

Facies analysis of Sunakothi Formation, Kathmandu basin, Nepal and its significance

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ABSTRACT

This study decipher facies characteristic of Sunakothi Formation at southern part of Kathmandu Basin. Thick sandy and muddy sequence is found on an open lacustrine facies of the Kalimati Formation. Five facies associations have been recognized within the sandy and muddy facies. These are: (a) muddy rhythmites and silt and laminated to ripple sand bed of the prodeltaic origin (pd), (b) association of cross-stratification, ripple-drift and parallel lamination in the lacustrine delta front origin (df), (c) muddy flood-plain and alteration of the fine and coarse sediments of delta-plain origin (dp), (d) sandy to silty rhythmites of the marginal shallow lacustrine origin above the delta-plain (ml), and (e) association of fluvial origin (fl). Former three associations are interbedded by the thick gravel deposits, which is gravelly braided river origin. Transition from lacustrine to alluvial system is characterized by fluvial and deltaic system in the south. Sedimentology of the Sunakothi Formation indicates deposition during rapid lake level rise and also the thick channelized fluvial gravel beds within the sandy and muddy sequence indicate lake level fall. The cause could be climatic as well as activity of the basin margin tectonics. Sunakothi Formation is the southern counterpart of the Thimi-Gokarna Formations distributed in the northern part of the basin.

Key words: Kathmandu Basin, lake delta, lacustrine facies, Sunakothi Formation, tectonics

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INTRODUCTION

Kathmandu Valley is an intermontane basin in the Central Himalaya and was an ancient lake during Pleistocene time. The basin-fill sediments, particularly of 200 m thick muddy lacustrine sediments and the overlying fluvio-deltaic, as well as fluvial sediments, have contained important key information to resolve the problems related to disappearance of an ancient lake in Kathmandu valley. I have carried out surface geological mapping and drill core study of the basin-fill sediments at the southern part in order to reconstruct paleoenvironmental changes as well as examined sedimentary facies to sort out tectonics from climatic changes during Pleistocene time.

Depositional environmental changes in lake marginal areas are the direct response either to the tectonics or climatic or both events. Lake margin deposits and its landform have been used as a key indicator to distinguish existence of lake-level (e.g. Karabiyikoglu, 1999). Lake can be filling from peripheral accretion owing to progradation of shoreline or outbuilding of lacustrine delta, or from uniform deposition over the entire lake area (Alan P., 1978). The synchronous change in fluvial regime and lake level hydrological balance have considered in other area for climatic change rather than a base level control (Klinger et al 2003). For the case of Kathmandu basin, Yoshida and Igarashi (1984) argued upheaval of the Mahabharata

Range in the south is the main cause for the shifting of the lake. However, they did not critically explain sedimentological records as well as processes of lake shifting from the south. Paudel (2004), Paudel and Sakai (2008,2009) discussed various evidences about stratigraphy and sedimentological records of the southern marginal part of the Kathmandu basin. Gajurel (2011) has evidenced lake level fluctuation from sedimentary facies analysis at the southern marginal part particularly in the Buranchuli and Pyangaon areas. Nonetheless, the gap in study of litho-facies variation towards center of the basin has been bridging by this study.

Sunakothi Formation is located between the central and southern part of the basin. It is underlain by Lukundol Formation and overlain by terrace gravel deposits (Sawamura, 2001). Researcher like Sha et al., (1995) considered the conglomerate-sand-clay sequence belonging to Lukundol Formation (oldest sequence) in the southern margin gradually changes into the Sunakothi Formation, while Sakai (2001,2002) considered the southern extension of the Thimi Formation comprising fluvio-deltaic sequence in the northern part of the Kathmandu Basin. Moreover, Yoshida and Gautam (1988) shows the Gokarna and Thimi Formations in the whole periphery of the Kathmandu basin without considering the definition, dominate

lithology of these formations that mentioned by Yoshida and Igarashi (1984). Critical explain of depositional environmental changes in the southern part of the basin is lacking. This article attempts to focus on depositional environmental changes of the Sunakothe Formation by using facies analytical tool.

GEOLOGICAL SETTING

Kathmandu basin is situated on Kathmandu Nappe (Stocklin and Bhattarai, 1981; Rai, 2001). The basement rock at southern

part of the basin is comprised by fossiliferous early Paleozoic Tethyan sequence of the Phulchoki Group, which rest on the metamorphosed Bhimpheedi Group, while northern slope of the valley is composed of granite, gneiss and schist (Fig.1).

The valley is filled up with the materials sourced from nearby hills. In northern part sediments like sand and silt are dominant, while in the central and south pebbly clay, conglomerate and diatomaceous earth with peat occur. The

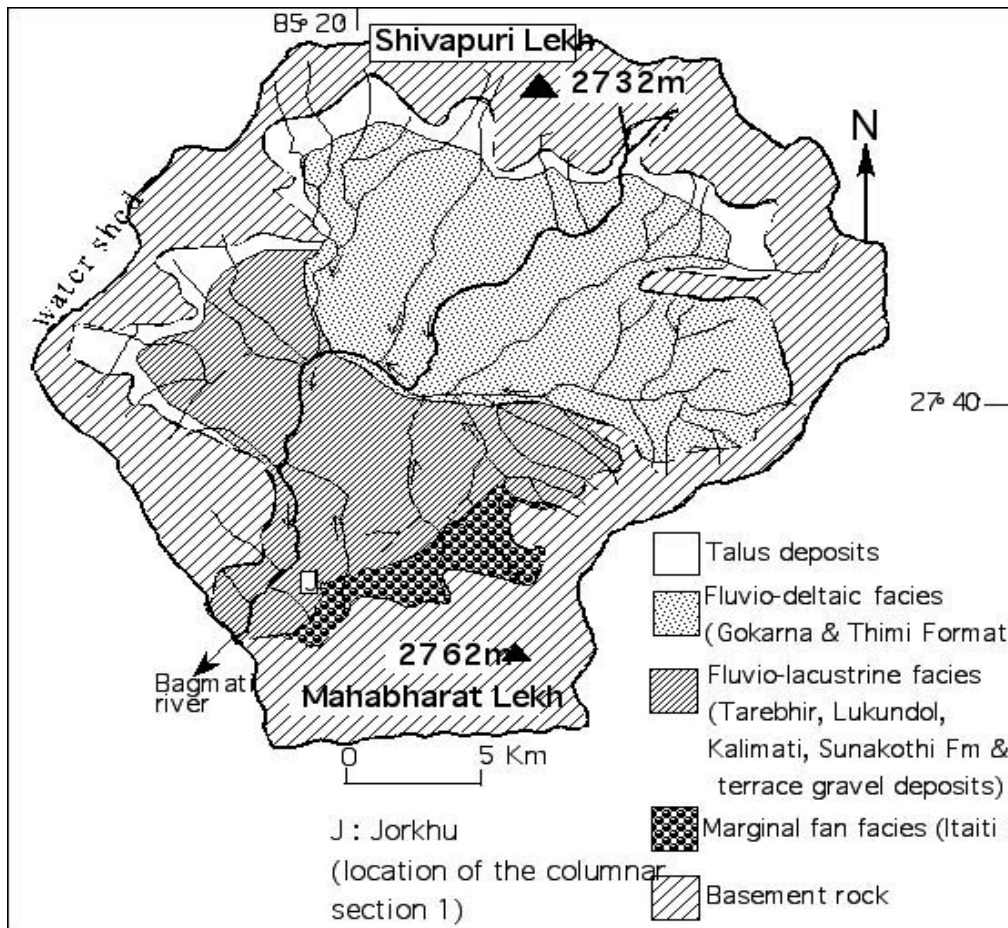


Fig.1: Facies map of the Kathmandu Basin showing fluvio-deltaic, fluvio-lacustrine and fan sediments (modified after Sakai 2001b).

sediments have been broadly divided into three facies: fluvio-deltaic in the north, fluvio-lacustrine in the south and center, and alluvial fan in the southern margin (Fig.1).

STRATIGRAPHY AND DISTRIBUTION

Sunakothe Formation is located above the muddy part of the Kalimati Formation (Fig.2). It is covered by the distal part of the Itaiti Formation known here as fluvial gravel deposits and it rest on the Lukundol Formation at upstream of the Nakhu Khola. Sunakothe Formation is extensively distributed in the

southern part of the Kathmandu basin ranging in altitude from 1400 m in south to 1300 m in the central part of the basin (Fig.2). Type locality is found at Sunakothe village, 3 km to the south from Patan (Paudel, 2008). Well-exposed sub-type sections are encountered at upstream of the Godawari Khola around Damaitar, around the Nakhu Khola, around the confluence of the tributary flowing from Dhapakhel and Kodkhu Khola, and around Khayakadol Khola between Jorkhu and Parigaon (Fig. 2). Average thickness of the Sunakothe Formation is 45 m and changes in thickness from south to the central part of the basin. The maximum thickness of this formation is between the central and southern part of the basin where thick fluvial

gravel is interbedded within the sandy and muddy sequence.

This formation consists of massive to laminated, thick to thin bedded, gray to dark clay, silty clay, coarse to fine-grained sand with occasionally white diatomaceous silt, carbonaceous black clay and pebble to large boulder size gravels. Sedimentary structures characterized in the formation are large to small-scale cross bedding, parallel and climbing ripple lamination, occasionally wavy ripple, trough and flaser beddings. Fine-grain sand and silt beds contain climbing ripple lamination, while the medium to coarse grain sand beds contain small to large-scale cross-beddings. Synsedimentary deformation structures such as slump and distorted bedding,

deformed sedimentary layers, and small-scale fault structure are present within the sedimentary beds of this formation. Usually strike of the beds is running in NW-SE direction and bed dips due north with amount ranging from 4° to 12°. Dip amount decreases toward the center of the basin.

SEDIMENTARY FACIES

On the basis of facies assemblage, five major facies associations have been identified within the Sunakothi Formation. These associations mainly consists of clastic sediments formed by low turbidity deposits in the shallow offshore lake condition known as pro-deltaic association (facies association Pd), sandy channel-fill or delta front

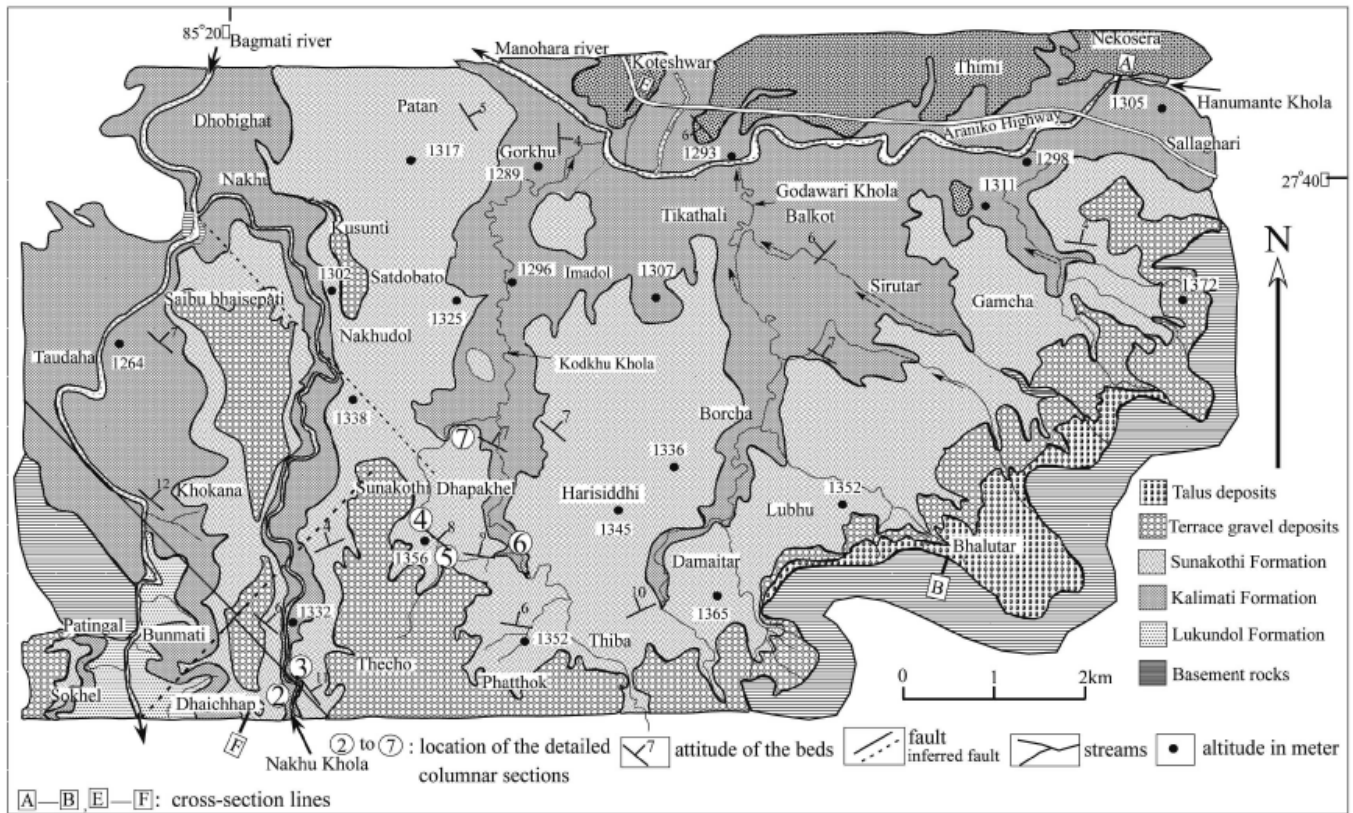


Fig. 2: Geological map of southern and central part of the Kathmandu basin showing distribution of the different stratigraphic units (After Paudel and Sakai 2009).

association (facies association df), sandy and gravelly channel fill and muddy flood plain of the delta plain association (facies association dp) and shallow marginal lacustrine facies association (facies association ml), sandy and gravelly fluvial facies association (facies association fl). From base to top and south to center, braided river deposits changes into meandering river deposits.

(I) Delta plain association (dp)

Frequent repetition of the fine and coarse sediments is the characteristic features of this association. Highly bioturbated

and black fine sand and silty mud facies are present within this association (Fig.3). Among the sandy facies, climbing ripple and small cross-laminated fine sand is dominated facies. Silt and silty sand beds show black color. Repetition of the fining-upward sandy sequence from coarse sand to mud is the characteristic features of this facies. Some silty sand and silt beds contain fossil leaf (Fig.3). Silt bed is gently inclined and is traceable from delta-plain to delta front region, which is clearly observed toward the basin center (Fig.4). Subparallel to parallel laminated sand changes upward into climbing ripple lamination. The climbing ripple laminated sand is sharp-based and interbedded within the mud. This sequence shows flood

generated sequence that changes into diminishing condition of the flood indicated by climbing ripple sand. This type of sequence or depositional condition indicates progradation of the lacustrine delta due to lake level lowering condition. Occasionally, increase in water flow velocity within this association may have produced small-scale features such as ripples, lenticular and flaser bedding (Fig.3). Highly bioturbated horizon within the silt beds may suggest a rather

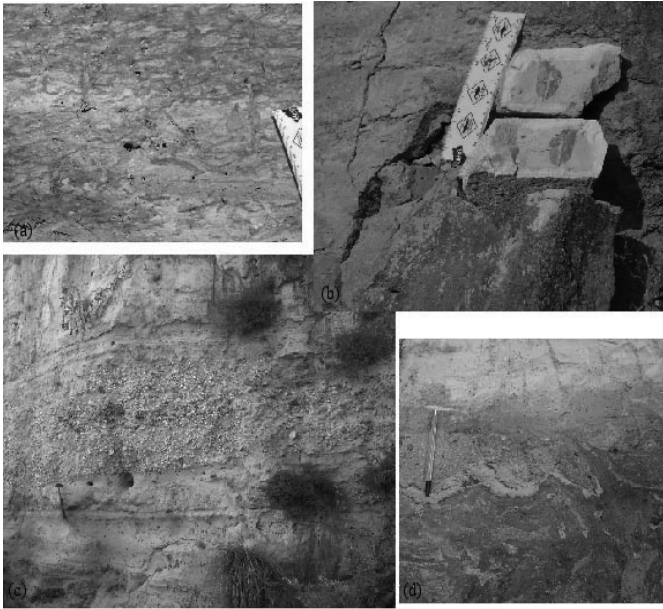


Fig. 3: Photographs show various structures found in the delta-plain association of the Sunakothi Fm, (a) highly bioturbated silty sand, (b) silty clay with plant leaf, (c) thick gravel bed within the sandy sequence, and (d) convolute structure within the silty clay.

slow rate of sedimentation. This association indicates sandy and gravelly channel-fill, and muddy flood plain with swamp deposits. Lithofacies analysis indicates that this association corresponds to the lacustrine delta plain with meandering and gravelly braided river origin.

(II) Delta front association (df)

The delta front association mainly consists of sandy fluvial sequence characterized by fining-upward sandy sequence from coarse sand to mud. Following types of beds are recognized within this association (Fig.5): cross-laminated coarse sand, parallel laminated medium sand, laminated gray silty sand, wavy climbing ripple laminated sand, very low angle cross stratified sand, trough cross bedded medium sand and some black carbonaceous layers. This association is characterized by wavy ripple and low angle cross-laminated sand.

The sedimentary features show combine fluvial and basinal depositional processes. Very low proportion of the mud facies is observed within this association and regional extent of sands suggest that deposition occurred during the period of increased discharge as well as sediment supply to the basin. Many



Fig.4:Small outcrop showing fine silt bed of the delta-plain (dp) to delta front (df), arrow indicates traceable surface and G is the thick coarse gravel bed within the delta front.

enecontemporaneous deformation structure such as slump and distorted bedding, deformed sedimentary layers, and small fault and folded (Fig.5) structures are characteristic features of this association. These syndimentary-deformed structures within the sand beds indicate sediments were deposited at the time of rapid gravity mass transport. It is concluded that this association corresponds to the flood dominated sandy braided river within the delta front environment.

(III) Pro-deltaic association (Pd)

It consists of black to gray muddy rhythmites. Laminated black silty clay and very fine silty sand are the dominant lithology of this association. Laminae are less than 5 to 10 mm thick and beds of very fine silty sand layers are 10 mm to 50 mm thick (Fig.6). Black carbonaceous clay laminae are present within this facies. This type of facies is recognized in all sections from southern to the central part of the basin (Fig.5). Toward the center of the basin silty clay contains shells and trapas in some locality. Massive mud with shell remains indicates probably offshore low energy condition. Rhythmic sequence of silt and fine sand indicates seasonal variation of the sediment supply to the lake basin. On the other hand, shell and trapa within the silty bed indicates hydrologically calm depositional environments. Sedimentological study of this association indicates low turbidity current deposits before the peak fluvial flood from lake margin to the shallow lake offshore. In some section interbed of climbing ripple sand and gravel beds within this association indicates bed load transport from the delta front association. These types of characters shows peak flood from delta-front due to abrupt climatic change of the basin.

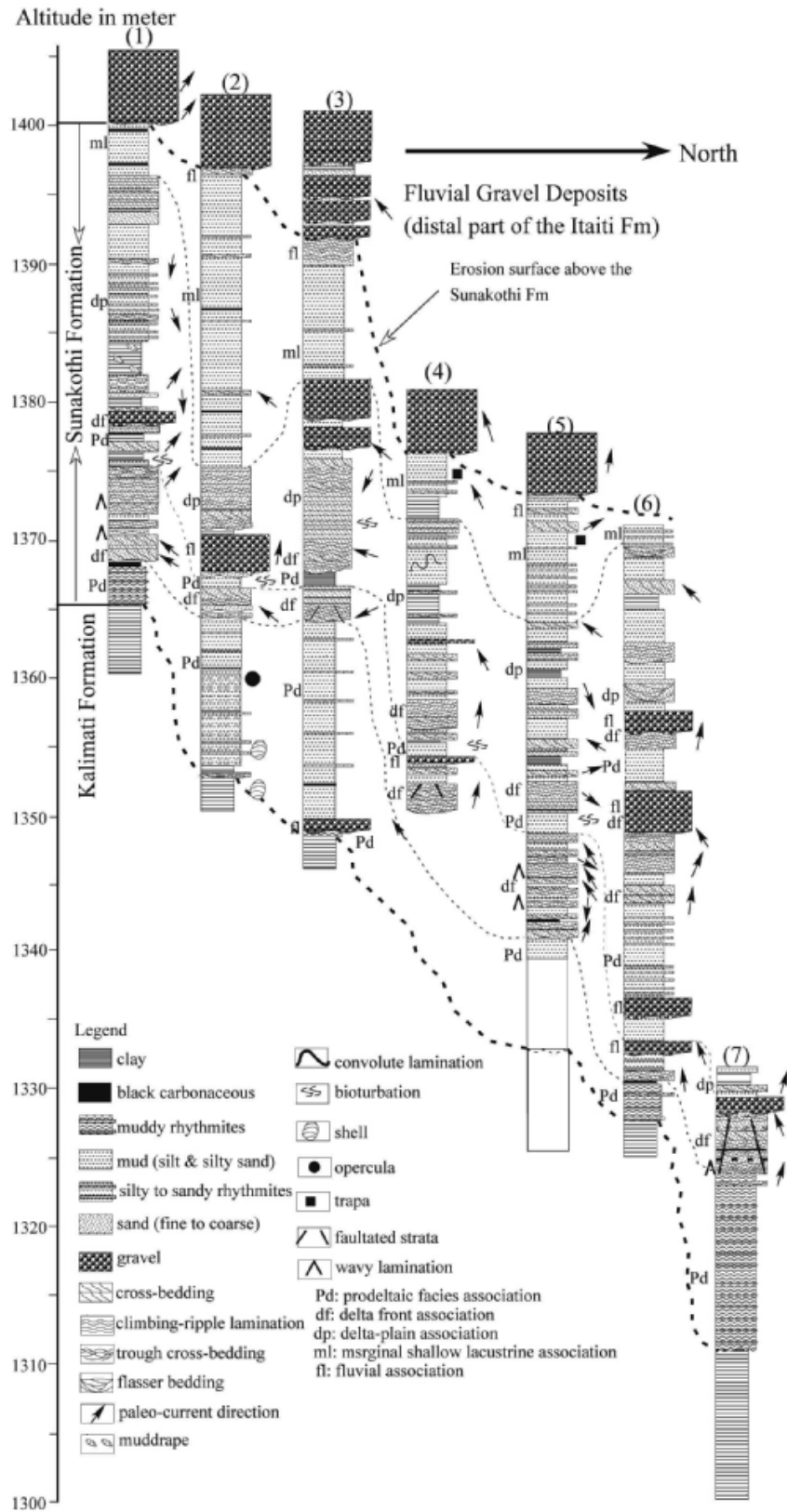


Fig.5: Columnar sections show changes in facies from south to north in the Sunakothei Formation, where the fluvial gravel deposits cover the top surfaces.

(IV) Marginal shallow lacustrine association (ml)

This association is characterized by sandy to coarse silty rhythmite. Occasionally silty mud contains fossil trap, abundant plant detritus and leaf (Fig.3). These types of facies are thick and widely distributed in the southern part. Intercalation of thin sand bed with wave ripple structures is well developed within the laminated silt beds. The wavy structure indicates shallow water condition. Pebble size green vivianite minerals are also found within this association. On the basis of laminated silt, silty sand and abundant plant leaf with detritus, it is interpret that this association is related to the shallow marginal lacustrine environment over or within the delta-plain environment. This association indicates delta-plain was inundated by water for long period of time.

(V) Fluvial association (fl)

Fluvial association is characterized by thick channelized gravels and fluvial sand beds. These facies are distributed within the delta front association and above the shallow marginal lacustrine facies associations (Fig.5).

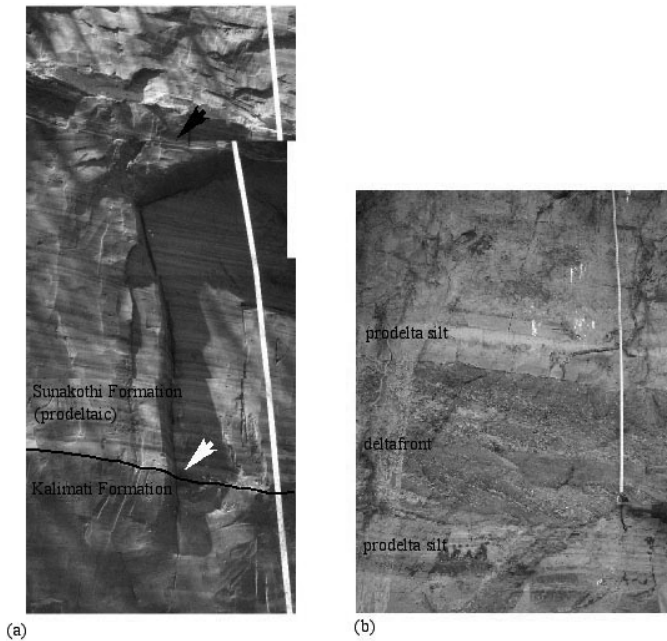


Fig.6 : (a) Photograph shows a pro-deltaic association of rhythmic sequence, white arrow indicates boundary of the Kalimati and Sunakothi Formation, (b) Thick delta front gravelly sand locates between prodeltaic silt and silty sand beds.

DISCUSSION

Facies and lake level changes

Lateral and vertical facies changes in the Sunakothi Formation and their significance are discussed here. The studied sections (Fig. 5) reveal three types of progradation in the lacustrine delta system: (1) From location 1 at southern margin to 3 in northward direction, delta progradation

occurred during the lake level rise and prolonged stabilized condition indicated by the prodelta, delta front, and delta plain association. Terrace surfaces in the three locations are more or less at same elevation. (2) From the location 4 further north to location 6, delta progradation occurred due to rapid lake level fall indicated by the different elevation of the top surface of the terrace from location 3 to 4. From location 4 to 6, delta aggradation is indicated by repetition of prodelta, delta front and delta plain association. It indicates that delta aggradation occurred due to further lake level rise. (3) Further rapid lowering of the lake level is indicated by high value elevation differences of the top surface of terrace from location 6 to further north at location 7.

Depositional environments

Detritus of the Sunakothi lacustrine delta and overlying gravel beds are mainly derived from quartzite and sandstone of the Tistung Formation being distributed to the south in the Mahabharat Range. Paleocurrent directions obtained from both formations also indicate that provenance was from the south. Sedimentological evidences of this formation in the southern part of the basin show fluvio-lacustrine depositional environment. It is not the fluvial terrace deposits as visualized by Yoshida and Igarashi (1984) above the older Kathmandu lake sediments known as the Lukundol Formation.

The transition from lacustrine to alluvial system of the Paleo-Kathmandu lake in the southern part is characterized by flood-dominated lacustrine delta and fluvial system occurred from south to the central part of the basin (Fig.5). Basal part of this formation is characterized by graded rhythmites with slightly erosional surface above the muddy part of the Kalimatic Formation that indicates river generated underflow before the catastrophic floods within the lake basin. It is also supported by rhythmites, which does not show any mottling and bioturbation.

The most common succession of sand, silt and mud with intercalation of the thick lenticular gravel beds in this formation further to the center indicates development of the lacustrine delta from the south. From south to center, lower part of the sand bed having thick green color medium to coarse sand with cross and climbing ripple indicates that the sediments were directly transported by river bringing from southern source. Sedimentological study in the delta plain area shows that meandering river system accumulated the sediments. This association shows marshy and flood plain environment. The cross-bedded sand bed within the delta-plain silt beds supports small channel frequently interrupted within the delta plain. Fine and coarse sediments within the delta plain shows lake level was frequently fluctuated during the deposition of this sediment. Toward the center of the basin delta-plain silt beds is traceable from delta-plain to delta front region (Fig.4). Top part of the delta-plain shows development of extensive flood-plain and at southern part of the basin flood-plain environment changes into shallow lacustrine that found in the upper part of this formation. Facies study indicates that fluvio-lacustrine

sediments (Sunakothi delta) of this formation were prograding from south of the Kathmandu Basin. Finally, at the center of the basin, open lacustrine deposits of the Kalimati Formation is covered by fluvio-lacustrine deposits of Sunakothi Formation at the south and fluvio-deltaic sediments of the Gokarna-Thimi Formation at the north. These facts suggest that Sunakothi Formation is a southern counterpart of the fluvio-deltaic Thim-Gokarna Formation that were deposited in the northern half of the basin.

Control on sedimentation: climatic and/or tectonics

Thick clastic detrital sequence and their wider distribution from the south to the central part of the Kathmandu Basin indicate that a wide accommodation space was available before deposition of these sediments. This wide space was most probably result from the higher rate of upliftment of the Mahabharata Range in the south and Shivapuri Range in the north. Thick muddy part of the Kalimati sequences which are dipping toward center at the southern margin, and thick fluvial gravel beds within the sandy sequence showing the paleocurrent direction from south and southeast indicate that the rate of upliftment of the Mahabharat range in the south was infrequent and higher than the Shivapuri range during the deposition of these sediment. Gently inclined vertical sequence of this formation is overlain by thick monotonous gravelly sequence of braided river deposits, which indicates upliftment of the Mahabharata range in the south was continue during and after the deposition of this formation. On the other hand, thick fluvial sandy and gravelly sediments within the Sunakothi Formation indicate greater runoff and large volume of sediments yield due to greater relief and elevated precipitation at the time of deposition. Moreover, repetition of fine and coarse sediments indicate seasonal high and low amount of precipitation rate within the Kathmandu Basin during the deposition of this sediments.

In the south, minor fluctuation in the lake level produced progradational sequence involving muddy rhythmite at the base that is followed by sandy and gravelly sequence. Lake level rise is indicated by the following evidences: (1) widely traceable prodeltaic deposits that formed during the lake level rise (2) thick shallow lacustrine succession above the delta-plain deposits also indicates lake level rise condition. Rapid lake level fall after the rise of the lake level is strongly supported by the following criteria (1) delta front deposits are composed of very coarse gravel and sandy sediments of the fluvial origin, (2) cross-stratification is mostly gentle, (3) erosion surface within the delta front and delta plain region also indicates rapid lake level fall during the deposition of these sediments. Sedimentary sequence shows vertical and lateral increase of the lenticular sand and gravel bodies (Fig.5) that denote increased sand supply by the river to the lake basin. It represents lake regression when sandy and gravelly braided river extended farther center into the Paleo-Kathmandu lake. Hence, thick fluvial clastic sequence, and basin ward coarse

gravel and sand bed distribution in this formation indicate that climatic conditions played major role for the deposition of these sediments.

It might be possible that tectonic activity of the basin margin could provide additional role for the lake level fluctuation. Furthermore, interbedded, highly developed synsedimentary structures within the undeformed sequence indicate catastrophic events followed by period of relative stability.

CONCLUSION

- (1) Stratigraphy of the southern part of the basin is redefined into Tarebhir, Lukundol, Kalimati, Sunakothi, Itaiti Formation and terrace gravel deposits.
- (2) Newly defined Sunakothi Formation is underlain by muddy lacustrine facies of the Kalimati Formation and Lukundol Formation covered by fluvial gravel deposits.
- (3) Well aggradation of the lacustrine delta, extensive shallow marginal lacustrine condition above the delta-plain, as well as the thick prodeltaic sequence from south to the central part indicates maximum lake level rise condition before the lake level fall.
- (4) Very thick lenticular gravel beds and sand with erosion surface within the deltaic sequence indicate lake was rapidly lowering during the deposition of these sediments. On the other hand, lacustrine sequence in between the sandy and gravelly sequences indicates, stable or lake level rise condition.
- (5) Stratigraphic study of the southern and northern part of the basin shows, open lacustrine deposits of the Kalimati Formation at centre is covered by Sunakohti Formation in the south and Gokarna-Thimi Formation in the north, while in the southern part of the basin Lukundol Formation is covered by Sunakothi Formation, and again it is covered by distal part of the Itaiti Formation. It indicates that whole lacustrine sequence in the southern part of the basin is covered by Sunakothi Formation. This fluvio-lacustrine (delta) sequence is covered by fluvial gravel deposits.

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