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Architecture and Source of Alluvial Fan deposits of the Gish and Lish Rivers, Sikkim-Darjeeling Himalaya, India

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Abstract

The Gish and Lish rivers are flowing through Higher Himalaya, Lesser Himalaya, Sub Himalaya and Quaternary Alluvium of the Sikkim- Darjeeling region. These thrust bounded tectonostratigraphic zones are comprised of different lithologies. Comparative sedimentological studies of the sediments of these rivers were undertaken to understand landforms developed by these rivers and source to sink relationships of these sediments. The Gish River fans are broad and wider as compared to the narrow and linear shaped fans of the Lish River. Textural analysis of these fan sediments revealed high energy conditions of deposition within these rivers. The petrographic analysis of the Gish River sediments shows dominance of Quartz ($Qt_{63\%}F_{4\%}L_{33\%}$) in the framework components, while the Lithic metamorphic fragments ($Lm_{62\%}$ $LV_{0\%}$ $Ls_{38\%}$) show dominance over Lithic sedimentary fragments. This is also supplemented by the dominance of Quartz Polycrystalline grains ($Qp_{62\%}$ $Lv_{0\%}$ $Ls_{38\%}$) over Lithic sedimentary fractions. The Lish river sediments show dominance of Lithic fragments ($Qt_{39\%}$ $F_{2\%}$ $L_{59\%}$) in the framework components, while the Lithic sedimentary fragments ($Lm_{44\%}$ $Lv_{0\%}$ $Ls_{56\%}$) show dominance over lithic metamorphic fragments. This is also supplemented by Lithic sedimentary fractions ($Qp_{41\%}$ $Lv_{0\%}$ $Ls_{59\%}$) dominance over the Quartz Polycrystalline grains. These results of Quartz dominance in the Gish River sediments indicate higher contribution is from gneissic and metamorphic sources. While, Lithic dominance in the Lish River sediments infers higher contribution from sedimentary and metamorphic sources.

Keywords- *Gish River; Lish River; Petrography; Fluvial, Provenance*

Introduction

The major rivers of Himalaya i. e., Indus, Ganges and Brahmaputra and their tributaries have developed their drainage system in the Himalayan terrain. These rivers provide best opportunity to study their landforms and their processes of formation. The landforms in the river courses are the result of fluvial processes influenced by different controlling factors such as climate and tectonics (Burbank and Anderson 2001; Srivastava et al., 2016; Mukul and Singh 2016). These rivers are characterized by their depositional landforms like alluvial fans, braided channels and deltas. The alluvial fans develop in the river system in response to the rapid changes in topographic gradient; therefore the majority of rivers flowing from Himalayan mountain ranges enter into planer terrains leading to formation of alluvial fans (Gupta, 1997; Chakraborty and Ghosh, 2010; Decelles and Cavazza 1999). The alluvial fan system is a very important depositional landform developed in the Himalayan foreland basin, which mark and preserve the record of fluvial processes which were active during the deposition of the Siwalik Group of deposits. This is still continuing in the form of number of alluvial fans developed along the foothills of the Himalaya by major and minor river system (Valdiya 1999, Burbank et. al., 1996; DeCelles and Giles, 1996; Najman et al., 2004; Bera et al., 2008; Kumar, 2003).

The structural framework of the Sikkim-Darjeeling Himalaya shows deformation of the region in the form of development of thrust system separating different lithounits in the area (Martin and Mukul, 2010, Mitra et al., 2010). The sedimentary record of the Himalayan foreland basin embedded within the Siwalik Group of sediments in the region has been studied from palaeontological, depositional environment, petrographic studies, palaeocurrent analysis and provenance point of view (Chakraborty et al., 2013; Mandal et al., 2014; Kundu et al., 2012, 2016; Taral et. al., 2017). The Quaternary deposits in the region are represented by well developed alluvial fans along the Himalayan foothills which preserve the record of neotectonics and climate change (Bisaria, 2012; Goswami et. al., 2013, 2019; Kar et al., 2014; Singh et. al., 2016). These alluvial fan deposits have not been studied in depth for understanding their development and, provenance and tectonic setting. The present study is focussed on sedimentary record preserved in the fans of the Gish and Lish rivers, the tributaries of Tista River (Fig.2) which discharges its sediment load into the mighty Brahmaputra River. These tributaries of Tista River carry large sediment load from different lithotectonic units of Himalaya and deposit them along the foothills zone. This provides an opportunity to analyse these deposits for facies architecture, textural analysis and petrography in order to understand the source to sink relationships and landform development by the Gish and Lish rivers in the region.

Regional Geology

The study area comprises a part of Sikkim-Darjeeling Himalaya. The stratigraphic succession in the area is ranging from Precambrian to Recent. The succession comprises of tectonostratigraphic zones of Higher Himalaya, Lesser Himalaya, Sub Himalaya and Quaternary Alluvium. These different tectono-stratigraphic zones are separated by number of major thrusts in the area i. e., Main Central Thrust (MCT), Ramgarh Thrust (RT), Main Boundary Thrust (MBT), and Main Frontal Thrust (MFT). The lithology of the region comprises of Darjeeling/ Kanchenjunga Gneiss, Paro Gneiss, Lingtse Gneiss composed of biotite schists and gneisses, the Daling Group comprising of phyllites, quartzites and slates, the Gondwana Group comprising of sandstones, shales, carbonates, diamictites and quartzites, the Siwalik Group comprising of conglomerates, sandstones and shales (Valdiya, 1980; Bhattacharya and Mitra, 2009; Mukul, 2010). The Tista River is a major river flowing through this region, while its tributaries Lethi, Lish, Gish, Ramathi, and Churanthi form drainage network in the area.

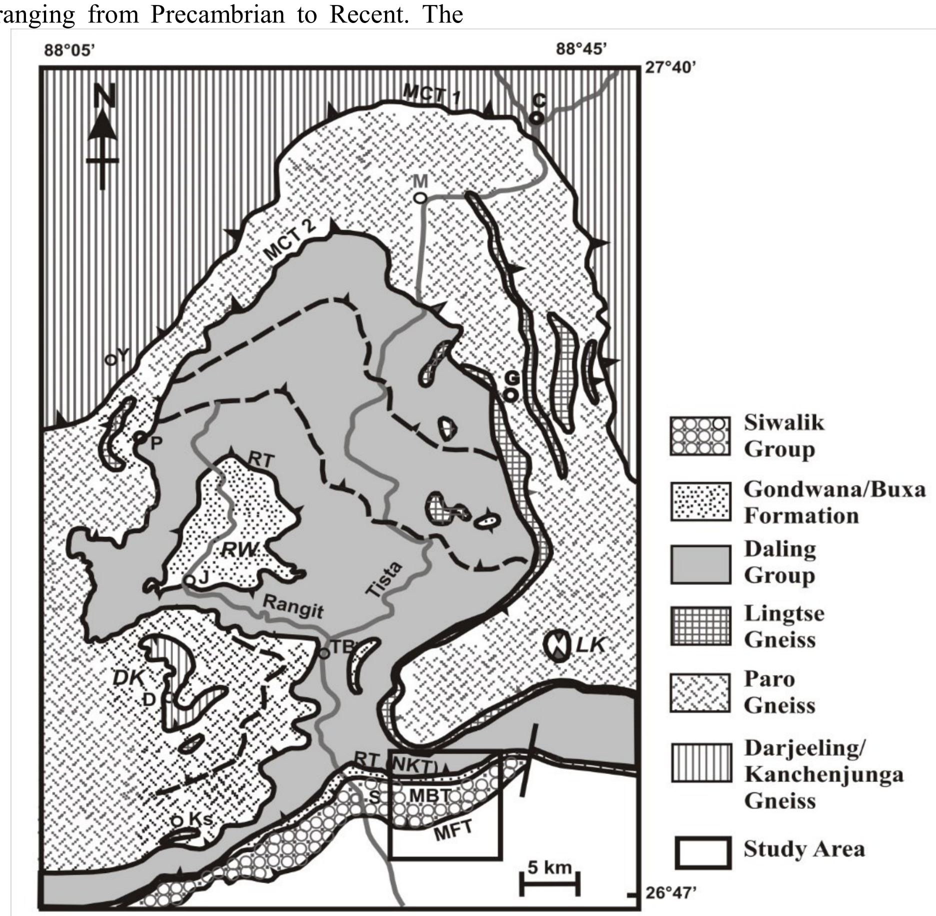

Fig.1 Regional geological map and the study area geology (Bhattacharya et al., 2010)

Materials and Methods

The methodology used for the present study consists of field sedimentology, grain size analysis and compositional analysis of sediments from the Gish and Lish rivers, collected from near Odalabari town, Jalpaiguri district in the state of West Bengal. The Field sedimentology included detailed documentation of sedimentary deposits to delineate different sedimentary facies. Then the systematic sampling was carried out by adopting standard procedures by collecting grab samples from surface as well as beds exposed in the outcrop sections of these river deposits (Fig. 2). Conning and quartering of the fine clastic samples was done to select representative samples for grain size analysis in the laboratory. They are collected from proximal, middle and distal parts of the alluvial fans. The facies terminology after Miall (1978) was adopted for the facies description. The grain size analysis was done by wet sieving using sieve shaker with sieves of 2000, 850, 425, 300, 180, 53 micron sizes and a base pan collector. The sieve data was used to calculate statistical parameters with the help of GRADISTAT V8 software (Blott and Pye, 2001). Then the sediments were used for petrographic analysis by preparation of polished thin sections and identification of minerals under the microscope.

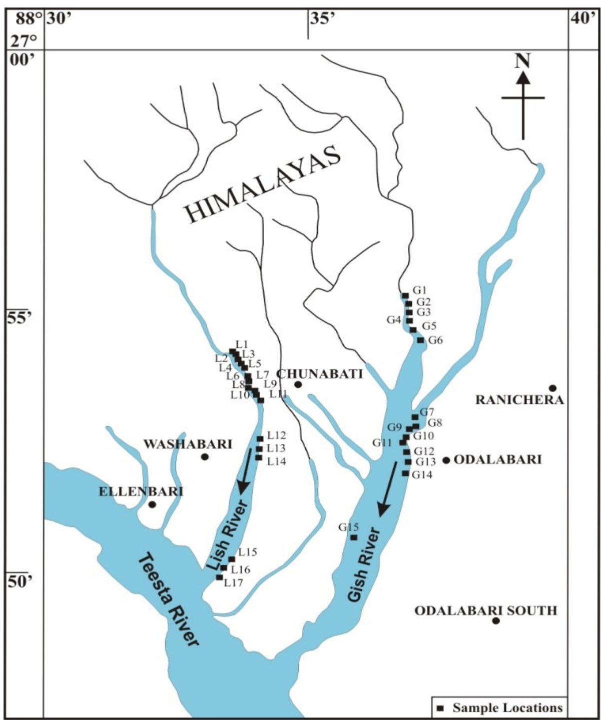

Fig.2: Sample location map (modified after Bisaria, 2012)

Field Sedimentological observations

The Gish and Lish rivers are major river systems developed in the study area (Fig.2). These rivers are flowing through major tectonostratigraphic zones of study area and contribute mixed lithological constituents to the basin. The sediment samples from both the rivers were collected from the recent representative fans situated along the river courses from south of MFT to their confluence with Tista River. These sediments were collected from the proximal-, mid- and distal parts of the alluvial fans.

The field sedimentological studies show, in both the rivers, the proximal parts are characterized by debris flows and stream flow deposits. The mid fan parts show braided stream deposits while distal parts are dominated by flood plain deposits (Fig.3 & 4). In comparative approach, the Gish River form broad and wider alluvial fan development whilst the Lish River forms narrow and linear shaped fans. These alluvial fans are formed in the frontal parts of the mountains in the vicinity of thrusts. Apparently the mountain front is comparatively more active in the Lish River area restricting spread of the alluvial fans than the Gish river area. This reflects the tectonic control in the region on the shape of alluvial fans. The proximal part of the Gish river fan is dominated by active and abandoned channel deposits than the Lish River. The proximal part in the Lish River is more gravely in nature with abundant large size boulders than the Gish River. This is reflected in the facies encountered in the proximal part of both the rivers. The Gish River comprises of Gm, Gp and St facies association, while the Lish River comprises of Gms, Gm and Gt facies. This facies distribution pattern in the proximal part of the Gish River fan is characterized by stream deposits. On the other hand in the Lish River, facies of the fans are dominated by debris flow deposits. The Gish River mid fan deposit is more braided type and migratory in nature than the Lish River fan deposit. The facies recorded in the mid fans of the Gish River are Gt, Gp, St, and Sh, whereas in the mid fans of the Lish River, the facies observed include Gm, Gt, Gp, Sp, and St. The distal fan parts of both the rivers are characterized by Gp, Sh and Fl facies interfingering with flood plain deposits of gravely nature.

Grain Size analysis

The textural studies were carried out on sand size sediments and data are presented in Tables 1 & 2 for both the rivers and sample location is shown in Figure 2. The total 32 samples were used for this analysis, 15 samples from Gish River and 17 samples from Lish River. The statistical parameters of both the river samples show coarse size sand fractions are dominating, which is supported by finely skewed nature indicating coarser size fraction are contributing more to the sediments. The sorting is dominated by poorly sorted nature of sediments showing different size fractions are present in the sediments. This is also supported by dominance of bimodal nature in the samples. These sediments also show platykurtic dominance inferring coarser as well as finer size fractions are contributing to the sediment deposits. These observations suggest deposition of the sediments under high water flowing energy conditions of the stream with rapid sedimentation at the break of slope gradient leading to mixed size fractions.

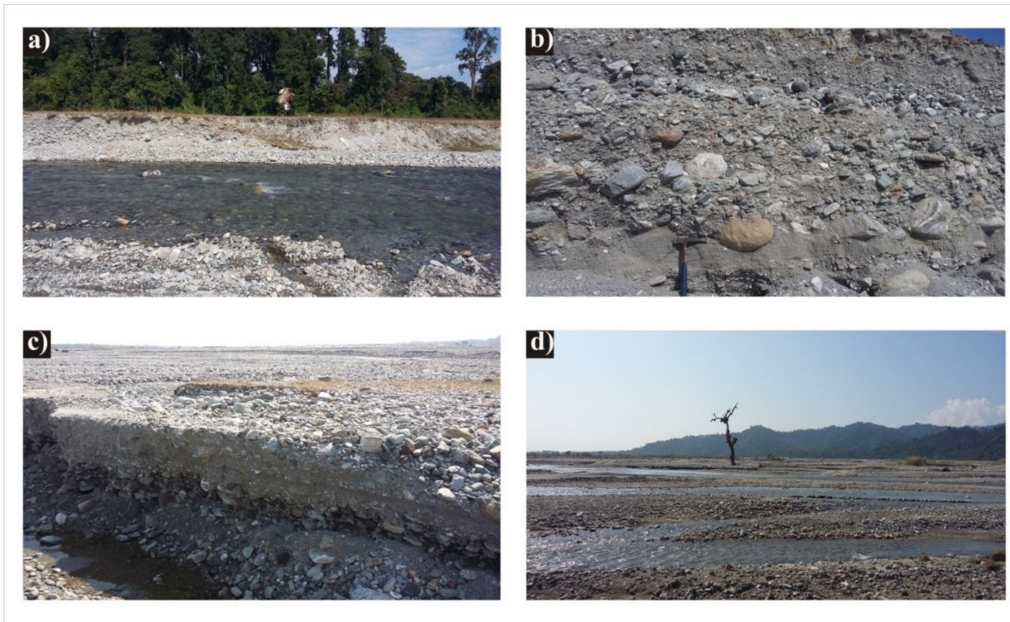

Fig.3: Field photographs showing sediment deposits of the Gish River a) Proximal part of alluvial fan, b) profile of proximal part the deposit, c) Profile of the mid fan bars, d) Mid fan bars.

Fig.4: Field photographs showing sediment deposits of the Lish River fan deposits, a) Proximal debris flow deposit, b) Proximal stream flow deposit, c) Proximal deposit profile, d) Mid fan profiles,. e) Distal fan characterized by flood plain deposit, f) Distal fan with channel deposit.

Table 1: The statistical parameters calculated from grain size analysis of the Gish River sediments.

Sample name	Folk and Ward method				Folk and Ward method (description)			
	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting	Skewness	Kurtosis
GS1	0.720	1.537	1.377	0.494	Coarse Sand	Poorly Sorted	Very Fine Skewed	Very Platykurtic
GS2	0.237	1.010	1.375	0.639	Coarse Sand	Poorly Sorted	Very Fine Skewed	Very Platykurtic
GS3	1.419	1.715	-0.175	0.724	Medium Sand	Poorly Sorted	Coarse Skewed	Platykurtic
GS4	1.444	1.605	0.050	0.454	Medium Sand	Poorly Sorted	Symmetrical	Very Platykurtic
GS5	0.905	1.468	0.711	0.548	Coarse Sand	Poorly Sorted	Very Fine Skewed	Very Platykurtic
GS6	1.643	1.770	-0.274	0.591	Medium Sand	Poorly Sorted	Coarse Skewed	Very Platykurtic
GS7	0.403	1.034	0.530	0.476	Coarse Sand	Poorly Sorted	Very Fine Skewed	Very Platykurtic
GS8	0.705	1.418	1.012	0.585	Coarse Sand	Poorly Sorted	Very Fine Skewed	Very Platykurtic
GS9	0.637	1.389	0.216	0.704	Coarse Sand	Poorly Sorted	Fine Skewed	Platykurtic
GS10	-0.070	0.617	1.877	1.888	Very Coarse Sand	Moderately Well Sorted	Very Fine Skewed	Very Leptokurtic
GS11	-0.446	0.125	-0.025	-0.850	Very Coarse Sand	Very Well Sorted	Symmetrical	Very Platykurtic
GS12	-0.371	0.312	-3.879	-1.431	Very Coarse Sand	Very Well Sorted	Very Coarse Skewed	Very Platykurtic
GS13	-0.185	0.517	2.071	-2.343	Very Coarse Sand	Moderately Well Sorted	Very Fine Skewed	Very Platykurtic
GS14	-0.558	-0.117	1.551	-0.351	Very Coarse Sand	Very Well Sorted	Very Fine Skewed	Very Platykurtic
GS15	0.553	0.948	0.437	0.583	Coarse Sand	Moderately Sorted	Very Fine Skewed	Very Platykurtic

Petrographic analysis

The total 32 thin sections of the Gish and Lish river sediments were studied for petrographic analysis. The sediment fractions of 180 micron size of all the samples were used for thin section preparations. The detailed petrographic analysis was carried out using Gazzi-Dickinson point counting method (Gazzi, 1966; Dickinson, 1970). The counting of more than 300 grains per thin section was carried out and normalized to 100% and the results are presented in Tables 3 & 4. The Framework constituents were classified into quartz monocrystalline (Qm), polycrystalline quartz (Qp), feldspar (F), lithic sedimentary fragments (Rs/Ls), metamorphic lithic fragments (Rm/Lm), and lithic igneous fragment (Ri/Ls). The petrographic framework components of the sediments are presented in Figures 5 and 6 along with ternary plots representing their contribution from different sources.

Gish River sediments petrographic results

The total 15 thin section slides were analyzed from sediment samples of Gish River (Table 3). The compositional study of the framework components of each sample reveals average contribution of different framework constituents i. e., Qm_{41} Qp_{22} F_4 Ls_{13} Lm_{20} Li_0. This shows dominance of quartz as compared to feldspar and lithic fragments. In quartz the Q_m are more abundant than Qp indicating crystalline as well as metamorphic contributions. The Lm fragments are more abundant than Ls fragment inferring that metamorphic sources sedimentary provenance is also contributing to the sediments. The presence of abundant lithic fragments indicates compositionally immature sediments.

Table 2: The statistical parameters calculated from the grain size analysis of the Lish River sediments.

Sample name	Folk and Ward method				Folk and Ward method (description)			
	Mean	Sorting	Skewness	kurtosis	Mean	Sorting	Skewness	Kurtosis
LS1	0.062	0.802	1.696	1.417	Coarse Sand	Moderately Sorted	Very Fine Skewed	Leptokurtic
LS2	0.150	0.912	1.590	0.676	Coarse Sand	Moderately Sorted	Very Fine Skewed	Platykurtic
LS3	0.195	1.008	1.507	1.132	Coarse Sand	Poorly Sorted	Very Fine Skewed	Leptokurtic
LS4	0.288	1.102	1.304	0.742	Coarse Sand	Poorly Sorted	Very Fine Skewed	Platykurtic
LS5	-0.581	-0.175	4.047	-0.104	Very Coarse Sand	Very Well Sorted	Very Fine Skewed	Very Platykurtic
LS6	0.078	0.849	1.580	4.589	Coarse Sand	Moderately Sorted	Very Fine Skewed	Extremely Leptokurtic
LS7	0.101	0.807	1.569	11.970	Coarse Sand	Moderately Sorted	Very Fine Skewed	Extremely Leptokurtic
LS8	1.368	1.738	-0.094	0.677	Medium Sand	Poorly Sorted	Symmetrical	Platykurtic
LS9	0.634	1.303	0.910	0.656	Coarse Sand	Poorly Sorted	Very Fine Skewed	Very Platykurtic
LS10	0.089	0.838	1.693	0.620	Coarse Sand	Moderately Sorted	Very Fine Skewed	Very Platykurtic
LS11	-0.067	0.645	1.734	-3.894	Very Coarse Sand	Moderately Well Sorted	Very Fine Skewed	Very Platykurtic
LS12	0.489	1.191	1.078	0.672	Coarse Sand	Poorly Sorted	Very Fine Skewed	Platykurtic
LS13	1.469	1.682	-0.133	0.545	Medium Sand	Poorly Sorted	Coarse Skewed	Very Platykurtic
LS14	0.417	1.135	1.065	0.681	Coarse Sand	Poorly Sorted	Very Fine Skewed	Platykurtic
LS15	0.481	1.305	1.418	0.766	Coarse Sand	Poorly Sorted	Very Fine Skewed	Platykurtic
LS16	1.667	1.643	-0.078	0.436	Medium Sand	Poorly Sorted	Symmetrical	Very Platykurtic
LS17	0.540	1.240	0.952	0.685	Coarse Sand	Poorly Sorted	Very Fine Skewed	Platykurtic

The recalculated values of Qp%, Lv%, Ls% show decreasing percentage of Qp% (avg. 69%) in the proximal samples and (avg. 58%) in distal part samples. This may be due to addition of sediment load from tributary in the distal part, while lithic sedimentary contribution indicates provenance from the Siwalik Group of rocks. The recalculated Lm%, Lv%, Ls % values show higher (avg. 62%) contribution of Lm% than lower (38%) contribution of Ls %, inferring metamorphic dominant source in the Daling Group than the Siwalik Group. The ternary diagrams of the framework constituents (after Folk, 1974) show the distribution of samples clustering in Lithic-Arenites range. The Q%, F%, L% diagram shows sand samples clustering in the areas of recycled orogen, while Qp, Lv, Ls triangular plots depicts their source in the collision suture and fold belt. The Lm, Lv, Ls ternary plot shows the clustering of samples in the suture zone.

Table 3: Framework composition and components of triangular plots of the Gish River sediments

Sample Name	Framework components recalculated to 100%						QFL recalculated to 100%			Q_t FL recalculated to 100%			Q_p L_v L_s recalculated to 100%			L_m L_v L_s recalculated to 100%		
	Q_m	Q_p	F	L_s	L_m	L_i	Q	F	L	Q_t	F	L	Q_p	L_v	R_s	L_m	L_i	L_s
GS1	38	31	6	8	16	0	38	6	56	69	6	25	79	0	21	66	0	34
GS2	45	22	5	10	19	0	45	5	50	66	5	28	69	0	31	66	0	34
GS3	54	22	3	7	14	0	54	3	43	76	3	21	76	0	24	68	0	32
GS4	18	37	2	16	27	0	18	2	80	55	2	43	70	0	30	64	0	36
GS5	38	23	2	16	22	0	38	2	60	61	2	37	60	0	40	58	0	42
GS6	32	30	2	19	17	0	32	2	66	62	2	36	62	0	38	48	0	52
GS7	43	4	10	14	30	0	43	10	47	47	10	43	23	0	77	68	0	32
GS8	55	20	5	4	16	0	55	5	40	75	5	20	82	0	18	79	0	21
GS9	39	16	2	22	21	0	39	2	59	55	2	43	42	0	58	49	0	51
GS10	38	17	1	27	18	0	38	1	61	54	1	45	38	0	62	41	0	59
GS11	37	28	6	14	14	0	37	6	57	66	6	28	66	0	34	50	0	50
GS12	50	16	2	14	19	0	50	2	49	65	2	33	54	0	46	59	0	41
GS13	59	20	7	4	11	0	59	7	34	79	7	14	85	0	15	74	0	26
GS14	18	40	1	12	29	0	18	1	81	58	1	41	77	0	23	72	0	28
GS15	50	11	3	10	27	0	50	3	47	61	3	36	53	0	47	73	0	27

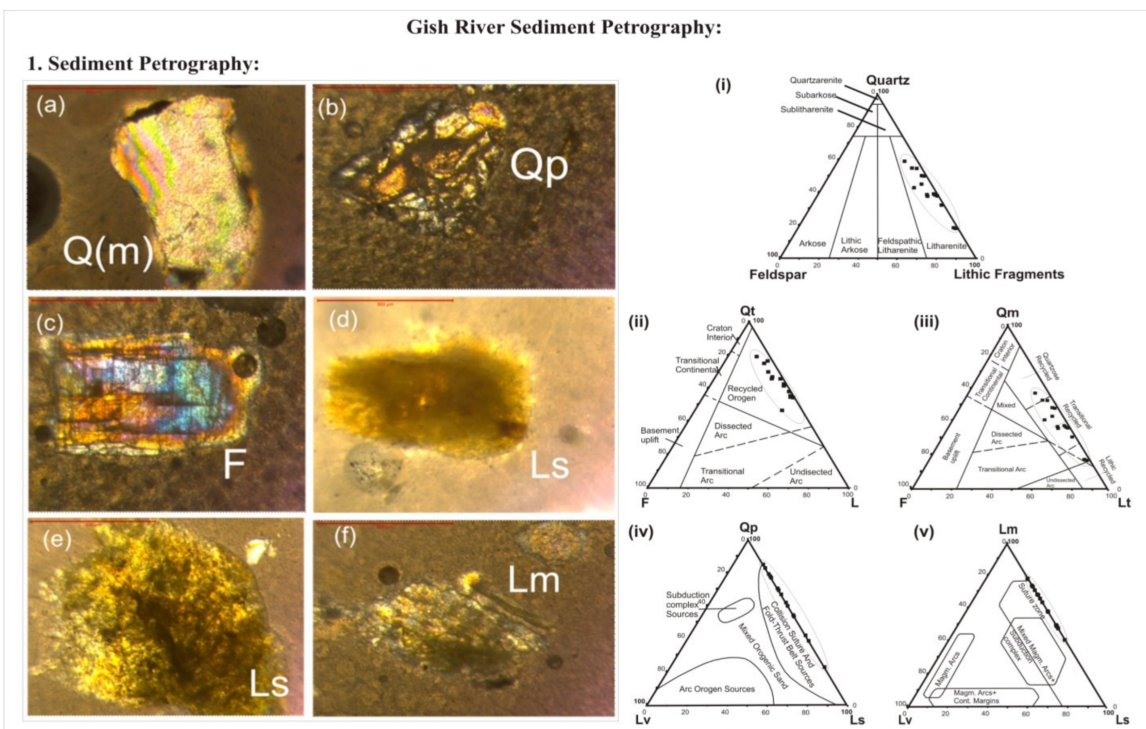

Fig. 5: Microphotograph of sediment samples from Gish River shows (a) Quartz, (b) Quartz Polycrystalline, (c) Feldspar, (d) Lithic sedimentary, (e) Lithic sedimentary and (f) Lithic metamorphic. Ternary diagram of framework components are presented in Figs 5: (i) QFL%, (ii) Qt FL%, (iii) Q_mFL_t%, (iv) Q_p L_v L_s% and (v) $L_mL_vL_s$%.

Lish River sediments petrographic results

The 17 thin sections of the samples were used for petrographic analysis of the Lish River and the results are presented in Table 4. The framework components of these sediments contribute average percentage of Qm_{17} Qp_{22} F_2 Ls_{33} Lm_{26} Li_0. This shows that lithic fragments are present in abundance than quartz and feldspar. This indicates sediments are compositionally immature in nature. Qp is dominating over the Qm, inferring metamorphic sources are contributing more than the crystalline sources. In the Lithic fragments Ls are contributing more than the Lm, indicating sedimentary provenance of Siwalik Group along with metamorphic provenance from Daling Group. The recalculated QmFL% (avg. Qm_{17} F_2 L_{81}) shows lithic grains are dominating throughout the samples. The recalculated QtFL% also show Quartz and Feldspar contribute less than Lithic fragments in the proximal part (avg. Qt_{35} F_2 L_{63}), mid fan part (avg. Qt_{43} F_2 L_{55}) and distal fan part (avg. Qt_{48} F_1 L_{51}). The recalculated QpLvLs% (avg. Qp_{39} Lv_0 Ls_{61}) shows lithic sedimentary fragments are more abundant than the Quartz polycrystalline indicating metamorphic provenance. This is also supported by recalculated LmLvLs% (avg. Lm_{44} Lv_0 Ls_{56}) which also shows sedimentary lithic fragments are dominating over the metamorphic sedimentary fragments.

The ternary diagram for the framework grains shows (after Folk, 1974) clustering in the Lithic-Arenites Zone. The Ternary diagram of QtFL shows recycled orogen source of these sediments. The QmFLt ternary diagram shows lithic recycled source of these sediments. The dominance of lithic fragments is also reflected in QpLvLs triangular diagram which depicts their origin in collision suture and fold thrust belts. The triangular plot for LmLvLs shows the clustering of samples in the suture zone.

Table 4: Framework composition and components of triangular plots of the Lish River sediments

Sample Name	Framework components recalculated to 100%						QFL recalculated to 100%			Q_t FL recalculated to 100%			Q_p L_v L_s recalculated to 100%			L_m L_v L_s recalculated to 100%		
	Q_m	Q_p	F	L_s	L_m	L_i	Q	F	L	Q_t	F	L	Q_p	L_v	R_s	L_m	L_i	L_s
LS1	12	20	2	34	32	0	12	2	86	33	2	66	38	0	62	49	0	51
LS2	13	17	1	37	32	0	13	1	87	30	1	69	32	0	68	46	0	54
LS3	20	21	3	40	17	0	20	3	78	41	3	57	34	0	66	30	0	70
LS4	15	28	3	31	24	0	15	3	83	43	3	55	47	0	53	44	0	56
LS5	17	13	2	47	21	0	17	2	81	30	2	68	22	0	78	30	0	70
LS6	18	15	2	45	20	0	18	2	80	33	2	65	25	0	75	31	0	69
LS7	27	16	3	32	22	0	27	3	71	43	3	54	33	0	67	41	0	59
LS8	17	18	1	33	32	0	17	1	83	34	1	65	35	0	65	49	0	51
LS9	9	15	3	38	34	0	9	3	87	25	3	72	29	0	71	47	0	53
LS10	12	34	3	34	17	0	12	3	85	46	3	51	51	0	49	34	0	66
LS11	22	9	3	31	36	0	22	3	76	31	3	67	22	0	78	54	0	46
LS12	13	28	2	34	22	0	13	2	84	41	2	56	45	0	55	39	0	61
LS13	16	32	3	21	29	0	16	3	82	47	3	50	60	0	40	58	0	42
LS14	18	24	0	29	30	0	18	0	82	41	0	59	45	0	55	51	0	49
LS15	23	19	2	33	24	0	23	2	76	41	2	57	36	0	64	42	0	58
LS16	24	26	0	23	26	0	24	0	76	51	0	49	53	0	47	53	0	47
LS17	16	36	1	28	19	0	16	1	83	53	1	46	57	0	43	41	0	59

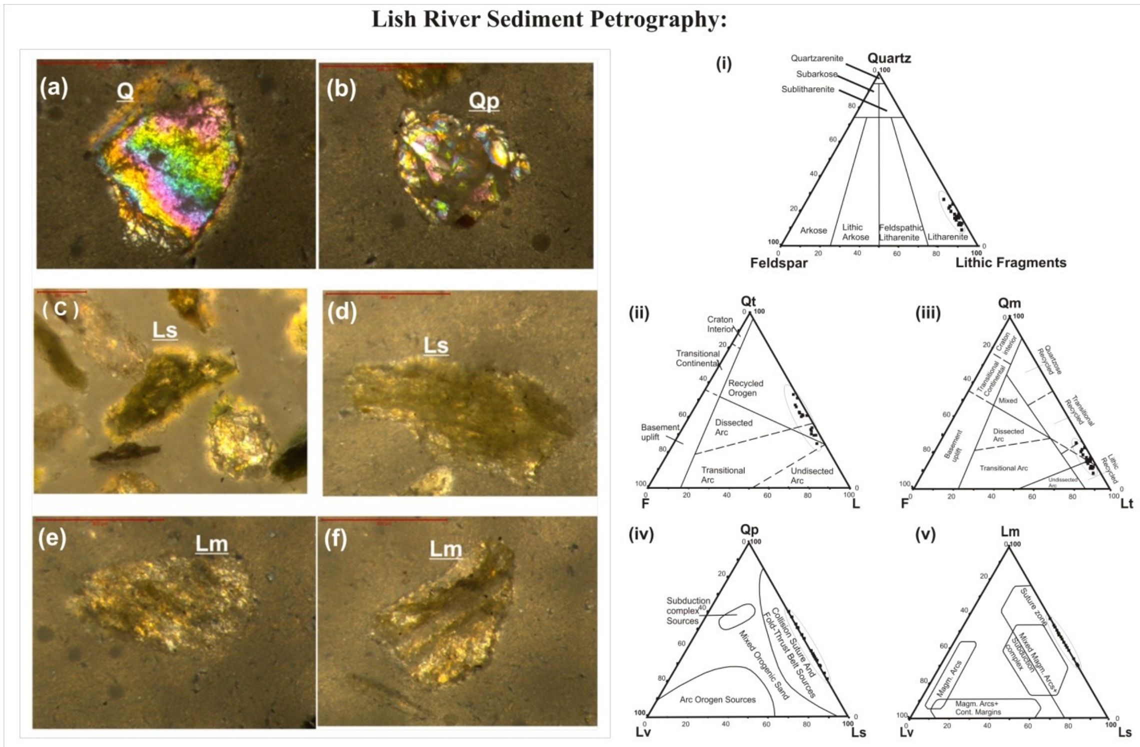

Fig. 6: Microphotograph of sediment sample from Lish river shows (a) Quartz, (b) Quartz Polycrystalline, (c) and (d) Lithic sedimentary, (e) and (f) Lithic metamorphic. Ternary diagram of framework components are presented in Figs 5: (i) QFL%, (ii) Qt FL%, (iii) Q_mFL_t%, (iv) Q_p L_v L_s% and (v) $L_mL_vL_s$%.

Conclusions

The alluvial fan deposits developed by the Gish and Lish rivers are characterized by differential landform geomorphology. The Gish River deposits have formed in response to higher sediment load and wider accommodation space while that of the Lish River deposits have formed in response to higher sediment load and comparatively narrow accommodation space. This infers the tectonic processes operating along the thrusts influence the shape of the basin. The textural immaturity of both the river deposits represents higher sediment load carried by the rivers and depositing in the foothills zone of the Himalaya. This is also reflected in the compositional immaturity of the sediments inferring proximity to the sources. The source rock lithology is contributing differentially in sediments. i. e., higher contribution of Lithic metamorphic fragments in the Gish river is from the Lesser Himalayan provenance, while the higher contribution of Lithic sedimentary fragments in the Lish river is from Sub-Himalayan provenance. Furthermore, metamorphic fragments are higher in the Gish River which infers maximum contribution from the Daling Group of rocks, while that of sedimentary rock fragments are dominant in the Lish River sediments indicating higher contribution from the Siwalik Group of rocks.

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