Quaternary Research 72 (2009) 377–387

Contents lists available at ScienceDirect

Quaternary Research

journal homepage: www.elsevier.com/locate/yqres

Ecological variations in diatom assemblages in the Paleo-Kathmandu Lake linked with global and Indian monsoon climate changes for the last 600,000 years

Tatsuya Hayashi [a,*], Yoshihiro Tanimura [a], Yoshihiro Kuwahara [b], Masao Ohno [b], Mami Mampuku [b], Rie Fujii [c], Harutaka Sakai [c], Toshiro Yamanaka [d], Takeshi Maki [e], Masao Uchida [f], Wataru Yahagi [g], Hideo Sakai [g]

[a] Department of Geology and Paleontology, National Museum of Nature and Science, 3-23-1 Hyakunin-cho, Shinjuku-ku, Tokyo 169-0073, Japan
[b] Department of Environmental Changes, Faculty of Social and Cultural Studies, Kyushu University, Motooka, Nishi-ku, Fukuoka 819-0395, Japan
[c] Department of Geology and Mineralogy, Kyoto University, Kyoto 606-8502, Japan
[d] Graduate School of Natural Science and Technology, Okayama University, Tsushima, Okayama 700-8530, Japan
[e] Japan Agency for Marine-Earth Science and Technology, Natsushima, Yokosuka 237-0061, Japan
[f] Environmental Chemistry Division, National Institute for Environmental Studies, Tsukuba 305-8560, Japan
[g] Department of Earth Sciences, Toyama University, Gofuku, Toyama 930-8555, Japan

A R T I C L E I N F O

Article history:
Received 10 August 2008
Available online 27 August 2009

Keywords:
Paleo-Kathmandu Lake
Nepal Himalaya
Middle to late Pleistocene
Indian monsoon
Fossil diatom
Monospecific diatom assemblage
Biogenic silica content
Productivity
Composition of diatom assemblage

A B S T R A C T

Variations in fossil diatom assemblages and their relationship with global and Indian monsoon climate changes for the last 600,000 yr were investigated using a core of ancient lake (Paleo-Kathmandu Lake) sediments drilled at the Kathmandu Basin, Nepal Himalaya. Chronological scales of the core were constructed by tuning pollen wet and dry index records to the SPECMAP $\delta^{18}O$ stack record. Examinations of biogenic silica contents and fossil diatom assemblages revealed that variations in productivity and compositions of diatom assemblages were closely linked with global and Indian monsoon climate changes on glacial and interglacial time scales. When summer monsoonal rainfall increased during interglacials (interstadials), diatom productivity increased because of increased inputs of terrestrial nutrients into the lake. When summer monsoonal rainfall reduced and/or winter monsoonal aridification enhanced during glacials (stadials), productivity of the diatoms decreased and lake-level falling brought about changes in compositions of diatom assemblages. Monospecific assemblages by unique *Cyclotella kathmanduensis* and *Puncticulata versiformis* appeared during about 590 to 390 ka. This might be attributed to evolutionary fine-tuning of diatom assemblages to specific lake environmental conditions. Additionally, low-amplitude precessional variations in monsoon climate and less lake-level changes may have also allowed both species to dominate over the long periods.

Introduction

The Indian monsoon is a dominant climate system controlling environmental conditions in South Asia. Knowledge concerning Indian monsoonal activity and associated environmental changes during the Pleistocene has increased by investigations of marine sediments at the northern Indian Ocean, especially the northwest Arabian Sea (e.g., Clemens and Prell, 1990, 1991, 2003; Clemens et al., 1991, 1996; Prell et al., 1992; Anderson and Prell, 1993). In contrast, such knowledge obtained from the continental interior is extremely limited. In this point, basin-fill sediments of an ancient lake, named the Paleo-Kathmandu Lake, in the Kathmandu Valley on the southern slope of the Nepal Himalaya are expected to record history of changes in the Indian monsoon climate and in associated lake environment over the middle to late Pleistocene (Sakai, 2001a). Therefore, we undertook core-drillings in the Kathmandu Basin and retrieved a 218-m-long core, called Rabibhawan (RB) core (Sakai et al., 2001).

Preliminary studies revealed that sediments of the RB core are abundant in fossil diatom valves (Hayashi et al., 2002; Hayashi, 2007). Interestingly, the fossil diatom assemblages appear to be characterized by periodical changes in abundance and compositions. Fossil diatom assemblages preserved in sediments in large lakes are known to be potential indicators of climatic and environmental changes (Bradbury, 1999). Thus, the fossil diatom assemblages in the RB core sediments are expected to record changes in the Indian monsoon climate and the associated lake environment.

A goal of this study is to reveal variations in productivity and compositions of the diatom assemblages in the RB core sediments and to examine their relationship with global and Indian monsoon climate changes. For these objectives, however, an age model of the RB core is needed. Although it is known that the history of the Paleo-Kathmandu Lake dates back to ca. 1 Ma (Sakai et al., 2006), a preliminary paleomagnetic study revealed that the bottom of the RB core does not reach the Brunhes-Matuyama polarity boundary at about 780 ka, and

* Corresponding author. Fax: +81 3 3364 7104.
E-mail address: hayashit@kahaku.go.jp (T. Hayashi).

0033-5894/$ – see front matter
doi:10.1016/j.yqres.2009.07.003

intensity of remanent magnetization of the RB core sediments is too weak to identify geomagnetic events and excursions and to use them for dating (Yahagi and Hideo Sakai, unpublished data). In addition, it is generally difficult to employ radiometric dating methods except AMS ^{14}C for lake sediments during the Brunhes Chron. For those reasons, most of the chronology of the RB core has remained uncertain, and this has prevented the detailed examination of relationship of changes in fossil diatom assemblages in RB core sediments with global and Indian monsoon climate changes. Therefore, we construct the age model of the RB core based on pollen climate records reconstructed by Fujii (2002) and Maki (2005) before discussing the variations in the diatom assemblages.

Materials and methods

The Kathmandu Basin is an intermontane basin surrounded by mountains of more than 2000 m above the sea level: the Shivapuri Lekh to the north and the Mahabharat Lekh to the south (Fig. 1). The average elevation of the basin floor is approximately 1340 m above sea level. The catchment area of rivers is confined within the inside slope of the valley, and the sedimentary system in the valley is virtually closed. Only the Bagmati River cuts the Mahabharat Lekh to the south of the valley and flows out to the Gangetic Plain.

The RB core was drilled at Rabibhawan in the west-central part of the Kathmandu Basin (27°49′N, 85°29′E, 1303 m above sea level) (Fig. 1). The RB core is lithostratigraphically divided into the Patan and Kalimati Formations (Sakai et al., 2001) (Fig. 2). The Patan Formation, the uppermost 12-m-thick sequence, mainly consists of medium- to very coarse-grained micaceous granitic sands that were derived from the Shivapuri Lekh. This formation is believed to reflect the fact that the lake water started to drain at around 17 ka, and the majority of the Paleo-Kathmandu Lake disappeared by 15 ka (Sakai, 2001b; Hayashi, 2007). The Kalimati Formation, the lower 206-m-thick sequence, is composed of lacustrine sediments in which clayey silt predominates. The lower-most part of the Kalimati Formation, a 38-m-thick sequence below 180 m depth of the RB core, comprises shallow to marginal lacustrine sediments and pebbly mud interbeds, but the core recovery of this part is very poor.

In 83–89.5 m depth of the RB core, a sand bed is interbedded in the lacustrine mud beds of the Kalimati Formation. The sand bed is not observed in the other cores drilled at northern and southern sites of the Kathmandu Basin (see Fig. 5 in Sakai, 2001c). This means that the sand

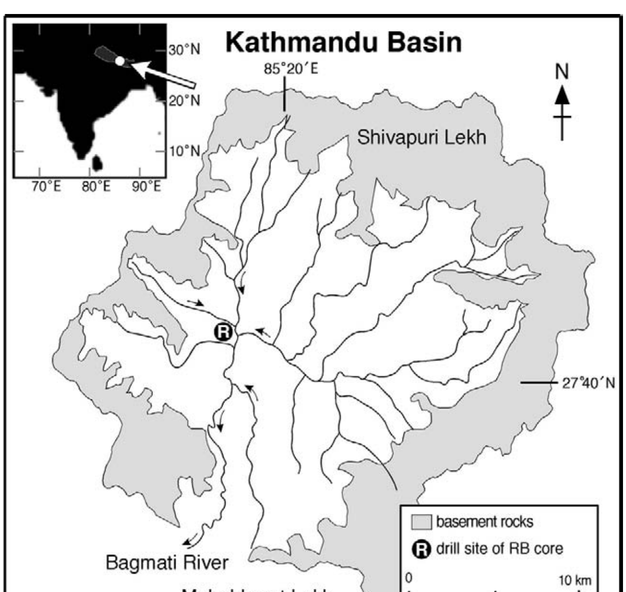

Figure 1. Locations of the Kathmandu Basin and the drill-site of the RB core (27°49′N, 85°29′E, 1303 m above sea level).

bed is not extensively distributed and the lacustrine clayey sequence continues in the subsurface of the Kathmandu Basin. Thus, the sand bed is considered to have deposited in a short period by a local event, such as gravity flow (Sakai, 2001c; Sakai et al., 2001; Hayashi, 2007). In addition, immediately above and beneath the sand bed, significant changes are not observed in fossil diatom assemblages in the RB core that are sensitive to environmental changes (Hayashi, 2007).

For the analysis of biogenic silica (Bio-Si) contents, samples were collected from the RB core at 50-cm intervals from 10.0 to 181.0 m in depth. Organic matter in all Bio-Si samples was removed by 5 ml of 10% H_2O_2 solution, and carbonates and iron oxides were removed by 5 ml of 10% HCl solution. Dissolved Bio-Si contents were extracted by the alkaline extraction method of Mortlock and Froelich (1989) with 0.5 M Na_2CO_3 solution at 85°C, and then Bio-Si values were determined by molybdate-blue spectrophotometry (Strickland and Parsons, 1968).

For the analysis of valve concentrations, dry weights of duplicate samples used for the Bio-Si analysis were measured, and then 10-ml suspensions were created. The 1-ml suspensions were concentrated on membrane filters (0.45-μm pore size) by the Millipore® filter transfer method. At least 300 valves in individual samples were counted along radiuses of the filters under scanning electron microscope (SEM) observation, and numbers of valves per 1 μg were calculated. Then, relative abundances of total planktonic diatoms, total benthic diatoms and individual species were calculated. Degree of overlap of diatom assemblages was calculated using the α index by Pianka (1973):

$$\alpha_{jk} = \sum p_j p_k / \left(\sum p_j^2 \sum p_k^2\right)^{1/2}$$

where p_j and p_k are relative abundances of individual species between adjacent core samples.

In Figure 2, we plot the analytical results of Bio-Si contents and diatom valve concentrations with pollen wet and dry index records reconstructed by analyses of RB core samples at 10-cm intervals from 7.1 to 37.0 m depth, and at 100-cm intervals from 37.5 to 180.5 m depth by Fujii (2002) and Maki (2005). The wet index is defined as total pollen of *Alnus*, *Betula* and *Carpinus* per arboreal pollen, and the dry index is defined as total pollen of *Artemisia*, *Chenopodiaceae*, *Compositae* and *Gramineae* per arboreal and nonarboreal pollen, on the basis of relationship among pollen assemblages of the RB core, present vegetation distribution, and vertical climatic zones in the valley and surrounded mountains (Fujii, 2002; Maki, 2005). Since the wet (dry) index record lacks obvious fluctuation when the dry (wet) index shows high averages, e.g., 127.5–116.5 and 69.5–63.5 m in depth (Fig. 2), a composite wet–dry (CWD) index was calculated by subtracting standardized dry index from standardized wet index in order to examine relative changes between wet and dry conditions. The increase in CWD index value, namely the increase in wet index value and/or the decrease in dry index value, indicates wetter condition.

Spectral analyses (Blackman–Tukey cross-spectral analyses; Jenkins and Watts, 1968) on the time-series pollen CWD index, Bio-Si content, and diatom valve concentration records were performed using the AnalySeries software (Paillard et al., 1996).

Results

Biogenic silica contents

The Bio-Si record of the RB core is characterized by two kinds of fluctuation patterns (Fig. 2). One is large-scale fluctuations repeated at intervals of several tens of meters. There are five major peaks at depths of 52.5 m (16.7 wt.%), 92.0 m (17.5 wt.%), 105.0 m (19.2 wt.%), 136.5 m (21.1 wt.%) and 159.5 m (17.4 wt.%). The large-scale fluctuations are further composed of small-scale fluctuations repeated at 4–6 m intervals. The small-scale fluctuations are pronounced especially at 41.5–54.0, 74.0–119.0 and 134.5–142.5 m depth, with amplitude of 10–