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Late Pleistocene paleoenvironmental changes of the Kathmandu Basin-fill sediments revealed by the minerals composition

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ABSTRACT

The amounts and their variation of minerals in the present river sediments (PR) and basement rocks (BR) of the Kathmandu Valley were estimated by using the X-ray diffraction (XRD) method, in order to estimate the source of the Kathmandu Basin sediments and to interpret paleoenvironmental and paleoclimatic condition of the past Kathamdu Valley. XRD result of the BR and PR samples roughly correspond along respective parts of the Kathmandu Valley, except calcite (carbonate rocks in the eastern, southern, and western parts). The non-clay minerals are quartz, K-feldspar, plagioclase, mica, chlorite, calcite, and illite, chlorite, kaolinite,, smectite, mixed layer illite-chlorite are detected within the clay fraction of the PR sediments. The clay fraction is < 5 wt % within the PR-sediments. Among non-clay fraction, BR and PR from the north contains more or less equal amount of mica, feldspars and quartz, while those from south, east and west are rich in quartz. Therefore, the amount of silicate minerals in the sediments within the Kathmandu Basin is the key to grasping the provenance of the sediments about northern and the other origin. Chlorite in the PR-North is likely a weathering product of mica because chlorite was not included in the BR-North samples. The chlorite and mica were greater in the lower course of the river from the north than in the upper course of the river. Plagioclase is tends to be poor and K-feldspar is rich in the PR-samples, while the amount of the two feldspar are similar to each other in the BR-samples. This tendency may be due to the difference in stability to weathering between the two feldspars. Calcite was probably dissolved during weathering, erosion, and transportation processes, because calcite included in the BR samples was hardly detected in the PR samples. This mineralogical information is applied to the mineralogical studies in the past basin-fill sediments of the Kathmandu Basin (RB-drill core) and to estimate the source of the sediments and paleoenvironmental and paleoclimatic information on this region. Calcite detected in the past basin-fill sediments of the Kathmandu Basin is an important key mineral showing cold and dry climate within the RB drill core. It can also be used to correlate the strata.

Key words: Kathmandu Valley; present river sediments; basement rock samples; mica; provenance; carbonate

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INTRODUCTION

Indian monsoon plays important role in the global climate system (Clemens 1991) and widely influences to the terrestrial and marine environments in the South Asia. Precipitation plays important role in the formation, weathering, erosion, and transportation of secondary minerals to the depositional basin (Chamley 1989). The Kathmandu Basin is located on the most intense southwest Indian monsoon influence zone of the South Asia, and its basin-fill sediments have good records of the Quaternary climatic history (Yoshida and Igarashi 1984; Sakai 2001). In summer, large amount of precipitation concentrated on the southern slope of the Himalaya are responsible for weathering and erosion. On the other hand, this basin is a tectonic basin located at ~1300 m altitude and bounded by the Lesser Himalaya in the south and Crystalline Injection Complex in the north (Stöcklin 1980). So sedimentation and mineralogical composition within the sediments might be directly or indirectly related to the regional or local tectonics of the basin margin.

Mineralogical study on the basin-fill sediments, provides various valuable information about depositional environments, provenance of the detritus, tectonics as well as climate in the region (Chamley 1989). In order to interpret Paleoenvironment on the basis of mineralogical data on the Kathmandu Basin-fill sediments, it is equally significant to understand mineralogical variation within the recent sediment and basement rocks. In the lake, the mineral composition is significantly influenced by the local watersheds geology and soil composition than the marine environments (Fagel et al. 2007). However, the mineralogical studies on the Kathmandu Basin-fill sediments and on the present river sediments (different rivers which are flowing from different direction of the basin) and the basement rocks have scarcely been performed. Clay minerals of the drill-core of the Kathmandu Basin were described and used for paleoclimatic interpretation by Kuwahara et al. (2001). Fujii et al. (2001) reported that mineral variation in the drill-core sediments may depend on not only the depositional environmental changes of the Kathmandu Basin but also the paleoclimatic change of the Kathmandu Basin. Sawamura (2001) studied the clay and non-clay minerals of the Lukundol Formation in the southern part of the basin and suggested that the amount of plagioclase and quartz is low in the shallow, and is high in the open lacustrine condition. Paudel et al. (2004) first estimated the variation of the mineral composition of the present and past basin-fill sediments of the Kathmandu Valley, and suggested that change of the mineral composition of the present river sediments with respect to different direction shows the provenance of the basin-fill sediments to be not just one particular direction. If such mineralogical study will be performed on not only the present river sediments but also the basement rocks around the valley, source of the basin-fill sediments may be determined.

Here, in this paper I have focussed on the PR, BR and drill-core RB from 7 to 40m depths. On the basis of the variation of these minerals obtained from XRD result of basin-fill sediments, present river sediments basement rocks and geology of the Kathmandu Valley, I have determined the source of the present river sediments. The mineralogical data have been used for estimation of the provenances of the basin-fill sediments and the paleoenvironmental and paleoclimatic condition of the Kathmandu Valley.

MATERIALS AND METHODS

In this study 28 samples were collected from present rivers (PR) of the Kathmandu Valley flowing from the different directions. Same number of the basement rocks samples (BR) of the Kathmandu Valley and RB drill core sediments from 7 to 40 m depth at 10 cm intervals were used for this study (Fig. 1). The BR samples were divided into three parts (north, west (and east), and south parts) and the PR samples into four parts (north, west, east, and south parts), based on the distribution of the basement rocks and the route of different streams (Fig. 1, Table 1). The mineralogical characteristics of the BR samples in the western part can be expressed as those of the rocks in the eastern part, since both parts have same geological formation, that is, the Tistung and Chandragiri Formations. The Tistung Formation is composed of weakly metamorphosed sedimentary rocks and arenaceous limestone, and the Chandragiri Formation comprises arenaceous and argillaceous limestone (Funakawa 2001; Rai 2001).

The PR samples were dried for 24 hours at 50ºC in air bath and then weighed. The dry samples were divided into clay fraction (less than 2 µm) and non-clay fraction (greater than 2 µm) by gravity sedimentation method. The non-clay fraction samples were dried in air bath again and then weighed. The dried, non-clay fraction samples and the BR samples were ground to powder in agate morter, and then 10 wt% of zincite (ZnO) was added to the individual powder samples as an internal standard for the quantitative analysis (Srodon et al. 2001).

Each clay fraction of the PR sample was collected by the Millipore® filter (0.45 µm pore, 47 mm diameter) transfer method to provide an optimal orientation (Moore and Reynolds 1989). Both air-dried (AD) and ethylene glycol solvated (EG) preparations were done for each sample. The potassium-saturated treatment (KS) was also performed for selected samples.

All XRD measurements were done by the Rigaku X-ray Diffractometer RINT 2100V, using CuKα radiation monochromatized by a curve graphite crystal in a step of 0.02°with a step-counting time of 2 second for the BR and non-clay sample of the PR and 4 seconds for clay samples of the PR. The XRD raw data of both the BR samples and non-clay fraction samples of the PR ones were treated by a program Mac Diff (Petschick 2000) on an Apple Macintosh computer, in order to determine the integrated intensity (peak area) of XRD peak corresponding to each mineral. The relative amounts of minerals were determined by each calibration curve obtained from integrated XRD peak intensity ratio of each standard mineral, which were collected from sand samples in the core drilled at Rabibhawan in the western central part of the Kathmandu Basin (Sakai 2001) and from gneiss of Shivapuri Injection Complex, to the internal standard zincite. The total amount of the main component minerals were normalized to 100 wt % to compare each sample, although there are somewhat minor minerals and amorphous materials in the samples.

RESULTS

Basement rocks of the Kathmandu Valley (BR samples)

Six minerals were detected namely quartz, plagioclase, K-feldspar, mica (mainly muscovite), chlorite and calcite (Figs. 2 and 3). The basement rocks of the four parts in the Kathmandu Valley rather differ in main constituent minerals. The main constituent minerals in the northern part

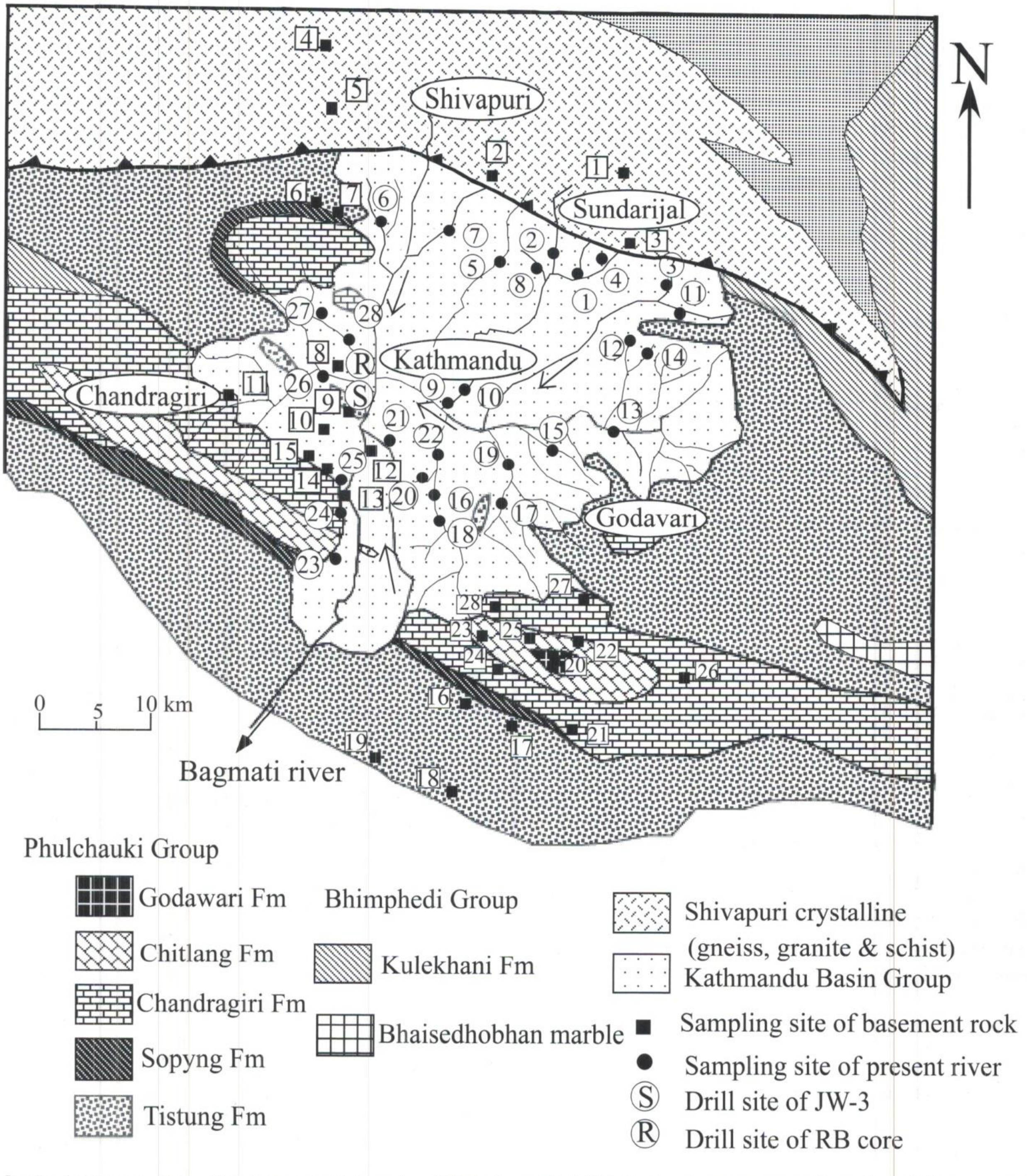


Fig. 1: Geological map of the Kathmandu Valley (modified from Rai, 2001) showing the sampling sites of the present river sediments and basement rocks used in this study. Drill-sites (JW-3 and RB) are also shown. Fm: Formation.

of the BR sample (BR-North) were quartz, mica, K-feldspar and plagioclase. The Shivapuri Injection Complex from northeastern part (Fig. 1) (BR-North-A) was rich in mica, while granite and gneiss in the northwestern part (BR-North-B) were poor in mica and instead rich in feldspars (Fig. 3 and Table 1). Chlorite was in very minor amount only in one sample in the BR-North sample (Fig. 3).

Between the two subgroup of BR-west (east), first subgroup (BR-west-A) is characterized by a large amount of mica (muscovite) quartz and a small amount of feldspars and chlorite, which is composed of mica-schist of the Sopyang and Chandragiri Formations (Fig. 3 and Table 1). The other group (BR-west-B) is characterized by a very large amount of calcite that composes limestone and siliceous limestone.

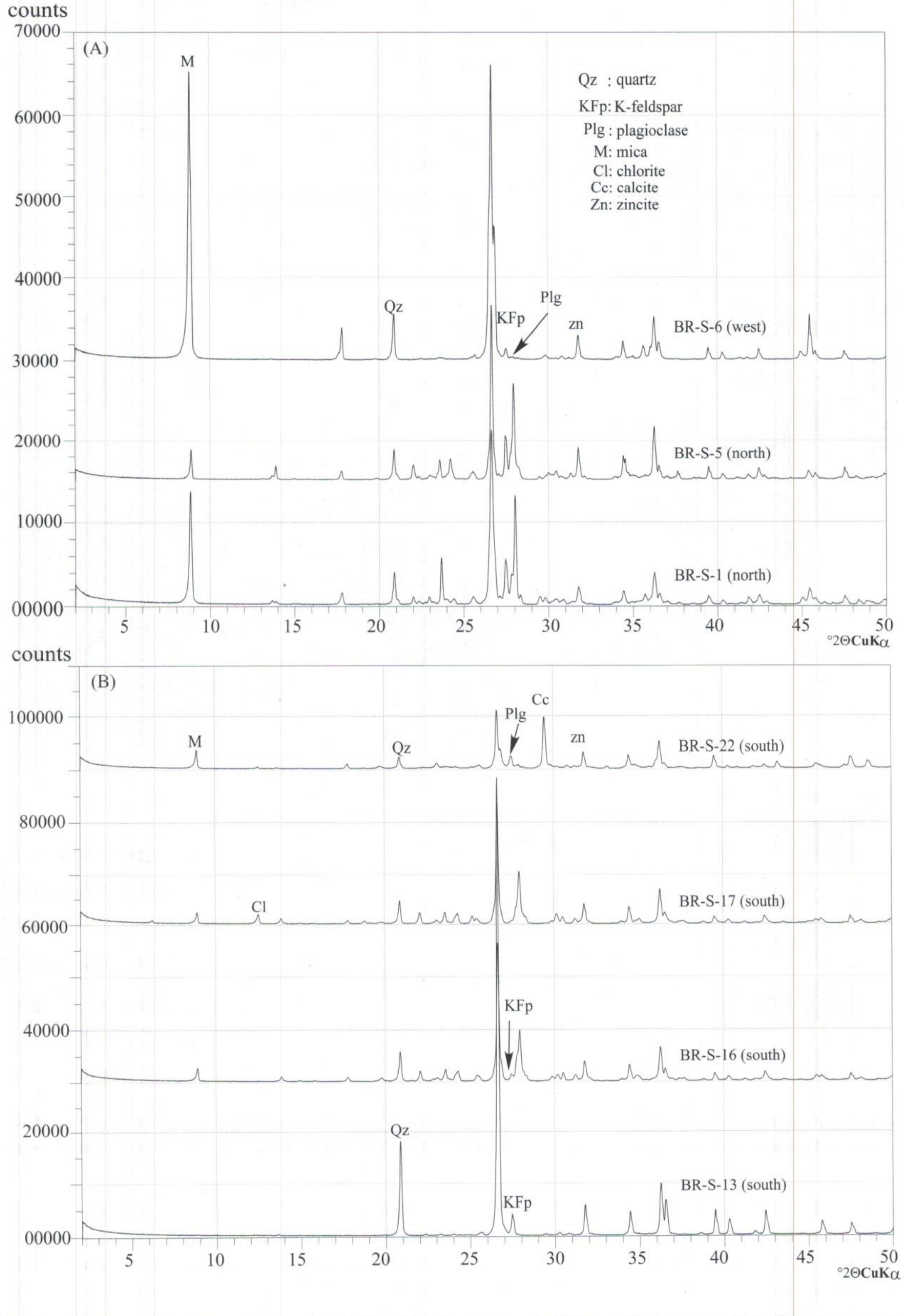


Fig. 2: XRD patterns of the basement rocks (BR) of the Kathmandu Valley. The main mineral component of the rocks in the north and west parts (A), and in the other parts (B).

Among the silicate minerals, quartz and mica are in minor amount in the BR-west-B sample.

The amounts of calcite and silicate minerals vary from about 20 wt% to 80 wt % within the whole BR samples collected from the basement rocks of Kathmandu valley. In the last subgroup (BR-south-D), calcite in Godawari Limestone account for over 90 wt% of the component minerals. The mineral composition of the BR-south -D is similar to that of the BR-west-B. The BR-south samples were also divided into four subgroups, like as the BR-west ones. The first subgroup (BR-south-A) is composed of metasandstone and quartzite of the Chandragiri Formation in the southwestern part of the Kathmandu Valley (Table 1, Fig. 3) and is characterized by a very large amount of quartz and no calcite. These rocks slightly include feldspars. Metasandsotne of the Chandragiri Formation contains a relatively large amount of mica and a very small amount of chlorite, in addition to quartz. The second subgroup (BR-south-B) comprises mainly metasandstone of the Tistung Formation in the southern part of the Valley and is characterized by a large amount of quartz, plagioclase, that is larger than in the BR-south-A, and a small amount of mica, K-feldspar, chlorite and calcite. The third subgroup (BR-south-C) contains calcite and silicate minerals (quartz, feldspars, mica, and chlorite) that compose siliceous limestone of the Chandragiri and Chitlang Formations.

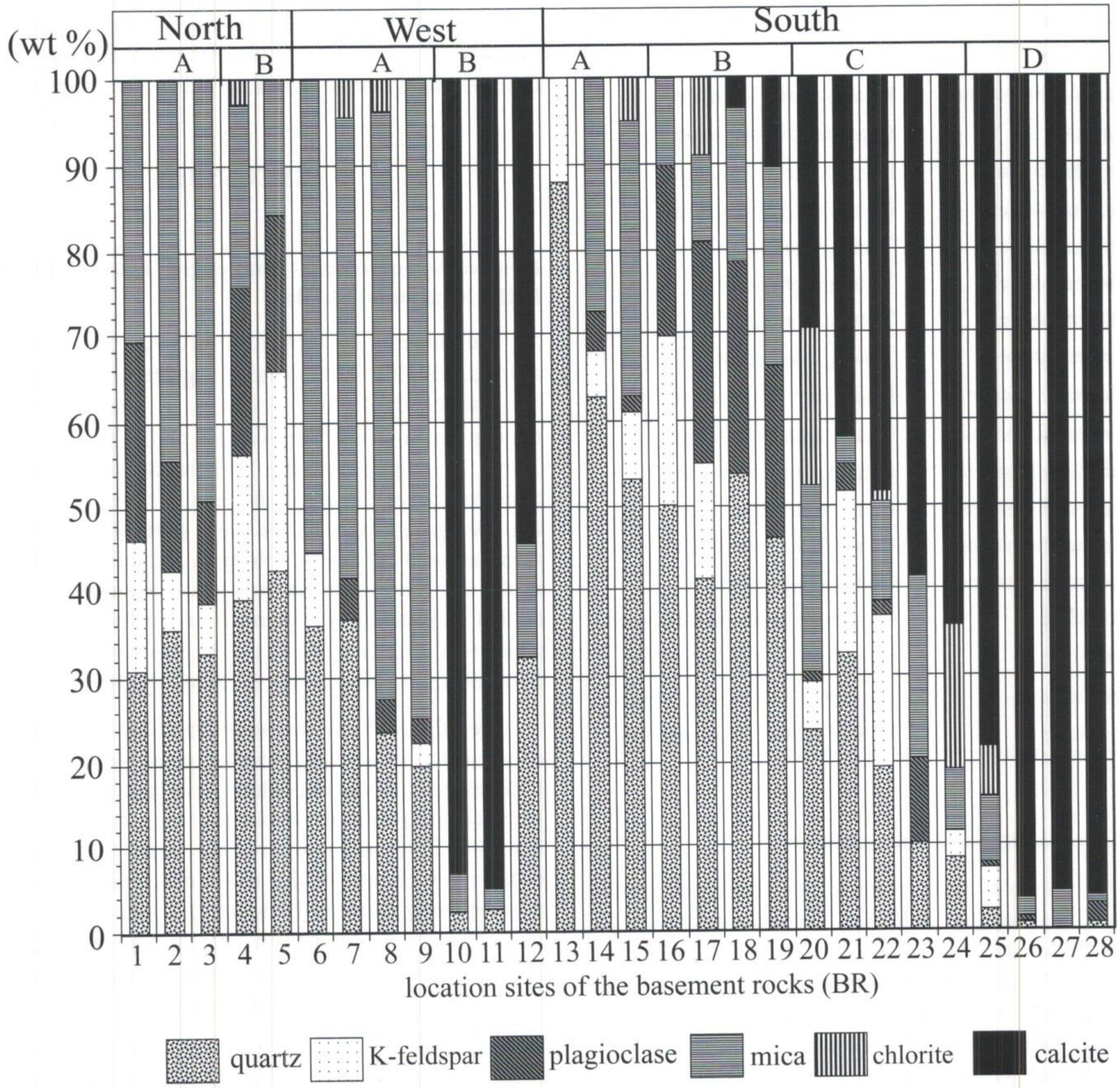


Fig. 3: Mineral composition of the basement rocks (BR) in the Kathmandu Valley. The numbers from 1 to 28 are the sampling sites (see Fig. 2).

Table 1: Rock types of the basement rocks (BR) of the Kathmandu Valley used for the XRD-analysis.

No. Rock name	Formation
1. Gneiss	Shivapuri Injection Complex
2. Gneiss	Shivapuri Injection Complex
3. Gneiss	Shivapuri Injection Complex
4. Gneiss	Shivapuri Injection Complex
5. Ganitic pegmatite	Shivapuri Injection Complex
6. Mica schist	Sopyang Formation
7. Mica schist	Sopyang Formation
8. Mica schist	Chandragiri Formation
9. Mica schist	Chandragiri Formation
10. Limestone	Chandragiri Formation
11. Limestone	Chandragiri Formation
12. Siliceous limestone	Chandragiri Formation
13. Quartzite	Chandragiri Formation
14. Metasandstone	Chandragiri Formation
15. Metasandstone	Chandragiri Formation
16. Metasandstone	Tistung Formation
17. Metasandstone	Tistung Formation
18. Metasandstone	Tistung Formation
19. Metasandstone	Tistung Formation
20. Calcareous siltstone	Upper part of Godawari Fm.
21. Siliceous limestone	Chandragiri Formation
22. Siliceous limestone	Chandragiri Formation
23. Siliceous limestone	Chandragiri Formation
24. Siliceous limestone	Chandragiri Formation
25. Siliceous limestone	Chitlang Formation
26. Limestone	Upper part of Godawari Fm.
27. Limestone	Upper part of Godawari Fm.
28. Limestone	Upper part of Godawari Fm.
29. Limestone	Middle part of Godawari Fm.

Present river sediments (PR samples)

The PR samples were divided into four parts (north, west, east, and south), based on the distribution of the basement rocks and the route of a stream, as described above (Fig. 5, Table 1). Fig. 4 shows the XRD pattern of the main components minerals. The main component minerals of the north part of the PR samples (PR-North-A, B) were quartz, feldspars (both K-feldspar and plagioclase), mica and chlorite. The central part (PR-North-B, Figs. 1 and 3), which is the lower course of the river from the PR-north–A were somewhat richer in mica and chlorite and poorer in plagioclase than the PR-north-A (Fig. 5).

The mineralogical composition of the other parts (PR-West, PR-East, and PR-south) were similar to each other. The predominant mineral in those parts was quartz, exceeding 50%. Mica and K-feldspar were the next dominant minerals, but mica in those parts tends to be lower than in the PR-north samples. The amount of plagioclase and chlorite were much small. Calcite in the PR samples was only little, although the BR-west-B, BR-south-C and D samples showed a higher amount of calcite.

The amount of the clay size fraction within the PR samples was relatively low (below 6 wt %) (Table 2). Clay mineral assemblage of the PR sample was illite, kaolinite, chlorite, smectite, vermiculite, and illite-chlorite mixed layer mineral, judging from the XRD measurements for AD, EG, and KS samples (Fig. 6). Among these clay minerals, illite was richest in all samples (Table 2 and Fig. 6).

DISCUSSION

Comparison of mineral composition between BR and PR in the Kathmandu Valley

The mineral compositions between the BR and PR samples roughly correspond along the respective parts of the Kathmandu Valley, except calcite (carbonate rocks in the eastern, southern, and western part of the Valley) (Figs. 3 and 5). Judging from the XRD results, the mineralogical composition of the PR sediments can be broadly divided into two groups. One is the north part (origin) where each mean amount of quartz, feldspars and mica (and chlorite) in the PR-North samples was nearly equal, corresponding to that in gneisses and granites of the BR-North samples. Chlorite was detected from the PR-North samples while the BR-North samples scarcely included chlorite.

Therefore, chlorite is most probably a weathering product of mica in gneisses and granites of the BR-North samples (Paudel et al. 2004). The chlorite and mica tend to be greater in the central part of the Basin (the lower course of the river) than in the northern margin of the Basin (the upper course of the river). It may be due to the difference in the stability to weathering between feldspars that plagioclase was poor and instead K-feldspar tended to increase in the PR-North samples while the amounts of the two feldspars were similar to each other in the BR-North samples.

The other part (origin) except the North part is characterized by quartz that exceeds 50 wt% in the PR sediments. This quartz is probably from the metasandstone, siliceous limestone, and quartzite of the Chandragiri, Tistung, and Chitlang Formations that distribute around the south, east and west of the Kathmandu Valley (Table 1). The

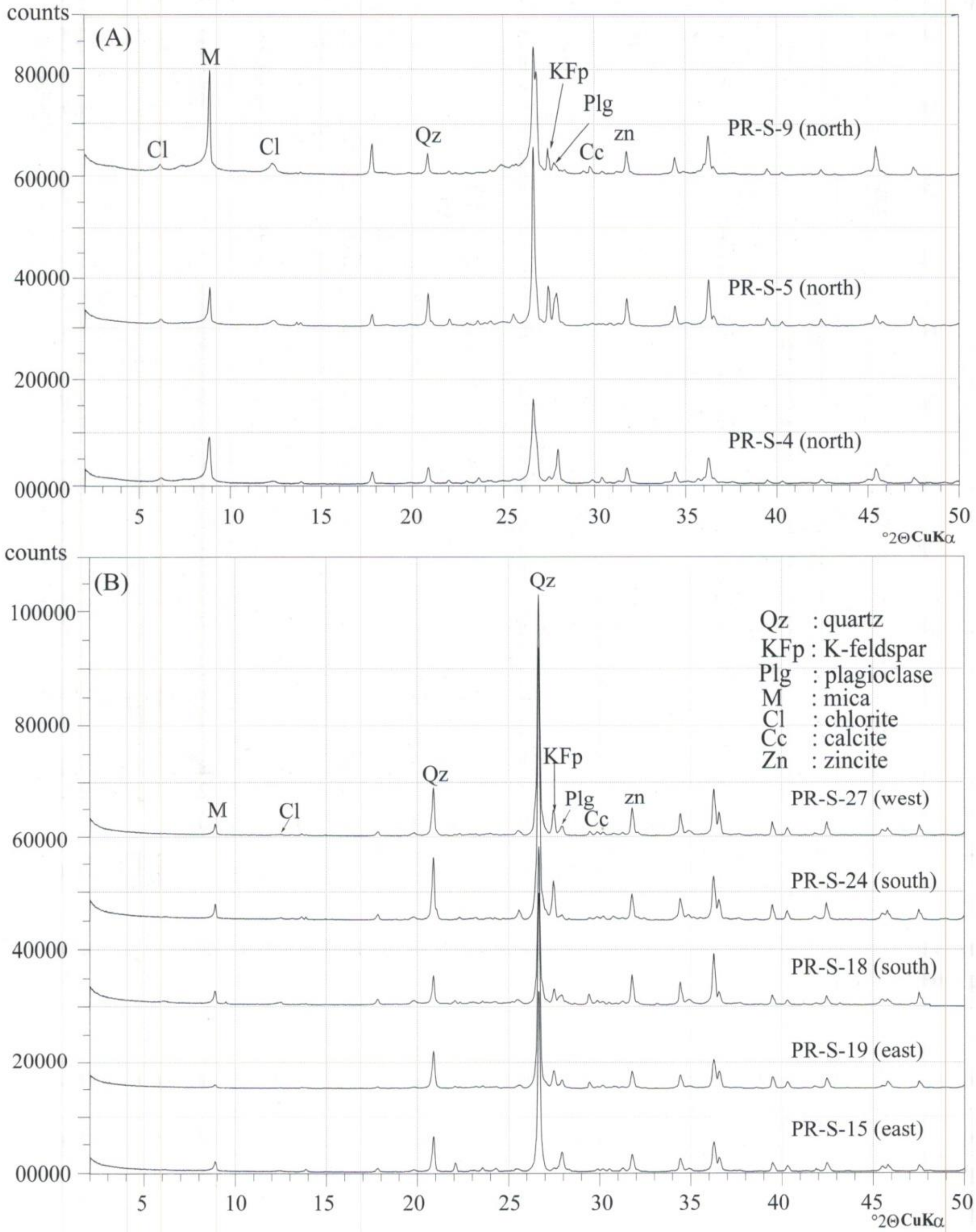


Fig. 4: XRD patterns of the present river sediments (PR) of the Kathmandu Valley showing (A) the sediments in the North part (B) in the other parts.

amount of mica and chlorite in these part of the PR samples were lower than in the north part although the BR-west samples which are mica schist of the Chandragiri Formation were rich in mica (Table 1 and Fig. 3). The tendency to be rich in K-feldspar and poor in plagioclase was similar to that in the north part. Very few amount of calcite was detected from the PR samples, although some of the BR samples were carbonate rocks and were rich in calcite. It is clear that calcite was dissolved during weathering, erosion and transportation processes.

Judging from the above results, it is strongly expected that the amounts of quartz and mica (and chlorite) in the sediments within the Kathmandu Basin are the key to grasping the provenance of the sediments, at least about the

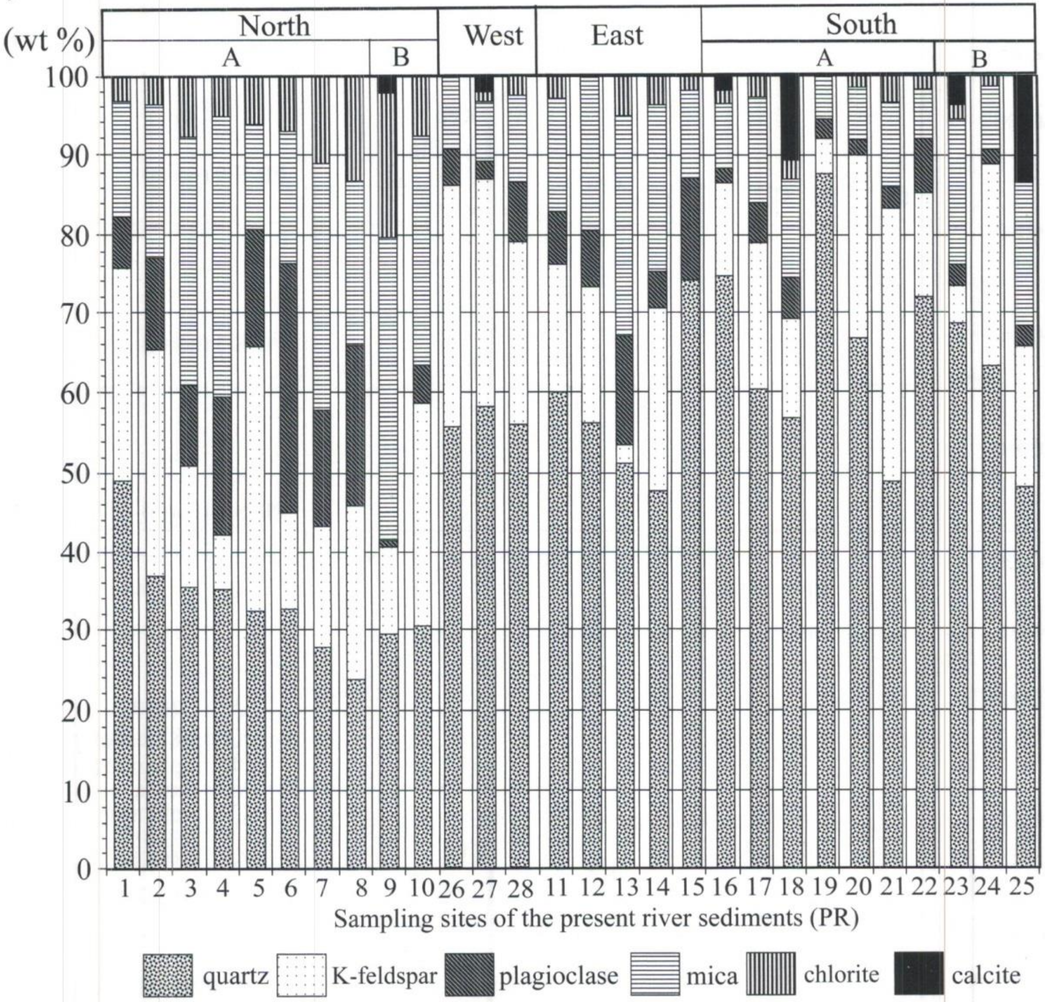


Fig. 5: Mineral compositions of the present river sediments (PR) in the Kathmandu Valley. The numbers from 1 to 28 are sampling sites (see Fig. 2).

Table 2: Amount of clay minerals within the present river sediments (PR) of the Kathmandu Valley.

Area	Locality	Clay wt%	Smectite	I/C (R=1)	Illite	Chlorite	Kaolinite
North	4	3.3	-	++	+++	+	++
North	5	0.3	+	++	+++	+	++
North	6	4.8	-	++	+++	+	++
North	7	0.1	-	++	+++	+	++
North	9	3.2	-	++	+++	+	++
West	26	0.5	-	++	+++	++	+
West	27	0.4	+	++	+++	+	+
East	15	5.0	-	++	+++	+	++
South	24	1.7	+	+	+++	+	+
South	23	1.9	-	+	+++	+	+

Trace amount: - ; low amounr : + ; medium amount : ++; higher amount: +++

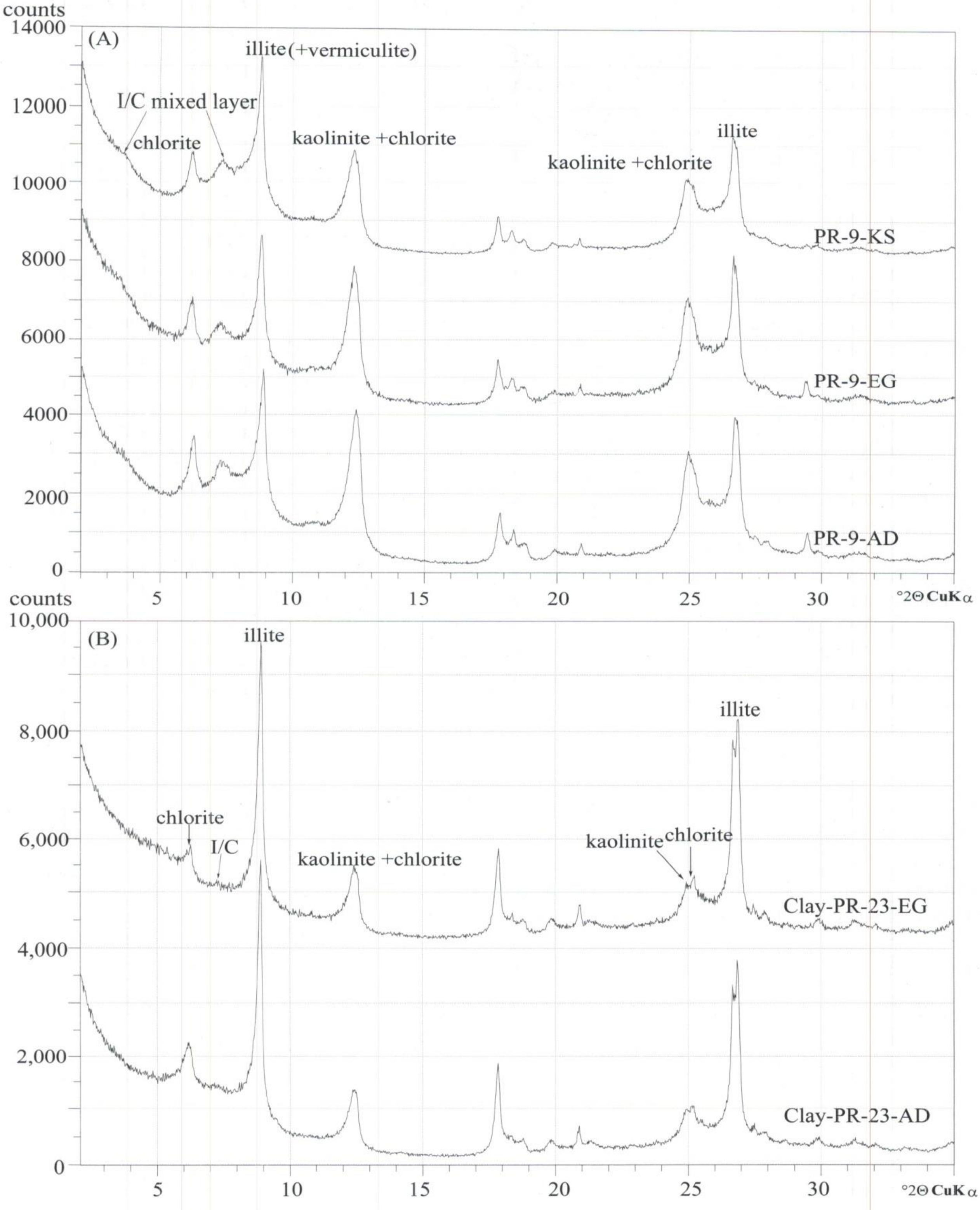


Fig. 6: XRD patterns of the clay size fraction samples in the present river sediments (PR) from the North (A) and other parts of the Kathmandu Valley (B). AD: air-dried samples, EG: ethylene glycol solvated preparation, KS: potassium solvated treatment.

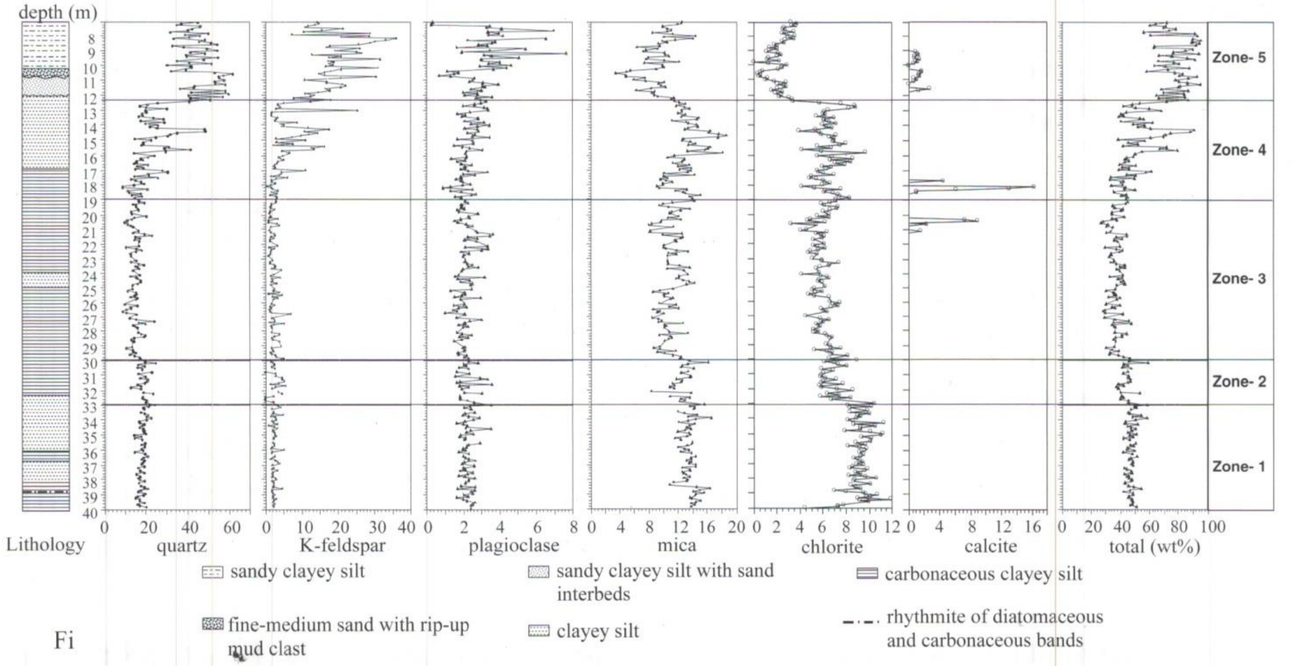
northern and the other origin. The variation of the mica and chlorite in the sediments may also relate to a distance of transportation of the detritus (or a distance to a lake margin). On the other hands, it is difficult to detect the difference in mineralogical characteristics between the south, east, and west part of the Valley, because the basement rocks distributed around these part of the Valley are similar each other.

The amount of the clay size fraction in the PR samples was very low (below 5 wt%, Table 2), irrespective of the individual parts of the Basin. Similar results have been reported by XRD studies for the core which was drilled at Rabibhawan by PKL Project (Sakai et al. 2001) in the western central part of the Kathamdu Basin (Paudel et al. 2004; Kuwahara et al. 2004; Kuwahara 2006). According to previous authors, topmost part of the RB core from 7 to 12.5 m in depth, which corresponds to fluvial beds overlying lacustrine Kalimati Formation, was poor in the clay size fraction (<5 wt.%) (Fig. 7). Clay mineral assemblages in their reports were also identical to those in this study. On the other hand, in the lacustrine mud part of the RB core between 12.15 m and 40 m in depth, the amount of the clay size fraction varied with the change of wet-dry climatic condition in the Kathmandu Valley (Paudel et al. 2004; Kuwahara et al. 2004; Kuwahara 2006). Therefore, clay minerals in the sediments of the Kathmandu Basin may have information on climate and/or depositional environments rather than on provenance (Kuwahara et al. 2001; Kuwahara 2004).

Paleoenvironment and paleoclimate revealed by mineral assemblages

West et al. (2005) suggested that transportation and kinetics of the reaction is the main controlling factors for the chemical weathering of the silicate minerals. According to them latter factor depends upon the temperature and precipitation within the source region. On the other hand, sedimentation within the lacustrine basin of the middle mountain range of Nepal is controlled by the monsoon environments (Ross et al. 1999). Here, I used variation of phyllosilicate (mica and chlorite) and non-phyllosilicate (quartz and feldspar) as the key mineral for the depositional and environmental change of the Kathmandu Basin.

White et al. (1999) reported that cation released from the mica weathering is faster than the plagioclase in cold glacial watersheds, whereas the tropical climates should favor plagioclase relative to mica. Considering the above suggestion, the amount of phyllosilicate is high in wet climatic condition within the lacustrine environments of the Kathmandu Basin. As the amount of precipitation increased, erosion of the micaceous basement rock within the water shed and transporation rate from water shed to the lacustrine basin is fast. Consequently, the amount of phyllosilicate would be expected to increase within the lake basin. On the other hand, Li et al. (2007) suggested that mica in the coarse grain-size fractions are further enriched by floating. The products of water floating are layer silicates such as muscovite, biotite and chlorite but also contain small amount



TFig. 7: Changes in mineral composition of the RB-core (7–40 m depth) drilled at Rabibhawan located in the western central part of the Kathmandu Basin.

of quartz and feldspars.

Moreover, because of their flaky shape and despite their higher density they tend to be collected along with finer sands and silt. Therefore, I used phyllosilicate as an indicator of wet climatic condition and lacustrine depositional environment. Conversely, in cold period, amount of phyllosilicate mostly mica is low due to higher rate of weathering of mica. On the other hand, during the cold period, weathering of the mica within the watershed is higher rate because it has low activation energy, which promotes to increase weathering rate of mica in cooling environments. In addition, at the time of cold period, rainfall is low, consequently, lake started to shrink and lowering. During this period the suspension deposition is less active than the slow bed load deposition so phyllosilicate did not reach the basin center. Consequently, phyllosilicate mica and chlorite became low during the cold period. In addition, highly monsoon influenced basin like Kathmandu Basin, the input of the water and sediments is strongly seasonal. In dry/cold climatic condition, water level in the lake was started to become shallow and dissolved calcareous matter were precipitated in the lake bottom. The precipitation of the calcite mineral indicates that the pH of the lake water at the time of deposition may be very alkaline condition. Hence, in this time period total amount of silicate mineral decreased due to the dissolution of silicate. Considering the above scenario within the Kathmandu Basin-fill sediments from 7 to 40 m depths (RB core, Fig. 7), I suggest following paleoclimatic and paleoenvironmental condition: Paudel et al. (2004) showed change in mineral composition of the upper part (40 to 7 m in depth: ca. 40 to 15 ka,) of the RB core sediments (Fig. 7). On the basis of this study, the gradual decrease of mica and chlorite from the zone 1 to 3 may show a gradual shrinkage of the lake, corresponding to a change from warm and wet climate (MIS3) to cold and dry climate (MIS2). It is also correlated to the pollen result reported by Fujii et al. (2004).

In the zone 4 (Fig. 7), the sediments supplied would start to be controlled by the route of a stream and the basement rocks behind the stream, with advance of dry-up the lake, and finally the sediments in the zone 5 would be supplied by river from west and/or south of the Kathmandu Valley, like as the present.

CONCLUSIONS

The mineralogical study on the present river sediments and the basement rocks in the Kathmandu Valley provides valuable information about provenance of the present and past basin-fill sediments, depositional environments and climate, and this mineralogical evidences can be applied to the sediments of the Paleo-Kathmandu Lake. Variations in silicate minerals as quartz and mica in the sediments may indicate especially those in the provenance of the Kathmandu Basin-fill sediments and/or depositional environments. Calcite in the sediments plays not only an important indicator of cold and dry climate but also a key mineral in correlation of the sediments. This mineralogical study in addition to clay mineral analysis will help us to interpret upcoming mineralogical information on the Kathmandu Basin sediments.

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