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Depositional Environment and Geochemical Characterization of Quaternary Sediments along National Highway in Samba and Kathua Districts, Jammu and Kashmir, India

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Abstract

The Quaternary sediments are well exposed along the National Highway between Samba and Kathua districts of Jammu and Kashmir, India. These sediments represented by loose / unlithified sediments ranging in size from boulder conglomerate to fine clay particles. In the present study, three sections *viz.* Basanter North, Samba South East and Dhalta West has been chosen for facies and grain size analyses, geochemical characterization and X-ray diffraction (XRD) analysis to know the depositional environment, provenance and mineralogical composition of Quaternary sediments. Based on the facies study and grain size analysis, a mixed type of depositional environment suggested for Basanter North, Samba South East and Dhalta West sections. Major Oxides, Trace and REE elemental data and XRD analysis indicate that the source was felsic in composition and sediments are from lesser and Outer Himalayas.

Keywords: Quaternary Sediments, Depositional Environment, Provenance, Mineral Composition, Jammu and Kashmir

Introduction

Quaternary sediments are primarily recognized for their unconsolidated nature (sand, silt, clay, gravel, pebble, boulders). These unconsolidated sediments play an important role to shape the distinct landform produced on the earth surface with help of different weathering agencies (glaciations, fluvial, colluvial, alluvial, aeolian). The composition of sediments is influenced by a variety of factors, including the characteristics of the source rock, the extent of chemical weathering, hydraulic sorting, adsorption, digenesis, and metamorphism (Roy *et al.*, 2008). At global level, various authors carried out work on Quaternary sediments for tectonic and provenance (Bhatia, 1983; Bhatia and Crook, 1986; Herron, 1988; McLennan *et al.*, 1993; Bracciali *et al.,* 2007; Basu *et al.*, 2016; Bastia *et al.*, 2020; Kettanah *et al.,* 2021; Khan *et al.,* 2025), and mineral composition (Loubser and Verryn, 2008; Quader and Majeed, 2022; Xiao *et al.*, 2024). From time to time the work on paleoclimate, grain size analysis and depositional environment by the authors (Miall, 1977; Shrivastava *et al.,* 2012; Kanhaiya *et al.,* 2017; Kanhaiya *et al.*, 2019; Irfan *et al.*, 2022; Abishek *et al.,* 2024).

The Quaternary sediments of Jammu region stretching along foothills of Siwalik, is least studied for their provenance, depositional environments and grain size attributes (De Terra and Paterson, 1939; Dasarathi, 1968; Ganjoo, 1990; Verma *et al.*, 1990; Ganjoo, 1993; Ganjoo *et al.*, 2002; Ganjoo and Kumar, 2012). De Terra and Paterson (1939) studied the Quaternary sediment deposited in the foot of Siwalik hill and concluded that the deposition of Potwar plateau (Pakistan), was the result of gigantic windstorms with intermittent rains. Dasarathi (1968) gave a detailed account on the geological aspects of Tawi river valley. On the basis of LANDSAT imagery studies, Ganjoo (1990) discussed that the entrenchment by the Tawi River at foot of Trikuta limestone and presence of deep gorges indicate neotectonism and this is the result of the integration of river system. He also suggested the presence of some rock material of lesser Himalaya in the Late Pleistocene deposits. Verma *et al.* (1990) divided post-Siwalik silts of the Jammu region into two subdivisions, Older Alluvium and Newer Alluvium. The Older Alluvium, which is situated above the flood level, comprises beds that are gradually depleted, whereas the Newer Alluvium is composed of current flood deposits, actively forming in the region. Ganjoo *et al*. (2002) worked on the early Pleistocene palaeosol of Jammu region for its genesis and climatic significance and reveal that the warm humid to semi-arid climatic conditions for the late Pleistocene palaeosol deposits of Jammu. Ganjoo and Kumar (2012) conducted study on Quaternary fine silt deposits in the Jammu province, focusing on genesis, climatic significance, grain size characteristics, and depositional environment. They suggested a fluvial depositional environment for certain areas, where fluctuating water budgets and periods of

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non-deposition were associated with weak paedogenesis. Furthermore, Ganjoo (1993) argued in favour of fluvio - aeolian genesis of the deposits. A late Pleistocene to Holocene age of fine silt on the basis of granulometric, geographic extension, and geochemical correlations with the loess silt (Potwar) of Pakistan was suggested by Ganjoo and Kumar (2012).

In the present study, three sections of Quaternary deposits of Samba and Kathua districts of Jammu and Kashmir are chosen to evaluate depositional environment, geochemical characterization and grain size analysis (Fig.1).

Geologic and Tectonic Setting

The Jammu region is part of the outer fold-thrust belt of the north-western Himalayas and bounded to the north by the high mountain ranges of Zanskar and Pir Panjal and to the south by the Indo-Gangetic Plain (Ganjoo, 2014). The ongoing convergence between the Indian and Eurasian plates has resulted in the uplift of the region and the deposition of significant sediments from the Pleistocene to the Holocene (Dasarathi 1968; Ganjoo, 2014). The region experiences ongoing tectonic movements, contributing to Active Mountain building, faulting, and folding (Ganjoo, 1990). The Quaternary sediments lie in the south of Siwalik Group of rocks. The Lower Siwalik Subgroup is composed of argillaceous rocks, Middle Siwalik Subgroup composed of arenaceous rocks and the Upper Siwalik Subgroup is composed of rudaceous rocks. Siwalik is bounded by main boundary thrust from the north and Himalayan frontal fault to the south respectively. The various tectonic units of Himalaya from older to younger and quaternary sediments (Boulder Conglomerate + Post Siwalik sediments) (Fig. 2).

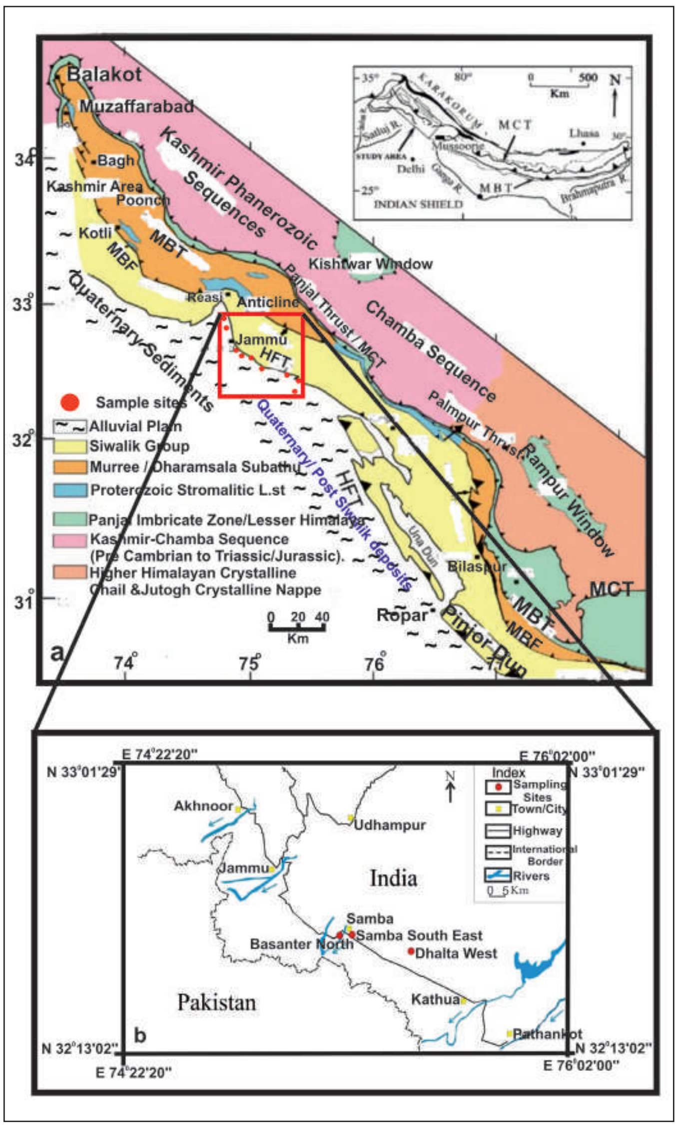

Fig.1. (a) Geology map of Jammu and Pathankot regions and (b) location map of the study area

Material and Methods

In the present study, three section *viz.* Basanter North, Samba South East and Dhalta West sections were chosen for facies study, grain size analysis, geochemical characterization and mineralogical composition. In the field, measurements of sections, structures, lithology, texture, nature of sediments has been studied for facies analysis. For grain size analyses, geochemical characterization and mineralogical composition, eighteen samples were collected and prepared, (six samples for each analysis) and sent to Wadia Institute of Himalayan Geology laboratory for analysis.

In the laboratory, these samples were first sun-dried for 2-3 days and were prepared for analysis after manually removing pebbles, plant materials, fibres or other contaminants. Coning and quartering technique was used to homogenize the sample.

For grain size analysis six samples were treated with dilute Hydrogen chloride (HCl) and 6% hydrogen peroxide to remove the carbonates and organic matter. After this, samples were washed and neutralized with distilled water. After washing and cleaning, the samples were subjected to grain size analysis by means of a Malvern 2000 laser grain size analyzer.

Major oxides and trace elements were analyzed using a Wavelength Dispersive X-ray Fluorescence (WD-XRF)

Quaternary Sediments Of Jammu region	**River terraces T1-T5 (Holocene)**	
	Post Siwalik Sediments/Quaternary deposits (Upper Pleistocene)	
	--------------------Himalayan Frontal Fault (HFF) -------------	
	Upper Boulder Conglomerate Formation (Middle Pleistocene)	
	---------------------Unconformity----------------------	
	Lower Boulder Conglomerate (Lower Pleistocene)	
Upper Siwalik Subgroup	Pinjor Formation (Pliocene)	
	Tatrot Formation	
Middle Siwalik Subgroup	Dhokpathan Formation	
	Nagri Formation	
Lower Siwalik Subgroup	Chinji Formation	
	Kamlial Formation	
	-----------------Main Boundary Thrust (MBT) -------------	
	Lesser Himalaya	
	-----------------Main Central Thrust (MCT) ------------------	
	Higher Himalaya	
	---------------------Indus Tsang Suture Zone (ITSZ) -------------------	

Fig.2. Geologic and tectonic setting of Jammu region (*after* Gupta, 1988)

Spectrometer (Bruker S8 Tiger). The samples were processed to a particle size of less than 74 micrometers, with a weight of approximately 5–6 grams per sample. Each sample was blended with a binding agent, such as cellulose wax, and compressed under a pressure of 20–30 tons to produce uniform pellets. These pellets were subsequently mounted in plastic sample cups, supported by a plastic film base. This ensures a flat surface to the X-ray analyzer and sample to be supported over the X-ray beam. XRF analysis was carried out using sequential, fully automatic wavelength dispersive spectrometers controlled via Pcs running Super Q XRF application package. For major element analysis, fused beads were prepared by heating a mixture of 0.9 g of sample and 9.0 g of flux at 1200 °C. Loss on ignition was determined on platinum crucible, 1 g sample heated at 1050°C for one hour. Calibration was conducted using USGS reference standards (GXR-2 and GXR-5), ensuring measurement accuracy within 5% relative standard deviation (%RSD) for major oxides and within 12% for trace elements. The analytical precision consistently remained within 1.5%.

For rare earth element (REE) analysis, an Inductively Coupled Plasma Mass Spectrometer (ICP-MS; PerkinElmer SCIEX ELAN DRC-e) was used, following the open-system rock digestion method (Khanna *et al.*, 2009). Each 100 mg sample (200 mesh) was digested in a 10 ml solution of hydrofluoric acid (HF) and nitric acid (HNO_3) in a 2:1 ratio. The residue so obtained was subsequently dissolved in 10 ml of 20% nitric acid (HNO_3) for further analysis. To ensure the accuracy and reliability of the results, sediment calibration and validation were performed using USGS reference materials (SCO-1, MAG-1, and SRG-1).

For mineralogical composition, the powder of sample was put in the sample holder (silica wafer) of Xray diffractometer. The surface was leveled by removing excess sample powder with the help of a microscope glass slide. The voltage was 45kV while the filament emission was 40 mA. The samples were scanned over 2-theta and ranged from 5° to 90°. Positions and intensities of the recorded pattern are then analyzed with regards to quantitative, qualitative and the lattice constant using appropriate computer software. The resulting XRD data are referenced to powder diffraction patterns found in the powder diffraction file (PDF) database. The diffractograms were analyzed using the Reference Intensity Ratio (RIR) Method, which provides semi-quantitative estimations of mineral abundances. The identified minerals were quantified based on peak intensities and scale factors derived from standard databases.

Results

Field observations and Facies Study

A detailed facies analysis of Basanter North, Samba South East and Dhalta West sections has been carried out. These sections composed of unconsolidated sediments and exposed along the national highway between Samba and Kathua district of Jammu and Kashmir. The following field observations were made.

Basanter North Section (Fig. 3a-b)

This section exposed near the Basanter River towards north and composed of gravel, pebble, sand and silt. The thickness of the section is 4.5 meters. In Basanter section, three lithofacies has been observed from bottom to top:

a) Msmg Facies (Matrix Supported Massive Gravel Facies)

This facies consists of unconsolidated lithologies, including silt, sand, pebbles and gravel. The gravel present in this facies is high in percentage than the pebble. The sand and silt present in small amounts which acts as binding material. No sedimentary structure is visible. This facies is 0.8meter thick and overall color is grey.

b) Sd Facies (Sand Facies)

Sd facies is 0.2 meter thick composed of unconsolidated course to medium grained to fine grained sand. The sand exhibits poor sorting characteristics and friable nature. The color of sand is grayish.

c) Msmg Facies (Matrix Supported Massive Gravel Facies)

This facies is composed of massive unconsolidated pebbly gravel unit. The thickness of this facies is 0.5meter and grey in color. A very small amount of sand and silt is present which bind the pebble and gravels.

d) Sd Facies (Sand Facies)

This facies is composed of lose friable sand. The sand is medium to find grained texture, poorly sorted and light brown to grayish in color. This facies has a thickness of 2 meters.

e) St Facies (Silt Facies)

This facies occur at the top of the section and composed of unconsolidated silt. *St facies* is 1 meter thick and the color of silt is light grey to pale brown. At the top, some vegetation is there.

Samba South Section (Fig. 3c-d)

This section is exposed 2km away from south of Samba city towards southeast. The section composed of loses gravels, silt and mud and have 5 meters thick. Three lithofacies observed in this section are *Msmg facies*, *St facies* and *Md facies*. The details of lithofacies facies observed from bottom to top in the section are as under

a) Msmg Facies (Matrix Supported Massive Gravel Facies)

This facies occur at the bottom of the section and composed of gravel with small amount of sand and silt act as matrix supporting material. The facies measure 1.0 meter thick. The gravel deposited displays poor sorting. This facies is overlain by *St facies*.

b) St Facies (Silt Facies)

The silt facies shows sharp contact with underlying *Msmg facies (*Matrix supported gravel facies). The facies is composed of light grayish to light brown colored silt. Its thickness is 1.4 meters. No primary sedimentary structure is recorded in this facies.

c) Msmg Facies (Matrix Supported Massive Gravel Facies)

The *Msmg facies* is composed of sand, silt and gravel which is

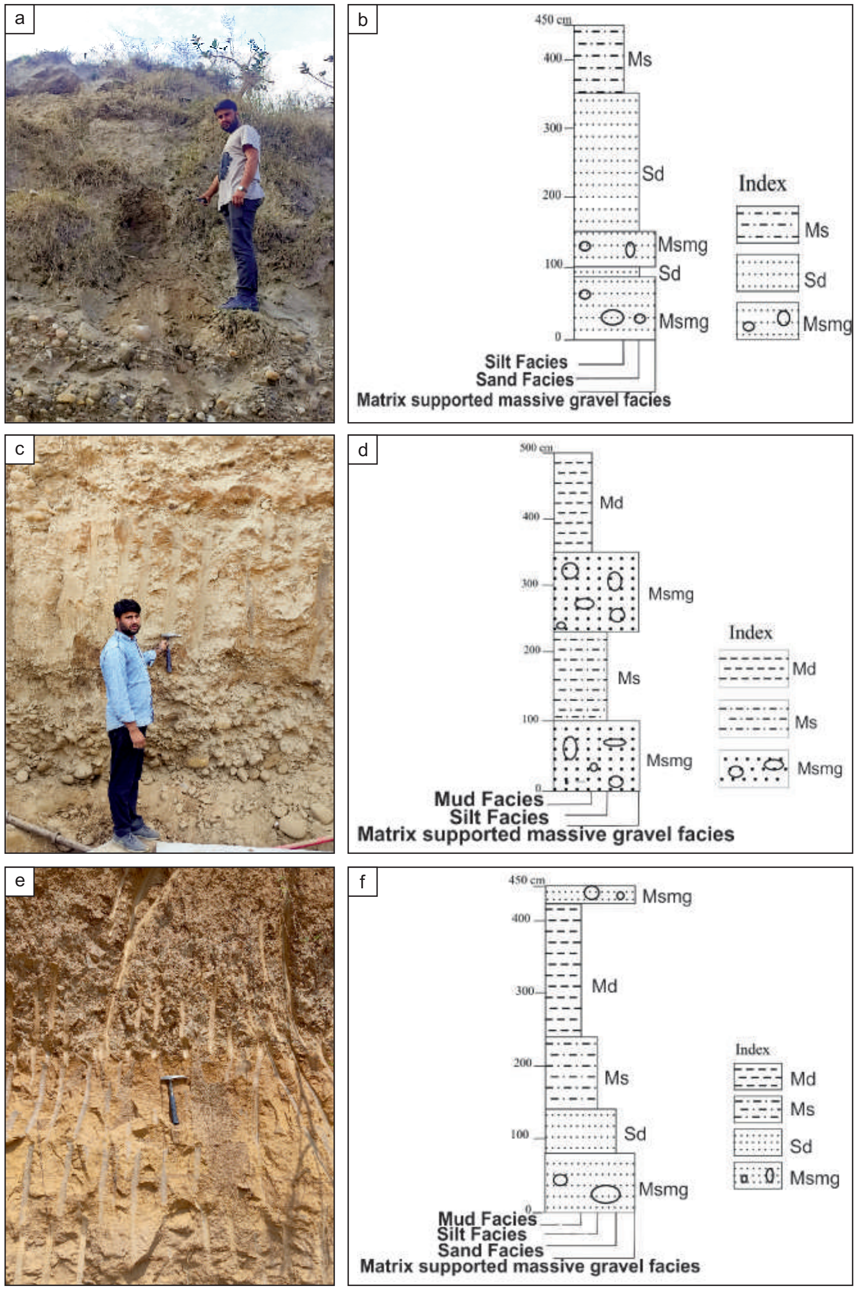

Fig.3. Showing Basanter North section (a-b): a. field photograph b. lithofacies; Samba South East Section(c-d): c. field photograph d. lithofacies and Dhalta West Section (e-f): e. field photograph, f. lithofacies

light brown to grey in color. Sand and silt act as matrix to bind the gravels. The thickness of this facies is 1.3meters. This facies has sharp contact with underlying silt facies and gradational contact with overlying Mud facies.

d) Md Facies (Mud Facies)

Md facies composed of unconsolidated massive mud. The mud bed is 1.3 meters thick. The color of the facies is light to dark brown.

Dhalta West Section (Fig.3e-f)

Dhalta West Section is exposed approximately 500 meters west of Dhalta village of Kathua district (Jammu and Kashmir). This section is 4.5 meter thick and lithofacies observed in this section from bottom to top are as under

a) Msmg Facies (Matrix Supported Massive Gravel Facies)

The msmg bed is exposed at the bottom of the Dhalta section, consisting of gravel, sand, pebbles and silt. Sand and silt act as matrix support to bind the gravels. The colors vary from grey to dark brown. The thickness of this facies is 0.75meters and shows graditional contact with overlying *St facies*.

b) Sd Facies (Sand Facies)

This facies is mainly composed of coarse to medium to fine grained grayish sand. Its thickness is 0.50 meters.

This facies displays very fine parallel lamination at some part of beds.

c) St Facies (Silt Facies)

The massive silt bed exhibits a light yellow to light brown coloration and has a measured thickness of 1.0 meter. It is composed of massive, poorly sorted, unconsolidated and friable silt.

d) Md Facies (Mud Facies)

The thickness of this facies is 2.0 meters. The mud bed has massive unconsolidated lithology. The massive mud facies is light yellow in color. Pebble layer of overlying facies is present at the top of this facies.

e) Msmg Facies (Matrix Supported Massive Gravel Facies)

The matrix supported gravel bed occurs at the top of this section. The color of this facies is brown to grey. The thickness of this facies is 0.25 meters at the top some roots of plants are preserved and covered with vegetation.

Grain Size Analysis

Particle size analysis is a very important and fundamental tool in sedimentology, widely used to classify sedimentary environments, interpret transport mechanisms, and reconstruct depositional histories (Folk and Ward, 1957; Kanhaiya *et al.*, 2017; Irfan *et al.*, 2022). The grain size parameters of sediments in different combinations provide critical insights into the energy conditions, the degree of sediment processing and processes responsible for their deposition. To analyze these characteristics, key statistical parameters such as mean grain size, sorting, skewness, and kurtosis were determined using the percentile method outlined by Folk and Ward (1957). Ternary diagrams and bivariate scatter plots were employed to interpret sedimentary processes that operate in depositional environments. Mean size versus sorting diagram was utilized to distinguish channel deposits from floodplain sediments (Kanhaiya *et al.*, 2017; Table 1).

Grain Size Distribution

The findings reveal that the study area is predominantly composed of silt and sand-sized sediments. The sand content varies from 25.06% to 89.77%. The Samba south section (SS1) has the lowest sand concentration while Basanter North section (B2) contains the highest percentage of sand. Similarly, silt content varies from 9.38% to 69.81%. The lowest silt concentration is observed in B2 sample of Basanter North section and the highest silt concentration is in SS1 of Samba South East section. Further, the clay content is lowest in B2 sample of Basanter Noth section and highest clay content is in sample D1 of Dhalta West section.

The grain size analysis showed that silt and sand are dominated component in the area understudy with small proportions of clay percentage. The data of six samples from three lithosections for grain size distribution has been plotted (Fig. 4) on the ternary diagrams proposed by Folk (1954, 1980). The results suggest that only 33 percent of samples fall within the zone of sandy silt and around 67 percent samples fall within the zone of silty sand.

Table 1: Weight percentile of sand, silt and clay of Quaternary sediments, Jammu

Sample name	Sand (%)	Silt (%)	Clay (%)
B1	62.05393	34.92262	3.023445
B2	89.77741	9.383166	0.839424
SS1	25.06015	69.81066	5.129188
SS2	62.96756	32.92684	4.105606
D1	31.94719	58.92211	9.130696
D2	51.59293	42.32692	6.080155

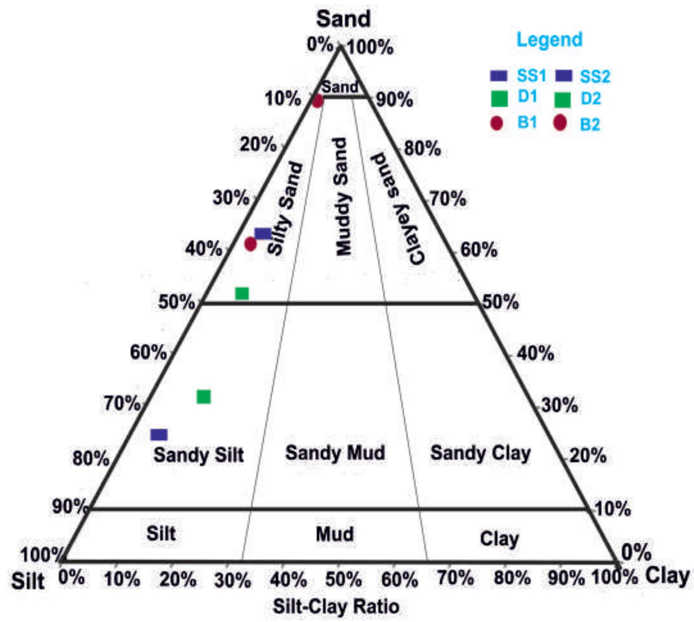

Fig.4. Samples plotted on ternary diagrams for classification of sediments (Folk, 1954, 1980).

Grain Size Parameters

Grain size parameters (mean size, standard deviation, skewness, kurtosis) are very helpful in interpreting sedimentary processes that occur in depositional environment (Sengupta 1977; Vijay Lakshmi *et al.*, 2010). The data of grain size parameters of the samples is given in Table 2.

Mean size

The mean grain size reflects the average particle size within

Table 2: Showing Mean size, Standard deviation, Skewness and Kurtosis values of samples of Quaternary sediments, Jammu

Sample Name	Mean	SD	Skew-ness	Kur-tosis	Description
B1	3.707	1.759	0.280	1.147	Very fine sand, Poorly sorted, Fine skewed, Leptokurtic
B2	2.427	1.359	0.295	1.393	Fine sand, Poorly sorted, Fine skewed, Leptokurtic
SS1	4.887	1.591	0.148	1.124	Very coarse silt, Poorly sorted, Fine skewed, Leptokurtic
SS2	3.406	2.172	0.391	0.853	Very fine sand, Very poorly sorted, Very fine skewed, Platykurtic
D1	5.02	2.088	0.083	0.814	Coarse silt, Very poorly sorted, Symmetrical, Platykurtic
D2	4.158	2.041	0.271	0.879	Very coarse silt, Very poorly sorted, Fine skewed, Platykurtic

the sediment population. The mean size in the sediment depends upon the source, depositional conditions and mode of transportation. It also serves as an indicator of the energy conditions. The maximum value of mean size of Quaternary sediments of study area is 5.02Φ in D1 sample of Dhalta West section and the minimum value of mean size is 2.427Φ in B2 sample of Basanter North section. The average value of mean size of all samples of Quaternary sediments is 3.93Φ. One sample fall into coarse silt (D1), two (SS1 and D2) in very coarse silt, one (B2) in fine sand and two (B1 and SS2) into very fine sand category.

Standard Deviation / Sorting

The standard deviation is the mathematical expression of sorting. It indicates the fluctuations in the kinetic energy and hence, the velocity of depositing agent (Sahu, 1964). In present study, the minimum value of the SD is 1.359Φ in B2 sample of Basanter North section and maximum value of the SD is 2.172Φ in S2 sample of Samba South East section. The average value of the SD of all samples is 1.835Φ. Three samples (B1, B2, and SS1) are poorly sorted and three samples (SS2, D1, and D2) are very poorly sorted.

Skewness

The skewness measures the asymmetry in the frequency curves and also marks the position of mean with respect to median. A coarse skewed sample indicates that the velocity of depositing agent operated at higher level than the average velocity for long duration in sediments of varying sizes (Sahu, 1964). A fine-skewed distribution suggests that the sediment was transported under lower velocities compared to the average flow conditions. The maximum value of skewness is 1.845Φ in sample B2 of Basanter North section and the minimum value of skewness is -0.099Φ in sample D1 of Dhalta West section. The average value is 0.686Φ. Four samples (B1, B2, SS1 and D2) are fine skewed, one (SS2) is very fine skewed and one (D1) is symmetrical.

Kurtosis

Kurtosis quantifies the sharpness or peakedness of a grain size distribution curve, providing insight into the deviation from a normal distribution. Mathematically, it reflects the internal sorting or concentration of particle sizes within the sample (Cadigan 1961). The minimum value of Quaternary sediment of our study area is 0.814Φ in D1 sample of Dhalta West section and the maximum value is 1.393Φ in B2 sample of Basanter North section. The average value is 1.035Φ. Among the six samples, three (SS2, D1, and D2) exhibit a platykurtic distribution, while the remaining three (B1, B2, and SS1) display a leptokurtic nature.

Interrelationship Among Grain Size Parameters

The relationship between the grain size parameters is important for understanding the transport and depositional environment of sediments and is an excellent tool for identifying different sedimentation processes as pointed out by following researchers (Passega, 1957, 1964; Friedman, 1961, 1967; Passega and Byrarnjee, 1969; Mycielska-Dowgiallo, 2007; Ludwikowaska-Kedzia, 2011). Bivariate plot is prepared by using different pairs (mean size and sorting) of grain size parameters (Kanhaiya *et al.,* 2017).

Mean Size vs. Sorting

Bivariate plots of mean size versus sorting can be utilized to discriminate between flood plain and channel sediments (Kanhaiya *et al.,* 2017). In present case the corresponding plot shows that all sediments fall in the zone of the floodplain field (Fig. 5).

Geochemical Characterization

Geochemistry analysis (Major oxides, trace elements and rare earth elements) plays an important role to determine the provenance (Roser and Korsch, 1986; McLennan *et al.,* 1993), paleoclimate and tectonic environment of sediments (Bhatia, 1983; Kettanah *et al.,* 2021). The data obtained from WIGH lab of major oxide, trace elements and rare earth elements concentrations of the Quaternary sediments understudy are given in Table 3.

Major Oxides

The Quaternary sediments of Samba and Kathua districts have high SiO_2 concentrations, varying between 64.96 % and 85.08 % (average 75.02%). Next in order of decreasing abundance are Al_2O_3(6.39%-13.57%), Fe_2O_3 (2.57%-4.70%), CaO (0.21%-5.86%), K_2O (1.85%-2.46%), MgO (0.92%-2.02%), Na_2O(0.47%-1.14%), TiO_2(0.40%-0.57%), P_2O_5 (0.04%-0.15%) and MnO (0.05%-0.09%) with average concentrations 75.02%, 9.98%, 3.635%, 3.035%, 2.155%, 1.47%, 0.805%, 0.485%, 0.095% and 0.07%, respectively. Figure 6 illustrates the measured concentrations of major oxides. All the samples are highly rich (64.96 -85.08%) in SiO_2 content (64.96 -85.08%) indicates source was highly rich silica rock.

For textural and mineralogical maturity, diagram of log ratios of SiO_2/Al_2O_3 *vs* Na_2O/K_2O (Pettijohn *et al.,* 2012) is used to classify the Quaternary sediments (Fig.7). The data of log ratios SiO_2/Al_2O_3, Na_2O/K_2O is given in Table 4. The sediments are classified as arkose, sub-arkose and litharenite in composition. This suggests that the sediments are relatively texturally and mineralogically immature. The SiO_2/Al_2O_3 ratio in clastic sediments serves as an indicator of their textural maturity.

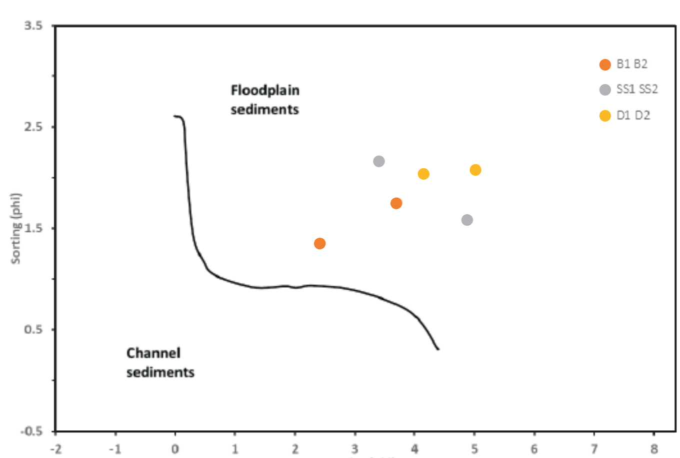

Fig.5. Mean size and Sorting with subdivisions (Kanhaiya et al., 2017). All samples fall within the domain of floodplain sediments.

Table 3: Major oxides,Trace elements and Rare earth elements of Quaternary sediments of Jammu

a) Major Oxides

Sample	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3
B1	1.14	1.40	10.11	77.46	0.08	2.25	1.25	0.47	0.08	3.31
B2	1.09	0.94	7.53	81.06	0.08	1.97	0.92	0.40	0.07	2.57
SS1	1.06	2.02	11.80	64.96	0.15	2.46	5.86	0.54	0.07	3.96
SS2	0.47	0.92	7.53	83.48	0.04	1.85	0.21	0.42	0.05	2.68
D1	0.48	1.72	13.57	71.96	0.04	2.40	0.36	0.57	0.09	4.70
D2	0.58	0.96	6.39	85.08	0.06	1.88	0.27	0.46	0.07	3.45

b) Trace elements

Sample Name	Ba PPM	Cr PPM	V PPM	Sc PPM	Co PPM	Ni PPM	Cu PPM	Zn PPM	Ga PPM	Pb PPM	Th PPM	Rb PPM	U PPM	Sr PPM	Y PPM	Zr PPM	Nb PPM
B1	292	274	61	7	8	23	21	51	12	12	14	101	1.5	70	23	227	13
B2	307	88	47	5	5	11	16	34	BDL	10	14	84	0.5	66	20	258	10
SS1	362	114	81	11	11	33	26	59	15	20	16	97	0.7	145	27	243	12
SS2	270	128	54	6	5	14	20	37	9	10	12	84	BDL	40	19	252	10
D1	404	220	88	10	13	40	30	69	15	14	15	119	0.9	50	28	217	13
D2	82	902	71	8	9	30	21	41	11	10	15	81	1.4	41	23	286	12

c) Rare earth elements

Lab No.	Sample ID	139 La	140 Ce	141 Pr	142 Nd	152 Sm	153 Eu	156 Gd	159 Tb	164 Dy	165 Ho	166 Er	169 Tm	174 Yb	175 Lu
		Concentration in parts per million (ppm)													
Standard	*PKSS-1	30.828	56.985	6.417	21.999	3.954	0.897	2.877	0.384	2.079	0.363	1.173	0.177	1.218	0.228
Standard	*SO-1	53.886	112.290	13.605	46.200	8.202	1.725	6.471	0.849	4.536	0.768	2.415	0.357	2.268	0.348
1	B1	40.284	74.184	8.802	30.138	5.820	0.996	4.884	0.690	3.804	0.654	2.100	0.318	2.052	0.300
2	B2	41.298	78.090	9.036	30.942	5.724	0.900	4.770	0.642	3.600	0.618	1.956	0.306	1.932	0.288
3	SS1	43.908	82.842	9.864	33.162	6.552	1.122	5.598	0.792	4.416	0.738	2.274	0.336	2.142	0.312
4	SS2	34.518	66.624	7.614	26.124	4.950	0.816	3.882	0.522	2.916	0.510	1.578	0.246	1.542	0.240
5	D1	40.884	76.482	9.054	31.026	6.186	1.122	5.274	0.762	4.332	0.756	2.304	0.348	2.154	0.330
6	D2	41.466	79.242	9.120	31.848	5.874	0.972	4.884	0.660	3.606	0.606	1.896	0.288	1.788	0.276

Trace and Rare Earth Elements

Trace elements play an important role to know the source of sediments**.** Th/Yb verses La/Th (Bhatia and Crook, 1986) plot also used to know the source, whether the sediments are felsic or mafic in nature. The data of Th/Yb and La/Th of samples understudy falls within felsic domain and indicate felsic source (Fig. 8; Table 5).

The sediments carry the REE concentration as REE are nearly quantitively transferred to terrigenous sediments and thus provide a valuable tracer of the source . Felsic source rocks typically exhibit higher LREE/HREE ratios along with pronounced negative europium (Eu) anomalies, whereas mafic rocks are generally characterized by lower LREE/HREE ratios and minimal or absent Eu anomalies (Cullers, 1994). The chondrite normalized value of six samples of Quaternary sediments is given in Table 6 and plotted on spider diagram (Fig.9). The analyzed samples of the Quaternary sediments indicate LREE enrichment (high LREE/HREE ratios), flat HREE pattern and strong negative of the Eu anomalies, in the chondrite normalized diagram indicative of parent material being felsic.

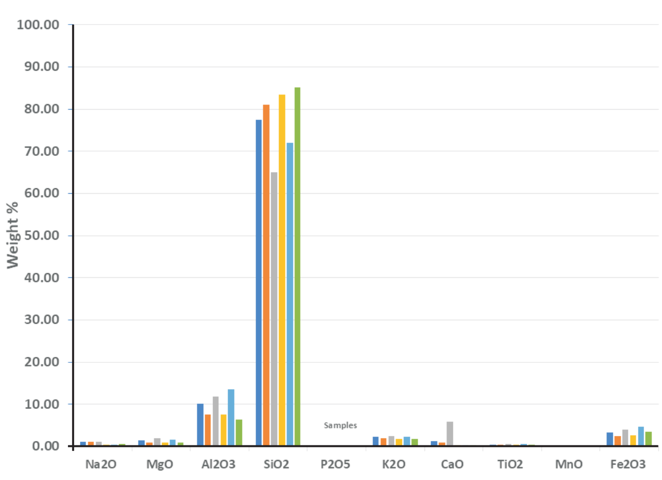

Fig.6. Concentration of major oxides in the Quaternary sediment samples of Samba -Kathua districts, Jammu province.

Table 4: Shows log ratios SiO_2/Al_2O_3 and Na_2O/K_2O

Sample 1	$Log(SiO_2/Al_2O_3)$	$Log(Na_2O/K_2O)$
B1	0.8843	-0.295
B2	1.032	-0.257
SS1	0.7408	-0.366
SS2	1.0448	-0.595
D1	0.7245	-0.699
D2	1.1243	-0.511

Table 5: La/Th and Th/Yb (Bhatia and Crook, 1986)

Sample	La/Th	Th/Yb
B1	2.877429	6.822612
B2	2.949857	7.246377
SS1	2.74425	7.469655
SS2	2.8765	7.782101
D1	2.7256	6.963788
D2	2.7644	8.389262

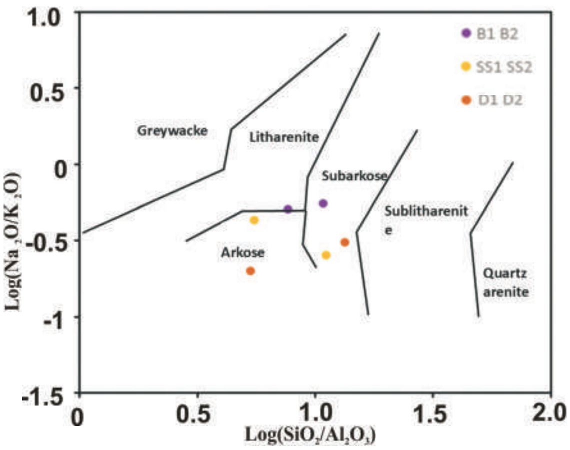

Fig.7. log ratios (SiO_2/Al_2O_3) and Na_2O/K_2O) (Pettijohn *et al.,* 2012) for classification of Quaternary sediments

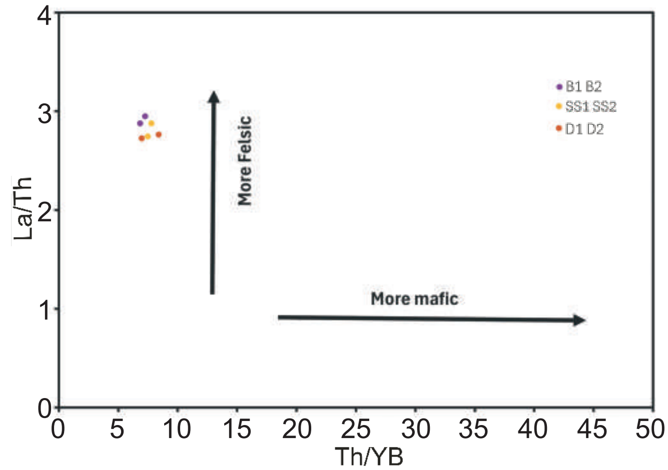

Fig.8. Th/Yb verses La/Th (Bhatia & Crook, 1986) indicate the felsic source

Table 6: Chondrite normalized value of six samples of Quaternary sediments of Jammu

Sample	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
B1	169.9747	121.2157	92.65263	64.53533	38.03922	17.17241	23.76642	18.4492	14.97638	11.55477	12.68882	12.47059	12.07059	11.81102
B2	174.2532	127.598	95.11579	66.25696	37.41176	15.51724	23.21168	17.16578	14.17323	10.91873	11.81873	12	11.36471	11.33858
SS1	185.2658	135.3627	103.8316	71.01071	42.82353	19.34483	27.24088	21.17647	17.38583	13.03887	13.74018	13.17647	12.6	12.28346
SS2	145.6456	108.8627	80.14737	55.94004	32.35294	14.06897	18.89051	13.95722	11.48031	9.010601	9.534743	9.647059	9.070588	9.448819
D1	172.5063	124.9706	95.30526	66.43683	40.43137	19.34483	25.66423	20.37433	17.05512	13.35689	13.92145	13.64706	12.67059	12.99213
D2	174.962	129.4804	96	68.197	38.39216	16.75862	23.76642	17.64706	14.19685	10.70671	11.45619	11.29412	10.51765	10.86614

Mineralogical Composition

XRD analysis used to determine the relative abundances of various mineral phases and assess their implications for provenance, depositional environments, and post-depositional alterations. The minerals present in the Quaternary sediments were identified by employing XRD analysis of six samples. The minerals present in the studied samples include Quartz (Low), Lavendulan, Birnessite, Kamacite, Zircon, Gadolinite, Muscovite, Pyrochlore, Magnesium-rich calcite, Polylithionite, Mica, Osbornite, Chlorite-Serpentine and Faujasite (Table 7).

Discussion

Facies Study

The facies study reveals that mainly four types of facies observed in the studied sections *viz. Msmg facies, Sd facies, St facies* and *Md facies*. *Msmg facies* and *St facies* have been reported from all the three sections, *Sd facies* reported only in two sections *viz.* Basanter North Section and Dhalta West Section, and *Md facies* reported only in Dhalta West Section. According to Miall (1996), the *Msmg facies is* indicative of massive gravels that are matrix-supported, with weak grading. The *Msmg facies* typically consist of a heterogeneous mix of coarse and fine-grained materials, including gravel, sand, and silt. While grain sizes vary, gravel and sand dominate, with finer materials, such as mud, comprising the matrix. The sorting of these sediments is generally poor, consistent with the chaotic nature of mass flow processes. Larger particles, such as gravel and coarse sand, are often poorly sorted and matrix-supported, while finer particles, like mud and silt, fill the interstitial spaces. The depositional structures in these facies are from massive to laminated, with occasional grading from course to fine, signifying a reduction in flows energy during deposition. The *Sd facies* are primarily sandy, with grains ranging from very fine to

Table 7: Mineralogical composition of analyzed samples of Quaternary sediments of Jammu province

Sample name	Quartz (%)	Other Minerals (%)
B1	51.2%	Zircon (48.8%)
B2	92.2%	Gadolinite (7.8%)
SS1	82.6%	Calcite with magnesium (17.4%)
SS2	96.5%	Polylithionite (3.5%)
D1	84.2%	Mica (2.0%), Osbornite (13.8%)
D2	98.0%	Corundum (2.0%)

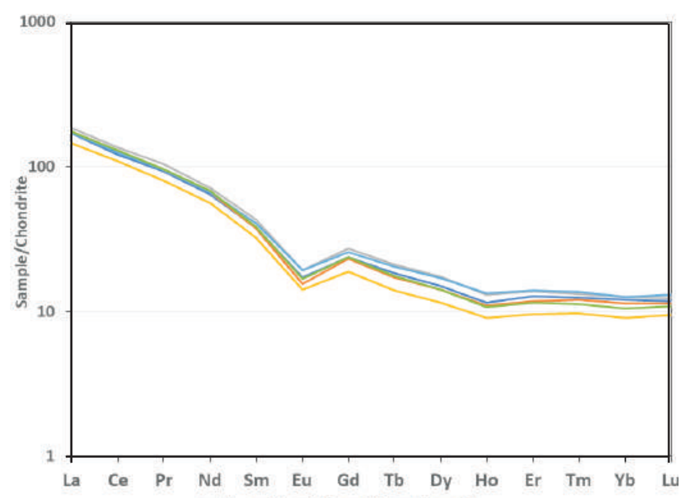

Fig.9. Spider diagram of chondrite normalized samples of Quaternary sediments of Jammu province

fine, and typically represent low-energy depositional environments. Composed mainly of fine-grained materials such as clay and silt, the *Sd facies* are characterized by their laminated structure, where the fine particles are deposited in thin, uniform layers. These fine-grained sediments are too small to require a microscope for detailed analysis. The deposits are generally well-sorted, with relatively uniform grain sizes, although there may be slight variations due to intermittent high-energy events, such as occasional floods. Shale, the rock typically associated with these facies, forms from the consolidation of these fine-grained particles. The *Sd facies* form in low-energy environments where sediment accumulation rates are high for the deposition of fine materials, but not sufficient to transport coarser materials. *St facies* is dominated by silt in association with mud and exhibits massive sedimentary structures (large – scale sedimentary features within sedimentary rocks) that suggest deposition in abandoned channels. Sorting within the *Fsm facies* is typically moderate to poor, with fine-grained mud filling the interstitial spaces between coarser sand grains. Deposits of these facies often display laminated and bioturbated bedding which indicates periods of slower sedimentation and activity of organisms inhabiting the depositional environment respectively. The *St facies* are typically associated with shallow water settings, such as estuaries, deltaic plains, or nearshore zones of continental shelves, where deposition is influenced by tidal, wave, and riverine processes. The *Md facies* typically consist of a mixture of fine-grained sediments (clay and silt) and medium-grained sands. The sorting in *Md facies* is generally moderate to poor, as the mixed nature of the sediments reflects fluctuating energy conditions. Sand particles may show poor sorting due to varying depositional energy, though some degree of sorting may be observed when finer or coarser materials dominate at different times. This facies is characteristic of transitional or mixed-energy environments, where both sand and mud are deposited together in variable proportions, often resulting from tidal, riverine, or deltaic interactions. The comparative study of Miall (1996) facies classification scheme and facies under study is given in Table 8.

Grain Size Analysis

The dominance of sand and silt in all analyzed samples suggests that the sediments were deposited under varying energy conditions, influenced by fluvial and alluvial processes. The low clay content across all samples indicates limited suspension settling and an environment dominated by traction and saltation transport mechanisms (Van Hateren *et al.,* 2020). The variability in sand content across different samples suggests differences in energy conditions at the time of deposition. The Basanter North section (B2) exhibited the highest sand concentration (89.77%), indicative of a high-energy depositional environment, such as a river channel. Conversely, the Samba South East section (SS1) contained the lowest sand content (25.06%) and the highest silt concentration (69.81%), suggesting deposition in a relatively low-energy environment, such as a floodplain (Ghosh *et al.,* 2016). Variations in grain size parameters offer key insights into the processes governing sediment deposition and help infer the depositional environment. The mean grain size values indicate that the sediments range from fine sand to coarse silt, suggesting deposition by fluctuating energy conditions. Poor to very poor sorting in all samples suggests multiple transport and reworking episodes, as well as variable flow dynamics. The skewness values indicate that most of the samples are fine-skewed, implying deposition under moderate to low-energy conditions with finer sediments dominating. The kurtosis values show that the samples are either leptokurtic or platykurtic, signifying variations in sorting and sediment transport processes (Folk and Ward, 1957; Friedman, 1961; Blott and Pye, 2001). Furthermore, the mean size versus sorting plot, based on Kanhaiya *et al.* (2017), categorizes all sediments within the floodplain domain. This strongly indicates that these sediments were predominantly deposited in a floodplain environment, subject to periodic flooding and variable flow regimes. The presence of silty sand in 67% of the samples and sandy silt in 33% further confirms a transitional depositional setting between active channels and floodplains (Aslam *et al.*, 2023).

Geochemical Characterization and Mineralogical Composition

The high SiO_2 content of the sediments and a strong negative correlation of SiO_2 with other major oxides is the consequence of hydrodynamic fractionation and sorting during sediment transportation. On the other hand, the positive correlation of other major oxides with Al_2O_3 is consistent with the presence of aluminous clay and heavy minerals (Hussain *et al.*, 2017). The small concentrations of CaO and Na_2O are attributed to the dominance of fine-grained sediments, as suggested by Roser and Korsch (1988). In the Chondrite normalized diagram, the sediments show high LREE/HREE ratios, LREE enrichment and mostly flat HREE and pattern similar to UCC normalised on chondrite. Strong negative Eu anomalies suggest derivation from felsic sources and subsequent removal of feldspars by chemical weathering and erosion (Taylor and McLennan, 1985). The Higher Himalayan and Lesser Himalayan felsic rocks are the most probable sources. From the ratios of immobile trace elements, it is inferred that the ratios of these sediments are within the range of sediments derived from felsic rocks. The quartz occurred as major portion in association with Lavendulan, Birnessite, Kamacite, Zircon, Gadolinite, Muscovite, Pyrochlore, Magnesium-rich calcite, Polylithionite, Mica, Osbornite, Chlorite-Serpentine and Faujasite. The high percentage of quartz in sample indicates felsic nature of sediments

Table 8: Comparative study of facies classification scheme (Miall, 1996) and facies under study

Proposed facies		Miall, 1996		
Facies codes	Facies	Facies codes	Sedimentary structures	Interpretation
Msmg facies	Matrix supported massive gravel facies	Gmm facies	Weak grading	Plastic debris flow, high strength/energy, ciscous
Sd Facies	Sand very fine to coarse, may be pebbly	Sh facies	Horizontal laminations parting or straming lineation	Pane bed flow, critical flow
St facies	Silt, mud	Fsm facies	Massive	Back swamp or abundant channel deposits
Md facies	Mud, silt	Fm facies	Massive, dessication cracks	Overbank, abundant channel deposits or drape deposits

and the sediments derived from the outer and lesser Himalayas (Ray *et al.,* 2022).

Conclusions

Facies study of Quaternary sediments suggests a mixed type of depositional environment under fluctuating energy conditions (low to high energy) influenced by fluvial and alluvial processes. The low clay content across all samples indicates limited suspension settling. The presence of silty sand (67%) and sandy silt (33%) in the samples, further confirms a transitional depositional setting between active channels and floodplains. All samples rich in silica content suggested the source of sediments was felsic in nature and this is also validated by Th/Yb vs La/Th plots. The LREE enrichment over HREE indicates strong negative Eu anomalies and also points the source of felsic composition. Log ratios (SiO_2/Al_2O_3) vs Na_2O/K_2O) suggested sediments are classified as arkose, sub-arkose and litharenite in composition. XRD values indicate the dominance of quartz in mineral composition and the sediments were derived from the outer and lesser Himalayas.

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Authors Contributions

SNK: Writing, Original Draft, Methodology, Reviewing and Editing. **BR**: Data Curation and Formal Analysis. **NUN**: Conceptualization and Investigation. **NI**: Conceptualization and Investigation. **MI**: Visualization. **SS**: Formal Analysis

References

Abishek, S.R., Christinal, J. and Ravindran, A.A. (2024). Assessment of depositional environmental factors in quaternary sediments: a case study of Thamirabarani River basin, Srivaikundam region of southern India. Discov. Geosci.*, v.* **2(**13), pp.1-20. https://doi.org/10.1007/s44288-024-00012-6

Aslam, A., Ranjan, R. K. and Dass, A. (2023). Pattern of spatial variability in granulometric and mineralogical characteristics across an ecologically sensitive sub-tropical wetland (Bihar, India). Inter. Jour. Sed. Res.., v.38(4), pp.516-529.

Bastia, F., Equeenuddin, S.M., Roy, P.D. and Hernández-Mendiola, E. (2020). Geochemical signatures of surface sediments from the Mahanadi river basin (India): Chemical weathering, provenance, and tectonic settings. Geol. Jour.*,* v.55 (7), pp.5294-5307. https://doi.org/10.1002/gj.3835

Basu, A., Bickford, M.E. and Deasy, R. (2016). Inferring tectonic provenance of siliciclastic rocks from their chemical compositions: A dissent. Sediment. Geol.*,* v.336, pp.26-35.

Bhatia, M.R. (1983). Plate Tectonics and Geochemical Composition of Sandstone. *Jour. Geol.*, v.91, pp.611-627.http://dx.doi.org/10.1086/628815

Bhatia, M.R. and Crook, K.A.W. (1986). Trace Element Characteristics of Greywackes and Tectonic Setting Discrimination of Sedimentary Basins. *Contrib. Mineral. Petrol.,* v.92, pp.181-193. http://dx.doi.org/10.1007/BF00375292

Blott, S.J. and Pye, K. (2001). GRADISTAT: A grain size distribution and statistics package for the analysis of unconsolidated sediments. Earth Surf. Process. Landf.*,* v.1**(***26*), pp.1237–1248. https://doi.org/10.1002/esp.261

Bracciali, L., Marroni, M., Pandolfi, L. and Rocchi, S. (2007). Geochemistry and petrography of western Tethys Cretaceous sedimentary covers (Corsica and Northern Apennines): From source areas to configuration of margins. *Geol. Soc. Am.,* Special Paper, v.420, pp.73-93.

Cadigan, R.A. (1961). Geological interpretation of grain size distribution measurements of Colorado Plateau sedimentary rocks. Jour. Geol., v.69 (2), pp.121–144.

Cullers, R.L. (1994). The controls on the major and trace element variation of shales, siltstones, and sandstones of Pennsylvanian-Permian age from uplifted continental blocks in Colorado to platform sediment in Kansas, USA. Geochim. et Cosmochim Acta*,* v.58 (22), pp.4955–4972.

Dasarathi, N. (1968). A note on certain geological aspects of Tawi Valley Tertiaries. Kashmir Sci*.,* v.5 (1-2), pp.222-232.

De Terra, H. and Paterson, T.T. (1939). Studies on the Ice Age in India and associated human cultures. Washington: Carnegie Publications, 493p (reprinted in 1993, Aryan Books International, New Delhi).

Folk, R.L.(1954). The distinction between grain size and mineral composition in sedimentary rock nomenclature. Jour. Geol., v.62, pp.344–359.

Folk, R.L. (1980). Petrology of sedimentary rocks. Hemphill publishing company, Austin, 184p.

Folk, R.L. and Ward, W.C. (1957). Brazos River bar: A study in the significance of grain size parameters. Jour. Sediment. Petrol., v.27, pp.3–26.

Friedman, G.M. (1961). Distribution between dune, beach, and river sands from textural characteristics. Jour. Sediment. Petrol., v.31, pp.529-545.

Friedman, G.M. (1967). Dynamic processes and statistical parameters compared for size frequency distribution of beach and river sands. Jour. Sediment. Petrol., v.37, pp.327-354.

Ganjoo, R.K., Verma, R.K. and Achyuthan, H. (2002). Lower Pleistocene palaeosols of the Upper Siwalik in Jammu: Evidence of seasonality. Jour. Geol. Soc. India, v.60 (4), pp.371-380.

Ganjoo, R.K. (1990). Late Pleistocene fluvial response to tectonics in Jammu, Jammu and Kashmir. Jour. Geol. Soc. India, v.35 (4), pp.390-394.

Ganjoo, R.K. (1993). Late Quaternary climato-tectonic history and re-assessment of the chronology of prehistoric culture of Jammu, sub-Himalaya, India. In: Ganjoo, R.K. & Ota, S.B. (Eds.), Curr. Adv. Indian Archaeol., Nagpur: Datt Sons, *v.1.*, pp.111–127.

Ganjoo, R.K. and Kumar, V. (2012). Late Quaternary fine silt deposits of Jammu, NW Himalaya: Genesis and climatic significance. Jour. Ear. Syst. Sci., v.121 (1), pp.165-182.

Ghosh, S., Sanyal, P., Sinha, R., Kumar, R. and Sinha, A. (2016). Fluvial sedimentology and basin analysis of the Himalayan Foreland Basin. Sediment. Geol., v.341, pp.1–19.

Herron, M.M. (1988). Geochemical classification of terrigenous sands and shales from core or log data. Jour. Sediment. Res., v.58 (5), pp.820–829.

Hossain, H.Z., Kawahata, H., Roser, B.P., Sampei, Y., Manaka, T. and Otani, S. (2017). Geochemical characteristics of modern river sediments in Myanmar and Thailand: Implications for provenance and weathering. Geochemistry, v.77 (3), pp.443–458.

Irfan, M., Singh, B.P. and Kanhaiya, S. (2022). Textural behavior, facies, and depositional environments of the Middle Siwalik Subgroup of the Jammu area, Jammu & Kashmir State, NW Himalaya. Jour. Palaeontol. Soc. India, v.67 (1), pp.85-92.

Kanhaiya, S., Singh, B.P., Singh, S., Mittal, P. and Srivastava, V.K. (2019). Morphometric analysis, bedload sediments, and weathering intensity in the Khurar River Basin, central India. Geol. Jour., v.54 (1), pp.466-48.

Kanhaiya, S., Singh, B.P., Tripathi, M., Sahu, S. and Tiwari, V. (2017). Lithofacies and particle-size characteristics of late Quaternary floodplain deposits along the middle reaches of the Ganga River, central Ganga Plain, India. Geomorphology, v.284, pp.220–228.

Kettanah, Y.A., Armstrong-Altrin, J.S. and Mohammad, F.A. (2021). Petrography and geochemistry of siliciclastic rocks of the Middle Eocene Gercus Formation, Northern Iraq: Implications for provenance and tectonic setting. Geol. Jour., v.56 (5), pp.2528–2549.

Khan, M., Li, H., Algeo, T.J., Khan, A., Förster, M.W. and Ullah, Z. (2025). Geochemistry and geochronology of A□type intermediate□felsic rocks in NW Himalaya, Pakistan: Implications for petrogenesis and tectonic evolution of northern Gondwana. Geochem., Geophys., Geosyst., v.26 (1), e2024GC011802

Khanna, P.P., Saini, N.K., Mukherjee, P. and Purohit, K.K. (2009). An appraisal of ICP-MS technique for determination of REEs: Long term QC assessment of silicate rock analysis. Him. Geol., v.30, pp.95-99.

Loubser, M. and Verryn, S. (2008). Combining XRF and XRD analyses and sample preparation to solve mineralogical problems. S. Afr. J. Geol.., v.111 (2-3), pp.229-238.

Ludwikowska-Kędzia, M. and Pawelec, H. (2011). Osadyglacigeniczne w rejonie MąchcocicKapitulnych [Glacigenic sediments near Mąchocice Kapitulne]. *In:* M. Ludwikowska – Kędzia & M. Wiatrak (Eds.), Geology and Geomorphology from the Holy Cross Region. Institute of Geography, Jan Kochanowski University, Kielce, pp.71–87.

McLennan, S., Hemming, S., McDaniel, D. and Hanson, G. (1993). Geochemical approaches to sedimentation, provenance, and tectonics. Geol. Soc. Amer., Special Paper, v.284, pp.21-40.

Miall, A.D. (1996). The geology of fluvial deposits: sedimentary facies, basin analysis and petroleum geology. Heidelberg: Springer-Verlag Inc., 582p.

Miall, A.D. (1977). A review of the braided river depositional environment. Ear. Sci. Rev., v.13, pp.1-62.

Mycielska-Dowgiałło, E. (2007). Research methods for textural features of clastic deposits and the significance of interpretational results. In: Research into the Textural Features of Quaternary Sediments and Some Dating Methods, E. Mycielska-Dowgiałło and J. Rutkowski (Eds.), The Family Alliance School of Higher Education Press, Warsaw, pp.95–180.

Passega, R. (1957). Texture as characteristic of clastic deposition. Am. Assoc. Petrol. Geol., v.41, pp. 1952-1984.

Passega, R. (1964). Grain size representation by CM patterns as a geological tool. Jour. Sediment. Res., v.34, pp. 830-847.

Passega, R. and Byramjee, R. (1969). Grain-size image of clastic deposits. Sedimentology, v.13, pp. 233-252. https://doi.org/10.1111/j.1365-3091.1969.tb00171.x

Pettijohn, F.J., Potter, P.E. and Siever, R. (2012). Sand and Sandstone. Springer Science & Business Media.

Quader, B.O. and Majeed, S.A. (2022). Sedimentary and mineralogy characteristics of late Quaternary sediments, Garmian area, Kurdistan Region, NE Iraq. Kuwait Jour. Sci., v.49 (4), pp.1-13.https://doi.org/10.48129/kjs.15731

Ray, Y., Sinha, S. and Ghosh, S. K. (2022). Provenance of the Proterozoic Lesser Himalayan siliciclastic, northwest Himalaya, India: Implications to terrain accretion and crustal evolution. Geosyst. and Geoenvir., v.1(2), pp.100016.

Roser, B.P. and Korsch, R.J. (1988). Provenance signatures of sandstone-mudstone suites determined using discriminant function analysis of major-element data. Chem. Geol., v.67 (1–2), pp.119–139.

Roy, P.D., Caballero, M., Lozano, R. and Smykatz-Kloss, W. (2008). Geochemistry of Late Quaternary Sediments from Tecocomulco Lake, Central Mexico: Implications for Chemical Weathering and Provenance. Geochemistry, v.68 (4), pp.383-393.

Sahu, B.K. (1964). Depositional Mechanisms from the Size Analysis of the Clastic Sediments. Jour. Sediment. Petrol., v.34, pp.73–84.

Sengupta, S. (1977). Principles of Sedimentology. Oxford & IBH Publishing Co.

Shrivastava, J.P., Ahmad, M. and Srivastava, S. (2012). Microstructures and compositional variation in the intra-volcanic bole clays from the Eastern Deccan Volcanic Province: Palaeoenvironmental implications and duration of volcanism. Jour. Geol. Soc. India, v.80 (2), pp.177-188.

Taylor, S.R. and McLennan, S.M. (1985). The continental crust: Its composition and evolution: An Examination of the Geochemical Record Preserved in Sedimentary Rocks. Blackwell Science, Oxford, 312p.

Van Hateren, J.A., Van Buuren, U., Arens, S.M., Van Balen, R.T. and Prins, M.A. (2020). Identifying sediment transport mechanisms from grain size–shape distributions, applied to aeolian sediments. Earth Surf. Dyn., v.*8* (2), pp.527-553.

Verma, S.N., Dhiman, L.C., Shali, A.K. and Singh, J. (1990). Report on Quaternary geological and geomorphological mapping in parts of Chenab basin covering area falling in Jammu and R.S. Pura Tehsils, Jammu District, J & K. Unpublished Report of Geological Survey of India.

Vijaylakshmi, C.S., Srinivasan, P., Murthy, S.G.N., Trivedi, D. and Nair, R.R. (2010). Granularity and textural analysis as a proxy for extreme wave events in the southeast coast of India. Jour. Ear. Sys. Sci., v.119, pp.297-305.

Xiao, K., Sun, X., Zhang, R., Zheng, M., Pei, T., Hollings, P. and Deng, J. (2024). Cassiterite geochronology and geochemistry of the Yunling Sn deposit: Implication for late Cenozoic mineralization in western Yunnan, China. Mineral. Depos., v.60(1), pp.165-183