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## Contents

Geology and structure of Raniban–Champadevi area, Kathmandu valley, central Nepal <i>K. K. Acharya and M. R. Dhital</i> .....	1
Mineral chemistry of augen gneisses from Tamakoshi–Likhu Khola area in east Nepal <i>Kamal Raj Regmi</i> .....	11
Microfacies analysis and diagenesis of the Lower Eocene Sakesar Limestone, Nilawahan Gorge, central Salt Range, Pakistan <i>S. Ghazi, A. A. Butt, and M. Ashraf</i> .....	23
Late Pleistocene pollen assemblages from Gokarna Formation (Dhapasi section) in Kathmandu valley, Nepal <i>Khum N. Paudyal</i> .....	33
Delineation of basement structure from gravity data: example from Nara basin, Japan <i>Dinesh Pathak</i> .....	39
Freezing–thawing effect and slake durability of some rocks from cold regions of Nepal and Japan <i>Ganesh P. Dhakal, Junichi Kodama, and Tatsuhiko Goto</i> .....	45
Comparison of arsenic and nitrate contaminations in shallow and deep aquifers of Kathmandu valley, Nepal <i>Jaya Kumar Gurung, Hiroaki Ishiga, Mohan Singh Khadka, and Nav Raj Shrestha</i> .....	55

## Late Pleistocene pollen assemblages from Gokarna Formation (Dhapasi section) in Kathmandu valley, Nepal

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### ABSTRACT

Pollen assemblages of the Gokarna Formation were studied from a 27 m thick section near Dhapasi, Kathmandu. The analysis of 42 sediment samples revealed six zones. The lower part of the sequence was deposited under temperate climatic conditions. The dominance of *Pinus*, *Abies*, and *Picea* with a very low percentage of *Quercus* and *Castanopsis* indicates a temperate climate during the deposition of the lower part of the sequence. The dominance of *Castanopsis* and *Quercus* along with other angiosperms (*Betula*, *Myrica*, *Ulmus*, and *Oleaceae*) over gymnosperms (*Pinus*, *Abies*, and *Picea*) indicates subtropical to warm climatic conditions in the middle part of the sequence. A change to a cool temperate climate took place towards the top of the sequence with the increase of *Pinus*, *Picea* and *Abies*, and decrease of *Quercus* and other woody angiosperms. The subtropical element *Castanopsis* decreases and ultimately disappears at the top of the sequence. An increase of herbaceous plants and Poaceae also supports the advent of a colder climate, which ultimately prevailed during the deposition of the Thimi Formation. A characteristic feature of the Gokarna Formation is the dominance of woody angiosperms over gymnosperms except in the lower part of the section.

### INTRODUCTION

The Kathmandu intermontane basin consists of late Pliocene to Holocene fluvio-lacustrine and fluvial sediments. Lithologically, these sediments have been divided into eight different units (Yoshida and Igarashi 1984; Yoshida and Gautam 1988). The Lukundol Formation of late Pliocene to early Pleistocene age was deposited throughout the basin. In the process of upheaval of the Himalaya, the old lake shifted from south to north resulting in the formation of the Pyanggaon, Chapagaon, and Boregaon terrace deposits. The Gokarna Formation, Thimi Formation, and Patan Formation represent younger (late Pleistocene) lake sediments deposited towards the northern part of the basin (Fig. 1). The lacustrine sediments rest unconformably on the Palaeozoic rocks of the Kathmandu Complex, which forms the Mahabharat mountain range surrounding the Kathmandu valley.

The Gokarna Formation is composed of alternating layers of black and grey clay, silt, fine- to coarse-grained arkosic sand, and gravel (Fig. 2). The thickness of clay and silt beds ranges from 0.3 to 3 m. The sand beds tend to be thicker and are often cross-bedded. Previous palynological works in this area (Kral and Havinga 1979; Vishnu-Mittre and Sharma 1984; Yoshida and Igarashi 1984; Igarashi et al. 1988; Nakagawa et al. 1996) prove the fertile nature of the sediments and their usefulness in deciphering depositional environment and climate.

### MATERIAL AND ANALYTICAL METHODS

Samples were taken from a 27 m thick Dhapasi scarp of the Gokarna terrace exposed near Maharajgunj Ring Road (27°44'50"N and 85°19'45"E) at an altitude of 1358 m (Fig. 1). Out of 42 analysed samples, 12 (G3, G4, G5, G6, G12, G14, G17, G18, G21, G28, G32, G33) were barren. In the remaining

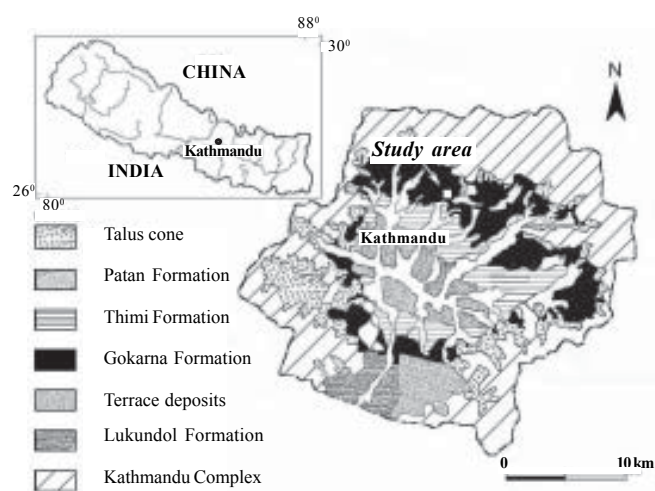


Fig. 1: Geological setting of the study area in the Kathmandu valley (after Yoshida and Igarashi 1984)

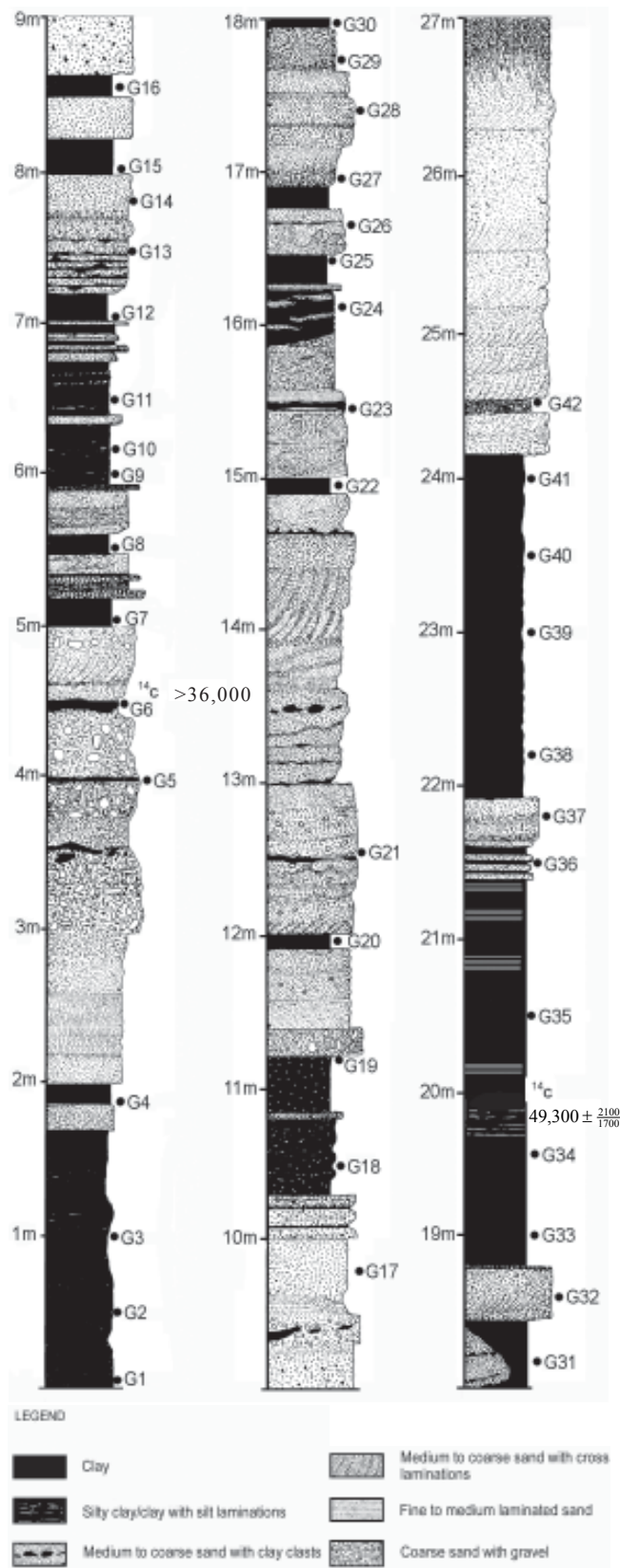


Fig. 2: Lithological details of the Gokarna Formation at Dhapasi

samples, carbonaceous clay and sometimes silt layers yielded well-preserved pollen. Numerous fossil wood pieces were found in the carbonaceous clays and arkosic sand layers. The radiocarbon ages of the wood fragments collected at depths of 7 m and 22.3 m from the top of the sequence were found to be  $49,300 \pm \frac{2100}{1700}$  and  $>36,100$  years BP, respectively. The radiocarbon age of the younger Thimi Formation was estimated at 41,700 and  $>37,000$  years BP (Paudyal and Ferguson 2004; Paudyal 2005). The age of the Thimi Formation is at or within the margin of radiocarbon dating limit. An erroneous age obtained for the Gokarna Formation indicates that its age may exceed the dating limit of radiocarbon method.

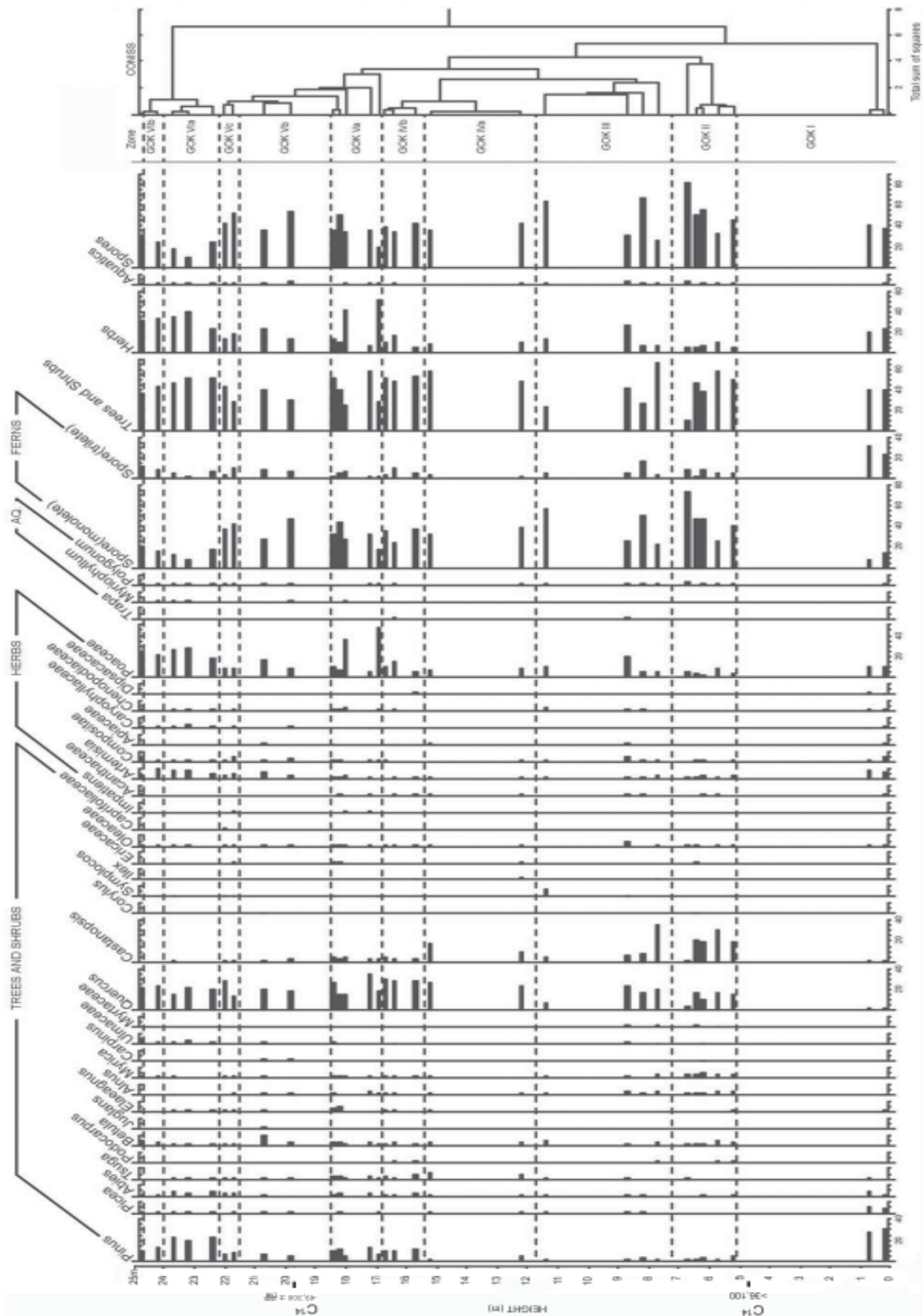
In order to isolate pollen, the samples were chemically treated in the laboratory following the method of Zetter (1989). The samples were heated in concentrated HCl to remove any calcareous material. They were then heated in concentrated HF to dissolve the siliceous matter. This was followed by heating again in concentrated HCl to remove HF crystals. The samples were treated with a saturated solution of sodium chlorate, acetic acid, and a few drops of concentrated HCl, and immersed in a hot water basin. They were then transferred to a solution containing nine parts of acetic acid anhydride and one part of concentrated sulphuric acid and immersed in boiling water to stain the pollen grains. They were washed with water and acetic acid before the start of each treatment. Finally, the sample was washed with acetic acid and separated from the residue using zinc bromide. After that, light microscopic (LM) and scanning electron microscopic (SEM) studies were undertaken at the University of Vienna.

A LM study was undertaken with a Nikon Optiphot-2 microscope at magnifications of  $\times 100$ ,  $\times 400$ , and  $\times 850$ . LM photographs were taken at a magnification of  $\times 850$ . About 400 pollen grains were counted to calculate the percentage of pollen and spores in each sample. For SEM study, the pollen was washed with absolute ethanol on an aluminium stub of scanning electron microscope and coated with gold. The pollen was studied with a JSM-6400 scanning electron microscope at different magnifications. The pollen diagram (Fig. 3) was prepared using a computer program TILIA (versions 1.07 and 2.0).

As different species of *Pinus* and *Quercus* are presently growing under different climatic regimes in Nepal, it was necessary to identify the fossil pollen at its species level to infer an accurate climatic signal (see Fig. 5 in Paudyal and Ferguson 2004). At least 100 *Pinus* pollen grains were observed under the light microscope to distinguish them at their species level. Similarly, 80–100 *Quercus* pollen grains were observed under the scanning electron microscope to identify them at their species level (Fig. 4).

## RESULTS OF THE POLLEN ANALYSIS

The Gokarna Formation is divided into six pollen assemblage zones (PAZ): GOK-I to GOK-VI in an ascending





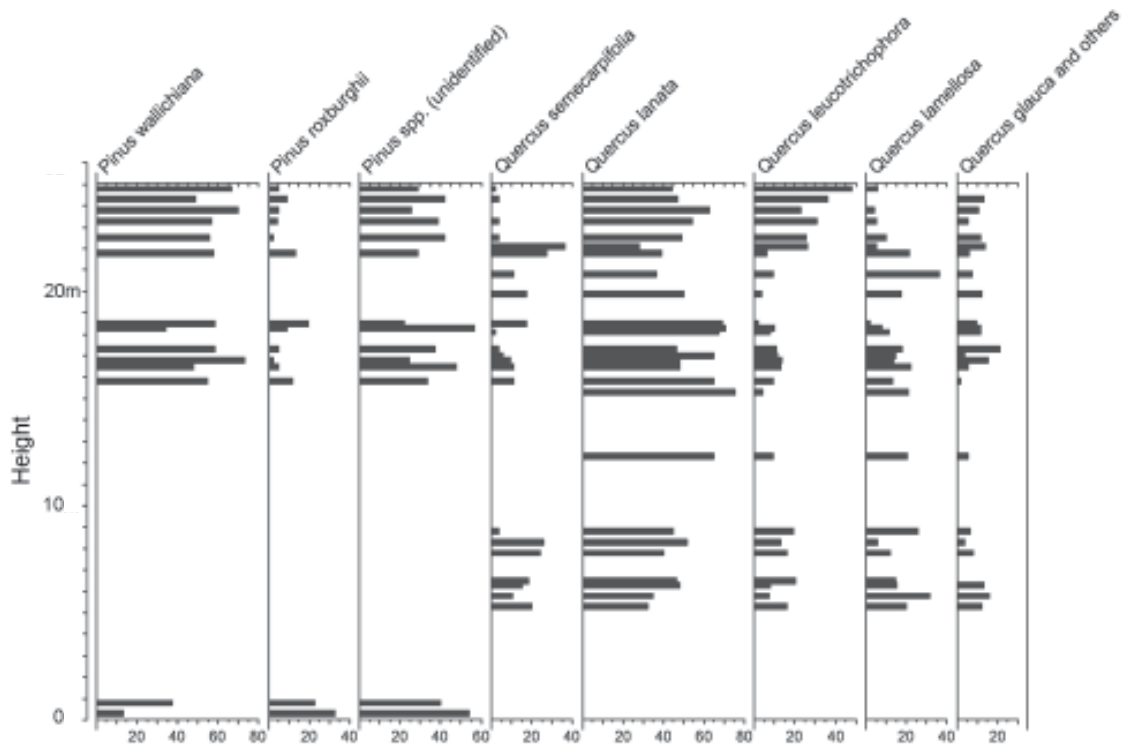


Fig. 4: *Pinus* and *Quercus* species from the Dhapasi section of the Gokarna Formation

order (Fig. 3). The Pollen zone GOK-IV is further divided into GOK-IVa and GOK-IVb sub-zones. Similarly, GOK-V is divided into three sub-zones: (GOK-Va, GOK-Vb, GOK-Vc), while GOK-VI is divided into two sub-zones (GOK-VIa and GOK-VIb) based on the composition of pollen assemblages.

#### Zone GOK-I

This zone is represented by a high percentage of *Pinus* (30%). *P. roxburghii* predominated initially but was subsequently replaced by *P. wallichiana*. *Abies spectabilis* and *Picea smithiana*, which reach 5% in the lower part of the zone, decrease in the upper part. *Quercus* and *Castanopsis* are only poorly represented (<2%). The Poaceae (9%) and *Artemisia* (6–8%) and other Compositae (4%) are reasonably well represented, but other herbs such as Acanthaceae, Apiaceae, Caryophyllaceae, Chenopodiaceae and Dipsacaceae never exceed 1%. The fern spores, which constitute 37–39% of the total pollen count, are mostly monolete.

#### Zone GOK-II

This zone is characterised by a decline in the Pinaceae. *Picea smithiana* is absent. *Abies spectabilis* and *Tsuga dumosa* each constitute <1% of the assemblage, while *Pinus* decreases from 5% at the base to less than 1% at the top. This change is accompanied by an increase in *Castanopsis* (2–30%) and *Quercus* (4–19%). *Q. lanata* is the most important of the four oak species. Other trees and shrubs such as *Alnus*, *Betula*, *Myrica* and the Oleaceae each comprise up to 4% of the assemblage. While the Poaceae

remain stable at up to 8%, *Artemisia* and other Compositae decline to <1–3%. In the upper part of the zone the mostly monolete fern spores constitute up to 70% of the total pollen sum.

#### Zone GOK-III

The Pinaceae were probably locally absent, as *Abies*, *Picea*, and *Pinus* are each represented by less than 1%. Although *Quercus* is well-represented (22%) to start with, it gradually decreases to no more than 5%. Of the oak species, *Q. lanata* remains dominant over *Q. semecarpifolia*, *Q. leucotrichophora*, and *Q. lamellosa*. *Castanopsis* likewise decreased from initially high percentages (35%). These genera are replaced by ligneous elements such as *Betula*, *Elaeagnus*, *Alnus*, *Symplocos*, and Oleaceae. *Artemisia* and other Compositae range between 1 and 3%, while Poaceae displays percentages of up to 20%. Fern spores constitute 30–70% of the total pollen count.

#### Zone GOK-I

This zone is divided into two sub-zones. In sub-zone GOK-IVa, *Pinus* increases but constitutes no more than 3%. *Quercus* and *Castanopsis* are represented by 23% and 10% respectively. Of the oak species, *Q. lanata* is better represented than *Q. leucotrichophora* and *Q. lamellosa*; *Q. semecarpifolia* is missing in this zone. While *Tsuga* has pollen values of up to 5%, *Picea smithiana* and *Abies spectabilis* never exceed 2%. While *Betula* remains stable, *Alnus*, *Symplocos* and Oleaceae drop to less than 1%. Likewise, the herbs *Artemisia*, other Compositae and

Acanthaceae are represented by less than 1%. The Poaceae, on the other hand, constitute 7% of the total pollen count. Ferns make up to 40%, most of which are monolete spores.

In sub-zone GOK-IVb, the *Pinus* percentages increase to 6–11%. *Tsuga* reaches 5%, while *Abies spectabilis* ranges between 1 and 3%. The presence of *Podocarpus neriifolius* (1%) is also recorded. While *Quercus* increases to 25–30%, *Castanopsis* falls to 2% in the upper part of this sub-zone and is never again well represented in the sequence. Of the oaks, 40–70% belongs to *Q. lanata*. The rest is divided between *Q. lamellosa*, *Q. leucotrichophora*, and *Q. semecarpifolia*. Other woody taxa such as *Alnus*, *Betula*, *Elaeagnus*, *Myrica*, and Oleaceae range between 0 and 3%. While the Chenopodiaceae, Caryophyllaceae, *Artemisia*, and other Compositae are represented by less than 2%, the Poaceae range between 4 and 14%. The percentage of fern spores is high, as usual.

### Zone GOK-V

This zone is characterised by high percentages of *Pinus*, *Quercus*, and the Poaceae. Three sub-zones have been recognised: GOK-Va, GOK-Vb, and GOK-Vc in an ascending order.

Sub-zone GOK-Va: *Pinus* percentages range between 6 and 12%, while other conifers such as *Abies spectabilis* and *Tsuga dumosa* are barely present (1–3%). *Quercus* remains the dominant tree with percentages between 14 and 34%. From 40 to 80% of this was derived from *Q. lanata*, 5–30% originated from *Q. leucotrichophora* and *Q. lamellosa*, and less than 15% came from *Q. semecarpifolia*. Although present throughout the zone, *Castanopsis* never exceeds 2–3%. Other noteworthy trees and shrubs are *Alnus* (0–2%), *Betula* (2–3%), *Elaeagnus* (0–3%), *Ilex* (<1%), *Myrica* (<1%), *Symplocos* (<1%), and Oleaceae (<1%). The herbs are dominated by Poaceae (6–48%), followed by *Artemisia* (0–3%), other Compositae (0–2%), Caryophyllaceae (1–3%), and Chenopodiaceae (1–3%). Fern spores constitute 34–54% of the total pollen sum.

Sub-zone GOK-Vb: The conifers are poorly represented. *Pinus* falls to 4–5% while *Abies spectabilis*, *Picea smithiana*, and *Tsuga dumosa* never exceed 1%. *Quercus* yields 17–19% of the pollen. While *Q. lamellosa*, *Q. lanata*, and *Q. semecarpifolia* are well represented, *Q. leucotrichophora* displays a remarkable decline in this sub-zone. *Betula* is better represented (2–9%) than in the previous sub-zone, followed by *Castanopsis* (1–3%). Other trees and shrubs such as *Alnus*, *Carpinus*, *Corylus*, *Elaeagnus*, *Myrica*, *Symplocos*, *Ulmus*, Ericaceae, and Oleaceae are represented by less than 1%. The Poaceae are less common, but with 8–16% are still better represented than the other herbs, e.g. Apiaceae (<1%), *Artemisia* (2–5%), other Compositae (1–2%), Caryophyllaceae (<1%), and Chenopodiaceae (<1%). The fern spores represent between 36 and 54%.

Sub-zone GOK-Vc: While *Picea smithiana* and *Tsuga dumosa* remain under 1%, *Pinus* (6–8%) and *Abies spectabilis* (2%) become slightly more common. With 12–28% of the

total pollen, *Quercus* retains its prominent position. *Q. semecarpifolia* (30%) and *Q. lanata* (20–40%) are the commonest species, followed by *Q. lamellosa* (20–25%) and *Q. leucotrichophora* (5–10%). Other woody taxa such as *Betula* (<2%), *Elaeagnus* (~1%), *Myrica* (<1%), *Symplocos* (<1%), *Ulmus* (<1%), Caprifoliaceae (<1%), Ericaceae (<1%), and Oleaceae (1–2%) are minor elements. Although they are still the most important herbs, Poaceae have declined to 8%. Additional herbs are *Artemisia* (3–4%), other Compositae (1–4%), Caryophyllaceae (<2%), Chenopodiaceae (<2%), and *Impatiens* (<2%). The ferns, which are well represented (40–50% of the total pollen count), consist largely of monolete spores.

### Zone GOK-VI

This zone, which represents the uppermost part of the Gokarna Formation, is characterised by an abrupt rise in *Pinus* and *Abies* pollen. Zone GOK-VI is divided into two sub-zones: GOK-VIa and GOK-VIb in an ascending order.

Sub-zone GOK-VIa: The Pinaceae percentages double or triple. *Abies spectabilis* now represents 4% of the pollen, while *Picea smithiana* and *Tsuga dumosa* each constitute 1–2%. At 20–22%, *Pinus* is now an important element in the vegetation. *Quercus* pollen reaches a maximum value of 22%. While *Q. semecarpifolia* and *Q. lamellosa* are less common, *Q. leucotrichophora* has increased and now predominates along with *Q. lanata*. *Castanopsis* remains low (<1%) and along with *Alnus* (<1%), *Betula* (<2%), *Elaeagnus* (<1%), *Symplocos* (<1%), *Ulmus* (1–3%), and Oleaceae (1 to 2%) represent only a minor proportion. The expansion of pine is accompanied by an increase in Poaceae (up to 27%) and *Artemisia* (7%). The values for other Compositae, Caryophyllaceae, and Chenopodiaceae vary between 1 and 3%. Fern spores constitute no more than 8–24% of the total pollen sum.

Sub-zone GOK-VIb: This sub-zone is characterised by a decline in *Pinus* to 9–12% and figures of less than 1% for *Abies spectabilis* and *Picea smithiana*. *Quercus* is still the most important forest tree with values between 20 and 23%. *Q. lanata* and *Q. leucotrichophora* are the chief species. *Betula* (2–4%), *Myrica* (<1%), *Ulmus* (1–2%), and Oleaceae (1–2%) are only minor elements. The Poaceae and *Artemisia* remain important with 25% and 9%, respectively. Other Compositae, Caryophyllaceae, Chenopodiaceae, and Acanthaceae are represented by less than 1% each. In this sub-zone, an increase of the ferns to 31% is noteworthy.

## DISCUSSION AND CONCLUSION

Based on palynological evidence, it is assumed that the climate during the deposition of the Dhapasi section of the Gokarna Formation was not uniform. During the deposition of its lower part (GOK-I), temperate climatic conditions existed. The dominance of grass pollen over the tree pollen suggests a cold and rather dry climate.

The first major change in vegetation in the Dhapasi section of the Gokarna Formation commences with

PAZ GOK-II where *Quercus lanata* becomes the dominant *Quercus* species. *Castanopsis* is also very abundant (35%, the highest percentage in the Gokarna section) along with other woody angiosperms such as *Alnus*, *Betula*, *Myrica*, Myrtaceae, and Oleaceae. The decrease of the gymnosperms below the 10% indicates that they remained insignificant until PAZ GOK-IVa. *Quercus* and *Castanopsis* are the major woody angiosperms in PAZ GOK-II, GOK-III, and GOK-IVa. The predominance of *Castanopsis* over all other woody angiosperms in PAZ GOK-II and the basal part of GOK-III indicates warmer conditions. *Castanopsis* might have been associated with *Schima* (due to its weak exine *Schima* pollen is rarely preserved) to form subtropical or warm temperate forest at this time. This was the highest warm phase in the studied section of the Gokarna Formation.

From the middle part of GOK-III, *Quercus* starts to replace *Castanopsis* and this trend continues to PAZ GOK-IVc. *Castanopsis* decreases rapidly until it disappears towards the top of the section. It is absent in PAZ GOK-VIa and VIb. This suggests a shift from the *Schima-Castanopsis* forest (subtropical) to more temperate forest (*Quercus leucotrichophora* to *Q. lanata* and *Q. lamellosa*) with a slow and gradual increase of gymnosperms and Poaceae towards the top of the sequence.

The second major change in vegetation comes in PAZ GOK-IVb and GOK-Va with the reappearance of *Pinus* along with *Abies* and *Tsuga* in significant percentages. *Quercus* reaches its highest values in these two zones of the section while *Castanopsis* remains in very low amounts. The pollen assemblages suggest a conifer-oak forest that grew under warm temperate conditions.

The third major change in the studied section of the Gokarna Formation comes in PAZ GOK-VIa and GOK-VIb with an increase of *Pinus* above 30% along with *Abies*, *Tsuga*, and *Picea* accompanied by a slight decrease of *Quercus* and the absence of *Castanopsis*. Deciduous trees such as *Betula* and *Ulmus* were also present. Another significant characteristic of these zones is relatively high amounts of Poaceae and *Artemisia*. The disappearance of *Castanopsis* and the increase of *Pinus* and other gymnosperms to more than 25% in these zones indicate a slight change to cooler temperate conditions towards the top of the section. This colder temperate climatic condition continued to prevail during the deposition of the Thimi Formation (Paudyal 2005).

The number of woody angiosperms reflects the zonal vegetation and displays minor fluctuations (in the range of 30 to 45%). In the Dhapasi section of the Gokarna Formation, *Castanopsis* reaches up to 35% of the total pollen assemblages. Within the sub-aerial facies, relatively high numbers of fern spores and Poaceae are assumed to reflect azonal herbaceous pioneer vegetation within the depositional environment. Thus PAZ GOK-II to GOK-V reflect taphonomically biased mixtures of zonal vegetation, mostly

woody angiosperms and a few gymnosperms together with azonal vegetation, mainly ferns and Poaceae.

The characteristic features of the Gokarna Formation in the study area are the dominance of woody angiosperms over gymnosperms except in the lower part of the section (i.e. PAZ GOK-I). Pteridophyte spores form an integral part of the pollen assemblages. Spores are very abundant and occur frequently, thus they provide some information about the forest vegetation. The climatic signals of fern spores are poorly understood in comparison with those of gymnosperms and angiosperms. Until the spores are accurately identified, their climatic signals will remain elusive.

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