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Palynological study of the drilled sediments from the Kathmandu Basin and its palaeoclimatic and sedimentological significance

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ABSTRACT

Palynological study of a series of slimes obtained from a 284-m-long drill well in the Kathmandu Basin revealed palaeoclimatic records and depositional environmental changes in the Kathmandu Valley during the last 2.5 myr. The slimes consist of fluvio-deltaic and lacustrine sediments comprising 218 m long muddy beds and 66.3 m of sandy beds. As a result of palynological study on the 189 pieces of slime, a totaxl 43 types of fossil pollen and spores were identified. They comprise arboreal pollen of one family and 20 genera, non-arboreal pollen of 10 families and 10 genera and spores. In the pollen diagram, *Quercus* and *Cyclobalanopsis* are predominant, with frequencies exceeding 70%. *Pinus*, *Alnus* and Gramineae are the next dominant taxa. Three fossil pollen zones, which reflect major climatic change, were discriminated: Zone I indicates a cool climate from ca. 2.5 to 2.1 Ma; Zone II shows a warm and relatively dry climate without remarkable fluctuation from ca. 2.1 to 1.0 Ma; and Zone III is characterized by seven cycles of warm-and-wet and cold-and-dry climate from 1.0 Ma to present, which reflect the repetition of glacial and interglacial periods. The last cold maximum at 11 m depth seems to correspond to the last glacial age around 20 kyr B.P.

The sedimentation rate of the drill-well was estimated from an approximate age-depth plot based on approximate ages inferred by comparison between the palaeoclimatic curve drawn by pollen analysis and $\delta^{18}O$ curve obtained from planktonic foraminifers of deep-sea sediments in the Indian Ocean. Consequently, the average sedimentation rate of the uppermost part from 115 m to 11 m in depth is estimated at 104 mm/kyr.

INTRODUCTION

The Kathmandu Valley is located in the southern slope of the Himalaya, and its basin-fill sediment is one of the best archives of the Himalayan uplift and past monsoon climate, as discussed in Sakai (2001a). The first comprehensive geological investigation on the Kathmandu Basin sediments was carried out by Yoshida and Igarashi (1984); Igarashi et al. (1988); and Yoshida and Gautam (1988), and they outlined the palaeoclimatic history in the Kathmandu Valley. However, they could not have reconstructed a continuous palaeoclimate record, because their analysed samples were limited to only surface exposures which were scattered and discontinuous. We could fortunately obtain a series of slimes taken from a 284.3-m-long drill well in the western central part of the Kathmandu Basin, and could have reconstructed rather continuous palaeoclimatic record during the last 2.5 myr by means of palynological study (Fujii and Sakai 2002). In this paper, we report the result of palynological study and discuss on the changes of the palaeoclimate and sedimentation rate in the Palaeo-Kathmandu Lake.

MATERIAL AND METHOD

We carried out pollen analysis by 189 pieces of slime, collected at one-metre intervals from a series of slimes obtained from a 284.3-m-long drill well, numbered JW-3. As the samples are discrete slimes of water saturated mud collected by a rotary auger, one sample is mixed material within each one-metre-section. The drill site is located on the west bank of the Bagmati River at Balkhu (local name is Sundarighat) in the western central part of the Kathmandu Basin (Fig. 1). The drilled sediments consist of 218 m thick of muddy beds and 66.3 m of sandy beds. The well reached basement rocks of the Kathmandu Complex. A sand-predominant lower part from 284.3 m to 233 m belongs to the Bagmati Formation, and overlying silt and clay-dominant part from 233 m to 6 m corresponds to the Kalimati Formation (Sakai 2001b). As the uppermost beds from 6 m to land surface are cultivated, the sediments except from samples of pollen analysis.

Fossil pollen and spores were extracted from the muddy samples (Fig. 2) by using 10% KOH-$ZnCl_2$ (s.g. 1.78)-acetolysis method (modified from Nakamura 1967). Microfossil slides of the treated material were mounted in glycerol. We counted the AP (arboreal pollen) over 200 grains for each sample. In the pollen diagram, percentage values for each genus of AP (arboreal pollen) were calculated on the basis of the sum of the AP. The relative frequencies of individual taxa for NAP (non-arboreal pollen: herb pollen and fern spore) were calculated as percentages of the total sum of pollen and spores.

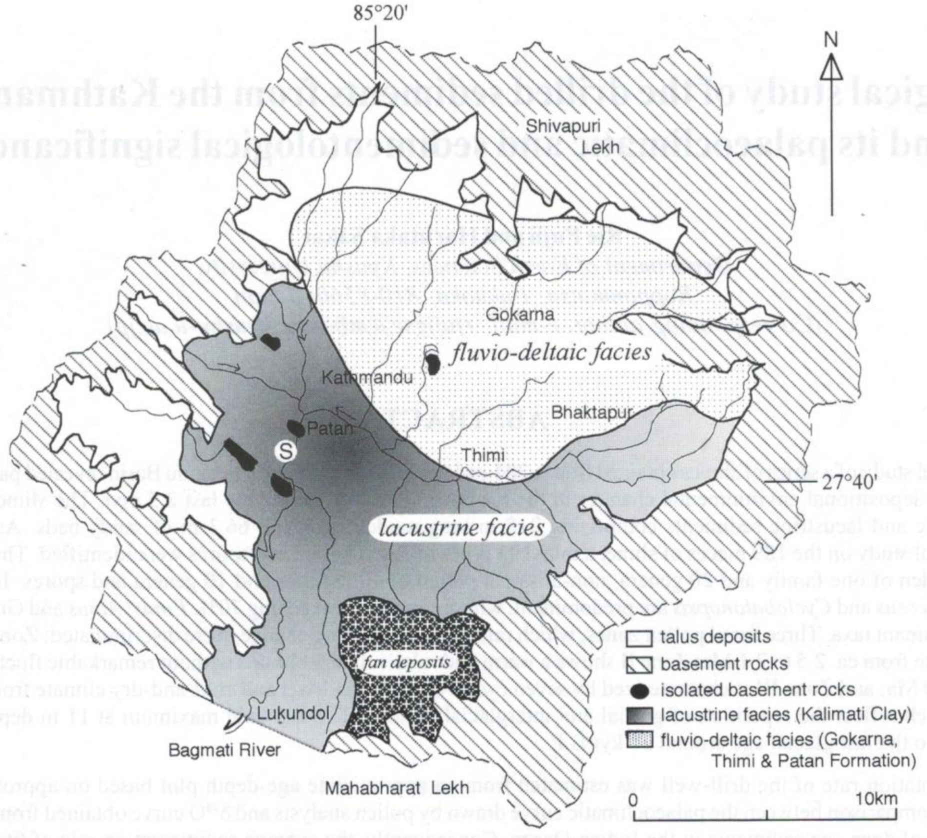

Fig. 1: Sedimentary facies map showing the distribution of lacustrine, marginal lacustrine, and alluvial depositional environments of the Palaeo-Kathmandu Lake during the late Pleistocene. S: Location of drill-well JW-3 at Sundarighat.

RESULTS OF PALYNOLOGICAL ANALYSIS

We identified a total of 43 types of fossil pollen and spores, of which comprise arboreal pollen of one family and 20 genera, non-arboreal pollen of 10 families and 10 genera and spores from the 189 pieces of samples (Table 1). Genera or families, which are difficult to identify, remain unknown. Pollen of 7 families and 20 genera and spores are plotted in Fig. 3. Pollen at less than 1% are not included in the pollen diagram. They are as follows: *Podocarpus*, *Symplocos*, *Elaeagnus*, *Ilex*, *Tilia*, *Fagus*, *Jasmium*, *Geranium*, Caryophyllaceae, *Iris*, *Trapa*, Ranunculaceae, Umbelliferae, *Nymphoides*. Among the arboreal pollen, the predominant taxa are *Quercus* (14–80%), *Pinus* (0–77%), *Cyclobalanopsis* (0–51%), *Alnus* (1–28%), and especially *Quercus* pollen maintains consistently high percentage in all horizons. Pollen of the warm temperate evergreen broad-leaved trees such as *Castanopsis* comprises 0 to 24%. Pollen of temperate and alpine conifer trees such as *Picea, Abies* and *Tsuga* are present, but each ratio is less than 3%.

Among non-arboreal pollen, Gramineae shows the highest percentage, and its frequency ranges from 1 to 35%. *Pediastrum*, a planktonic green alga, sporadically occurs in some horizons and increases in frequency up to 21% at a depth of 111 m. Aquatic plants such as *Trapa* are detected. Pollen of Cyperaseae and *Typha*, which lives at the waterside, are present.

We constructed the following three major pollen zones (Fig. 3), on the basis of significant changes of relative abundance and assemblage of fossil pollen. The boundaries were mainly based on changes of percentages of *Pinus* and *Quercus*.

Zone I (266-209 m)

This zone is characterized by high percentage of *Pinus* and common occurrence of *Tsuga*. Value of *Pinus* pollen is higher than that in Zone II, whereas *Quercus* is less than that in Zone II. *Castanopsis* pollen appears only from the upper part of this zone. Spores attain very high percentage from 221 m to 226 m. Pollen of aquatic plants such as *Typha* and *Trapa* are present at 0.3-4.4%.

Zone II (209-115 m)

The percentage of *Pinus* pollen in this zone decreased, whereas *Quercus* increased in comparison with Zone I. *Cyclobalanopsis* pollen shows particularly high percentage from 135 m to 148 m. Pollen of a evergreen broad-leaved tree such as *Castanopsis* was continuously present at 0.5–11% in this zone. Temperate and alpine conifer trees pollen such

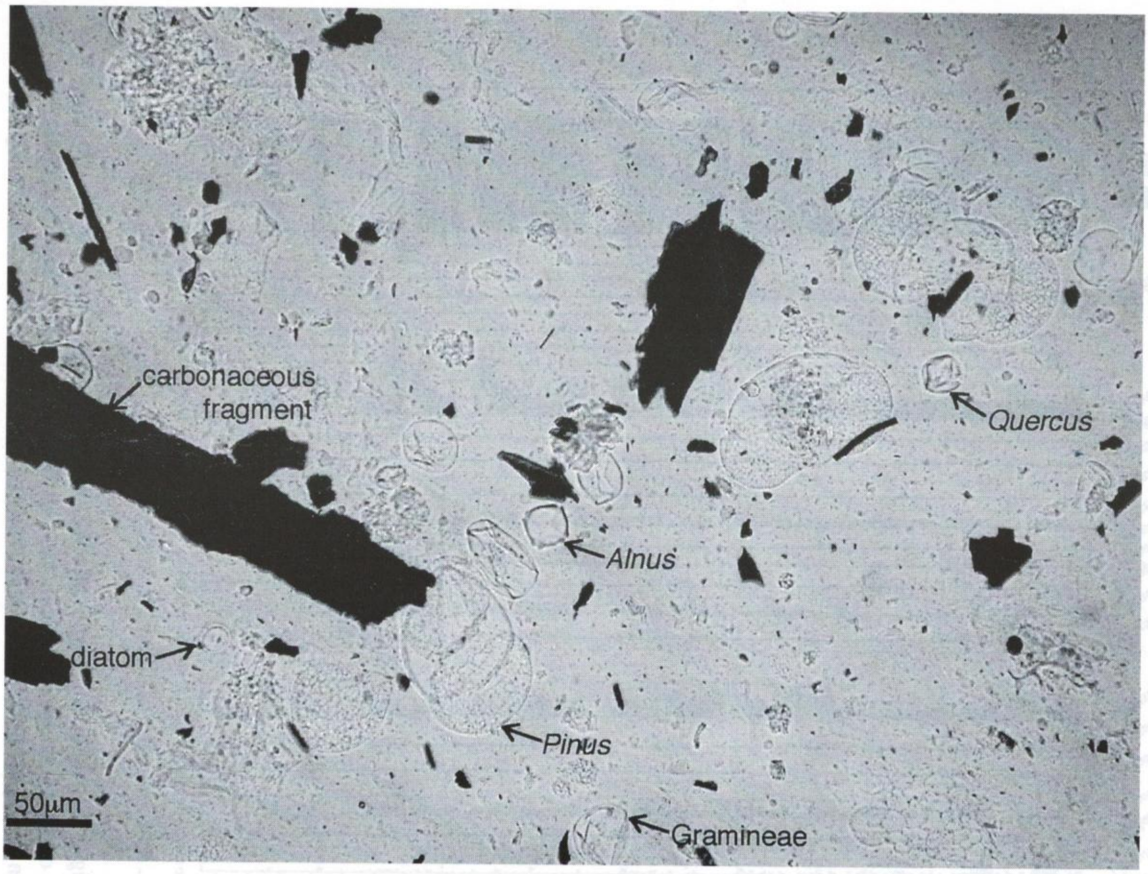

Fig. 2: Photo micrograph of fossil pollens and diatoms extracted from organic mud (Kalimati clay) at 96 m depth.

Table 1: List of fossil pollen detected in the 189 pieces of slime collected from a drill-well JW-3.

Gymnosperms	*Betula*	Geraniaceae	*Jasminum*
Pinaceae	*Carpinus*	*Geranium*	Gentianaceae
Abies	*Corylus*	Aquifoliaceae	*Nymphoides*
Picea	Fagaceae	*Ilex*	Compositae
Tsuga	*Castanopsis*	Balsaminaceae	*Artemisia*
Larix	*Fagus*	*Impatiens*	**Monocotyledons**
Pinus	*Quercus*	Tiliaceae	Typhaceae
Cedrus	*Cyclobalanopsis*	*Tilia*	*Typha*
Podocarpaceae	Ulmaceae	Elaeagnaceae	Gramineae
Podocarpus	*Ulmus*	*Elaeagnus*	Cyperaceae
Angiosperms	Polynonaceae	Hydrocaryaceae	Iridaceae
Dicotyledons	*Persicaria*	*Trapa*	*Iris*
Myricaceae	Chenopodiaceae	Umbelliferae	**Pteridophytes**
Myrica	Caryophyllaceae	Ericaceae	spore
Juglans	Ranunculaceae	Symplocaceae	**Algae**
Betulaceae	Cruciferae	*Symplocos*	*Pediastrum*
Alnus	Leguminosae	Oleaceae	

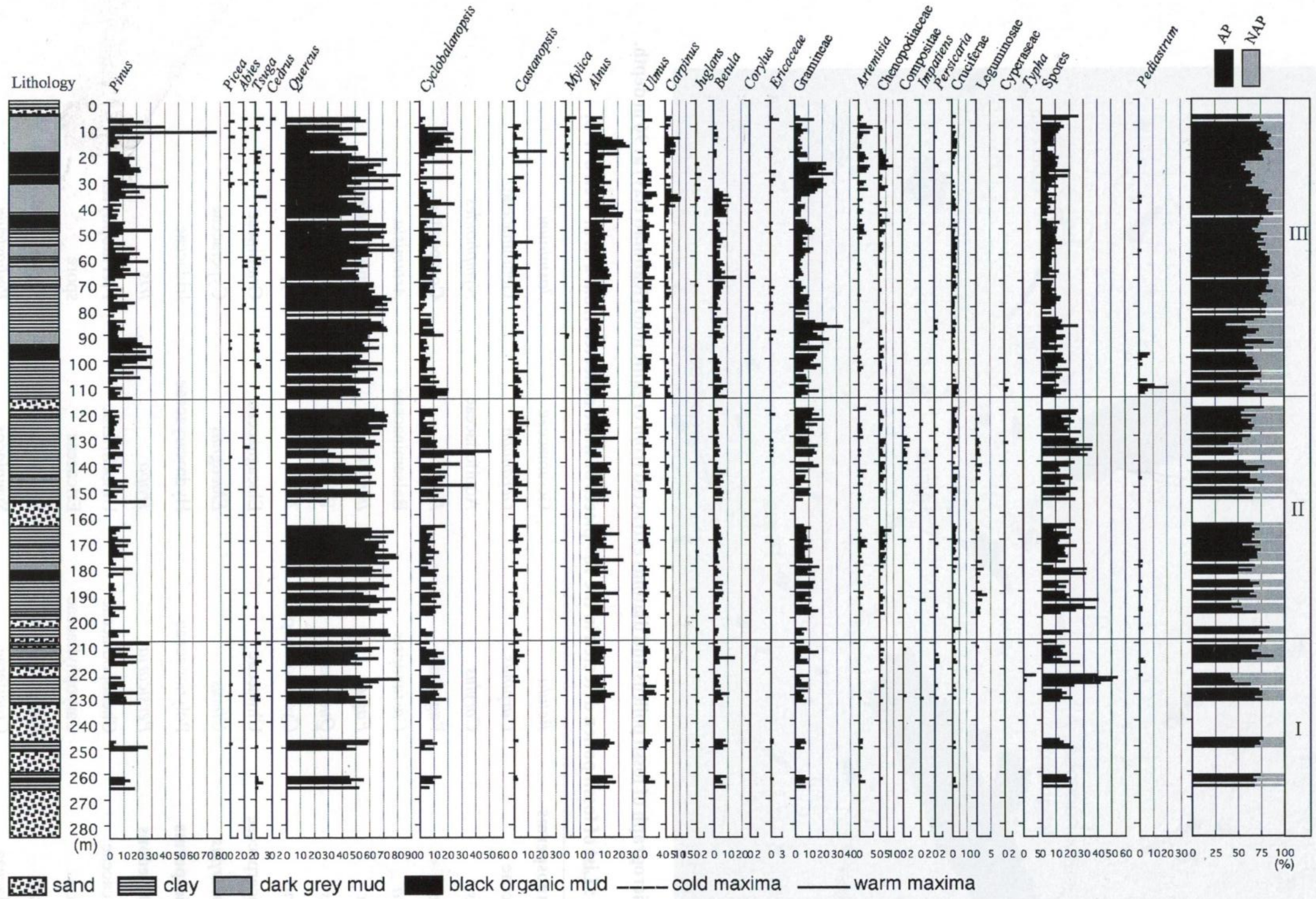

Fig. 3: Pollen diagram obtained from drill-well JW-3 at Sundarighat (Fig. 1). Lithostratigraphy of the 284 m drill-well is shown in the left hand column. Pollen relative frequencies from *Pinus* to *Ericaceae* are calculated on the total arboreal pollen sum, expressed as percentages for each taxon. Relative frequencies of pollen and spores from *Gramineae* to *Pediastrum* on the right hand side show the ratio of each taxon to the total sum of pollen and spores. The ratio of arboreal pollen to non-arboreal pollen is shown in the right column.

as *Picea*, *Abies* and *Tsuga* were extremely rare. Among the NAP, diversity of species becomes high, and spores show high values.

Zone III (115-6 m)

The most characteristic feature of this zone is the cyclic fluctuation of frequency of some pollen. *Pinus, Quercus* and *Cyclobalanopsis* repeat seven times at 10–25 m intervals. *Picea*, *Abies* and *Tsuga* are frequently present in comparison with Zone I and II, but their values are low. In several horizons, *Alnus*, *Betula*, *Carpinus* and Gramineae show prominent peaks. *Artemisia* and Chenopodiaceae increase in the upper part of the Zone III. The value of spores decreases. Cyperaceae pollen is present from 108 m to 113 m, but low percentage of 0.3-1.2%. *Cedrus*, which prefers drier condition and is not recently present in the Kathmandu Valley, occurs at 0.7-1.0% in three samples from this zone. Another characteristic feature is abrupt appearance and increase of *Pediastrum* at the beginning of the Zone III.

DISCUSSION

Reconstruction of palaeoclimate

In order to reconstruct the palaeoclimate in the Kathmandu Valley, we used fossil pollen of 7 families and 20 genera, shown in the pollen diagram (Fig. 3). The following genera and family were used as main indicators of palaeoclimate: *Pinus* as cold climate, *Quercus* and *Cyclobalanopsis* as warm climate, *Alnus* as wet climate, and Gramineae as dry climate. Changes of the pollen compositions both in our study and previous studies generally show the following similar trends; *Pinus* increases corresponding to appearance and increase of coniferous tree pollen such as *Picea*, *Abies* and *Tsuga*, whereas *Quercus* increases corresponding to appearance and increase of pollen of warm temperate, such as *Castanopsis*.

The ages of samples could not be estimated, because samples were discontinuous and mixed up slimes and not suitable for ^{14}C dating and palaeomagnetic study. We, therefore, estimated the age of the top of the drill-well JW-3 on the basis of the ^{14}C ages of core at Santibasti 400 m to the northeast and an open pit at Bir Hospital in Kathmandu (Fujii and Sakai 2002). Furthermore, we made a palaeoclimatic curve drawn by fluctuation of pollen and δ^{18}O curve obtained from planktonic foraminifers of deep-sea sediments in the Indian Ocean (Fig. 4 and 5; Fujii and Sakai 2002).

According to pollen assemblage and changes of frequency in the pollen diagram, we divided the palaeoclimatic record into three main periods corresponding to three pollen zones (Fig. 4).

2.5~2.1 Ma (Pollen zone I)

Zone I is characterized by high percentage of *Pinus* and frequent occurrence of *Tsuga* and *Betula*. This means that the climate in Zone I was cool. From 232 m in depth, *Persicaria* and Chenopodiaceae pollen begin to occur, and then percentages of spores and *Typha* are temporary high probably due to local environment changes such as formation of marshes at the site. This environmental change expected from the trends of NAP is also consistent with lithological change from sand dominant beds to mud dominant beds. In the upper part of the Zone I, *Castanopsis* pollen starts to occur, and then it consistently appears throughout the Zone II.

2.1~1.0 Ma (Pollen zone II)

Quercus pollen also increases in Zone II. On the other hands, *Pinus* pollen decreases in Zone II and coniferous trees such as *Tsuga*, *Picea* and *Abies* pollen are found only at some horizons throughout Zone II. Moreover, *Betula* pollen decreases, whereas *Gramineae* pollen increases and diversity of NAP becomes high. Hence, it was generally warm and dry climate in Zone II, except at the middle part which shows cool climate as shown by increase of *Pinus* and occurrence of *Picea* and *Abies*.

1.0 Ma~Present (Pollen zone III)

In Zone III, climate repeats prominent fluctuation in comparison with Zone I and II. *Pinus* and Gramineae pollen repeat increase and decrease in seven times. *Quercus* and *Cyclobalanopsis* repeat increase and decrease in six cyclic fluctuations. *Alnus*, *Carpinus* and *Betula* also show the similar fluctuation. Hence, the Zone III is characterized by seven times cycle of warm-and-wet and cold-and-dry climate, which reflects repetition of glacial and interglacial age.

Our palaeoclimatic reconstruction is incomplete and involves basic problems on identification of indicators of climate. As previous workers pointed out (Yasuda and Tabata 1988; Nakagawa et al. 1996), there are two types of pine tree in central Nepal: *Pinus roxiburghii* and *Pinus wallichiana.* The former is found in rather low altitude between 300 and 2,000 m under warm climate, on the other hand, the latter occurs from 1,800 m up to the tree line at about 4,000 m under cold climate (Jackson 1994). In addition, oaks grow in wide range of altitude from 450 to 3,800 m, though they are a dominant feature of the vegetation in the Nepal Lesser Himalaya. In order to estimate the accurate palaeoclimate on the basis of pollen analysis, we need to distinguish differences of each spices of pines and oaks by means of scanning electron microscope (Yasuda and Tabata 1988; Nakagawa et al. 1996). In the present study, observation and identification of fossil pollen were carried out by only optical microscope, because our study was precursory study for the academic drilling

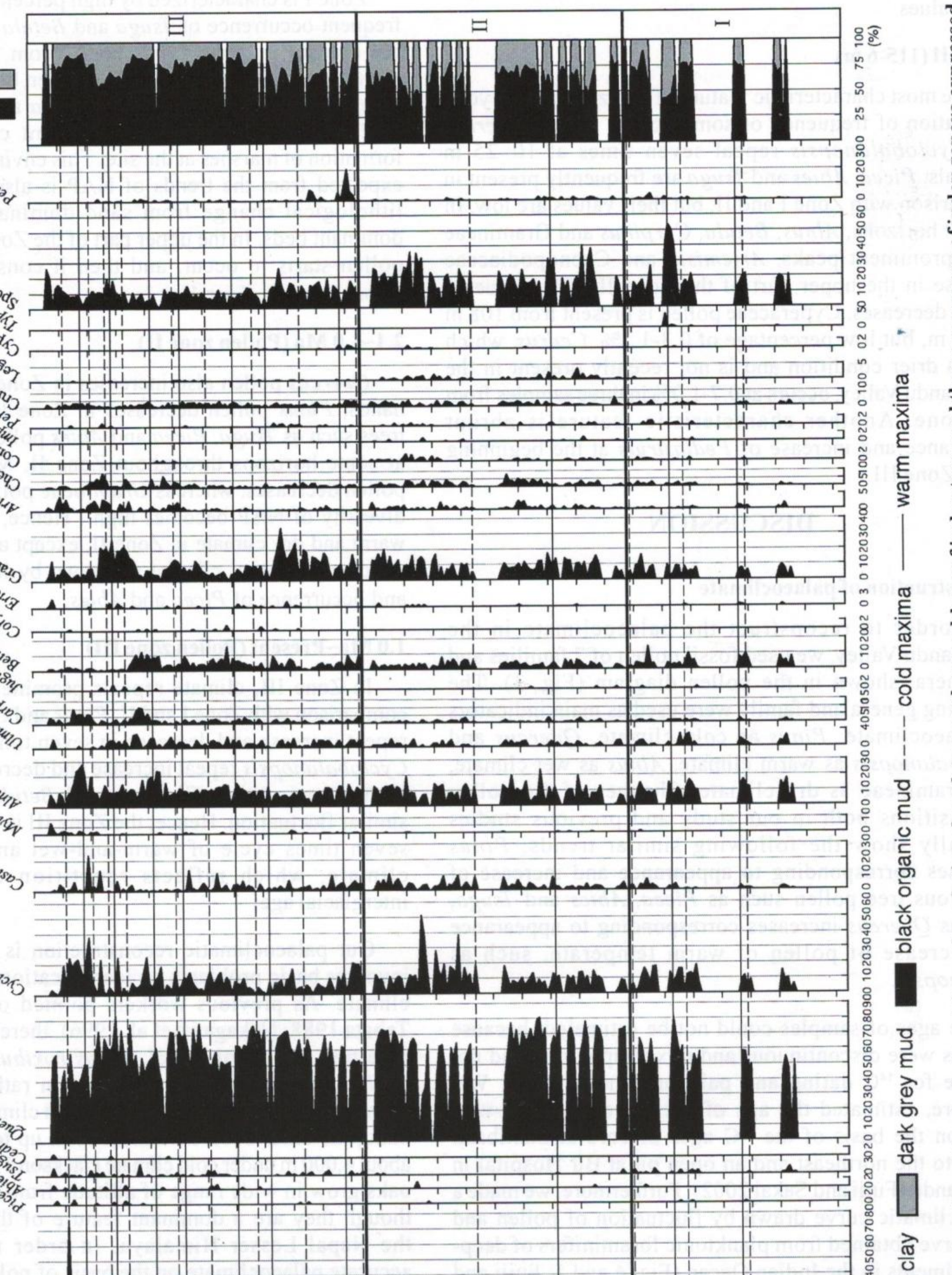

Fig. 4: Fluctuations in palaeoclimate deduced from the relative abundance and assemblage of index taxa and the appearance of index genera expressed in the pollen diagram. Solid lines show warm climate and dashed lines indicate cold climate maxima, respectively.

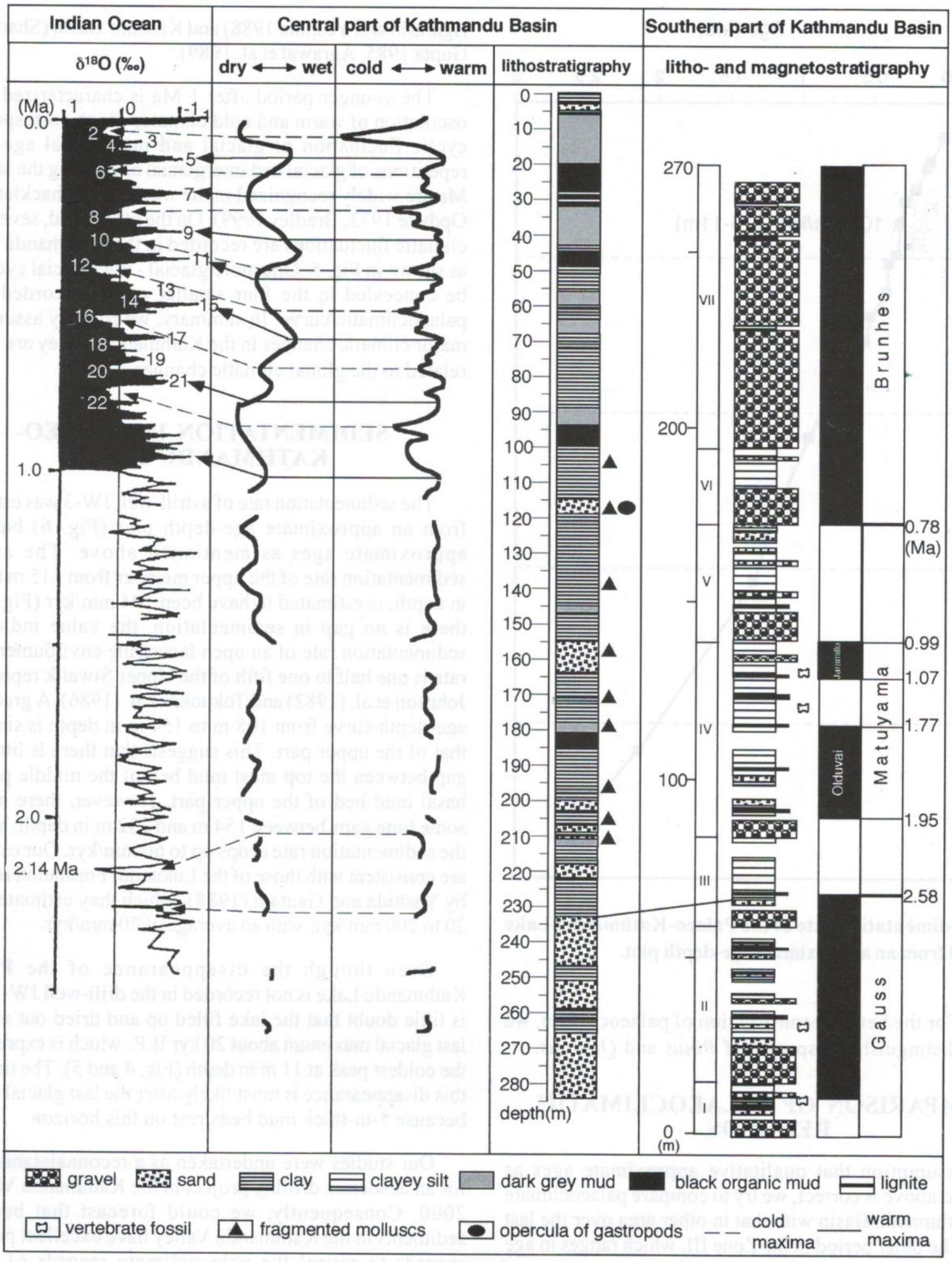

Fig. 5: Comparison of the δ18O variation curve from Ocean Drilling Program (ODP), site 722 (Prell et al. 1992), and a curve of palaeoclimatic changes based on pollen analysis of the 284-m-long drill-well from the central part of the Kathmandu Basin. Comparison of the lithostratigraphy of a series of slimes from the 284-m-long drill-well and the magnetostratigraphy of the Lukundol Formation in the southern part of the Kathmandu Basin (Yoshida and Gautam 1988).

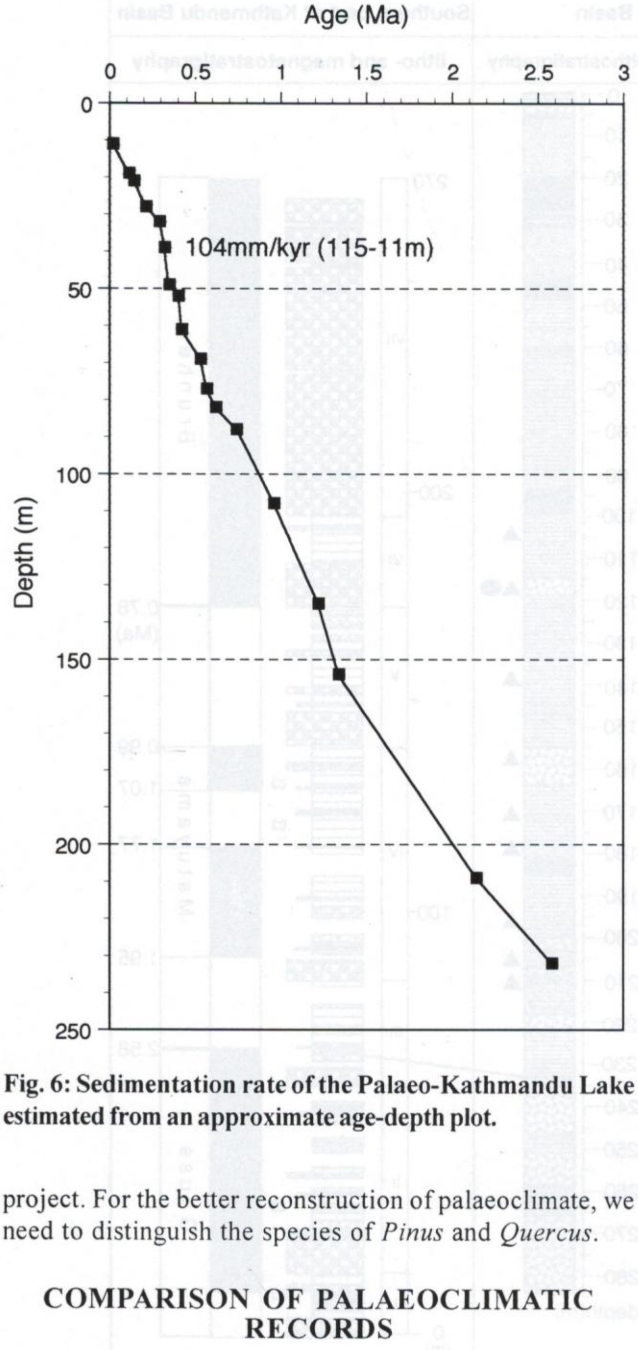

Fig. 6: Sedimentation rate of the Palaeo-Kathmandu Lake estimated from an approximate age-depth plot.

project. For the better reconstruction of palaeoclimate, we need to distinguish the species of *Pinus* and *Quercus*.

COMPARISON OF PALAEOCLIMATIC RECORDS

On assumption that qualitative approximate ages as mentioned above is correct, we try to compare palaeoclimate in the Kathmandu Basin with that in other area over the last 2.5 Ma. The older period in the Zone III, which ranges in age from ca. 2.5 to 2.1 Ma, is characterized by the dominance of a cool climate with relatively less climatic fluctuation.

The middle period covers about one million years, ranging in age from 2.1 to 1.1 Ma (Fig. 5) and shows generally warm and dry climate in the Zone II, which gradually changes from rather cold climate in Zone I. Temporary cold climate in the middle part of the Zone II, which ranges from 1.16~1.46 Ma, is also recorded in the palaeoclimate from this area (Igarashi and Yoshida 1988) and Kashmir Basin (Sharma and Gupta 1985; Agrawal et al. 1989).

The younger period after 1 Ma is characterized by the oscillation of warm and cold climate, which corresponds to cyclic fluctuation of glacial and interglacial age. Eight repetitions of glacial and interglacial age during the last 0.78 Ma are widely recognized in the world (e.g. Shackleton and Opdyke 1973; Bradley 1999). On the other hand, seven times climatic fluctuations are recorded in the Kathmandu Valley, as shown in Fig. 5. One more glacial - interglacial cycle may be concealed in the four smaller cycles recorded in the palaeoclimatic curve. In summary, we roughly assume that major climatic changes in the Kathmandu Valley are closely related to the global climatic changes.

SEDIMENTATION IN PALAEO-KATHMANDU LAKE

The sedimentation rate of a drill-well JW-3 was estimated from an approximate age-depth plot (Fig. 6) based on approximate ages as mentioned above. The average sedimentation rate of the upper member from 115 m to 11 m in depth, is estimated to have been 104 mm/kyr (Fig. 6). As there is no gap in sedimentation, the value indicates a sedimentation rate of an open lacustrine environment. This rate is one half to one fifth of the Upper Siwalik reported by Johnson et al. (1982) and Tokuoka et al. (1986). A gradient of age-depth curve from 108 m to 154 m in depth is similar to that of the upper part. This suggests that there is little time gap between the top most mud bed of the middle part and basal mud bed of the upper part. However, there must be some time gaps between 154 m and 232 m in depth, because the sedimentation rate drops up to 60 mm/kyr. Our estimates are consistent with those of the Lukundol Formation reported by Yoshida and Gautam (1988), which they estimated to be 20 to 200 mm/kyr, with an average of 70 mm/kyr.

Even though the disappearance of the Palaeo-Kathmandu Lake is not recorded in the drill-well JW-3, there is little doubt that the lake filled up and dried out after the last glacial maximum about 20 kyr B.P., which is expressed as the coldest peak at 11 m in depth (Fig. 4 and 5). The timing of this disappearance is most likely after the last glacial period, because 5-m-thick mud beds rest on this horizon.

Our studies were undertaken as a reconnaissance study for an academic drilling project in the Kathmandu Valley in 2000. Consequently, we could forecast that basin-fill sediments in the Kathmandu Valley have excellent potential records to reveal the palaeoclimate records of Indian monsoon. Fortunately, Japan-Nepal collaborative academic drilling project in the Kathmandu Valley, named "Paleo-Kathmandu Lake Project 2000" were inaugurated in 2000, and we could have valuable opportunities to drill three cores in the Kathmandu Valley in 2000. As a result, we could obtain a 218-m-long continuous core, and we are progressing palaeomagnetical, chemical, clay mineralogical and palynological studies. It is expected that those results will provide a more complete palaeoclimatic record in the Kathmandu Valley.

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REFERENCES

Agrawal, D. P., Dodia, R., Kotlia, B. S., Razdan, H., and Sahni, A., 1989, The Plio-Pleistocene geologic and climatic record of the Kashmir valley, India: a review and new data. Palaeogeogr. Palaeoclim. Palaeoecol., v. 73, pp. 267–286.

Bradley, R. S., 1999, Palaeoclimatology: Reconstructing climates of the Quaternary 2nd ed. International Geophysics Series 64, Academic Press, 613 p.

Fujii, R. and Sakai, H., 2002, Palaeoclimatic changes during the last 2.5 myr recorded in the Kathmandu Basin, central Nepal Himalayas. Jour. Asian Earth Sci., v. 20, pp. 255–266.

Igarashi, Y., Yoshida, M., and Tabata, H., 1988, History of vegetation and climate in the Kathmandu Valley. Proc. Indian natn. Sci. Acad. 54; A 4, pp. 550–563.

Jackson, J. K., 1994, Manual of afforestation in Nepal. Forest Research and Survey Centre, Ministry of Forests and Soil Conservation, Kathmandu, Nepal, 824 p.

Johnson, N. M., Opdyke, N. D., Johnson, G. D., Lindsay, E. H., and Tahirkheli, R. A. K., 1982, Magnetic polarity stratigraphy and ages of Siwalik Group rocks of the Potwar Plateau, Pakistan. Palaeogeogr. Palaeoclim. Palaeoecol., v. 37, pp. 17–42.

Nakagawa, T., Yasuda, Y., and Tabata, H., 1996, Pollen morphology of Himalayan *Pinus* and *Quercus* and its importance in palynological studies in Himalayan area. Review of Palaeobotany and Palynology., v. 91, pp. 317–329.

Nakamura, J., 1967. Pollen Analysis. Kokonshoin Publisher, Tokyo, 232 p. (in Japanese).

Prell, W. L., Murray, D. W., Clemens, S. C., and Anderson, D. M., 1992, Evolution and variability of the Indian Ocean Summer Monsoon: evidence from the western Arabian Sea Drilling Program. In: Duncan, R. A., Rea, D. K., Kidd, R. B., von Rad, U., Weissel, J. K. (eds.), Synthesis of Results from Scientific Drilling in the Indian Ocean. Geophys. Monogr. Ser. 70, AGU, pp. 447–469.

Sakai, H., 2001a, The Kathmandu Basin: An archive of the Himalayan uplift and ancient monsoon cliamte. Jour. Nepal Geol. Soc., v. 25 (Sp. Issue), pp. 1–8.

Sakai, H., 2001b. Stratigraphic division and sedimentary facies of the Kathmandu Basin Sediments. Jour. Nepal Geol. Soc., v. 25 (Sp. Issue), pp. 19–32.

Shackleton, N. J. and Opdyke, N. D., 1973, Oxygen isotope and palaeomagnetic strratigraphy of equatorial Pacific core V28-238: Oxygen isotope temperatures and ice volumes on a $10^5$and 10^6 year scale. Quaternary Research, v. 3, pp. 39–55.

Sharma, C. and Gupta, H. P., 1985, Palynostratigraphy and palaeoenvironments: Krachipatra, Lower Karewa, Kashmir. In: Agrawal, D.P., Kusumgar, S., Krishnamurthy, R.V. (eds), Climate and Geology of Kashmir and Central Asia: the Last 4 Million Years. Today and Tomorrow's Publishers, New Delhi, pp. 91–96.

Tokuoka, T., Takayasu, K., Yoshida, M., and Hisatomi, K., 1986, The Churia (Siwalik) Group of the Arung Khola Area, West Central Nepal. Memoirs of the Faculty of Science, Shimane University, v. 20, pp. 135–210.

Yasuda, Y. and Tabata, H., 1988, Vegetation and climatic changes in Nepal Himalayas II. A preliminary study of the Holocene vegetational history in the Lake Rara National Park area, west Nepal. Proc. Indian natn. Sci. Acad. 54; A 4, pp. 538–549.

Yoshida, M. and Igarashi, Y., 1984, Neogene to Quaternary lacustrine sediments in the Kathmandu Valley, Nepal. Jour. Nepal Geol. Soc., v. 4 (Sp. Issue), pp. 73–100.

Yoshida, M. and Gautam, P., 1988, Magnetostratigraphy of Plio-Pleistocene lacustrinedeposits in the Kathmandu Valley, central Nepal. Proc. Indian natn. Sci. Acad. 54; A 3, pp. 410–417.