Journal of the Palaeontological Society of India
Volume 67(1), June 30, 2022: 85-92

ISSN 0552-9360

Textural behaviour, facies, and depositional environments of the Middle Siwalik Subgroup of the Jammu area, Jammu & Kashmir State, NW Himalaya

M. Irfan[1], B. P. Singh[1*] & S. Kanhaiya[2]

JPSI

The Middle Siwalik Subgroup is dominantly comprised of multistoried sandstones. However, mudstones also occur at some intervals in the Jammu area, NW Himalaya. These sandstones and mudstones are evaluated for textural and facies analyses for interpreting depositional environments. The sandstones are characterized as very silty sandstone facies and the mudstones are characterized as very silty sandy mudstone facies and very silty slightly sandy mudstone facies. The sandstones are further classified as planar-bedded, trough cross-bedded, and tabular cross-bedded sandstone facies, and the mudstones are classified as laminated mudstone and mottled mudstone facies. Scour-fill facies occurring here is formed due to erosion of mud and filling of sand in the scours. The mottled mudstone facies contains carbonate nodules that formed during pedogenesis. Cumulative frequency curves of both the sandstones and mudstones suggest that the saltation and suspension load dominated during transportation. Mean size versus sorting bivariate plots suggest that both sandstones and mudstones were deposited in a river or a system of the river, and the bulk of the sedimentation occurred on floodplains. Rapid sedimentation and dumping controlled the planar-bedded sandstones that acquired massive thickness. The sheet-like geometries of the sand bodies with large lateral extent suggest that floodplains were of large dimensions during the Middle Siwalik sedimentation. Also, the flow pattern suggests that southerly flowing rivers (Transverse Rivers) deposited the sediments during Middle Siwalik in the Jammu area, northwest Himalaya.

ARTICLE HISTORY

Manuscript received: 23/02/2022
Manuscript accepted: 20/04/2022

Keywords: Texture; Facies, Depositional environment; Middle Siwalik Subgroup, NW Himalaya; India

*[1]Department of Geology, Institute of Science, Banaras Hindu University, Varanasi-221005, India; [2]Professor Rajendra Singh Institute of Physical Sciences, V. B. S. Purvanchal University, Jaunpur-222003, India.*Corresponding author's email corresponding author: drbpsingh1960@gmail.com*

INTRODUCTION

The Siwalik Group is on the order of 10^3 m thick sedimentary sequence forming the youngest mountain belt, extending from west to east in the form of Himalayan foothills. The Siwalik Group is considered as a sedimentary deposit of the Himalayan foreland basin (HFB) that formed as a result of the India-Asia collision in the Cenozoic. The Siwalik Group has been classified into a Lower Siwalik Subgroup, a Middle Siwalik Subgroup, and an Upper Siwalik Subgroup. It contains siliciclastic sedimentary rocks which vary in grain size from gravel to sand and mud. The Lower Siwalik contains sandstone, siltstone, and mudstones those are weakly to strongly bioturbated (Singh and Sudan, 1997). The Middle Siwalik contains sandstone and mudstone where sandstones dominate, while the Upper Siwalik contains sandstone, mudstone, and conglomerates.

The Siwalik rocks have been studied by a number of workers in the Jammu area. For example, Krynine (1937) and Pandita and Bhat (1995) studied them for petrography; Dasarathi (1968), Karunakaran and Ranga Rao (1979) established stratigraphy and Pandita and Bhat (1999) and Pandita *et al.* (2014) described facies of the Siwalik succession. Yokoyama *et al.* (1987), Ranga Rao *et al.* (1988) and Mehta *et al.* (1993) carried out fission track dating of the bentonite beds. Sharma *et al.* (1999) described facies and interpreted cyclicity based on statistical analysis of the Middle Siwalik Subgroup and Sharma *et al.* (2001) described facies and interpreted cyclicity in the Lower Siwalik Subgroup of the Jammu area. Also, Singh *et al.* (2004) carried out the heavy mineral analysis and interpreted the provenance of the Siwalik Group, while Ali *et al.* (2021) carried out geochemistry of the Upper Siwalik rocks and interpreted the provenance. Very little attention was given to the textural analysis of the Siwalik sedimentary rocks, although, they are texturally varied. To ascertain the texture of the Middle Siwalik sedimentary rocks, this study was conducted. The facies are made based on the textural analysis and have been, further, classified based on sedimentary structures. Based on facies anlyses of the Middle Siwalik Subgroup of the Jammu area, depositional environments are interpreted.

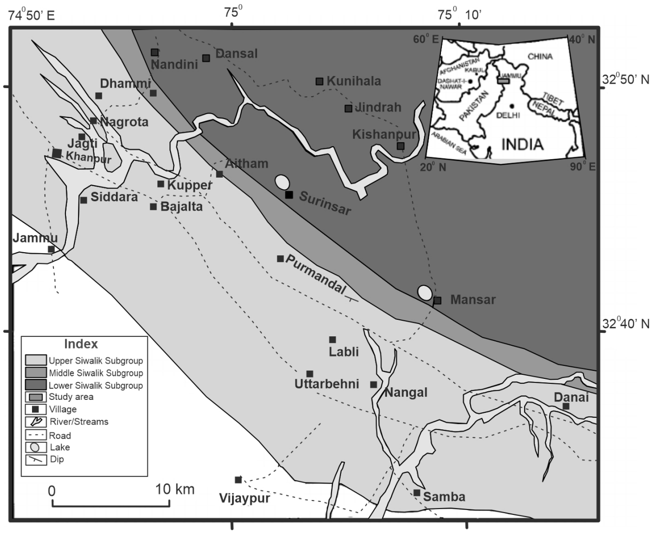

Fig. 1 Geological map of the Jammu area displaying various subgroups, (after Pandita and Bhat, 2014). Inset: Study area in the outline map of India.

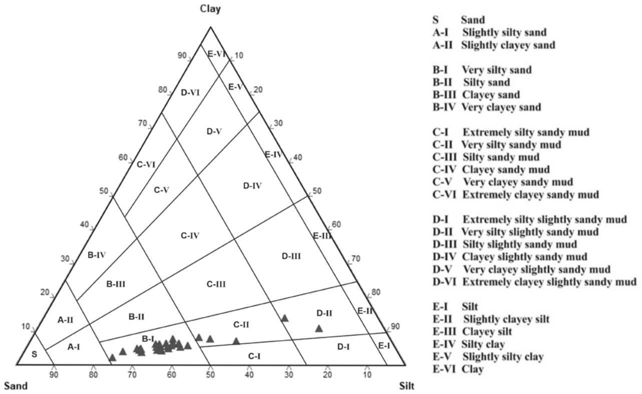

Fig. 2 Triangular plot showing the textural compositions of the various lithofacies (after Flemming, 2007).

GEOLOGICAL SETTING

Geologically, the Tertiary sequences occur as an inlier over the Precambrian Sirban Limestone in the Jammu area. The Subathu Formation occurs over the Precambrian basement and is overlain by the Murree Group. The Murree Group is, in turn, overlain by the Siwalik Group (Singh, 2000). The Siwalik Group forms a linear belt, and the older formations occur in the north and the younger formations occur in the south ending up in the Jammu city. The age of the Siwalik Group is considered as Miocene to Late Pleistocene based on vertebrate fossils. The Murree and Siwalik groups are separated by the Main Boundary Thrust from the Lesser Himalaya to the north and by the Himalayan Frontal Thrust from the Indo-Gangetic Plain to the south.

The study area is located in the Jammu district of Jammu and Kashmir State, India lies on both the banks of the Tawi River and the Jammu-Srinagar Highway. Jammu region unveils some remarkable exposures of a thick succession of Siwalik Group. Approximately, 6000 m thick succession is predominantly made up of sandstone, mudstone, and conglomerate (Pandita *et al.*, 2014). The transition from the Lower to Middle Siwalik succession, between 11 and 9 Ma shows variation in sandstone geometry and a decrease in the percentage of mudstone. A similar change was observed around 5 Ma with the commencement of the conglomerate sedimentation in the Upper Siwalik (Kumar *et al.*, 2003).

MATERIALS AND METHODS

After a systematic survey of the Middle Siwalik rocks occurring in the Jammu area, a total of 29 representative samples (semi-hard) were collected from various exposures found in the Bantalav area of the Jammu district. Thereafter, we carried out a grain size analysis of them. Approximately 10 grams of sub-samples were taken out from the bulk samples and we used coning and quartering technique to avoid bias. Contaminations of salts and organic matter were removed before the analysis. After washing the sub-samples with distilled water to remove salt, we treated them with 6% hydrogen peroxide (H_2O_2) to free them from organic matter. Oven-dried sub-samples were then subjected to grain-size analysis. Malvern 2000 laser grain-size analyzer housed in the Sedimentology Laboratory of the Department of Geology, Banaras Hindu University was used for grain size analysis. Azimuthal directions were measured from the cross-beds and rose diagram was prepared from this data for interpreting paleoflow directions.

RESULTS AND DISCUSSION

Facies based on Texture

The sedimentary rocks occurring in the Middle Siwalik Subgroup are sandy and muddy. The systematic analysis of the sandy facies assign them to be very silty sand, and to the muddy facies as very silty sandy mud and very silty slightly sandy mud (after Flemming, 2007). The very silty sandstone facies is the most dominant facies among the facies associations, and very silty sandy mudstone facies and very silty slightly sandy mudstone facies occur in small proportions (Fig. 2)

Very silty sandstone facies

This facies in the Middle Siwalik Subgroup contributes the major part within all facies spectrum. The facies dominated by sand ranges 53.3 – 74.1% along with 23.9 - 41.3% silt and 2 – 7.5% of clay. The average proportion of them is found as 61.1% of sand, 33.92% of silt, and 4.96% of clay (Fig. 2).

Table 1: Values of the textural parameters and sand, silt, and clay in sandstones and mudstones of the Middle Siwalik Subgroup.

S. No.	Sample Name	MZ	σ1	SK1	KG	C (µm)	M(µm)	Sand%	Silt%	Clay%
1	SL-1	4.52	1.81	0.3	1.1	307.79	52.56	40.01	53.13	6.86
2	SL-2	4.07	2.36	0.07	1	757.86	58.31	46.48	46.04	7.48
3	SL-3	3.83	2.27	0.3	1.02	659.75	88.39	55.9	36.6	7.5
4	SL-4	3.47	2.29	0.25	0.93	812.25	108.82	60.14	33.91	5.95
5	SL-5	3.7	2.13	0.23	1	659.75	88.39	56.53	37.45	6.02
6	SL-6	5.3	2.12	0.28	1.13	500	31.25	24.27	62.1	13.63
7	SL-7	2.73	1.9	0.17	0.99	1148.7	164.94	74.12	23.92	1.96
8	SL-8	3.33	1.88	0.35	1.07	615.57	125	65.81	29.76	4.43
9	SL-9	2.87	2.1	0.26	0.98	1231.14	164.94	70.62	25.64	3.75
10	SL-10	3.67	2.22	0.24	1.01	840.9	94.73	58.33	35.61	6.06
11	SL-11	3.5	1.85	0.31	0.96	535.89	108.82	60.61	35.4	4
12	SL-12	3.87	1.92	0.25	1.19	757.86	82.47	55.33	39.55	5.12
13	SL-13	4.27	2.08	0.31	1.25	659.75	66.99	48.99	43.02	8
14	SL-14	3.43	2.04	0.23	0.92	870.55	108.82	61.59	34.17	4.25
15	SL-15	3.43	2.16	0.17	0.93	840.9	101.53	58.53	36.81	4.66
16	SL-16	3.1	2.17	0.29	0.95	901.25	143.59	66.52	28.85	4.62
17	SL-17	3.7	2.22	0.25	0.98	757.86	94.73	57.31	37.16	5.54
18	SL-18	3.73	2.11	0.29	1.02	707.11	94.73	57.36	37.07	5.57
19	SL-19	3.37	2.28	0.3	0.85	812.25	125	60.22	34.35	5.43
20	SL-20	3.4	1.98	0.22	0.92	707.11	108.82	60.89	35.03	4.08
21	SL-21	3.23	1.96	0.24	0.99	870.55	125	65.9	30.58	3.52
22	SL-22	3.37	2.26	0.23	0.91	1000	116.63	61.43	33.44	5.13
23	SL-23	3.3	1.99	0.29	1.06	812.25	125	66.33	29.51	4.16
24	SL-24	3.87	2.04	0.2	0.95	574.35	76.95	53.26	41.34	5.4
25	SL-25	3.63	2.16	0.41	0.93	615.57	116.63	61.04	32.96	6
26	SL-26	3.33	2.06	0.36	1	732.04	133.97	65.71	29.73	4.56
27	SL-27	3.43	2.24	0.29	0.87	757.86	116.63	58.42	36.36	5.23
28	SL-28	5.3	1.65	0.2	1.15	554.78	29.16	16.91	72.44	10.65
29	SL-29	3.97	1.98	0.4	0.92	406.13	88.39	55.08	38.78	6.14

Very silty sandy mudstone facies

This facies in the Middle Siwalik Subgroup constitutes the second major facies within all facies present here. This facies is dominated by both sand and silt where sand ranges from 40 – 49%, averaging 45.59%, silt ranges from 43.02 to 53.13%, averaging 47.40% and clay ranges from 6.86 – 8%, averaging 7.45% (Fig. 2).

Very silty slightly sandy mudstone facies

This facies occurs in small proportion in the Middle Siwalik Subgroup. It is dominated by silt ranging from 62.10 – 72.44% averaging 67.27%, whereas sand ranges from 16.91 – 24.27%, averaging 20.59% and clay ranges from 10.65 – 13.63%, averaging 12.14% (Fig. 2).

Facies based on Sedimentary Structures

The sandstone and mudstone facies are further, classified into various facies based on sedimentary structures. Planar-bedded sandstone, tabular cross-bedded sandstone, trough cross-bedded sandstone, and scour-fill sandstone facies are part of the sandstone facies, while laminated mudstone and mottled mudstone facies form a part of the mudstone facies (Fig. 3).

Planar-bedded sandstone facies

Planar-bedded sandstone is the dominant facies of the Middle Siwalik. Here, the beds are confined between the lower bedding plane and the upper bedding plane. The entire unit forms 4.0-18 m thick succession within a single cycle, while the thickness of the individual beds varies from 20 cm to 1.2 m. These facies have erosional or sharp contacts with the underlying facies and sharp contacts with the overlying facies.

Tabular Cross-bedded sandstone facies

Tabular cross-bedded sandstone either occurs independently or within the planar cross-bedded sandstone. They form around a meter thick unit where the foresets show a thickness of 30-70 cm. Foreset inclinations are low angle (20-30º) and mostly directed towards south-south-west and south-south-east (Fig. 4). They have sharp contact with the underlying and overlying facies.

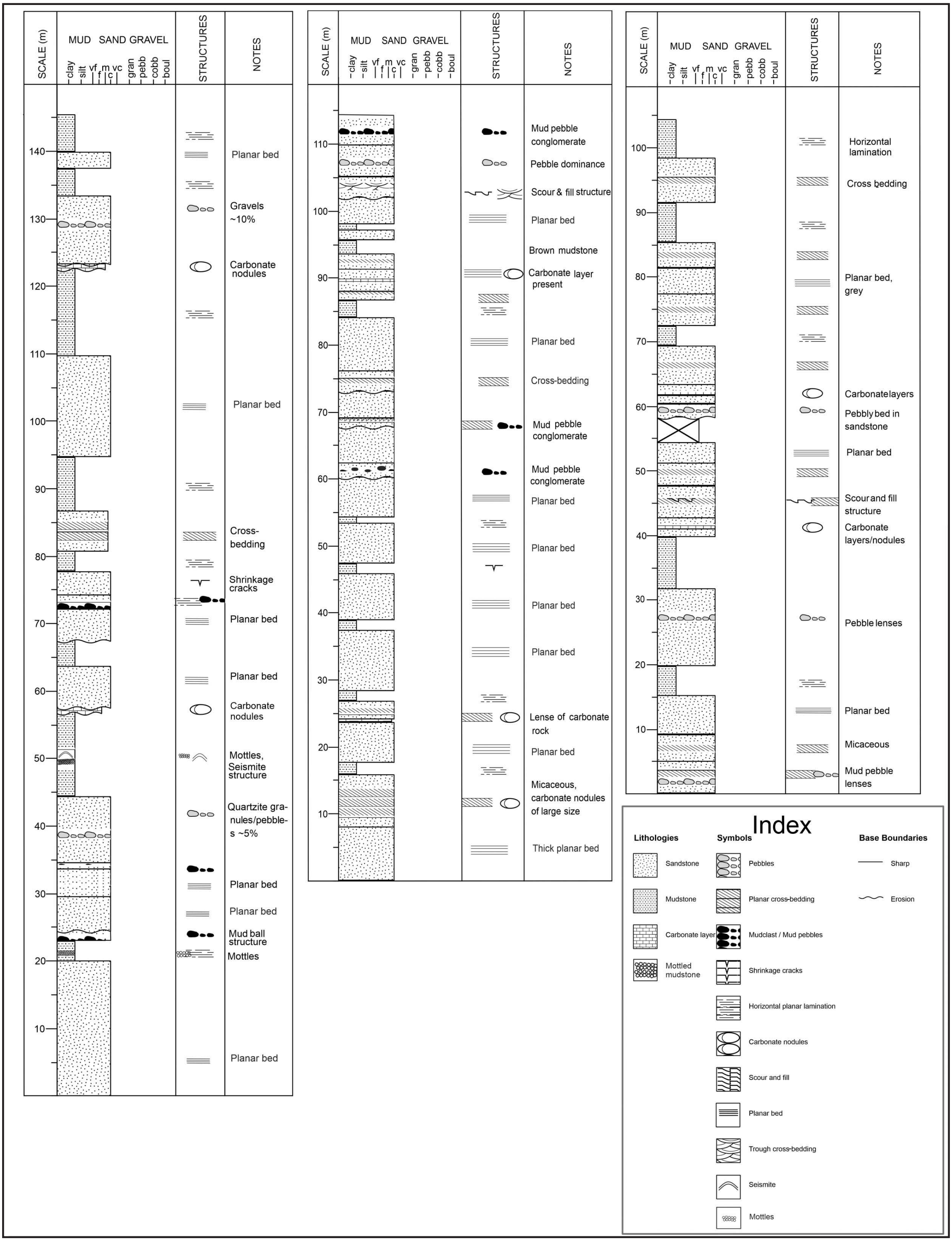

Fig. 3 Lithocolumns displaying various facies in the Middle Siwalik Subgroup of the Nandini-Bantalav section, Jammu. Three litho-columns are separated by the poor exposures.

Trough Cross-bedded sandstone facies

Trough cross-bedded sandstone facies either occur independently or cyclically. Their lower contacts are mostly erosional and upper contacts are sharp. In some cases, the bottom sets and top sets have been eroded away and the foresets occur in contact with each other. Coset thickness varies from 40-80 cm. At times, the trough cross-bedded sandstones are underlain by scour-fill structures. Some of the foreset laminae contain mud streaks. The foresets are mostly directed towards the south-west, south, and south-east.

Scour-fill sandstone facies

Scour-fill structures occur in the upper part of the Middle Siwalik Subgroup. Their dimensions vary from 2-3 m in length and 20-30 cm in depth. The erosional scour created in the mud or fine-grained sand is filled by the medium-grained white sand. The scours show mud linings and the fill structures are associated with the trough cross-beds.

Laminated mudstone facies

Laminated mudstone occurs in a small proportion in comparison to the sandy facies. It forms 30 cm to 2.5 m thick facies. Individual laminae are 4-10 mm thick. Its colour varies from light grey to dark grey. At some intervals, organic-rich layers are also recorded. Lower contacts of the laminated mudstones are sharp while the upper contacts are erosional with the sandy facies and diffused with the mottled mudstone.

Mottled mudstone facies

Mottled mudstone occurs only at one interval in the Middle Siwalik succession. Its colour varies from grey to yellow and white. Its thicknesses vary from 60 cm to 1.4 cm. It is devoid of any sedimentary structures and shows the presence of white nodules. Lower contact of the mottled mudstone is diffused with the laminated mudstone and the upper contact is sharp or erosional with the sandstone.

Cumulative curves and Textural parameters

Cumulative frequency curves prepared from the grain size data are useful in determining the mode of transportation and depositional conditions. Visher (1969) has suggested that the ideal cumulative curves have four different segments and each segment represents a particular mode or load of transportation. In the cumulative curves of sandy facies, we found that traction load forms less than 5%, while the saltation and suspension loads form more than 95% (Fig. 5). Similar is the case for the muddy facies too where saltation and suspension loads dominate (Fig. 6). Cumulative frequency curves have been further used to calculate textural parameters such as mean size, sorting, skewness, and kurtosis for ascertaining the broader depositional environments.

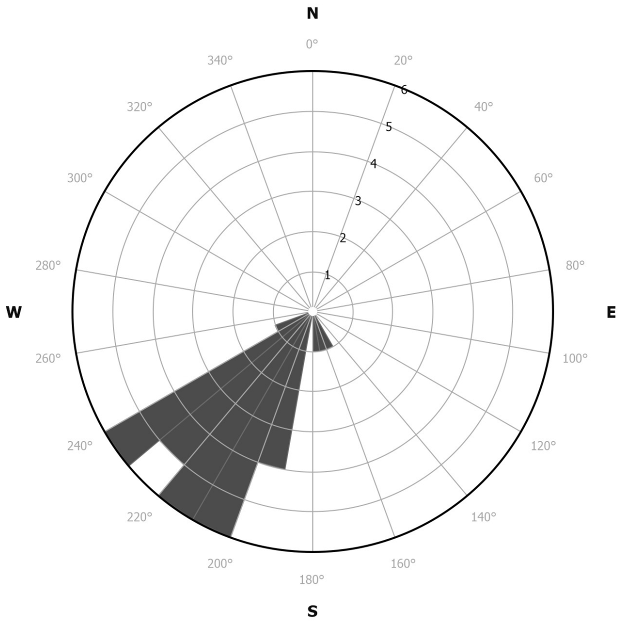

Fig. 4 Rose diagram prepared from the azimuthal data of the cross-beds. Note dominant SSW paleocurrent.

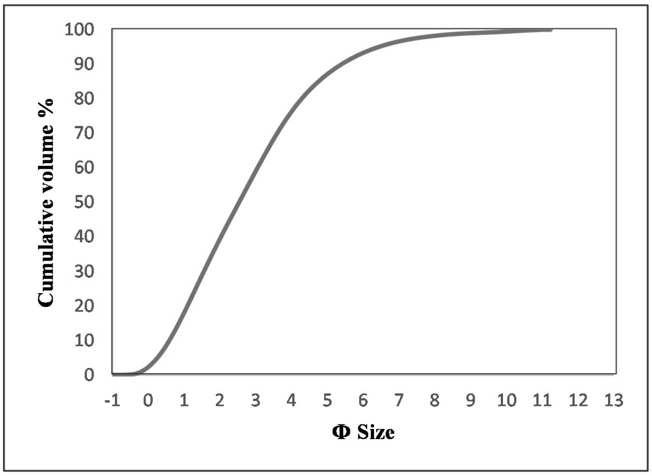

Fig. 5 A representative cumulative frequency curve of the sandstone.

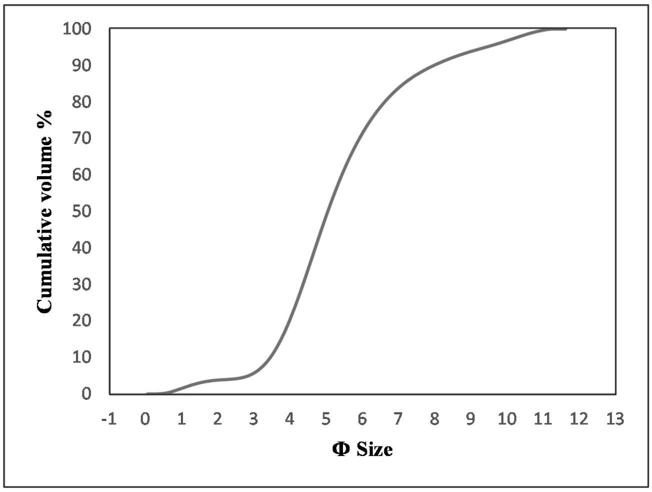

Fig. 6 A representative cumulative frequency curve of the mudstone.

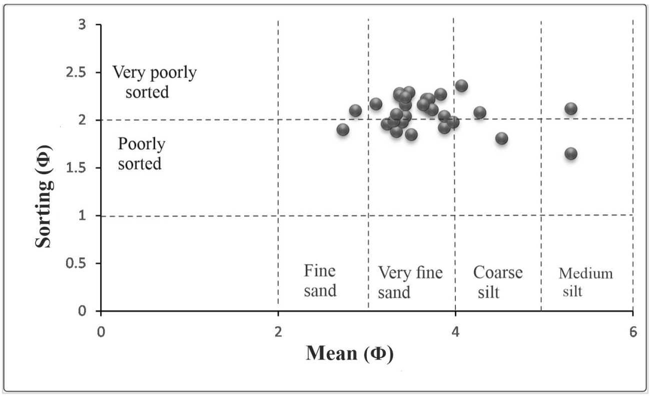

Fig. 7 Mean size vs. sorting bivariate plot.

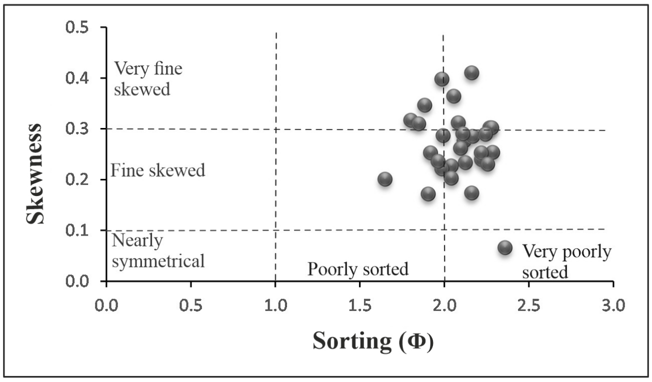

Fig. 8 Sorting vs. skewness bivariate plot.

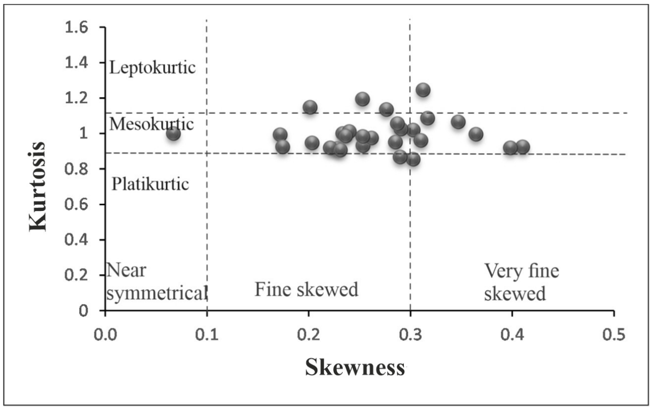

Fig. 9 Skewness vs. kurtosis bivariate plot.

Mean size values of sand vary from 2.73 –3.97 (phi), while that of mud varies from 4.07-5.30 (phi). Mean size shows that most of the samples are dominated by very fine sands. Sorting values of sand range from 1.85-2.29 (phi), while that of mud range from 1.65 – 2.36 (phi). Here, most of the samples fall in a very poorly sorted category whereas a few samples are poorly sorted as well (Fig. 7). Another parameter is skewness, which measures the asymmetry of the distribution curves. The skewness of the sand ranges from 0.17 – 0.41, while that of mud ranges from 0.07-0.40 indicating that most of the samples are finely skewed whereas few are very fine skewed (Fig. 8). Kurtosis indicates the peakedness of the curves. Its values for the sand range from 0.85 – 1.07, while that of mud range from 1.0-1.25 (Fig. 9). Thus, the majority of the samples show mesokurtic with very few showing leptokurtic kurtosis values. Poor and very poor sorting, fine and very fine skewness and mesokurtic and leptokurtic nature of the sediments suggest that they have been deposited in a fluvial system (Folk and Ward, 1957; Friedman, 1979).

Bivariate plots and Environments

The interrelationship between textural parameters has been widely used to reconstruct the depositional environments and is a very good tool to identify various operative processes of sedimentation. Mean size vs. sorting plot has been used for differentiating high and low-energy fluvial and estuarine environments (Tanner, 1991). In another study, this plot has been used for differentiating channel sediments and floodplain sediments deposited by a river (Kanhaiya *et al.* 2017).

Mean size vs. Sorting Plot (after Tanner, 1991)

The mean size versus sorting plot was proposed by Tanner (1991) to demarcate the zones of high and low energy fluvial and estuarine environments. It is quite clear from figure 10 that all the samples belong to the fluvial zone that is characterized by stream episodes in the studied samples.

Mean size vs. Sorting Plot (after Kanhaiya et al., 2017)

Kanhaiya *et al.* (2017) proposed a plot to differentiate between channel and floodplain sediments deposited by a river based on two textural parameters i.e., mean size and sorting. Despite, sediments being dominated by fine sands, poor to very poor sorting of the sediments are suggestive of their deposition on the floodplain environment. In the plot proposed by Kanhaiya *et al*. (2017), all the studied sediment samples fall in the zone of the floodplain field (Fig. 11).

Lithofacies and Depositional Environments

The planar-bedded sandstone facies most likely has formed in the upper flow regime where flow velocity was high. Massive sandstone lacking tractional structures and grading is supposed to be generated by rapid dumping of sand as a result of flow unsteadiness (Middleton, 1967, 1993; Lowe, 1982; Knellar and Branney, 1995, Singh *et al.*, 2006). Plane beds are associated with relatively large bedload as well as suspended load transport rates (Benett *et al.*, 1998). Thus, the massive sand beds in the Middle Siwalik deposited in a situation that arose through rapid sedimentation (dumping), due to insufficient time for bedforms to develop and the sediment transport rates were large.

The cross-bedded sandstone facies have formed in the lower flow regime when the flow velocity was low (e. g. Southard and Boguchwal, 1990). This is also supported by the very fine grain size of the sands. Also, the cyclic development of the cross-bedded facies in parts of the Middle Siwalik succession was a result of a similar situation being repeated several times. The erosional bases of the cross-beds destroying the lower bedding planes have developed during the accelerated flows at the beginning of the rains each time of a season or several times in a rainy season. The cross-beds have formed due to ripple sheet migration and the sediment supply was sufficient for the migration of the rippled bedforms (e. g. Miall, 1996).

Scouring may or may not occur during low flow, but fill occurs during the flood (Coleman, 1969). Episodic floods enhance the chances of substrate erosion/scouring in confined rivers (Singh *et al.*, 2006). The presence of scour-fill facies suggests the occurrence of floods during the Middle Siwalik sedimentation. The bar possessing scour-fill facies formed in the process of river maintaining the balance between the bar growth and the scour (e. g. Ashworth *et al.*, 2000).

The stability of bedforms is a function of several parameters such as flow velocity, sediment size, flow depth, suspension fall out and form roughness (Mazumder, 2000). Commonly a high energy situation is repeated followed by a slack-water period and suspension falls out. Laminated mud suggests sedimentation during the slack-water period in quiet-water environments (Singh *et al.*, 2006). Thus, the laminated mud facies were deposited during a slack-water period and were associated with the waning stage of the floods. This is supported by the fine-grain size (silt and clay) of the facies.

The mottled mudstone that is devoid of the primary sedimentary structures has again formed during the slack-water period and the sedimentary structures were destroyed during pedogenesis. Pedogenesis is an important process that occurs on floodplains (Berkland, 1999). Further, the mottling effect with yellow and white mottles suggests that the pedogenesis occurred in an oxidizing environment (Khajuria and Singh, 1992). The white patches and nodules suggest the impregnation of carbonate either during pedogenesis or diagenesis.

The sheet-like geometries of the sand bodies and their large lateral and horizontal extent suggest that the floodplains were of extensive dimensions during the Middle Siwalik sedimentation. Almost all the lithofacies were developed on the floodplain, which is also demonstrated by the grain-size discrimination diagram. The development of the floodplains was possible when the river attained the mature stage. Here, most of the sedimentation occurred beyond the channels on the floodplains those were also exposed at some intervals resulting in developments of the mottled mudstones.

The Middle Siwalik Subgroup is characterised by either axial flow running west to east, parallel to its lateral extent or transverse flow running north to south, oblique to its lateral extent (Kumar *et al.*, 2003). However, the SSW-SSE flow directions in the present case suggest that the river or system of rivers were flowing from north to south i.e. transverse to the main Siwalik exposures trend.

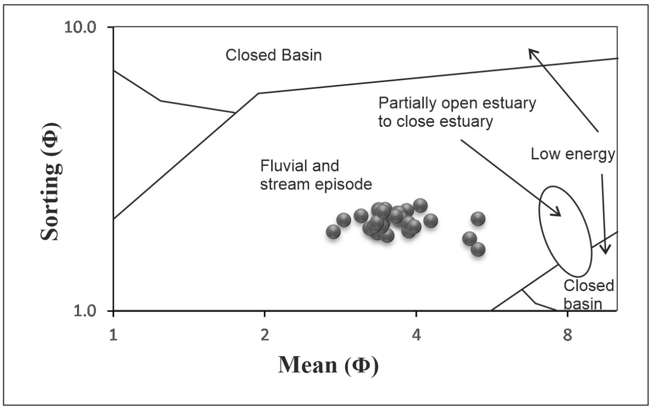

Fig. 10 Mean size vs. sorting discrimination diagram (after Tanner, 1991).

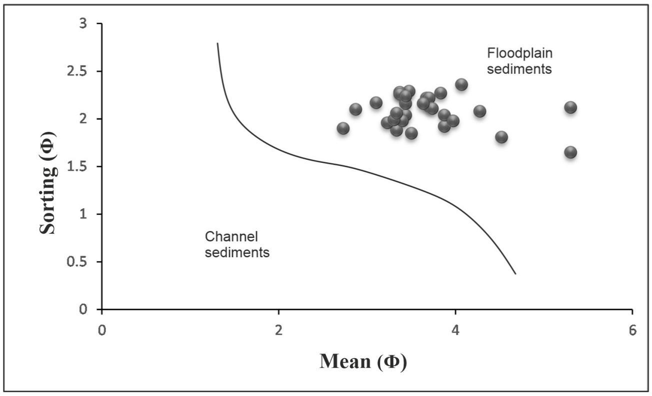

Fig. 11 Mean size vs. sorting discrimination diagram (after Kanhaiya *et al.*, 2017).

CONCLUSIONS

Following conclusions arising out of the present study:

Texturally, the sandstones are categorized as very silty sandstone facies and the mudstones are categorized as very silty sandy mudstone facies and very silty slightly sandy mudstone facies.

Based on sedimentary structures, the sandstones have been classified as planar-bedded, tabular cross-bedded, and trough cross-bedded facies and the mudstones have been classified as laminated mudstone and mottled mudstone facies.

Both textural parameters and facies characteristics suggest that the bulk of the sedimentation took place in a river system and that too on the floodplains.

Southery flowing rivers deposited the sediments along the floodplains that have a large extent during the Middle Siwalik sedimentation in the Jammu area, northwest Himalaya.

ACKNOWLEDGEMENTS

Authors are grateful to the Head, Department of Geology for providing working facilities. MI thanks to the CSIR for providing the SPM fellowship to him. BPS is grateful to Prof. D. M. Banerjee for inviting him to contribute a paper in the volume being brought in the memory of Prof. I. B. Singh. He is also thankful to Drs. R. Kumar and S. K. Ghosh for fruitful discussions. The constructive comments of the reviewers helped in improving this paper manyfold.

REFERENCES

Ali, S., Phartiyal, B., Taloor, A., Arif, M. and Singh, B. P. 2021. Provenance, weathering, and paleoclimatic records of the Pliocene-Pleistocene sequences of the Himalayan foreland basin, NW Himalaya. Arabian Journal of Geosciences, 14: 198

Ashworth, P. J., Best, J. L., Roden, J. E., Bristow, C. S and Klaassen, G. J. 2000. Morphological evolution and dynamics of a large sand braid-bar, Jamuna River, Bangladesh. Sedimentology, 47: 533-555.

Benett, S. J., Bridge, J. S. and Best, J. L. 1998. Fluid and sediment dynamics of upper stage plane beds. Journal of Geophysical Research, 103: 1239-1274.

Birkeland, P. W. 1999. Soils and Geomorphology, Oxford University Press, New York, 3rd edition, 430p.

Coleman, J. M. 1969. Brahmputra River: Channel processes and sedimentation. Sedimentary Geology, 3: 129-239.

Dasarathi, N. 1968. A note on certain geological aspects of Tawi Valley Territories. Kashmir Science, 5: 222-232.

Flemming, B.W., 2007. The influence of grain size analysis methods and sediment mixing on curve shapes and textural parameters: implications for sediment trend analysis. Sedimentary Geology, 202: 425–435.

Folk, R.L., and Ward, W.C. 1957. Brazos River bar: a study in the significance of grain size parameters. Journal of Sedimentary Petrology, 27: 3–26.

Friedman, G.M. 1979. Address of the retiring President of the International Association of Sedimentologists: differences in size distributions of populations of particles among sands of various origins. Sedimentology, 26: 3–32.

Kanhaiya, S., Singh B.P., Tripathi Maya, Sahu Sagrika, and Tiwari Veena, 2017. Lithofacies and particle-size characteristics of late Quaternary floodplain deposits along the middle reaches of the Ganga river, central Ganga plain, India. Geomorphology, 284: 220–228.

Karunakaran, C. and Ranga Rao, A. 1979. Status of exploration for hydrocarbon in the Himalayan region. Geological Survey of India Miscellaneous Publication. 41: 1-66.

Khajuria, C. K. and Singh, B. P. 1992. Geochemistry of the Infra-trappean beds of Marepalli and Inter-trappean beds of Naskal, Rangareddi district, Andhra Pradesh. Proceeding Indian National Science Academy, 58: 69-82.

Knellar, B. and Branney, M. J. 1995. Sustained high-density turbidity currents and the deposition of thick massive sands. Sedimentology, 42, 607-616.

Krynine, P. D. 1937. Petrography and genesis of the Siwalik Series. American Journal of Science, 34: 422-446.

Kumar, R., Ghosh, S. K. and Sangode, S. J. 2003. Mio-Pliocene sedimentation history in the northwestern part of the Himalayan Foreland Basin, India. Current Science, 84: 1006-1013.

Lowe, D. R. 1982. Sediment gravity flows; II, Depositional models with special reference to the deposits of high-density turbidity currents. Journal of Sedimentary Research 52: 279–297.

Mazumder, R. 2000. Turbulence–particle interactions and their implications for sediment transport and bedform mechanics under unidirectional current: some recent developments. Earth-Science Reviews, 50: 113-124

Mehta, Y. P., Thakur, A. K., Lal, N., Shukla, B. and Tandon, S. K. 1993. Fission-track age of zircon separates of tuffaceous mudstones of the Upper Siwalik Subgroup of Jammu-Chandigarh sector of the Panjab sub-Himalaya. Current Science, 64: 519-521.

Miall, A.D. *1996.* The Geology of Fluvial Deposits (Sedimentary Facies. Basin Analysis, and Petroleum Geology). Springer, Berlin, 565p.

Middleton, G. V. 1967. Experiments on density and turbidity currents III deposition of sediments. Canadian Journal of Earth Science, 4: 475-505.

Middleton, G. V. 1993. Sediment Deposition from Turbidity Currents. Annual Review of Earth and Planetary Sciences, 21: 89-114.

Pandita, S. K. and Bhat, G. M. 1995. Petrographic and facies evaluation of Middle Siwalik Subgroup of Jammu Himalaya. Journal of the Geological Society of India, 46: 369-374.

Pandita, S. K. and Bhat, G. M. 1999. Vertical and lateral facies variations, and their cyclicity in Middle and Upper Siwalik Subgroups, Jammu. Journal of Indian Association of Sedimentologists, 18: 159-185.

Pandita, S. K., Kotwal, S. S., Thakur, K., Bhat, G. M. and Singh, Y. 2014. Lithofacies association and depositional history of Boulder Conglomerate Formation, Upper Siwalik Subgroup. Jammu Himalaya. Himalayan Geology, 35: 135-145.

Ranga Rao, A., Agrawal, R. P., sharma, U. N., Bhalla, M. S. and Nanda, A. C. 1988. Magnetic polarity stratigraphy and vertebrate paleontology of the Upper Siwalik Subgroup of Jammu Hills, India. Journal of the Geological Society of India, 31: 361-385.

Sharma, M., Sharma, S., Khan, Z. A., Singh, I. B. and Srivastava, P. 1999. Partial independence and entropy analysis of Middle Siwalik succession, Jammu area, India, Geoinformatics, 10: 169-185.

Sharma, S., Sharma, M. and Singh, I. B. 2001. Facies characteristics and cyclicity in the Lower Siwalik sediments, Jammu area: A new perspective. Geological Magazine, 138: 455-470.

Singh, B. P. 2000. Sediment dispersal pattern in the Murree Group of the Jammu area, NW Himalaya, India. Himalayan Geology, 21: 189-200.

Singh, B. P. and Sudan, C. S. 1997. Trace fossil assemblage in the Lower Siwalik Subgroup of Jammu region, J&K state. Journal Geological Society of India, 50: 357-359.

Singh, B. P., Mithila and Pawar, J. S. 2006. Lithofacies of a small Himalayan braided river, Tawi River, India. Himalayan Geology, 27: 1-13.

Singh, B. P., Pawar, J. S. and Karlupia, S. K. 2004. Dense mineral data from the northwestern Himalayan Foreland sedimentary rocks and recent river sediments: Evaluation of the hinterland. Journal of Asian Earth Sciences, 23: 25-35.

Southard, J. B. and Boguchwal, L. A. 1990. Bed configuration in steady unidirectional water flows; Part 2, Synthesis of flume data. Journal of Sedimentary Research, 60 (5), 658-679.

Tanner, W.F., 1991. Suite statistics: the hydrodynamic evolution of the sediment pool. In: Syvitski, J.P.M. (Ed.) Principles, Methods and Applications of Particle Size Analysis. Cambridge University Press, Cambridge, UK, pp. 225 – 236.

Visher, G.S. *1969.* Grain-Size Distribution and Depositional Processes. Journal of Sedimentary Petrology, 39: 1074-1106.

Yokoyama, T., Verma, B. C., matsuda, T., Gupta, S. S. and Tiwari, A. P. 1987. Fission track age of a bentonitized ash bed and mammalian fauna from Nagrota Formation (Upper Siwalik) of Jammu District (J&K), NW India. Indian Minerals, 41:13-23.