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MORPHOLOGICAL FEATURES AND DEPOSITIONAL PATTERNS OF GEM-BEARING SEDIMENTS IN THE KALU GANGA BASIN, SRI LANKA

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ABSTRACT

Sri Lanka has a very long history of gem industry. Gem mining in Sri Lanka is mostly done in secondary gem deposits where gems are concentrated in gem-bearing gravel layers abundant in the alluvial deposits. Rathnapura is a major gem field that falls within the Kalu Ganga basin and is considered as one of the oldest and extensive gem producing fields in the country. Characteristics of basin morphometry are indeed useful in exploring gem-bearing gravel layers. Hence this research was first aimed to evaluate the morphometric parameters of the Kalu Ganga basin by digitized topographic maps and digital elevation models. The gemming filed at Rathnapura is composed of thick alluvial deposits, stratigraphic records of which can be used as an ideal archive for studies on fluvial response to climate and sea level changes during the Late Quaternary period. Therefore, this study was further focused to explore depositional and textural characteristics of the alluvial sediments that reflect the dynamics of fluvial system response to climate and sea level changes. In this study, five types of sedimentary gem deposits were identified in the Kalu Ganga basin: hill slope and stream valley deposits in the upper catchment, hill slope and stream valley deposits in the middle catchment and stream valley deposit in the lower catchment. Out of them, stream valley deposits found in the lower catchment are the most important; they are very deep, characterized by a number of strata, inhomogeneous in composition and texture, formed by a series of geomorphological processes, influenced by sea level changes and climatic fluctuations, but not affected by recent tectonics. Hence, these deposits will be ideal proxies for paleo-environmental studies and sea level change.

Key words: *Gem, Sediment layer, Deposition, Kalu Ganga, Stratigraphy*

INTRODUCTION

Sri Lanka is well-known for its gems throughout the world having a large variety of precious minerals with a very long history in gem industry. The world's largest Blue Star Sapphire was discovered from a gem mine in Rathnapura, the famous gemming area in Sri Lanka, just two months ago. The Gemmology Institute has certified that this gem weighs 1404.49 carats and is worth at least $100million (BBC, 05th January 2016). This recent discovery has again drawn the attention of international community on Sri Lankan gems.

There have been recent technological advances in mining methods as well as in geological research with the intention of obtaining greater information on gem fields of Sri Lanka. Gem deposits in Sri Lanka are mainly found as primary or in-situ deposits and secondary or sedimentary deposits (Wadia, 1945). The in-situ or primary gem deposits have been classified into two categories as metamorphic or magmatic deposits (Rupasinghe and Dissanayake, 1985). Gems formed by metamorphism are mainly confined to high grade metamorphic terrain of the Highland Complex (Figure 1) and are formed by skarn reactions between the mineral calcite and other silicate rocks (Dissanayake and Rupasinghe, 1994). Magmatic deposits are mainly associated with pegmatites (Gunaratne and Dissanayake, 1995). Sri Lanka's main sedimentary deposits are concentrated in the gem fields of Ratnapura and Elahera areas, located in the south-western and southern fringe and north-eastern areas of the country (Figure 1). Sedimentary deposits are broadly classified

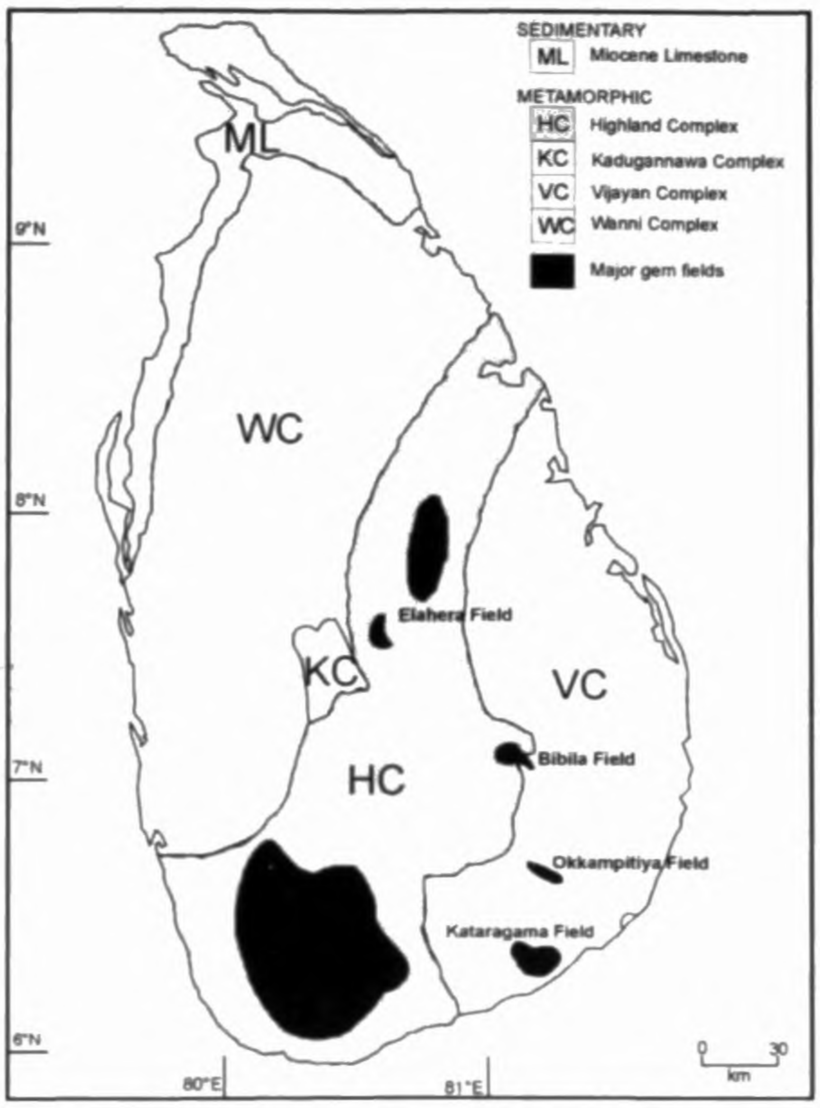

Fig. 1 Map showing the main gem provinces in Sri Lanka

into three types as residual, eluvial and alluvial deposits (Dahanayake *et al.*, 1980). Gem minerals originally integrated in the rocks are released by rock weathering and are then transported along the hill slope by surface runoff. Eluvial gem deposits are formed locally when these minerals are trapped within the depressions on hill slopes. Sediments in elluvial deposits are less transported and often associated with colluvial material. Alluvial gem deposits are the most prominent type, formed by transportation of sediments along the hill slopes and within the fluvial system over a long distance from the source rocks and then deposited within bed of the river, on the river flood plain or at the inner edge of a meander river as a point bar deposit. These gem bearing gravel layers are covered by thick alluvial layers up to 20 m in thickness. Such deposits, traditionally called "Rathnapura Beds", are extensively developed within the Kalu Ganga basin, which is the main gemming area of the country. Records reveal that these deposits had been developed over the Quaternary period (Deraniyagala, 1958). Even though the Kalu Ganga is renowned for supplying valuable gem minerals to alluvial deposits, morphological characteristics of the basin have not been completely studied. Instead, extensive studies have been conducted in understanding the genesis of primary gem minerals and in developing geochemical exploration methods to trace gem deposits.

Morphological features of river basins are widely assessed by determining morphometric parameters, which are the measurements and

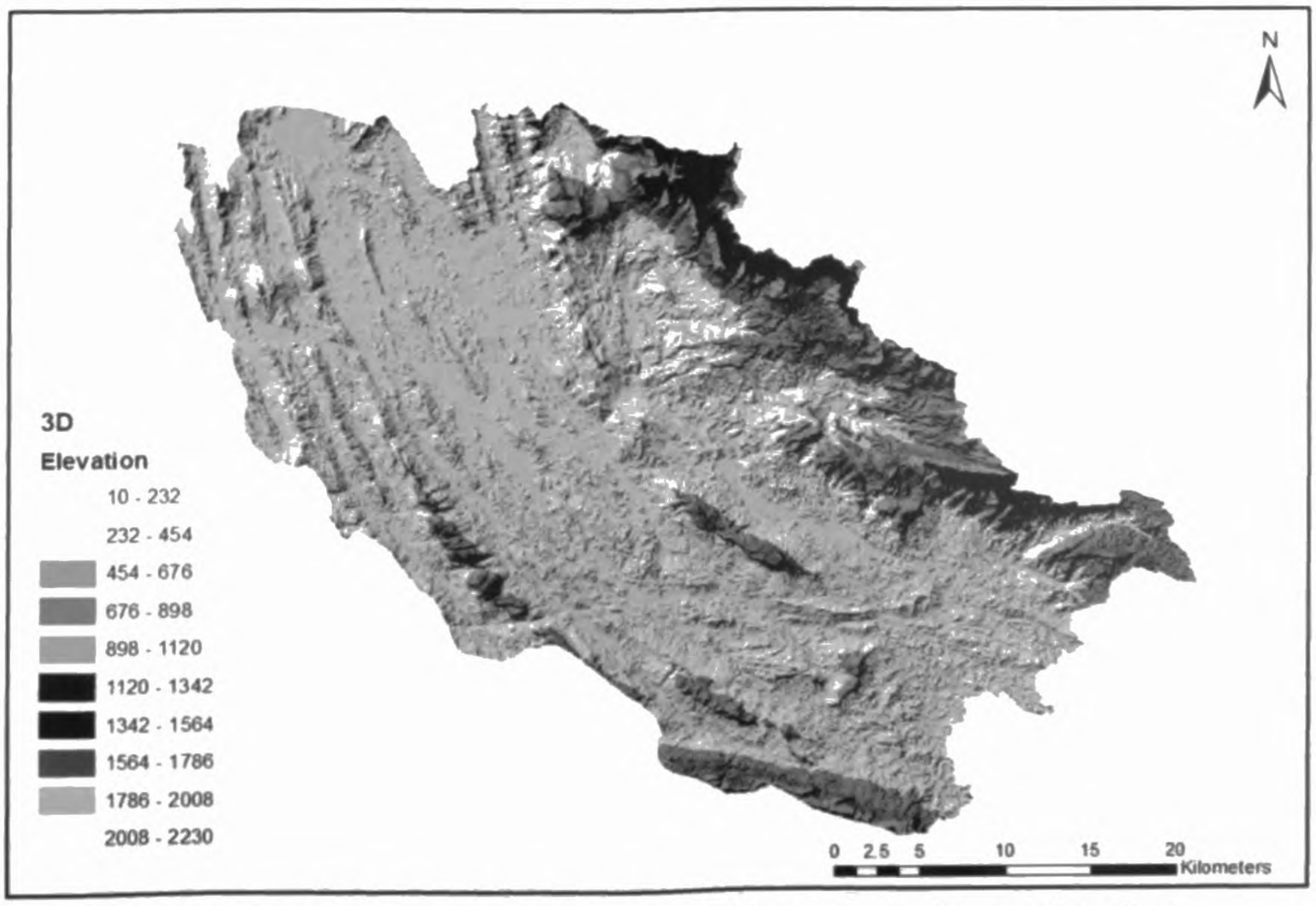

Fig. 2 Digital elevation model of the Kalu Ganga Basin showing the relief

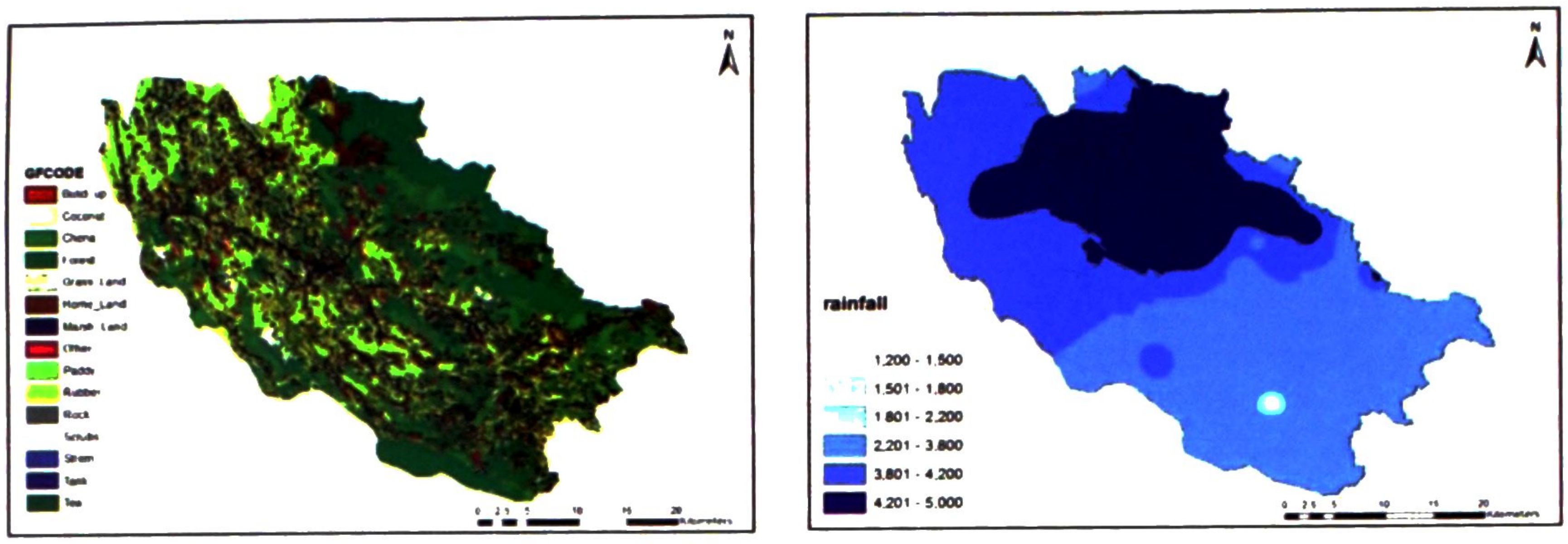

Fig. 3 (a) Spatial pattern of land use in the Kalu Ganga basin and (b) Spatial pattern of rainfall within the Kaluganga Basin

mathematical analyses of the configuration of the earth's surface. Morphometric parameters include linear aspects of the drainage network (stream order, stream number, stream length, mean stream length, stream length ratio, bifurcation ratio, etc.), areal aspects of the drainage basin (area, perimeter, etc.) and relief aspects (gradient, etc.) of the channel network and contributing ground slopes. These analyses play a crucial rule in understanding the evolution of fluvial systems and adjacent landscapes and also in studying the depositional history of alluvial deposits. Further, morphological parameters are beneficial for researchers who want to select sites to apply either geochemical or geophysical exploration methods to discover gem minerals that are hidden within the earth's surface. Therefore, the first objective of this research is to develop morphometric parameters of the Kalu Ganga basin while studying geological, land use and climatic settings of the basin (Figures 3 and 4, and Tables 1 and 2).

The term "alluvial gem deposit" is widely applied to describe sedimentary gem deposits in Sri Lanka, but the erosion and depositional processes involved in developing these deposits along the river profiles are yet to be understood. Their distribution is also highly diverse along the river profile and the processes involved for developing the alluvial layers are hitherto unknown. In general, erosion and deposition along a river profile is decided by fluctuations of base level caused either by active tectonics or climate and sea level change.

Sri Lanka is located in a region where tectonic forcing was absent over the Quaternary period,

Table 1 Land use pattern of the Kalu Ganga basin

Land use type	Upper Catchment		Middle Catchment		Lower Catchment		Total	
	km^2	%	km^2	%	km^2	%	km^2	%
Coconut	1.7	0.5	2.0	0.3	00	0.0	3.7	0.3
Chena	26.4	7.0	204.5	26.7	52.5	21.0	283.4	20.5
Forest	5.2	1.4	65.2	8.5	148.3	59.3	218.6	15.8
Grassland	24.1	6.5	0.7	0.1	0.5	0.2	25.3	1.8
Homesteads	80.8	21.8	128.5	16.3	14.4	5.8	223.7	16.2
Marsh	0.2	0.05	00	0	00	0.0	0.2	0.01
Other cultivation	6.1	1.6	20.3	2.7	0.7	0.3	27.1	1.9
Paddy	64.6	17.4	26.7	3.5	2.1	0.9	93.1	6.8
Rubber	135.4	36.5	205.2	26.9	2.2	0.9	342.9	24.8
Rock	0.03	0.0	1.2	0.2	4.6	1.8	5.8	0.4
Scrub land	2.8	0.7	14.7	1.9	4.8	1.9	22.3	1.6
Stream	10.2	2.7	7.9	1.03	0.9	0.4	19.1	1.4
Tea	13.8	3.7	86.1	11.4	18.1	7.2	118.5	8.6
Built up area	00	0	0.02	0.0	0.9	0.4	0.9	0.06
Tank	00	0	0.02	0.0	00	0.0	0.02	0.0
Total	371.4	100	763.6	100	250	100	1385	100

Table 2 Morphological Parameters of Kalu Ganga basin

Stream order	Number of streams	Length of streams (km)	Mean stream length (km)	Stream length ratio	Bifurcation Ratio
1	3356	1647.17	0.49	-	3.46
2	971	739.95	0.76	1.55	3.28
3	296	343.53	1.16	1.52	5.02
4	59	188.25	3.19	2.75	4.21
5	14	129.78	9.27	2.91	3.50
6	4	45.10	11.28	1.22	4.00
7	1	27.90	27.90	2.47	-
Total	4701	3121.68	-	-	-

hence any observed change in erosion and deposition pattern along the river should be instigated by base level fluctuation by climate and sea level change. Therefore, a study of alluvial stratigraphic records of gem bearing deposits along the river profile will perfectly reflect how the ancient fluvial systems had responded to the fluctuation in the base level that was caused by climate and sea level change. Therefore, this research is focused on systematic examination of alluvial stratigraphic records that are archived in gem deposits along Kalu Ganga River. We believe that outcomes of this study will form the ground work for those who intend to pursue further investigations on climate change over the Quaternary by bridging the disciplines of fluvial geomorphology, sedimentology and climatology coupling with advanced research tools.

METHODOLOGY

The study mainly attempts to identify the types of sediments and depth of sediment layers in relation to the gem bearing sedimentation process in the Kalu Ganga basin mainly focusing on alluvial gem deposits. Hence, the Upper and Middle part of the Kalu Ganga River which flows across the Ratnapura district of the Sabaragamuwa province was selected as the study area. This area represents approximately two thirds of the whole river basin. The absolute location of the study area is at 135000-195000mE and 140000-185000mN (Sri Lankan metric grid coordinates) and total extent of the area is 1385km^2. The study area was extensively studied for drainage pattern, geomorphology and geology by using digital topographic data purchased from the Survey Department of Sri Lanka (2012) and geological maps published by the Geological Survey and Mines Bureau (GSMB) using ARC GIS 10.1 software. During the field study, gem mining was actively being carried out in the area. Sixty gem pits, which were not previously disturbed by mining activities and thus represent the natural conditions, were selected to construct the detailed stratigraphy. Coordinates of the gem pit, depth to the gem bearing gravel layer from the surface, elevation to the bed of nearby stream from the gem-bearing gravel layer were recorded in the field. These data were plotted on digitized maps using ARC GIS 10.1 software and exact elevations of the gem pits were extracted from digitized maps.

In order to investigate the pattern that gem-bearing gravel layers are deposited along the river, the Kalu Ganga basin was divided into three main divisions, the first is from 10 to 100 m above the mean sea level (called as "Lower Catchment"), the second is from 101 to 500 m above mean sea level (called as "Middle Catchment"), and the third is above 500 m above the mean sea level (called as "Upper Catchment") (Figure 2). Stratigraphic analyses were conducted on sediment samples from these three sub catchments and the patterns of which these gem-bearing sediment layers were deposited in the three basins were separately formulated. Shape and size of the sediments of gem-bearing gravel were also studied in detail in selected gem pits to observe their differences within the three catchments.

GEOLOGICAL, CLIMATOLOGICAL CHARACTERIZATION AND LAND USE TYPES OF THE KALU GANGA BASIN

The study area of the Kalu Ganga basin is underlain mainly by a proterozoic deep crustal high grade metamorphic terrain (Highland Complex), which is a major lithotectonic unit of Sri Lanka (Schenk, 1991). This basement is overlaid by recent alluvial deposits termed as "Rathnapura beds" (Cooray 1984). The

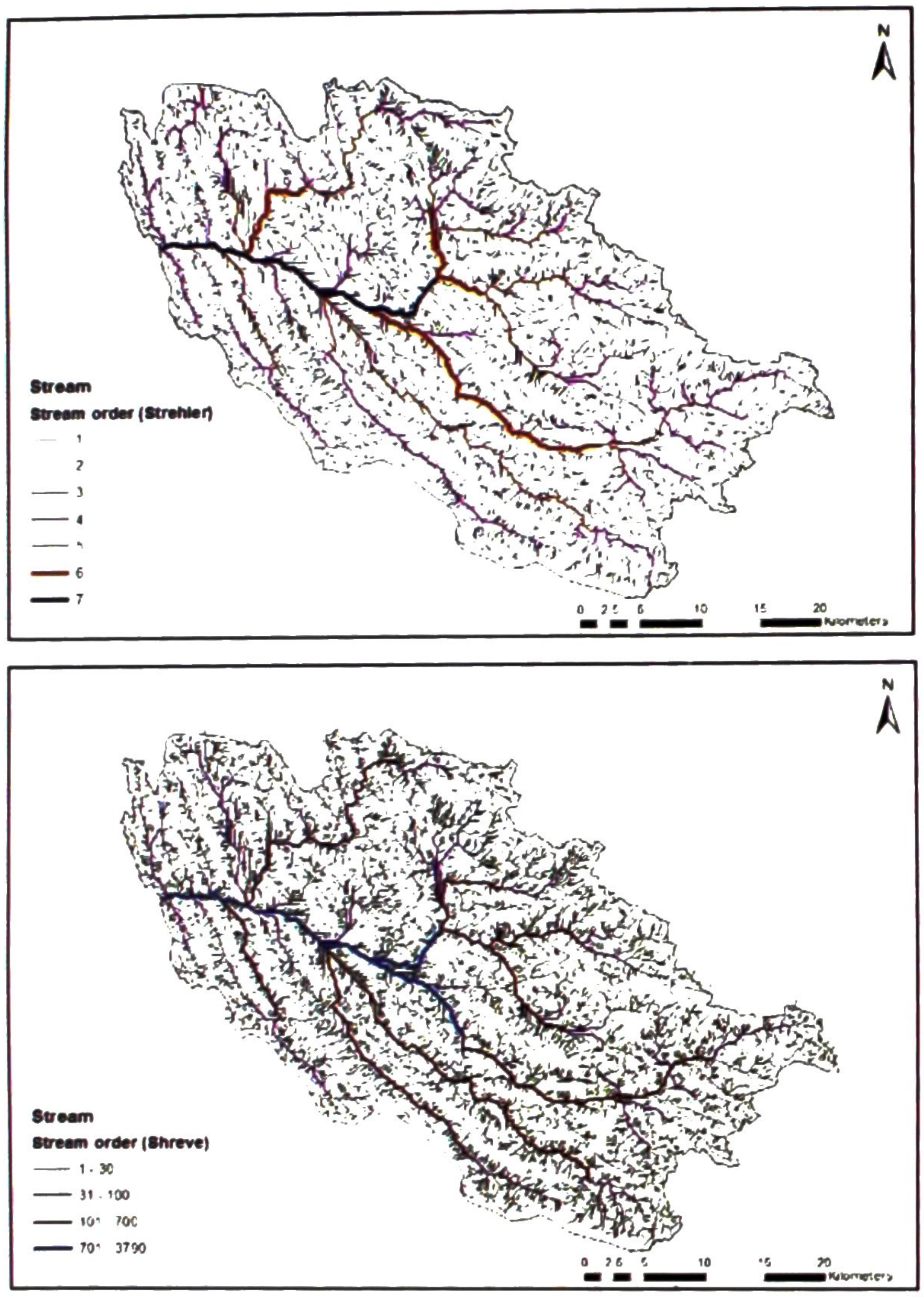

Fig. 4 Stream order in the Kalu Ganga Basin according to (a) Strahler'sand (b) Shreve's classifications

basement rocks consist mainly of NW-SE trending tectonically inter-layered bands of metasedimentary rocks paragniesses and metaigneous rocks (ortho-gneisses); mainly quartzites, marbles, garnet–sillimanite gneiss, charnockite and charnockitic gneisses. (Cooray, 1994). Major lithologies underlain in the Kalu Ganga basinconsists of chanockitic-gneisses, quatizites, impure quartzites, marble, calcsilicate-gneisses, garnet-sillimanite gneisses and biotite gneisess and few quartzites bands (Dissanayake et. al, *2000*). Especially, these rocks confine to hilly upper catchment areas of the study area. The lower catchment area is characterized by ridge and valley topography where the strike valleys are covered with unconsolidated alluvial sediments. This area is underlain by Highland Complex rocks consisting mainly of garnetiferous gneisses, hypersthene gneisses, and granulites with rare occurrences of marbles and pegmatites. This area includes garnetiferous gneisses from the main rock formation underlying the strike valleys as well as the bordering ridges. The underlying gneisses occur in a semi-weathered state with garnet and feldspar generating a brownish limonitic clayey appearance. Most common minerals observed in these gneisses are quartz, plagioclase, garnet, biotite, sillimanite and graphite with accessory, andalusite, apatite, corundum, ilmenite, magnetite, rutile, spinel, topaz and zirocon (Dahanayake and Ranasinghe 1985). In Kalu Ganga River, geological control on the course of rivers and streams is distinctly observed. The course of the river from its origin to the sea is controlled to a large extent by the nature of the underlying rocks.

Most of the area of the Kalu Ganga basin has been cleared for cultivation and there is only a small amount of natural forest cover preserved today. Land use in the upper part and middle part of the catchment is dominated by home gardens, where natural soil cover is disturbed and altered continuously. Grasslands and scrublands are former forest areas, cleared for tea, rubber and coffee cultivation during the colonial era. About 8.6% of the catchment area is covered by tea plantations (Figure 3a). According to the land use map of the study area, rubber cultivation is the dominant vegetation type which consists around 342 km^2 while other land uses such as chena cultivation, homelands, forest, paddy and tea plantations are comparatively significant in the catchment (Table 1). Precipitation is the most important factor that plays a major role in detaching gem minerals from the source rocks by weathering, transportation on hill slopes by runoff, transportation along the stream by water flow, and deposition on depressions when transportation power is lost. The rainfall in the study area is a result of number of events, namely the south-west monsoon, the inter-monsoon, depressions, and cyclonic activity (National Atlas, 2007). Rainfall due to the

Table 3 Shape of gem-bearing gravels (after washing) collected from the gem pits located in the stream valley deposits of the three catchments. Number of grains counted and their percentages in different shape classes are presented in the table

Catchment	Sample number	Shape Class			General Shape
		Very Angular	Sub Angular	Rounded	
Upper (above 500m)	01	22 (91%)	02 (09%)	00 (0%)	Very angular
	02	10 (71%)	03 (21%)	01 (08%)	Very angular
	03	148 (82%)	22 (12%)	10 (06%)	Very angular
Middle (100-500m)	01	45 (75%)	07 (13%)	06 (12%)	Angular
	02	30 (60%)	17 (34%)	03 (06%)	Sub angular
	03	18 (39%)	20 (43%)	08 (18%)	Sub angular
Lower (10-100m)	01	00 (00%)	03 (17%)	14 (83%)	Rounded
	02	03 (02%)	17 (15%)	90 (81%)	Rounded
	03	03 (10%)	06 (20%)	21 (70%)	Rounded

monsoons and inter-monsoons convection follows a regular pattern of precipitation distribution. Compared to the lower catchment area, precipitation in the upper catchment area is higher. The maximum annual rainfall in the south eastern sector of the study area is 3000 mm. However, the total annual rainfall received in the north part of the Kalu Ganga stream is more than 5000 mm (Figure 3b). Since the gem-bearing gravel layers have been formed in the alluvial deposits over the Quaternary period, understanding the variation in paleo-rainfall patterns are also important to investigate the alluvial deposits. Several studies have attempted to reconstruct the Late Quaternary fluctuations of monsoonal variability affecting Sri Lanka (Premathilake and Risberg, 2003, Ranasinghe et al., 2013a).

DRAINAGE AND MORPHOLOGY OF THE KALU GANGA RIVER BASIN

Streams of the Kalu Ganga basin were ranked in orders following Strahler's and the Shreve'sclassification schemes (Figure 4). According to the Strahler's classification, stream orders range in the Kalu Ganga basin vary from 1 to 7. The upper, middle and lower catchments have stream orders of 1 to 3, 1 to 5, and 1 to 7, respectively (Figures 4a). In the Shreve method, stream orders range from 1 to 15 in the upper catchment, from 1 to 700 in the middle catchment, and from 1 to 3790 in the lower catchment (Figure 4b). It was found that 981 streams exist in the upper catchment with a total length of 378km. In the middle catchment, 4383 streams were traced with a total length of 1548km. Number of streams present in the lower catchment is 3153 with a total length of 1193 km (Table 2).

The average slope of the basin is steep in the upper catchment from about 30-70 degrees and it becomes gentle to very gentle from the middle catchment (0-30 degrees) to the lower catchment (0-10 degrees) (Figure 2). As a result, runoff abruptly changes from very fast in the upper catchment to very slow in the lower catchment corresponding to the slope angle. The elevation in the study area ranges from 20 m to 2230 m giving a relief of 2210 m. This difference in elevation is noted only within a short distance of about 16 km.

Information collected in the field was used to ascertain any relationship between the stream order and the numbers of gem varieties mined from different locations. In the upper catchment, only one type of gems has been found close to the small streams, most times, but two or three varieties were also found in some mines. In the middle catchment, about 4-10 varieties of gemstones have been found in the gem pits. In the lower catchment, it is possible to discover gems in all the varieties characteristic to Sri Lanka. It was also exposed that stream order is an extremely important factor which determines the number of gem varieties to be discovered in a pit. For examples, Malpe Dola river is categorized as a 3rd order stream and only geuda has been found in the nearby mine, Kaluwara Dola river is classified as a 6th order stream and nearby mines produce cat's eyes, and Dawataya Amuna Ela is a 13th order stream.that produces geuda and star sapphires. In contrast, Maha Dola is a 99th order stream that supplies a range of gems namely spinel, moonstone, zircon, beryl, and tourmaline. It was found that about 15-20 varieties of gem minerals have been discovered in mines with higher stream orders, which are located in the lower catchment.

CHARACTERISTICS OF THE GEM-BEARING SEDIMENTS AND STRATIGRAPHY

Basically, five types of gem-bearing secondary deposits were recognized within the Kalu Ganga basin. In the upper catchment of the Kalu Ganga basin, gem-bearing gravels have been accumulated at two geomorphological settings; on the bottom stream valley known as stream valley deposits (Figure 5a) and on the hill slope known as hill slope deposits (Figure 5b). Similar to the upper catchment, stream valley deposits on the bottom of the valley (Figure 5c) and hill slope deposits on the hill slopes (Figure 5d) were identified in the middle catchment. The lower catchment is characterized by having only one type of sedimentary deposits that is the stream valley deposits.

Shape of the sediments present in the gem bearing gravel layers in the stream valley deposits of the upper, middle and lower catchments of the study area was determined in three representative samples collected from each catchment and their details are presented in Table 3. Overall, sediments in the gem-bearing gravel layers in the upper, middle and lower catchments are very angular, angular to sub angular, and rounded, respectively. The size of the sediments in gem-bearing gravel layers in the three catchments are shown in Table 4.

Average size of the sediments in the stream valley deposits of the upper catchment is about 3-40 cm in diameter whereas sediments in gem-bearing gravel layers in the hill slopes deposits are from 3cm to 300cm in diameter. The gem-bearing gravel layers in the stream valley in the middle catchment have sediments ranging in diameter from 2 to 30 cm while those in the hill slopes in the middle catchment have sediments ranging in diameter from 2 cm to 300 cm. Diameter of sediments from the gem-bearing gravel layers in lower catchment ranges from 0.5 cm to 20 cm depending on the depth of the layer.

Two stratigraphic profiles can be seen in the upper catchment in stream valley deposits and hill slope deposits. The stratigraphy in the hill slope has a topsoil layer in a depth of about 0.3-0.4 m. Below this soil layer, gem-bearing gravel layer is observed, whose depth is about 0.5 m. The stratigraphy in the stream valley deposits is characterized by a top soil layer with a depth of about 0.7 m which is underlined by a sand and rock fragments rich sediment layer having a

Fig. 5 Photographs showing the (a) stream valley deposits and (b) hill slope deposits in the upper catchment, (c) stream valley deposits and (d) hill slope deposits in the middle catchment, and (e) stream valley deposits in the lower catchment

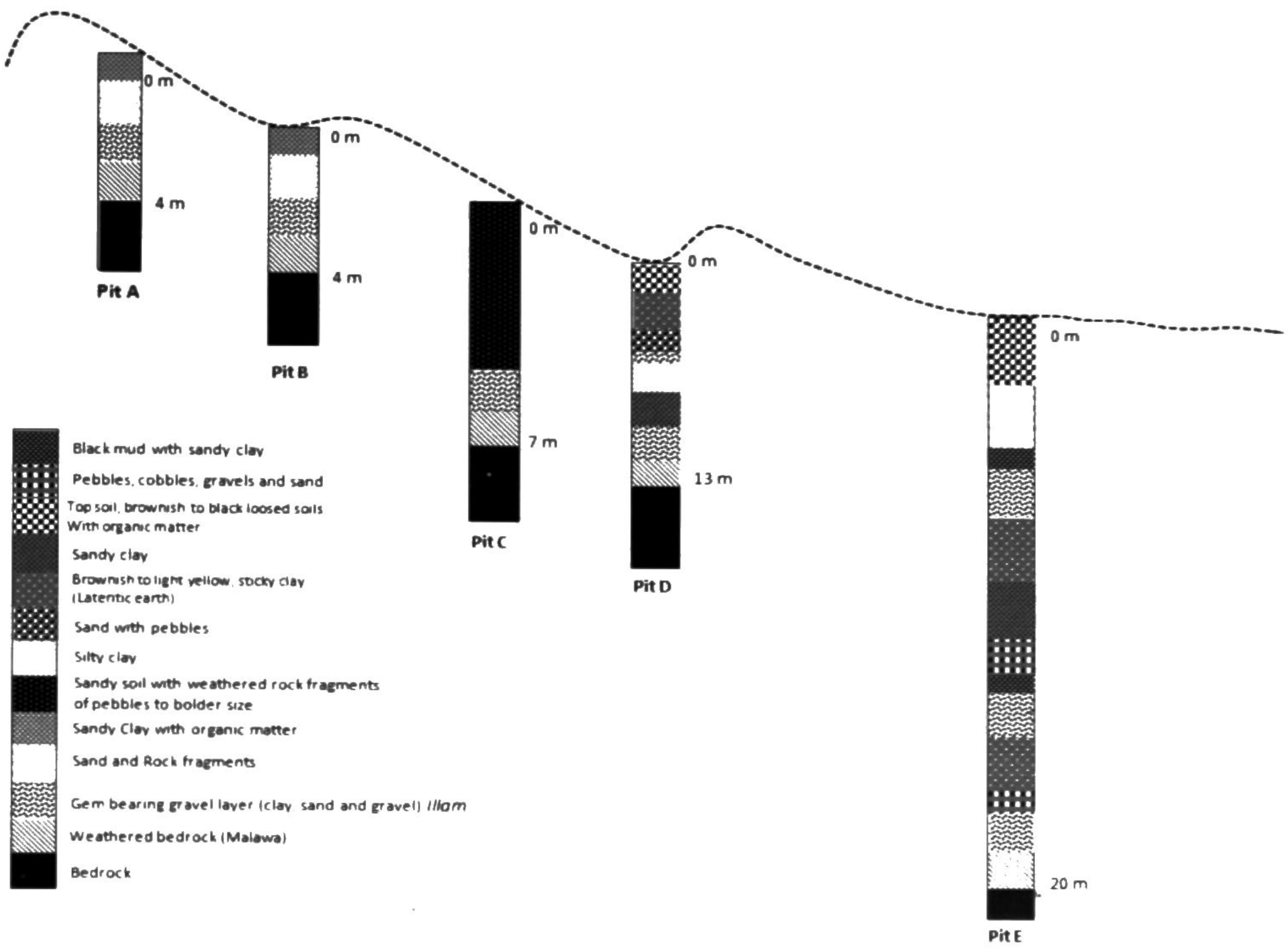

Fig. 6 Stratigraphy of (a) hillslope deposits and (b) stream valley deposits in the Upper Catchment, (c) hillslope deposits and d) stream valley deposits in the middle catchment, and (e) stream valley deposits of Kalu Ganga Basin

depth of approximately 1 m. At the bottom, gem-bearing sediment layer is found with a thickness of about 0.5 m and it is underlain by the weathered bedrock. Even though this is the general pattern of stratigraphy, slight variations in the stratigraphy were also observed within the upper catchment in some locations. Two distinct stratigraphic profiles were noted in the middle catchment on the stream valley deposits and on the hill slope deposits. In the stratigraphy on the stream valley deposits, the top soil layer is brownish to black in colour and rich in organic matter (humus) having a depth up to 1.5m from the surface. In the second layer, brownish to light yellow clayey soil and sticky clay (lateritic earth) were found. Rock fragments had been accumulated in the third layer. Below that, gem-bearing gravel layer occurs in 0.3m thickness as the fourth layer above the weathered bedrock. The lower catchment displays a deeply developed stratigraphy (Figure 6). On the top of the profile, a brownish to yellow, loose soil layer can be seen. Below that, a sandy clay layer with a thickness of about 3 m was observed. This is followed by a layer of sand and rock fragments and a layer of black mud. Gem-bearing gravel layer is placed below the mud layer. In many places, gem-bearing gravel layer is underlain by a layer of lateritic earth. Underneath the lateritic layer, a sandy clay layer, a sand layer with pebbles and cobbles, a black mud layer, and another gem-bearing gravel layer were placed. In some places, the second gem-bearing gravel layer is underlain by a succession of clay layers, sand with pebble and cobble layer. Then, the third gem-bearing gravel layer emerges. At the bottom of the profile of alluvial deposit, weathered bedrock is present (Figure 6). In the lower catchment, presence of two gem-bearing gravel layers is very common and occurrence of the third gem-bearing gravel layer is also observed. Another notable observation in the alluvial profiles in the lower catchment is the existence of mud layers with a high content of organics. All the profiles in the lower catchment are characterized by at least a single black mud layer and some of them contain two mud layers.

EROSIONAL AND DEPOSITIONAL PATTERNS ALONG THE KALU GANGA

Two types of gem-bearing sedimentary deposits are characterised in the upper catchment as hill slope deposits and stream valley deposits. In hill slope deposits, gem-bearing gravel layers are about 0.5 m in thickness, contain very angular sediments in highly irregular shapes, and have

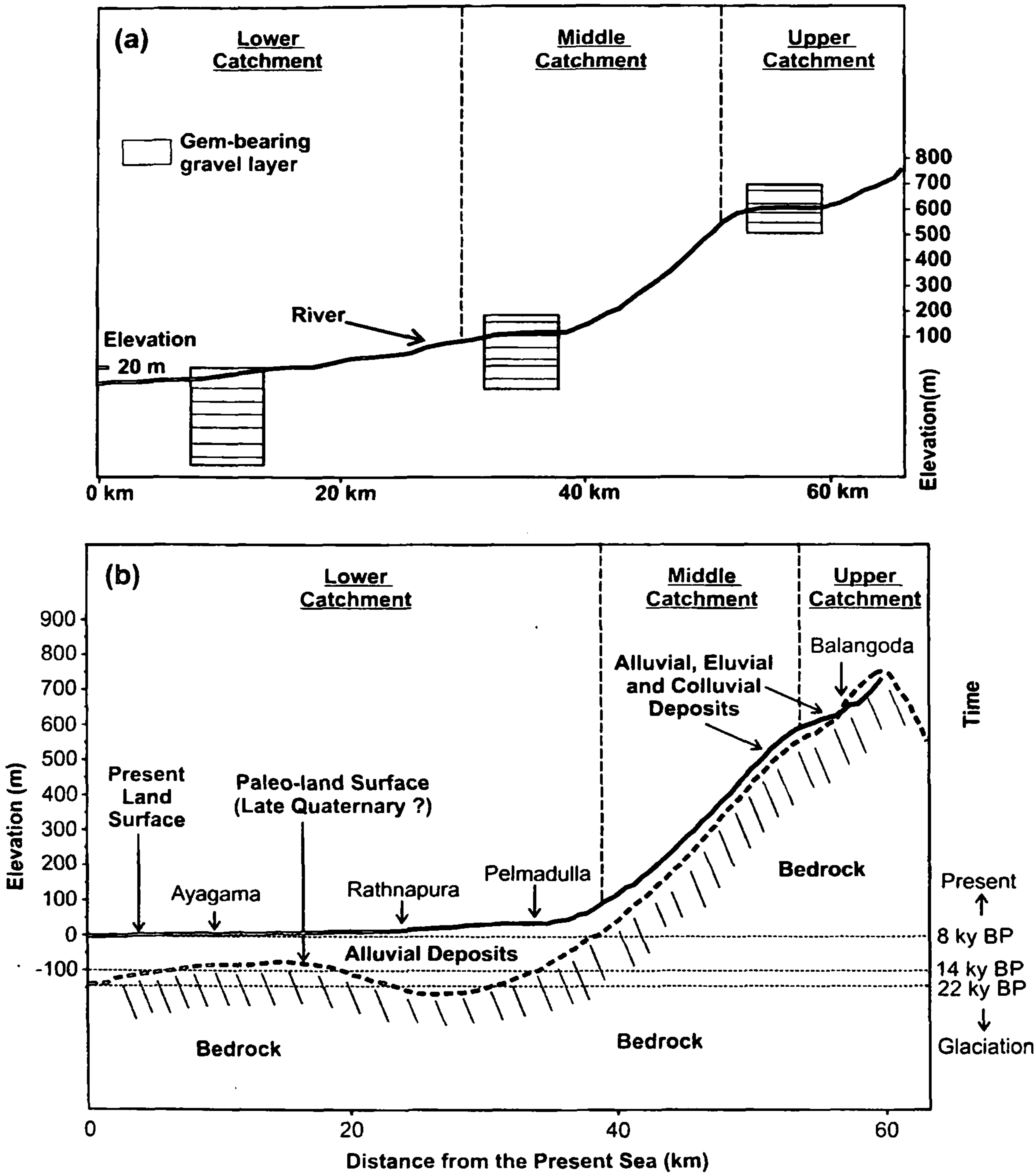

Fig. 7 (a) Sketch showing the place of deposition of gem-bearing gravel layers in the sedimentary profiles at different catchments and (b) Conceptualized cross section for the Kalu Ganga basin showing the present surface level and the paleo-surface level at the time of last glacial maximum. Paleo-surface level should have been changed from 24 ky BP to 8 ky BP in responding to the global sea level rise that should have influenced on the inland fluvial systems. Local seal level changes and monsoonal variability in the region are not considered for this preliminarily model. The rapid global sea level rise was reported for a period from 14 ky BP to 8 ky BP, where the base level of the fluvial system has suddenly elevated leading to rapid sedimentation in the inland sedimentary basins. Therefore, gem-bearing gravel layers in the Kalu Ganga basin are most likely to be formed during this rapid rate of sedimentation (14-8 ky BP). Note that this is purely a hypothetical explanation and a detailed chronological and sedimentlogical analysis will only permit in developing an accurate model.

been formed close to the source rocks. Sediments have not been transported by rivers and moved by the force of gravity along the slopes of 60 to 70 degrees and can be named as "elluvial" sedimentary deposits as defined by Dahanayake (1980). In stream valley deposits, gem-bearing gravel layers are located at a depth of 1.5m from the surface. Sediments in these layers are between 3cm and 40cm in diameter, relatively small, and show very angular shapes. These deposits have been formed through deposition by small streams that cannot transport large sediments and also over a long distance, as reflected in the texture in the alluvial sediments. The significant observation in the stream valley deposits of the upper catchment is that the gem-bearing gravel layer is always located at the same depth or at a slightly higher elevation than the bottom of today's stream bed (Figure 7a). This implies that the upper catchment area of the Kalu Ganga basin could have been dissected by vertical erosion during a period where base level was low.

Stratigraphy of mines located on hill slope deposits in the middle catchment is completely different from that in the upper catchment. In the middle catchment, sandy soil with weathered rock fragments up to boulder size extends to the 5m depth above the gem-bearing gravel layer. Sediments in the gem-bearing gravel layer are very angular ranging from 3cm to 300 cm in diameter. Field observations together with textural characteristics in the profiles indicate that hillslope deposits in the middle catchment have been developed by landslide events which are typical in this region. Middle catchments record the highest density of landslides in Sri Lanka, which are triggered principally by short interval, high intensity rainfalls that are typical in the south-western monsoon of this region (Gunatilaka, 2007).

In the stream valley deposits, one to two gem-bearing gravel layers present indicating the prevalence of a number of rainy periods. On the upper gem-bearing gravel layer, about 1m thick sand and pebble layer has been deposited also implying a wet period even after depositing the gem-bearing gravel layer. Sediments in the gem-bearing gravel layer have a diameter ranging from 3cm to 30cm and are sub-rounded in shape, indicating a fairly long-distant of transportation. The dominant stream order in the middle catchment is 4 according to the Strahler's classification and about 300 according to Shreve's classification. This specifies that in the middle catchment streams receive a considerable amount of water to transport the bed load in the stream.

The stratigraphy of the lower catchment shows a diverse lateral variation. Generally, the lowest gem-bearing gravel layer in the lower catchment locates at about 1.5 m above the present mean sea level. The bottom of today's river bed is situated well above the depth of the gem-bearing gravel layer (Annex 1, Figure 7a and 7b). The maximum grain size of the particles in the lowest gem-bearing gravel layer is about 20 cm and particles are rounded in shape (Tables 3 and 4). These sediments have been transported over a long distance and well sorted during a period where rivers were under an erosional phase with higher competence. Such a competence is expected when the base level of fluvial system was low, during the periods in which the sea level was lower than at present. Then, during the timings of high base level when the sea level had been rising, depositional processes should have become prominent by depositing bed load sediments as alluvial deposits. The middle gem-bearing gravel layer lies at a depth of 5 m above the mean sea level. The maximum size of grains in this layer is 20 cm in diameter having rounded grains (Table 4). When the difference between the present sea level and the local elevation of the gem-bearing gravel layer is considered, river's competence seems to be very low to transport a bed load material leading to form an alluvial deposit in the lower catchment. Therefore, it is speculated that sediments in this gem-bearing gravel layer were also transported at the time when the mean sea level had been lower than at present and, subsequently they were deposited. It also discloses that sea level in this region had been repeatedly fluctuating time to time changing the sedimentary regimes from erosion to deposition and vice versa. Several earlier studies also revealed that sea level in this region had changed over the Holocene period (Ranasinghe *et al.*, 2013b, Katupotha, 1994; Katupotha, 2013).

The upper gem-bearing gravel layer in the lower catchment is located at 11 to 12 m above the mean sea level. At locations about 2 km away from the river, this gem bearing layer lies at about 15–16 m above the mean sea level. The grain size of sediments in this layer is about 10cm in diameter with rounded grains (Table 4). The size and shape of the bed load sediments that are found in the rivers today are also very close to the average size and shape of the sediments observed in the gem-bearing gravel layer. A possible explanation for having smaller sediments in the river is that that the competence of the river has dropped due to the present elevated sea level making the transportation process of bed load more difficult. Yet, it is possible to propose that this upper gem-bearing gravel layer had also been formed at a time when the mean sea level was lower than the present.

The existence of very fine clay layers in all the alluvial profiles accepts the fact that in the geological history there may have been large pools in the lower catchment during some period allowing to settle fine particles under calm environments. However, in order to establish this with certainty, more detailed investigations are needed. A number of earlier studies have suggested the presence of lake sediments and existence of lakes in this area (Cooray (1984) and Deraniyagala (1958)). On the basis of several lines of evidence, chiefly on faunal evidences, an interesting message of the climate changes during the Quaternary was drawn by Deraniyagala (1958). He states that the Ratnapura phase was a cool fluvial phase, marked by moderate to heavy rainfall, tropical rainforest and savannah vegetation, and large lakes and swamps were supporting the survival of hippopotamus, rhinoceros and Paleoloxcdon.

CONCLUSIONS

From the observations made in the lower catchment, it is very clear that there had been fluctuations in the mean sea level and climatic conditions in this region. Such disruptions can cause changes in a river's base level which can in turn trigger changes in fluvial erosion and deposition processes. At the time of last glacial maximum, about 26 ky BP, ice sheets on the earth had reached their maximum positions and the sea level was about 150 m below the present sea level and the inland fluvial systems were in a phase of rapid erosion (Figure 7b). Under this situation, fluvial systems were supposed to be agitated and rivers were capable of transporting large sediments in bed loads over long distances. Deglaciation commenced approximately 19 ky BP, consequently sea level has gradually risen up until 14 ky BP, and then abruptly risen from 14 ky BP to 8 ky BP arriving to the present sea level (Clark *et al.*, 2009). Inland fluvial systems should have responded to this global sea level rise and also to the minor fluctuations in the local sea level, hence erosional and depositional processes along the Kalu Ganga River should have been switched to back and forth. Changes in the monsoonal rains in the region should have also greatly influenced on the fluvial processes and depositional pattern within the basin. However, exploration of impacts of local sea level changes and monsoonal variability on the fluvial processes of the Kalu Ganga basin is beyond the scope of this research. Hence, the preceding discussion is a kind of rough interpretation that should be supported by chronological evidences and paleo-climatic proxies. Therefore, a detailed dating of alluvial deposits and a paleo-climatic reconstruction using multiple proxies in this region is required for a better interpretation of the sedimentary archives in understanding the fluvial and sedimentary processes operated in the Kalu Ganga basin over the Quaternary period. In conclusion, the prevailed sea level changes and climatic fluctuations in the region are best reflected in the stratigraphic profiles in stream valley deposits in the lower catchment of Kalu Ganga basin, which have a large number of strata that are heterogeneous in composition and texture. They will be ideal archives for cutting-edge research in sedimentology and paleo-climatology.

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Annex 1 Geographical location of the gem pits, name of the adjacent stream, stream order, number of gem verities found, approximate elevation of surface of the gem pit, depth to the bottom of the lowest gem-bearing gravel layer from the surface, approximate elevation of the bottom of the lowest gem bearing gravel layer, approximate elevation of the bed of the adjacent stream for the studied gem pits

Gem Pit	Coordinates of the Gem pit X	Y	Name of the adjacent stream	Stream order of the adjacent stream (according to Shreve's classification)	Number of gem verities found in the gem pit	Surface elevation of the gem pit above the msl (m)	Depth to the lowest gem-bearing gravel layer from the surface (m)	Elevation of the gem-bearing gravel layer above the msl (m)	Elevation of the bed of the adjacent stream above the msl (m)	Location of the gem-bearing gravel layer relative to the elevation of present bed of the adjacent stream / Category of the catchment
1	159374	164090	Way Ganga	808	18-20	20	14	6	14	Below / Lower
2	159958	163884	Way Ganga	821	18-20	20	15	5	14	Below / Lower
3	161654	166047	Kalu Ganga	948	18-20	48	13	35	39	Below / Lower
4	161581	172198	Kabara Ela	11	4	82	3	79	79	Same / Middle
5	161582	172197	Kabara Ela	11	5	79	3	76	76	Same / Middle
6	161460	173190	Induru Ganga	37	7	113	2	111	111	Same / Middle
7	159677	173017	Guruwana Ela	2	1	193	8	185	192	Below / Middle
8	159678	173016	Guruwana Ela	2	2	193	8	185	192	Below / Middle
9	162937	169926	Maha Ela	202	8	36	13	23	25	Below / Lower
10	162964	169913	Kalu Ganga	168	5	37	13	24	28	Below / Lower
11	163647	171670	Rath Ganga	156	3	42	12	30	27	Above / Lower
12	163849	171770	Rath Ganga	127	3	46	12	34	31	Above / Lower
13	162818	167512	Denawaka Ganga	926	10	33	33	0	28.5	Below / Lower
14	163395	167597	Denawaka Ganga	541	8	38	35	3	33.5	Below / Lower
15	162336	167338	Kalu Ganga	4	2	30	22	08	15	Below / Lower
16	164640	157493	Wey Ganga	1	1	27	10	17	24	Below / Lower
17	164653	157497	Wey Ganga	4	3	27	10	17	24	Below / Lower
18	164721	158338	Maha Ela	694	7	31	6	25	29	Below / Lower
19	156501	169533	Maha Ela	37	3	20	6	14	18	Below / Lower
20	154398	175866	Pitadeniya Ela	23	4	30	2	28	27	Above / Lower
21	162798	167501	Kalu Ganga	926	10	35	12	23	23	Same / Lower
22	169495	166097	Malpe Dola	3	1	84	3	81	81	Same / Middle
23	174811	166154	Bambarabotu Ela	70	4	206	3	203	203	Same / Middle
24	176092	164031	Karuwala Dola	6	1	447	2	445	444.5	Above / Upper
25	176668	166751	Rukgaha Ela	54	2	370	1	369	368.5	Above / Lower
26	179642	166485	Diyabethme Ela	12	1	569	0.5	568.5	568	Above / Lower
27	187581	158616	Thumpavure Ela	59	3	311	1	310	310	Same / Middle
28	182703	155454	Wey Ganga	2	1	141	1.5	139.5	139	Same / Middle
29	177924	153664	Wey Ganga	327	8	122	7	115	117.5	Below / Middle
30	177924	153664	Wey Ganga	327	9	122	7	115	117.5	Below / Middle
31	174241	158533	Denawak Ganga	2	2	117	6	111	115	Below / Middle
32	170343	160172	Denawak Ganga	3	3	118	15	103	108	Below / Middle
33	146969	169666	Kalu Ganga	2804	18-20	18	5	13	16	Below / Lower

34	143731	170464	Kalu Ganga	3588	18-20	15	4	11	13.5	Below / Lower
35	144531	178076	Ellawala Ganga	2	2	15	4	11	11	Same / Lower
36	149563	180080	DawatayaAm unuEla	13	3	32	1	31	30.5	Above / Lower
37	158371	182077	LiyanagahaEl a	20	3	197	0.5	196.5	196	Above / Lower
38	164293	180335	No Name	30	1	1082	0.5	1081.5	1081	Above / Lower
39	172695	171364	Bandarawatta Ela	27	2	708	1	707	706.5	Above / Lower
40	141726	166662	Ammuna Dola	33	3	103	8	95	100	Below / Middle
41	146484	165669	Hal Dola	218	8	23	7	16	21	Below / Lower
42	148897	159125	Maha Dola	99	3	60	6	54	55	Below / Lower
43	155315	158726	Kahawatta Dola	231	5	37	15	22	27	Below / Lower
44	158443	159221	Kaka Ela	382	11	27	15	12	17	Below / Lower
45	158978	154603	Ginbokudola	185	4	106	4	102	102	Same / Middle
46	165553	154173	Hatpeella Dola	289	8	62	12	50	54	Below / Lower
47	169018	150215	Heen Dola	219	8	223	7	216	218	Below / Middle
48	174644	147377	Nammbi Dola	148	7	232	3	229	229	Same / Middle
49	159372	166745	Mala Dola	51	3	273	6	267	268	Same / Middle
50	160332	165965	Way Ganga	962	10-12	23	16	07	18	Below / Lower
51	160055	165995	Way Ganga	962	10-12	23	16	07	17.5	Below / Lower
52	159649	165319	Way Ganga	962	10-12	22	17	05	17	Below / Lower
53	159335	165335	Way Ganga	962	10-12	21.5	17	4.5	16.5	Below / Lower
54	159099	164774	Way Ganga	962	10-12	22	18	04	16.5	Below / Lower
55	158817	164630	Way Ganga	962	10-12	21	18	03	15	Below / Lower
56	158432	163925	Kalu Ganga	821	8-10	20	18	02	14.5	Below / Lower
57	158829	163460	Kalu Ganga	821	8-10	20	17	03	14.5	Below / Lower
58	158304	163310	Kalu Ganga	821	8-10	22	17	05	16.5	Below / Lower
59	158712	162920	Kalu Ganga	821	8-10	21	16	05	16.5	Below / Lower
60	158812	162720	Kalu Ganga	821	8-10	22	16	05	16	Below / Lower