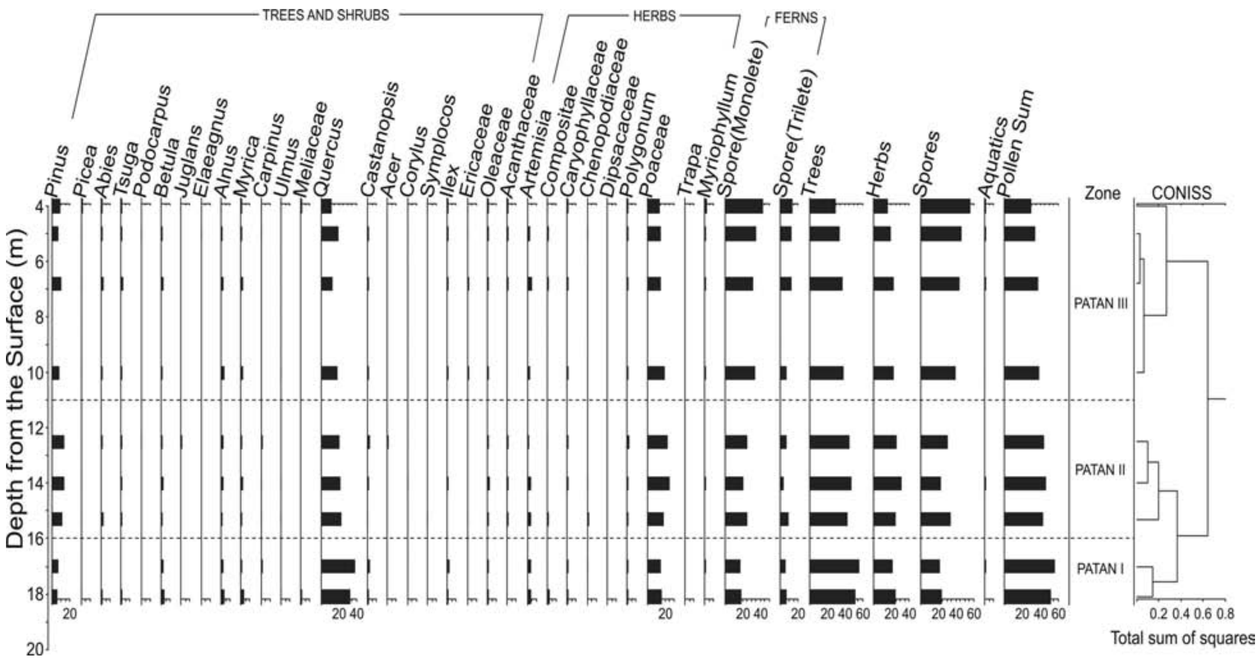

Fig. 3 Pollen diagram of the Patan Formation.

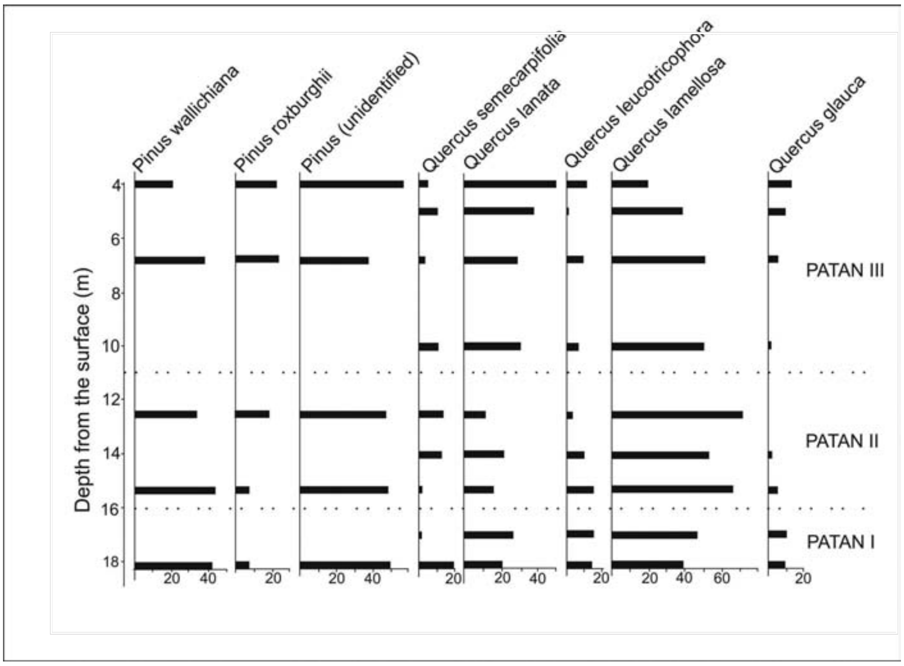

Fig. 4 Pollen diagram of the individual species *Pinus* and *Quercus* (P-Q diagram) from the Patan Formation.

to be poorly represented by *Abies spectabilis* (1–2%), *Picea smithiana* (<1%), and *Tsuga dumosa* (<1%). Although *Quercus* pollen is less common (20–22%), *Q. lamellosa* (53–71% of the oak sum) remains the predominant species, followed by *Q. lanata* (11–21%). *Q. leucotrichophora* (3–13%) and *Q. semecarpifolia* (2–13%) fulfil a subordinate role. Other shrubs and trees such as *Alnus* (1–2%), *Betula* (1-3%), *Carpinus* (<1%), *Castanopsis* (<2%), *Myrica* (1–2%), *Ulmus* (<1%), Ericaceae (<1%) and Oleaceae (1–2%) represent only minor components. With the exception of the Poaceae (18–25%), the herbs are rare which are represented by Acanthaceae (<1%), *Artemisia* (1–4%), other Compositae (<1%), Caryophyllaceae (1%), Chenopodiaceae (1%) and Dipsacaceae (<1%). Fern spores represent 22–32% of the total pollen sum.

PATAN-III

Pinus values fall to 6–10%, with *P. wallichiana* and *P. roxburghii* now represented in more or less equal proportions. *Abies spectabilis* (1–2%) and *Picea smithiana* (<1%) have similar values to PATAN-II, but *Tsuga dumosa* is slightly better represented (1–2%) than before. Although its percentage continues to fall, *Quercus* is still the commonest tree (12–19%). *Q. lamellosa* was initially the commonest species, but is replaced by *Q. lanata* in the course of this zone. *Q. leucotrichophora* and *Q. semecarpifolia*, which are present throughout, only played a minor role. Other trees and shrubs such as *Alnus* (1–3%), *Betula* (1–2%), *Castanopsis* (1–2%), *Elaeagnus* (<1%), *Ilex* (<1%), *Myrica* (1–2%), Ericaceae (1–2%) and Oleaceae (1–2%) were poorly represented. The herbs continue to be dominated by the Poaceae (13–19%). The remaining terrestrial herbs, such as *Artemisia* (1–4%), other Compositae (<1%), Caryophyllaceae (<1%), Chenopodiaceae (<1%) and Dipsacaceae (<1%) as well as the aquatic herbs, i.e. *Myriophyllum* (1–2%) and *Polygonum* (1–2%) represent minor elements. In the course of the zone the ferns increase from 39 to 55%.

MODERN POLLEN SPECTRA FROM THE KATHMANDU VALLEY FLOOR

In order to reconstruct the palaeovegetation, fossil pollen assemblages are compared with that of modern pollen assemblages. This can be successfully done when a modern analogue of the past vegetation exits (Bos 1998). The surface sample studies are an essential stage in the interpretation of fossil assemblages (Birks and Gordon 1985). Small waterlogged locations, such as ditches and moats are able in environmental archaeological studies because of their capacity to preserve a range of useful materials, including pollen and spores (Moore et al. 1991). Interpretation of fossil pollen data requires a thorough knowledge of the present day ecology of the taxa involved. However, the comparison of modern pollen assemblages with that of fossil pollen assemblage is more complex because of factors such as pollen production, meteorological factors influencing pollen transportation and physical, biological and chemical conditions of the depositional environment which affect deposition and preservation of the pollen. In this study, the comparative approach of modern pollen data with that of fossil pollen data is aimed to establish the similarities between modern and fossil spectra, so that the latter can be interpreted in terms of modern analogues. If similarities exist between modern and fossil assemblages, it is likely that the spectra were produced by broadly similar vegetation. Thus, a modern vegetation analogue can be proposed for the past vegetation. Such comparison provides a factual and repeatable basis for vegetation reconstruction (Birks and Gordon 1985). The pollen data obtained from the modern surface samples in the Kathmandu Valley floor clearly indicates the source of pollen, their dispersal mechanism and their spatial relation to the fossil pollen assemblages (Fig. 5).

Northern part of the Kathmandu Valley

Sundarijal area

Surface samples collected from forest floor, open pits and from the bank of the Bagmati River comprised both sediments as well as moss cushions. Out of ten samples collected from this area, only two moss samples (SU-M1 and SU-M2) and three surface sediment samples (SU-S1, SU-S2, and SU-S4) yielded enough pollen for quantitative analysis. The surface samples from Sundarijal area are characterized by high percentage of *Pinus* (12–43%), *Alnus* (23–55%) and other tree pollen such as *Abies* (1%), *Betula* (1–2%), *Elaeagnus* (<1%), *Quercus* (2–11%), *Castanopsis* (1–7%), *Symplocos* (1%), Ericaceae (<1%), *Artemisia* (1%), other Compositae (1–2%), Caryophyllaceae (1–2%), Poaceae (1–22%) and Pteridophyte spores (14–21%).

Guheshwari area

Out of five samples from the Guheshwari area, two surface samples were found to be rich enough to be worth counting. One of these was a sediment sample (GU-S1) from the bank of the Bagmati River; another was a moss cushion (GU-M2) from the forest floor behind the Guheshwari temple. The Guheshwari surface samples were more or less similar to those from Sundarijal with the exception of the percentage of Poaceae. The major pollen types found in this area were *Pinus* (12–17%), *Alnus* (8–12%), *Quercus* (17–23%), *Abies* (1–3%), Poaceae (16–20%), Oleaceae (2-4%), *Castanopsis* (1-2%), Acanthaceae (<1%), *Artemisia* (1–18%), Chenopodiaceae (<3%) and Pteridophytes (13–15%).

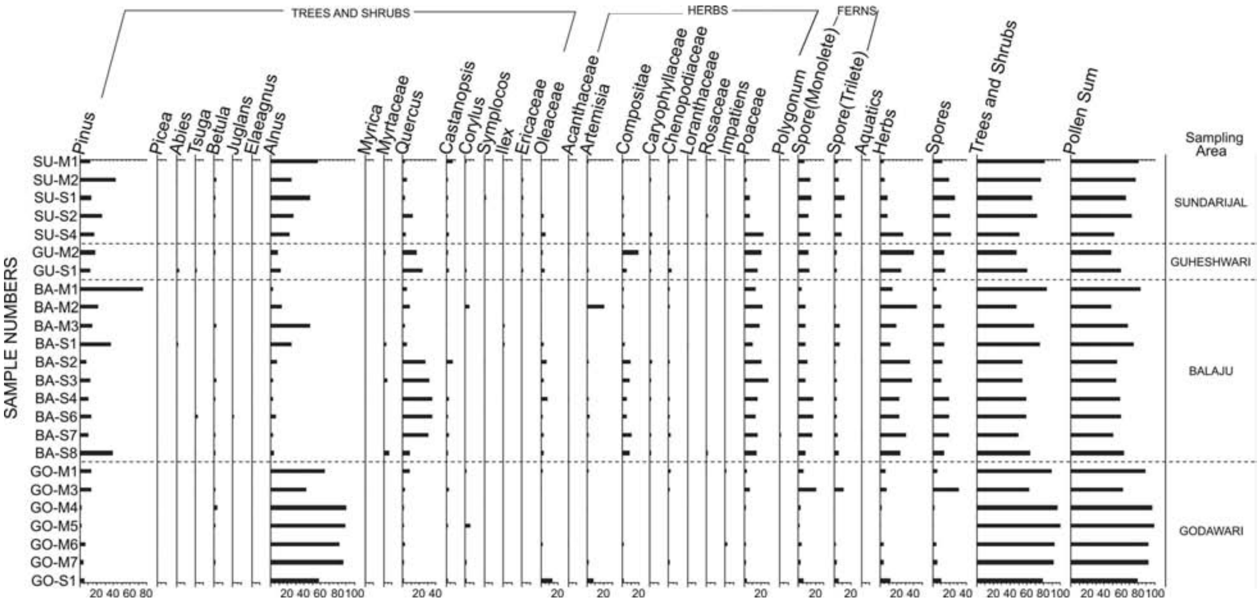

Fig. 5 Recent pollen diagram from the Kathmandu Valley.

Balaju area

Fifteen samples were collected from the Balaju area of which ten samples were found to be rich in pollen. Three of these samples (BA-M1, BA-M2 and BA-M3) were moss cushions, while seven samples (BA-S1, BA-S2, BA-S3, BA-S4, BA-S6, BA-S7 and BA-S8) were sediment from ditches and small pits. In these samples relatively high percentages of *Quercus* pollen were found. Other major types of pollen consist of *Pinus*, *Alnus*, Poaceae and Pteridophytes. However, percentages of the major pollen types were not found to be uniform throughout.

The two moss samples (BA-M2 and BA-M3) showed relatively high percentages of *Pinus* (14-21%), while in BA-M1, 75% of the total pollen count consisted of *Pinus*. The percentage of *Quercus* in moss samples was 2-8%. In samples BA-M1 and BA-M2 the percentage of *Alnus* was lower (2-13%) than in sample BA-M3 (47%). The sediment samples (BA-S1, BA-S2, BA-S3, BA-S4, BA-S6, BA-S7 and BA-S8) were found rich in *Pinus* (7-36%) followed by *Quercus* (5-35%) and *Alnus* (2-25%) in Balaju area. The trees and shrubs were represented by *Abies* (1-2%), *Tsuga* (<1%), *Betula* (1-2%), Myrtaceae (1-6%), *Castanopsis* (1-6%), *Corylus* (1-4%), *Symplocos* (1%) and Oleaceae (1-8%). The herbs were dominated by Poaceae (9-22%). The other herbaceous plants found were Acanthaceae (<1%), *Artemisia* (1-20%), other Compositae (1-10%), Caryophyllaceae (1-2%), Chenopodiaceae (1-2%) and Loranthaceae (<1%). The percentage of Pteridophyte spores ranges between 4-19% of the total pollen count.

Southern part of the Kathmandu Valley

Godawari area

Out of twenty samples collected from the Godawari area, only seven samples were found to be rich enough in pollen for a quantitative study. Out of seven rich samples, six (GO-M1, GO-M3, GO-M4, GO-M5, GO-M6 and GO-M7) were moss cushions and GO-S1 was a sediment sample.

The main pollen constituents of these samples were *Alnus* and *Pinus*. Among these two, *Alnus* highly dominates the total pollen sum ranging in between 42-90% while the percentage of *Pinus* ranges in between 1-13%. Other gymnosperms such as *Picea*, *Abies* and *Tsuga* were virtually lacking in these surface samples. Other trees and shrubs were *Betula* (1-4%), *Quercus* (1-8%), *Castanopsis* (1-2%), *Corylus* (81-5%) and, Oleaceae (1-13%). Herbaceous plants consist of Poaceae (1-6%), Caryophyllaceae (<1%) and, *Impatiens* (1-2%). Pteridophyte spores covered 30% of the total pollen count.

Comparison of pollen assemblage obtained from the modern surface samples with that of fossil pollen assemblage showed an interesting result. Most of the elements of modern analogue were also present in the fossil assemblages. The modern surface samples revealed the high percentages of *Pinus* and *Quercus* in the northern part, while percentages of *Alnus* are higher in the southern part of the Kathmandu Valley. The percentage of *Alnus* in the Patan Formation was very low than in the modern surface samples. The high percentage of few species may indicate the presence of the source plant very close to the surface samples. This is an indication of the fossil assemblages which reflect the local vegetation rather than regional vegetation. Analysis of modern surface sample also confirmed the absence of exotic pollen in the pollen assemblages.

DISCUSSION AND CONCLUSION

Different species of *Pinus* and *Quercus* are distributed in particular climate zones in Nepal (Stainton 1972). *Pinus wallichiana* grows from 1800 m up to 4100 m in cold areas (on south slopes) while *P. roxburghii* is distributed from 1100 m to 2100 m in warmer areas. Thus, the dominance of either of these two species can predict the climate in which they were growing during the geological past. Similarly different *Quercus* species grow under different climatic conditions. *Quercus semecarpifolia* inhabits cold areas mostly on south-facing slopes (altitudes between 1700 m-3800 m), whereas *Q. lanata* (between 1500 m-2900 m) and *Q. leucotrichophora* (between 1500 m-2400 m) grow in relatively warm areas. Another oak *Q. lamellosa* (between 1600 m-2800 m) prefers subtropical to warm temperate climate but does not reach as high as *Q. semecarpifolia*. *Quercus glauca* grows in wet and warm areas between 500 m-3100 m (Malla et al. 1976, 1986; Press et al. 2000). Because of their key role in the vegetation it is essential to distinguish fossil pollen of different *Pinus* and *Quercus* species (Nakagawa et al. 1996). It is possible to identify the *Pinus* spp. under LM because there are only two species exist in Nepal. Among them *Pinus wallichiana* is haploxylon and *Pinus roxburghii* is diploxylon. The haploxylon variety contains dot marks in leptoma area while the diploxylon lacks such marks. However for the identification of *Quercus* pollen to species level it is essential to use the SEM (Ferguson et al. 2007).

The Patan Formation reveals warm and humid climate condition with the significant presence of subtropical gymnosperm such as *Pinus roxburghii*, subtropical angiosperms such as *Castanopsis* and oaks species such as *Quercus lanata* and *Quercus leucotricophora* except in the middle part of the section. The percentage of *Pinus* was less than 10% (insignificant) except in the middle part of the section. The other gymnosperms such as *Picea*, *Abies* and *Tsuga* all were hardly found to be exceeded by 1% in the total sum which is very insignificant for any climatic interpretation. The woody angiosperms were dominated by *Quercus* spp. mainly *Q. lanata*, *Q. leucotricophora* and *Q. lamellosa*. Subtropical tree such as *Castanopsis* present 2% of the total pollen sum, it is showing its presence throughout the section. *Castanopsis* is the chief element of the modern subtropical *Schima-Castanopsis* forest. Earlier studies have shown that the older Thimi Formation absent *Castanopsis* pollen. However the Gokarna Formation which is older than Thimi Formation, the *Castanopsis* pollen attains their presence up to 37% in the total pollen count (Paudayal 2005, 2006). It appears that the cold temperate climate existed during the Thimi Formation changed to warm, humid and subtropical to warm temperate climate during the deposition of the Patan Formation.

In pollen assemblage zone PATAN-I *Quercus* spp. (Q. *lanata*, *Q. leucotrichophora* and *Q. lamellosa*) attain 40%, indicating a relatively warm climate. In PATAN-II *Pinus wallichiana* increases together with *Quercus semecarpifolia* and therefore indicates a shift to a warm temperate climate. In PATAN-III a reduction in *Quercus* is accompanied by an increase in *Pinus roxburghii* (insignificant), indicating a return to warmer climates. The climatic condition during the deposition of the Patan Formation was similar to that of the Gokarna Formation. The trend to present climate has started during the deposition of the upper part of the Patan Formation or afterwards.

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