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Mineral composition changes recorded in the sediments from a 284-m-long drill-well in central part of the Kathmandu Basin, Nepal

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ABSTRACT

The mineralogical study on the sub-surface obtained from drill-well JW-3, in the central part of the Kathmandu Basin was first performed by means of X-ray diffraction (XRD). The minerals detected in the sediments are quartz, feldspar, mica, smectite, chlorite, kaolinite, gypsum and calcite. The former three minerals are main constituent of the sediments and their relative proportion is over 70%. In general, the relative proportion of quartz is congruous with that of feldspar but is reverse proportion to that of mica. The clayey phyllosilicate minerals, such as smectite, chlorite and kaolinite are next dominant minerals in the sediments, and the relative proportion of these minerals shows a similar variation pattern to each other. Gypsum and calcite occur sporadically and their ratio is less than a few pecentages, except in some horizons where they exceed 5%.

Variation curves of relative amounts of the minerals are mainly divided into two zones, based on the variation patterns of the minerals. In Zone I below 115 m depth, the variation curves of minerals show gradual cyclic patterns with low amplitude except gypsum and calcite. On the other hand, the variations of mineral contents in Zone II above 115 m depth are larger than those in the Zone I. Particularly, the variation curves of quartz, feldspar and mica show repetition of shorter cycles at 4–7 m intervals which are overlapping a longer cycle at 30–40 m intervals. The change in variation pattern across 115 m depth of the drill-well is similar to that of frequency of each pollen in the same sediments, which depicts the climatic variations in the Kathmandu Basin (Fujii and Sakai 2002). Hence, the mineralogical variation must reflect not only the changes of depositional environments in the Kathmandu Basin but also the climatic variations there. Similar difference of variation pattern of mineral composition in the Zone I and Zone II are also reported from the pollen analysis of the same slimes. This difference seems to be related to global climatic changes.

INTRODUCTION

Mineralogical study on fine-grained detrital sediments provides many valuable information about depositional environments, provenance of detritus, tectonics, eustasy, as well as climate in the region (Chamley 1989). For example, Menking (1997) suggested that the variations in mineral assemblage, mineral composition and mean grain size of sediments in Owens Lake in southeast California reflect the lake-level variations and nature of sediments delivered to the lake varying in concert with global climate changes. There are also many reports that the mineralogical variation in Pliocene-Pleistocene sediments in Mediterranean Range reflects the influence of both southern and northern sources varying due to the uplift of the northern parts of the Range (e.g. Venkatarathnam and Biscaye 1971; Maldonado and Stanley 1981; Chamley 1989).

The basin-fill sediments in the Kathmandu Valley are one of the best archives of history of Indian monsoon and its linkage to uplift of the Himalaya-Tibet orogen (Sakai 2001a). We could fortunately obtain a series of slimes taken from a drill-well in the western central part of the Kathmandu Basin and have firstly reported the continuous climatic records during the last 2.5 million years by means of palynological and sedimentrogical studies (Fujii and Sakai 2002).

The continuous mineralogical study on the sediments, however, has not yet been performed. Thus, we attempt to clarify the variation of mineral composition recorded in a drill-well up to 284 m depth.

MATERIALS AND EXPERIMENTAL METHOD

In order to estimate the relative amount of minerals in the drilled sediments, we examined 211 pieces of slime collected at one-meter intervals from a drill-well JW-3 of 284.3 m in depth by X-ray diffraction (XRD) experiments. The drill-well was located on the west bank of the Bagmati River at Sundarighat in the western central part of the Kathmandu Basin (Fig. 1). The drill-well penetrates the whole sequence of the basin-fill sediments and attains the basement rock. The drill-well sediments consist of muddy beds of 218 m and sandy beds of 66.3 m. Detrital grains of sand beds in JW-3 drill-well are consistently composed of angular, very coarse sand and granules of meta-sediments and minor amount of quartz and feldspar grains.

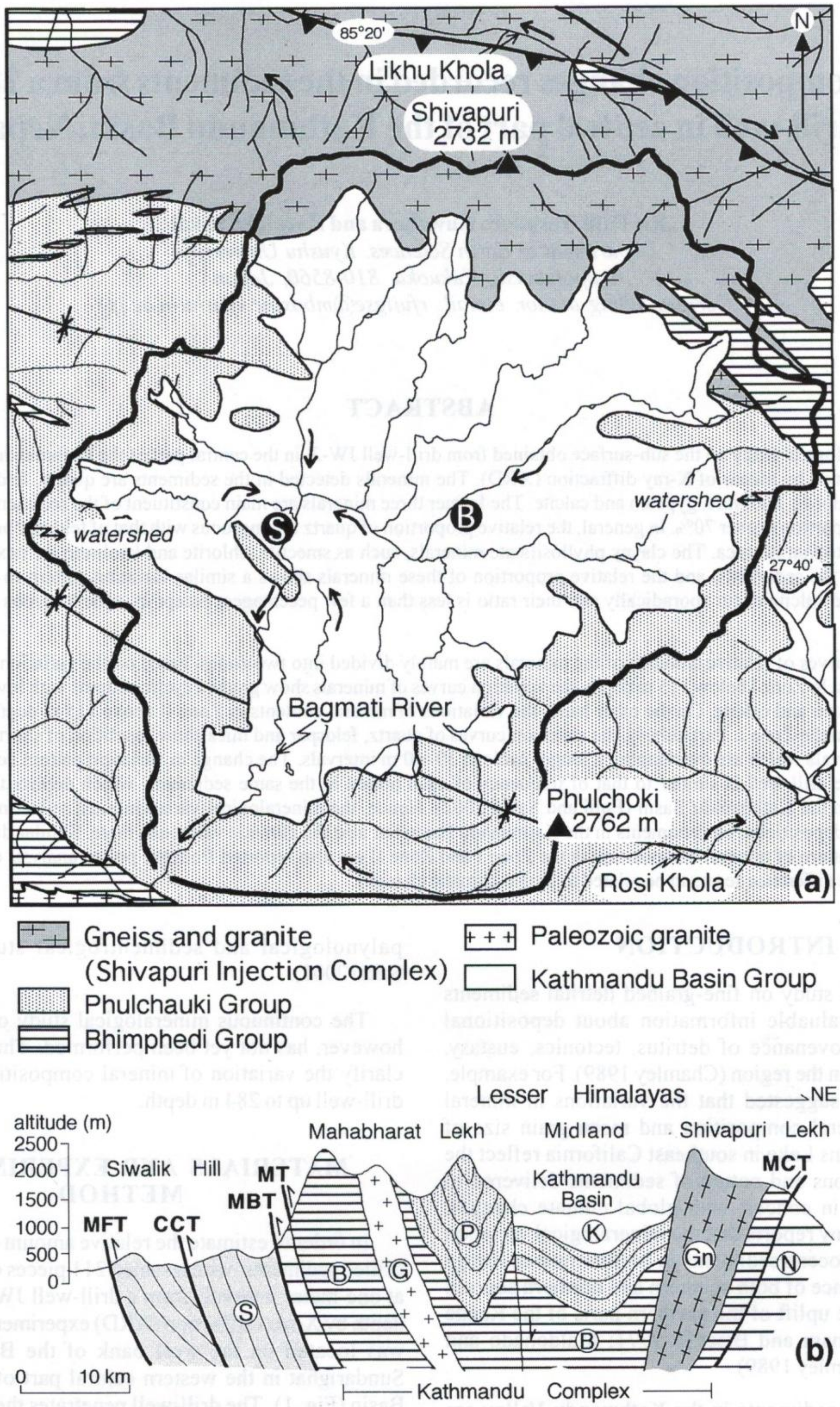

Fig. 1: (a) Simplified geological map of the Kathmandu Valley region (modified after Stöcklin and Bhattarai 1981). JW-3 at Sundarighat (S) and B-1 at Bodegaun (B) drilling sites. (b) A schematic geological cross-section in the Central Nepal Himalayas (modified after Stöcklin and Bhattarai 1981). S: Siwalik Group, B: Bhimphedi Group, P: Phulchauki Group, N: Nawakot Complex, G: Granite, Gn: Gneiss and Granite Complex, K: Kathmandu Basin Group, MFT: Main Frontal Thrust, CCT: Central Churia Thrust, MBT: Main Boundary Thrust, MT: Mahabharat Thrust (Main Central Thrust).

The drilled sediments are lithologically divided into three parts, sand-predominant lower part (284.3–233 m), silt and clay-dominant middle part (233–115 m), and silty mud-predominant upper part (115–6 m). According to the formation name of basin-fill sediments in the central part of the Kathmandu Basin, defined by Sakai (2001b), the lower part corresponds to the Bagmati Formation, and the middle and upper part to the Kalimati Formation. The uppermost beds from 6 m depth to ground surface are cultivated soil. A top bed of the middle part, from 119 to 115 m, comprises very coarse-grained sand containing abundant fossil teeth of fish, opercula of gastropods and fragmented molluscs (Sakai et al. 2002).

Firstly, the homogeneous part of each sample was carefully selected and was then ground to powder in agate mortar. The powder sample was filled in an XRD glass-holder, and the flat surface of the powder sample on the holder was finely serrated with a razor blade to minimize the preferred orientation (Liang et al. 1995; Kuwahara 2000). The samples were examined by a Rigaku X-ray diffractometer RINT 2100V, using CuKa radiation monochoromatized by a curved graphite crystal.

The XRD raw data obtained were treated by a scientific graphical analysis program XRD MacDiff (Petschick 2000) on an Apple Macintosh computer, in order to determine correctly the intensity (peak area) of XRD peak corresponding to each mineral. Here, we treated chlorite and kaolinite as a mixture, because the complex peak of chlorite and kaolinite could not be correctly separated into the individual peaks of the two minerals.

We, then, estimated the relative amount of each mineral using these data to draw the variation curve of mineral composition in the drilled sediment. The relative amount of each mineral was expressed as the relative peak intensity of a given mineral to the total peak intensities of all minerals.

RESULTS

We detected eight minerals, quartz, feldspar, mica, chlorite, kaolinite, smectite, gypsum and calcite in the sediments by XRD (Fig. 2). The main constituent minerals in the sediments are quartz (18-44%), feldspar (15-41%) and mica (12-46%) (Fig. 3). The total value of relative proportion of the three minerals shows over 70%, and also has even over 90% in some horizons. The three minerals generally indicate the trends that quartz and feldspar increase when mica decreases.

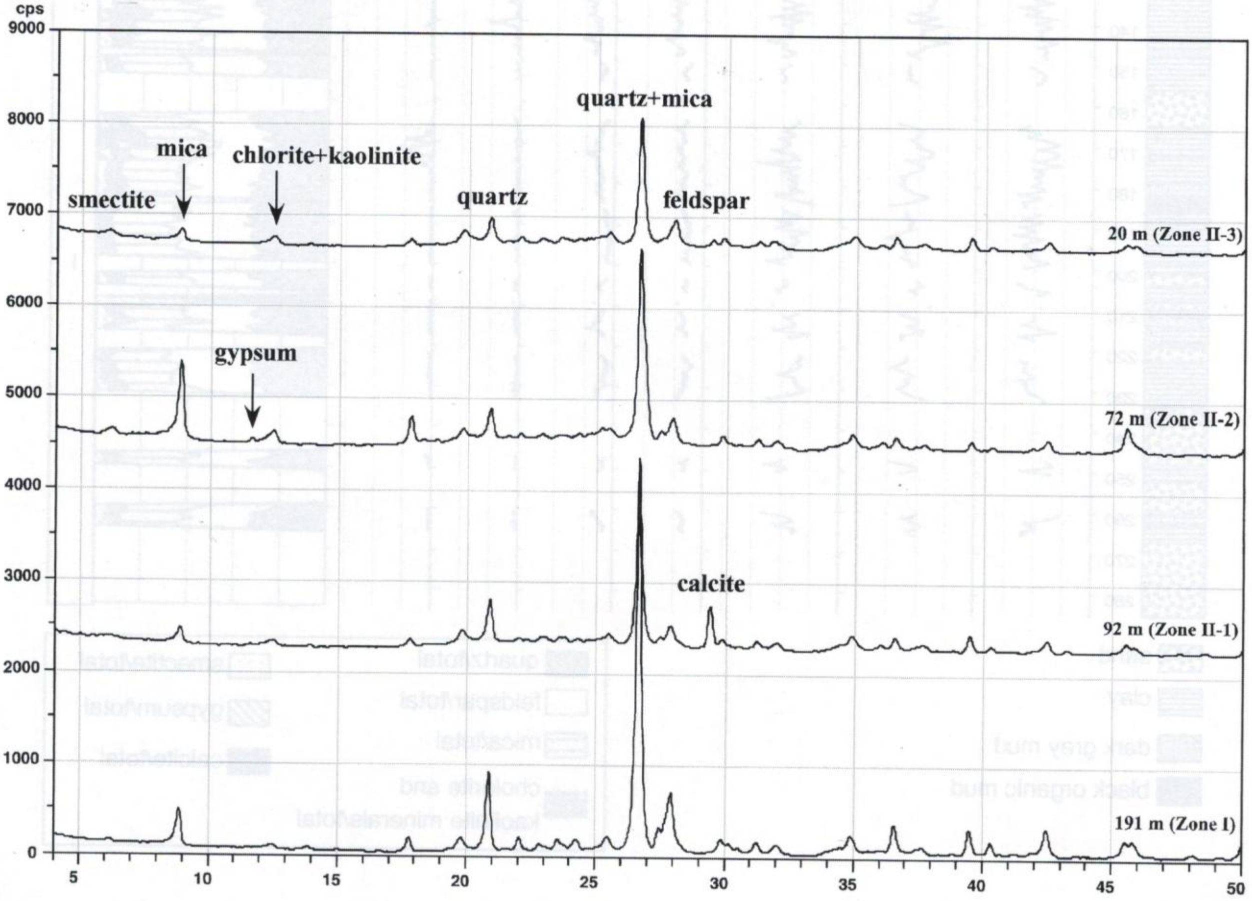

Fig. 2: X-ray diffraction patterns of four representative samples selected from 211 pieces of slime obtained from drill-well JW-3.

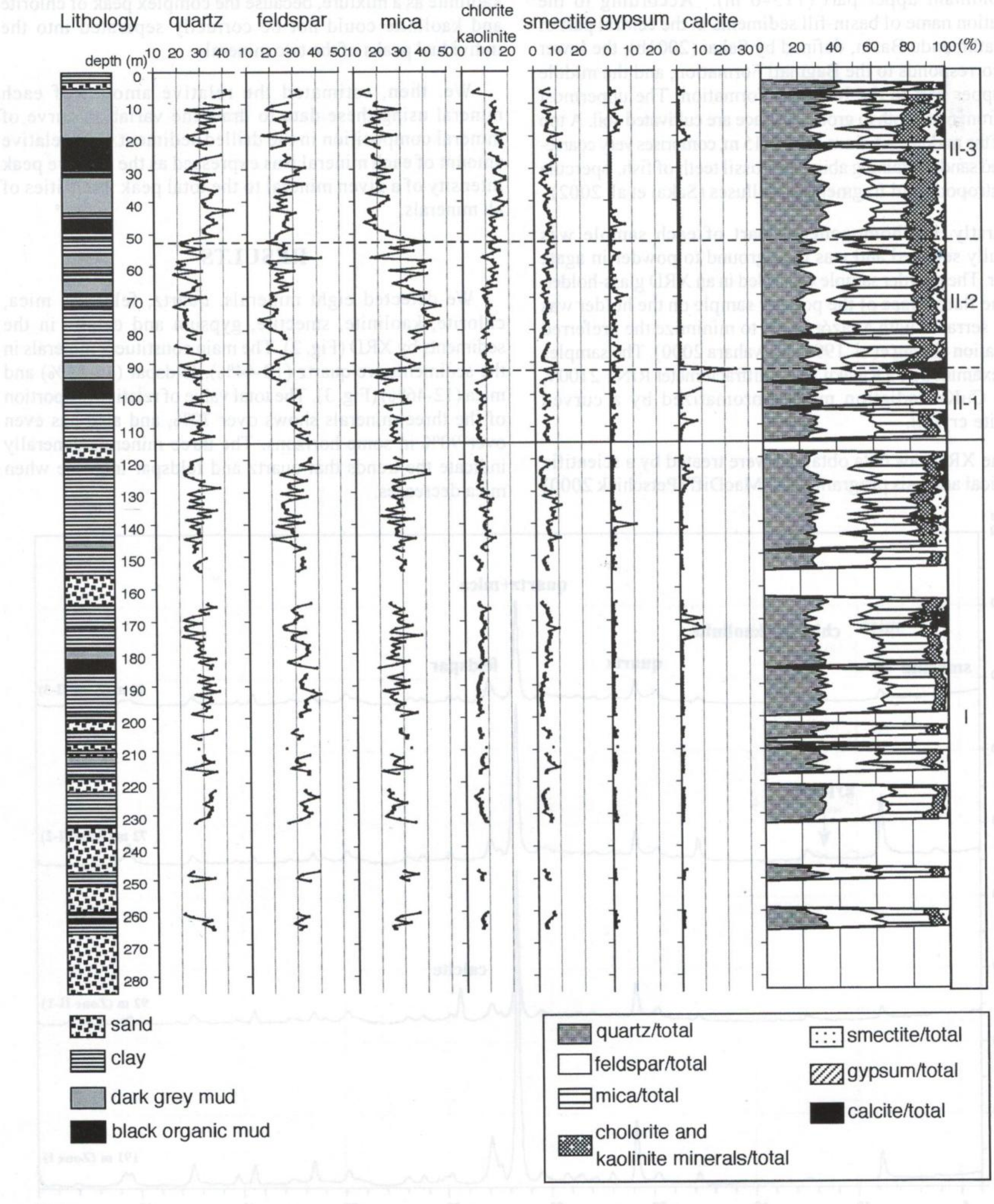

Fig. 3: Variations of relative abundance of all minerals detected in the slimes obtained from drill-well JW-3.

The clayey phyllosilicate minerals, chlorite and kaolinite minerals (4–19%) and smectite (1–12%) are next dominant ones (Fig. 3). The relative proportion of these minerals shows a similar variation pattern to each other. Gypsum and calcite occur sporadically and show in general low percentages at less than 3%, but in some horizons each rises rapidly to 5–10% and 5–24%, respectively.

Variation curves of relative amounts of the minerals are mainly divided into two zones at 115 m depth, based on the variation patterns of mineral composition (Fig. 3). The upper zone is further divided into three sub-zones.

Zone I (266-115 m)

The relative amounts of quartz, feldspar, and mica vary between 21-36%, 20-40% and 19-41%, respectively, without remarkable fluctuations (Fig. 3). Three gradual cycles with low amplitude at 35-45 m intervals, however, seem to be found in the variation curves of the three minerals in this zone. The gradual variation of quartz is in harmony with that of feldspar but is inversely proportional to that of mica.

Chlorite and kaolinite minerals, and smectite oscillate between 4-13% and 1-10% (Fig. 3), respectively, with three gradual cycles which are similar to those of mica. Gypsum shows very low percentage (~ 3%), except an abrupt increase (10%) at 140 m (Fig. 3). Calcite also shows generally very low percentage (~ 3%), but increases at 172-169 m (~10%) and at 128-122 m (~5%).

Zone II (115-6 m)

Zone II shows relatively large variation of each mineral content than the Zone I, particularly in quartz, feldspar and mica. The clayey phyllosilicate minerals chlorite, kaolinite and smectite tend to increase in the upper part of this zone (Fig. 3).

Subzone II-1 (115-92 m)

This zone is characterized by decrease of both feldspar (36 % to 16%) and mica (32% to 13%) toward the upper part and the discord of variation patterns of quartz and feldspar, which can not be found in any other zones (Fig. 3). Quartz, chlorite and kaolinite minerals, and smectite in this zone keep among 20-35%, 5-10% and 2-7%, respectively, without remarkable variations (Fig. 3). In addition, gypsum shows very low percentage. In contrast, calcite rapidly rises to 10-24% in the upper part of this zone (Fig. 3). Therefore, the decrease of feldspar and mica in this zone is likely to correspond to the increase of calcite.

Subzone II-2 (92-52 m)

The most characteristic feature of this zone is the variation curve of mica which shows one cycle with large amplitude. The percentage of mica is less than 15% at the bottom of this zone but it increases up to 46% in the middle part of this zone (Fig. 3). On the other hand, quartz and feldspar are roughly inversely proportional to mica, and hence have lower percentages in the middle part of this zone.

We also note that mica in this zone fluctuates with lower amplitude at relatively short intervals of 4-7 m (second order fluctuation) during the one cycle with large amplitude (first order fluctuation). These small fluctuations of mica seem also to be roughly inversely proportional to those of quartz and feldspar (Fig. 3).

Chlorite and kaolinite minerals and smectite, on the whole, tend to increase with the upper part of this zone (Fig. 3). However, these clayey minerals seem to fluctuate slightly, being in harmony with the small fluctuations of mica, although the fluctuations of these clayey minerals are much smaller than those of mica.

Gypsum in this zone frequently occurs in comparison with other zones, although the percentage is low (~ 7%) (Fig. 3). It also tends to show relatively high peak at every termination of cycles of the clayey minerals as mentioned above. The occurrence of calcite in this zone is extremely rare.

Subzone II-3 (52-6 m)

This zone starts with the rapid decrease of mica (40% to 14%) and with the simultaneous increases of quartz (20% to 44%) and feldspar (20% to 32%) (Fig. 3). Then, these three minerals slightly fluctuate at 10-15 m intervals, as the variations of quartz and feldspar are roughly inversely proportional to those of mica. In the upper part of this zone, quartz and feldspar tend to increase whereas mica tends to decrease (Fig. 3).

Chlorite and kaolinite minerals and smectite gradually increase showing the slight fluctuations (Fig. 3), but in the upper part of this zone these minerals turn to decrease such as mica. Gypsum indicates 0% from 42 m to 19 m, but increases after 18 m (~ 5%). Calcite observes from 20 m to 16 m (~ 5%).

DISCUSSION

Comparison of variation curves of mineral composition

The main constituent minerals of the whole slimes from a drill well JW-3 are quartz, feldspar and mica. In general, the variation of quartz is congruous with that of feldspar but is reverse proportion to that of mica, except the Subzone II-1 where both feldspar and mica decrease simultaneously (Fig. 3). The variations of the clayey phyllosilicate minerals, chlorite, kaolinite and smectite, which are next dominant minerals in the sediments, are similar to that of mica in the Zone I, but both do not always show similar variation in the Zone II.

Judging from these data, in Zone I, the phyllosilicate minerals (mica, chlorite, kaolinite and smectite) fluctuate in opposite way to the nonphyllosilicate minerals, e.g. quartz and feldspar. The variations of these minerals in the Zone I are gradual and form three cycles with low amplitude at 35-45 m intervals. The variations of mineral composition in the Zone II are very different from those in the Zone I, especially in

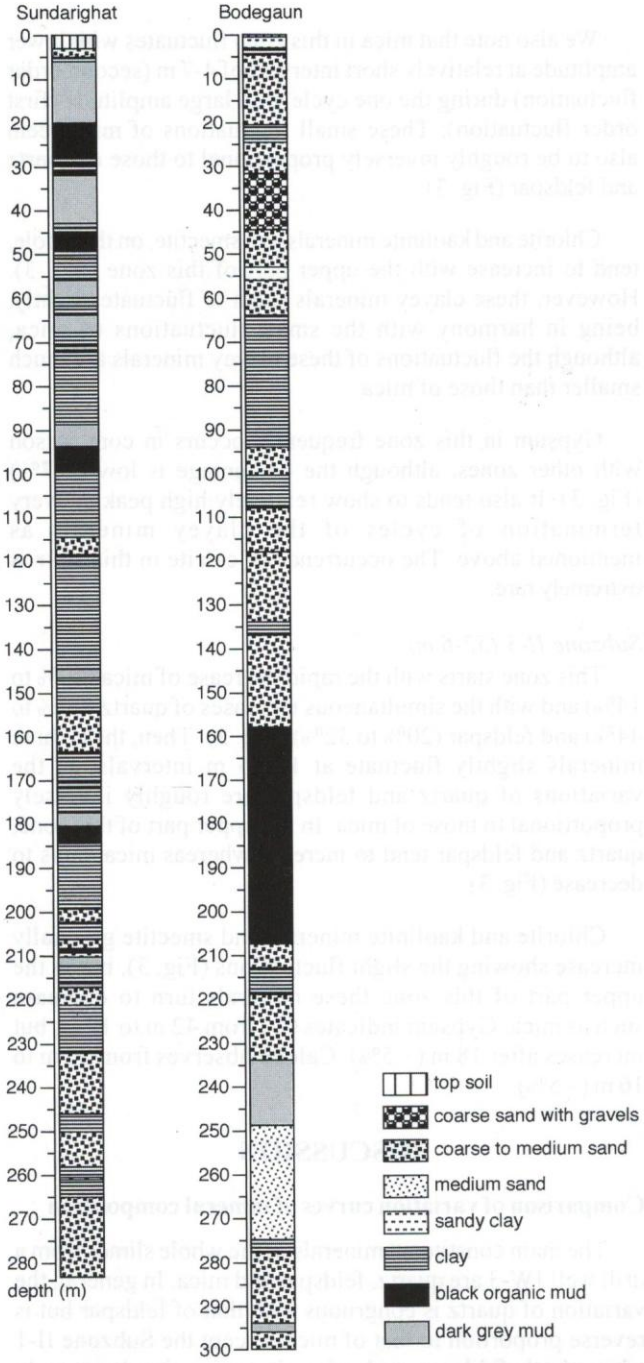

Fig. 4: Comparison of lithostratigraphy of two drill-wells obtained from the fluvial and lacustrine sediments at Sundarighat and fluvio-deltaic sediments at Bodegaun.

quartz, feldspar and mica. The Zone II shows larger variations of these mineral contents than in the Zone I. In addition, the variation curves of these minerals, especially in the Zone II-2, show repetition of shorter cycle at 4-7 m intervals overlapping a longer cycle at 30-40 m intervals.

Similar variations are shown in the pollen diagram of the same core (Fujii and Sakai 2001). They showed that no remarkable cyclic fluctuation of frequency of each pollen was shown below 115 m depth, whereas several pollen, particularly *Pinus*, *Quercus*, *Cyclobalanopsis*, exhibited remarkable fluctuations which were interpreted as reflection to repetition of glacial and interglacial age (Fujii and Sakai 2001). Therefore, such mineralogical variations in the core may reflect not only the changes of depositional system in the Kathmandu Basin but also the climatic changes in the Kathmandu Basin, although the fluctuation pattern of the mineral contents is not completely identical with that of pollen.

Comparison of variation curves of clayey minerals with those of other indicators seems to be very difficult, since XRD peaks on clayey minerals in bulk samples of these sediments are very small and can not probably distinguish individual clay minerals (e.g., chlorite and kaolinite) (Fig. 2). Kuwahara et al. (2001) carried out XRD analysis for the oriented samples of clay minerals in the sediments of the same core and showed that the variations of the illite crystallinity and the clay mineral composition are consistent with a fluctuation pattern of $\delta^{18}O$ obtained from planktonic foraminifers of deep-sea sediments in the Arabian Sea. Therefore, we may need to perform XRD experiments for not only the bulk sample but also the oriented clay samples in order to obtain the exact paleoclimatic information.

Provenance of detritus

The samples used in this study were collected from a drill-well JW-3 at Sundarighat in the western central part of the Kathmandu Valley (Fig. 1 and 4). The detrital grains are mainly composed of meta-sediments which are derived from the Phulchauki Group (Fig. 1). The Phulchauki Group is distributed in the eastern, western and southern part of the Kathmandu Valley, and comprises calcareous sandstone, quartzite, limestone, phyllite, and slate, which are more or less weakly metamorphosed (Fig. 1).

In contrast, a drill well data, at Bodegaun near Thimi (Fig. 1 and 4) indicates that 300-m-deep well is occupied by granitic sand beds of total 175 m in thickness. The granitic sand grains are certainly derived from the Shivapuri Lekh, just to the north. These facts show that the provenance of detritus of the Kathmadu Basin Group is strongly influenced by local depositional system, and hence the mineralogical characteristics of the Kathmandu Basin sediments may also vary in every location.

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