Jour. Indian Association of Sedimentologists, Vol. 36, No. 1(2019), pp.84-100
ISSN Online 2582 – 2020
ISSN Print 0970 – 3268

Significance of Parting lineation in paleoslope studies: An example from fluvial Siwalik sandstones of Ramnagar-Kaladungi area, Nainital, Uttrakhand

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Abstract: Parting lineation, a characteristic feature of many fine grained sandstone and siltstone, is widely used as additional parameter to deduce sediment transport direction especially where cross bedding and ripples marks are poorly developed. The Lower and Middle Siwalik Subgroups of Ramnagar-Kaladungi area exhibit paucity of cross-bedding, though parting lineation are well developed. A sum of 680 measurements of parting lineation from Lower (531) and Middle (149) Siwalik Sub group are statistically analyzed. Results suggest north-northeast – south-southwest line of sediment transport in the Lower and Middle Siwalik Subgroups of study area. The deduced line of sediment movement is in conformity with the southerly sediment transport obtained using cross-bedding data in this area and elsewhere in other parts of Siwalik foreland basin. These two-dimensional sedimentary structures may, therefore, provide additional support in deducing palaeoslope.

Keywords: Siwalik Group, Parting lineation, Palaeoslope, Ramnagar-Kaladungi.

Introduction

Primary sedimentary structures, characteristics of depositional sedimentary environments have long been used to interpret sediment dispersal pattern and hydrodynamics of fluvial system. Among these, the cross bedding and ripple marks are primarily used as directional structures (Potter and Pettijohn, 1977). Apart from hydrodynamic implications, the other sedimentary features as orientation of plant fossils (Tewari, 1998a), channel sandstone bodies (Tewari, 1998b), elongate imbricated clasts, and parting lineation are also useful in deciphering the line of sediment transport especially in areas where more reliable parameters are not so well recorded. Thus, these primary features of sedimentary rocks have been considered as additional tools in interpreting depositional conditions and sediment dispersal. Moreover, individual

sedimentary structures depict flow direction at that geographic point and at that instant of time but for regional problems statistical treatment of populations of sedimentary structures is desired (Boggs, 1995).

The Middle Miocene-Pleistocene Siwalik sandstones of Ramnagar-Kaladungi area of Uttrakhand and elsewhere in neighboring parts of basin show less cross bedding structures and ripple marks (Tandon, 1991; Khan and Tewari, 2015), though these sandstones are characterized by abundant parting lineation. The purpose of present study is to analyze statistically parting lineation with a view to decipher the line of sediment transport through space and time during Lower-Middle Siwalik sedimentation. The deduced mean is compared with the sediment transport direction obtained from less developed cross bedding data. Results are interpreted in terms of sediment transport and hydrodynamic conditions during Lower-Middle Siwalik sedimentation.

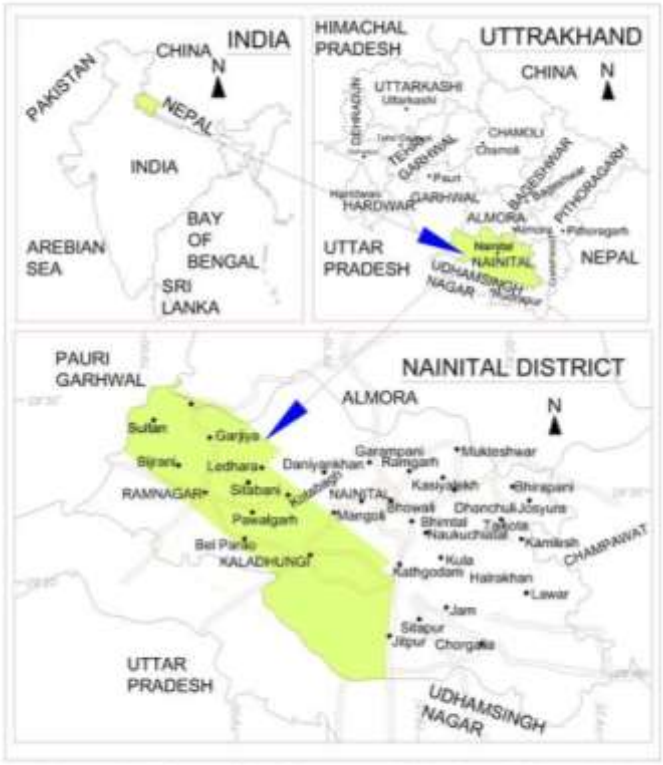

Fig.1: Location Map of the Ramnagar-Kaladungi . Area, Nainital, Uttrakhand

Geological and Tectonic setting

Siwalik basin extends for about 2500km along the tectonic strike from the Brahmputra River in the east to the Potwar plateau and Bannu plain in the west. On the basis of faunal assemblage Pilgrim (1910) subdivided Siwalik Group into three broad divisions in the Potwar region and parts of western Himalaya as Lower, Middle and Upper Siwalik Subgroups. This threefold classification has been extensively accepted, although irregular distribution of fossiliferous sections, rapid lateral lithofacies variation and discontinuity of strata are major constrains in this classification on regional scale. The basic and fundamental framework of Siwalik stratigraphy was laid down by pioneer efforts of Meddlicot (1864), Wynne (1878),

Oldham (1893), Holland and Tipper (1913), Pilgrim (1913), Cotter (1933) and Lewis (1937). Early workers, considering three Subgroups, further classified the Siwalik Group into seven Formations as Kamlial, Chingi, Nagri, Dhok Pathan, Tatrot, Pinjore, and Boulder Conglomerate in ascending order largely on palaeontological basis (Pilgrim, 1913) with a very little lithological control. It is now well known for Siwalik Group that time boundaries often cut obliquely through litho-boundaries. The available vertebrate fossils are of very local extent and do not permit to establish a biostratigraphic subdivision of regional significance. The abandonment of chronostratigraphic terms is necessitated to eliminate the further confusions and complications of Siwalik Group of rocks as the fossiliferous horizons are separated by large intervals of un-fossiliferous strata and the different divisions of the Siwalik Group are distinguished purely on the basis of lithological characters. The Siwalik stratigraphy traditionally bears a tripartite classification in India, Lower, Middle and Upper in the rank of formations/subgroups (Auden, 1935; Pascoe, 1950; Itihara et. al., 1972; Kayastha, 1979; Yoshida and Arita, 1982; Tokuoka and Yoshida, 1984; Acharyya, 1976, 1994; Bashyal et. al., 1989; Mandal *et al.*, 2014), although their structural sequence, in general, evinces position-reshuffling between the formations because of post-depositional thrusts (Mitra *et al.*, 2010; Mandal *et al.* 2014 and references therein). Present workers have divided and discussed the Siwalik Group into three subgroups, viz., Lower, Middle and Upper Siwalik subgroups and their formations (Valdiya, 2010).

The study area is located between Ramnagar and Kathgodam, the two major townships of Nainital District, Uttrakhand and falls between the north latitude 29◦14’:19◦31’ and east longitude 79◦58’:79◦31’ in Survey of India toposheet No. 53 O/3 and O/7 covering about 800 square meter (Fig.1). The Ramnagar-Kaladungi area of Uttrakhand, northern India represents the eastern part of the Siwalik foreland basin. In general agreement to the regional stratigraphic setting, the Siwalik Group of the Ramanagar-Kaladungi area is, likewise, represented by Lower, Middle and Upper Siwalik subgroups with distinct lithological characters. These three subdivisions are well demarcated in the geological map of Ramnagar-Kaladungi area (Fig. 2). Local gradational contacts observed

in upward transitions from the Lower to Middle and Middle to Upper Siwalik. Further subdivisions into Formations are not shown in the available geological map, perhaps due to structural complexity and lateral lithofacies variations. Therefore, the Siwalik Group of the study area is analyzed and discussed under the three broad divisions of Lower, Middle and Upper. The regional strike of Siwalik rocks is east-west and the dips are steep and highly variable from 30º to 82º direct towards NE.

Sedimentary Characters

Lower, Middle and Upper Subgroups represent about 1600m, 750m and 600m respectively. It is interesting to note that Siwalik sediments of the given area broadly represent coarsening upward succession from Lower through Middle up to Upper Siwalik Subgroup. The Lower and Middle Siwalik Subgroups are the subject matter of this study. The sedimentary characters of these subgroups as observed in the field are

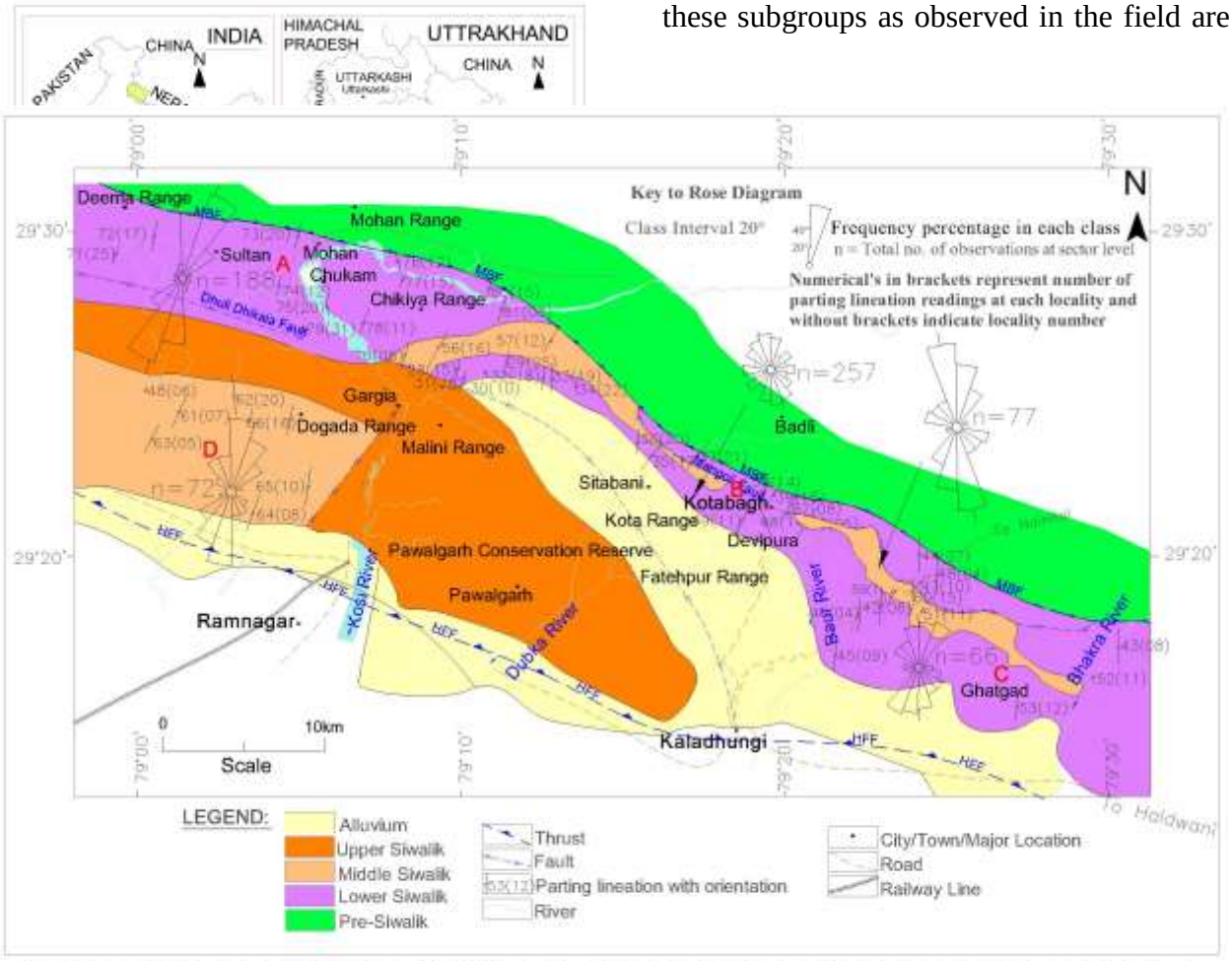

Fig. - 2 Geological map of Ramnager-Kaladungi area, District Nainital, Uttrakhand. Also shown the orientation of parting lineation at outcrop and sector level.

discussed here.

The Lower Siwalik Subgroup occurs all along southern boundary in the study area up to Kotabagh and is also exposed in the northwestern part of the area west of Kosi River (Fig. 2). The total thickness of Lower Siwalik in the east of Kathgodam is estimated up to 2000m (Karunakaran and Ranga Rao, 1979), though in the area under investigation only1800m thick Lower Siwalik sediments are recorded. In conformity with the other areas, the Lower Siwalik succession exposed here shows interbedded mudstone, siltstone, and fine grained sandstone. The lower most part of the Lower Siwalik is dominated by mudstone over sandstone where mudstone shares about 75%. The sandstones are tabular sheet like and multistory showing thin horizontal beds and occasional low angle planar cross beds. The ripple marks and parting lineations are well developed on bedding surfaces. On the average individual sandstone bodies are 0.5 to 3m thick and traceable along the strike for tens of meters. The multistoried sandstone bodies are up to 10m thick, where each body is separated by thin mudstone layer. Sandstones are highly indurated and often include concretions. The associated mudstones are on the average 0.5 to 2m, and rarely up to 3.5m. The mudstones are laminated as well as bioturbated. The upper part of the Lower Siwalik subgroup is marked by alternating beds of medium to coarse grained sandstone and variegated to dark grey mudstone. Sandstones are thicker than the mudstone beds and exhibit salt and pepper like appearance at places. The trough cross bedded to ripple cross-laminated, fine grained greenish grey sandstone interbedded with greenish grey to red purple mudstone with thin isolated lignite bands are rarely seen in the middle succession. Planer cross bedded fine to very fine grained greenish grey sandstone are also observed at the top of Lower Siwalik section close to the Main Boundary Thrust. Spheroidal weathering and bioturbation in greenish grey variegated to purple mudstone is not uncommon at places.

The Middle Siwalik Subgroup is exposed along the right bank of Kosi River towards north where it bends southwards, and to the north of Kotabagh as well as along the Kaladungi-Nainital road (Fig. 2), measuring about 120m and 760m in two stratigraphic sections. In general, there is an increase in the thickness of sandstone in the Middle Siwalik. These sandstones are medium to coarse grained and less indurated

showing peculiar salt and pepper texture. The Middle Siwalik sandstones are more channel shaped and multistoried than sheet like, interbedded with thin grey to black mudstone. The lower unit of about 300m is thickly bedded**,** multistoried grey sandstone containing lenses of intervening mudstones. Thickness of sandstone bodies varies from 4 to 15m. Grey sandstone bodies are as thick as 35m and contain multiple, vertically stacked channel deposits separated by internal erosion surfaces. The lower contacts of sandstone bodies are generally erosive and nearly planar, and the upper contact grades into overlying mudstones. Calcrete, mud balls, mud pellets, and extrabasinal quartzite clasts overlie basal erosional surfaces of many sandstone bodies. Scour-and-fill, horizontal beds, large scale trough cross-bedding and low angle planar cross beds are commonly developed in medium to coarse grained sandstone beds, whereas ripple marks are seen in medium to fine grained sandstone. Among these, the scour and fill structure commonly occurs in the basal parts of sandstone overlain by pebble beds. Close examination of individual sandstone bodies reveal fining upward sequence with respect to grain size and thickness of cross bedding. Similar feature of Middle Siwalik sandstones is recorded elsewhere in other areas (Khan and Tewari, 2011, 2015). However, the overall succession of Middle Siwalik exhibits coarsening upward cycle as sandstone beds of the upper bodies are coarser than the lower throughout this area and in other parts of Siwalik basin (Bhardwaj, 1981; Misra, 1981). The sandstone bodies exhibit lateral facies variation at places and grades to mudstone. The interbedded grey to brown mudstones with spheroidal weathering and bioturbation at places are well exposed. The calcrete nodules, immature palaeosols are also observed in the massive brown to grey mudstone at places.

Fig.-3: Photograph of sandstone surface showing parting lineation in Lower Siwalik, near Kotabagh.

As stated above, the Siwalik sandstones do not show much cross bedding and ripple mark structures. In addition, parting lineation is well developed on many exposed surfaces of fine grained sandstone

and siltstone of the Lower and Middle Siwalik (Fig. 3). They exhibit long narrow parallel to sub-parallel linear structures occurring generally in clusters. Individual lineation is 2-3 mm wide and extends to a few meters on a given outcrop. Due to fine to very fine grain size and low relief, it is sometimes difficult to measure accurate orientation. In view of their occurrences in fine grained rocks (Potter and Pettijohn, 1977), they are not recorded in the Upper Siwalik subgroup.

Analytical Methodology

In the present paper parting lineation (two dimensional linear structures) observed on the exposed bedding surfaces of fine grained Lower and Middle Siwalik sandstones are analyzed statistically. Sampling procedure for collecting two-dimensional orientation data is not guided by any pre-designed conventional plan apparently because of paucity of suitable structures and inaccessibility due to dense forest cover. Moreover, the data is collected largely along the road sides and the banks of rivers and their tributaries. Hence, all the accessible outcrops are taken into account and at least 4 to 6 measurements are recorded at each outcrop. The area under study is arbitrarily divided into sectors in such a manner that each sector contained a minimum of 40 measurements and includes at least 4 localities. The parting lineation orientation so collected in different parts of Ramnagar-Kaladungi area is 528 readings from the Lower and 149 from the Middle Siwalik, respectively. The Upper Siwalik subgroup is not included in the present study because of the paucity of parting lineation.

Parting lineation data was collected from 50 localities of fine grained sandstone and siltstone units as and where it is well preserved. In view of the steep dips of Siwalik rocks (35^o -75^o), the data so collected is corrected for tectonic tilt using Schmidt Stereographic net following the method outlined in Potter and Pettijhon (1977). The tilt corrected data is analyzed to deduce mean orientation, consistency ratio, variance and standard deviation following Currey (1956) and Potter and Pettijohn (1977). The orientation data is grouped at 20^o class intervals and analyzed at each outcrop, and also grouped into arbitrary sectors, and further separately for the Lower, and Middle Siwalik subgroups. Such hierarchical analysis at outcrop, sector and formation (sub-group) levels is the conventional method and provides detailed

overview of dispersal patterns of sediments through space and time.

A popular practice for presenting directional data is the current rose or rose diagram, which is a histogram converted to a circular distribution. The parting lineation orientation data is therefore plotted as rose diagrams using 20° class interval as recommended to represent two-dimensional structures (Potter and Pettijohn, 1977). Each class shows relative percent frequency distribution of the data, where the modal class records maximum frequency of occurrences. When measurements of structures which show direction of movement are plotted, the rose diagram indicated the line of direction towards which the current flowed. Most distribution produces a single dominant mode (unimodal), although some have two or more sub equal modes (bimodal, polymodal).

Geological Interpretation

Lower Siwalik Subgroup:

The orientation of parting lineation in the Lower Siwalik varies from unimodal to polymodal distribution at locality level, however, the unimodal distribution is more common than bimodal or polymodal distribution. The orientation of parting lineation exhibit unimodal at sector level as well as Subgroup level with modal class confined to 0-20° class in A and C sectors and 40°-60° class in B sector. The modal class is 0-20° for pooled data at subgroup level. Computed mean orientation of parting lineation at 3 sectors of Lower Siwalik varies from 02º-19º to 182º-199º (Table-1). The corresponding consistency (L %) varies from 18% to 78% and variance from 470 to 2071, suggesting moderate consistency of depositing streams (Potter and Pettijohn, 1967; Selley, 1968)

Table-1: VECTOR (ϕv), VECTOR MAGNITUDE (l%), STANDARD DEVIATION (S) AND VARIANCE (S^2) OF PARTING LINEATION

SECTOR	locality	OUTCROP LEVEL			SECTION LEVEL				
Locality	number	n	ϕv	L%	N	ϕv	L%	S0	S^2
MIDDLE SIWALIK									
D	48	6	10º	13					
	61	7	25º	84					
	62	20	175º	97	72	177º	51	53	1085
	63	5	28º	76					
	64	8	20º	93					

	65	10	8º	96					
	66	16	16º	77					
E	70	8	196º	68					
	56	16	30º	80					
	57	12	29º	72					
	58	5	35º	85	77	29º	48	36	1320
	59	10	32º	78					
	60	15	176º	68					
	51	11	15º	18					
LOWER SIWALIK									
A	71	25	18º	45					
	72	17	12º	80					
	73	20	15º	66					
	74	14	10º	48					
	75	20	170º	40					
	76	12	176º	60					
	77	15	23º	40	188	2º	18	46	2071
	78	11	19º	72					
	79	31	130º	22					
	80	15	15º	48					
	81	8	21º	63					
B	28	15	10º	48					
	29	25	15º	63					
	30	10	158º	16					
	31	28	10º	32					
	32	18	7º	57					
	33	19	178º	66					
	34	22	12º	39					
	35	17	14º	60					
	36	20	37º	90					
	37	21	37º	94					
	38	14	16º	35	257	19º	48	33	1099
	39	15	32º	65					
	67	8	28º	78					
	68	14	150º	18					
	69	11	27º	80					
C	44	7	12º	88					
	48	4	3º	94					
	47	13	45º	67					
	42	6	4º	97					

46	4	1º	83					
41	4	1º	46	66	2º	78	22	470
45	9	5º	76					
43	8	1º	88					
52	11	15º	18					
53	17	2º	65					

The above parameters of parting lineation evidently suggest north-northeast – south-southwest line of sediment transport during Lower Siwalik sedimentation in this area (Fig. 4).

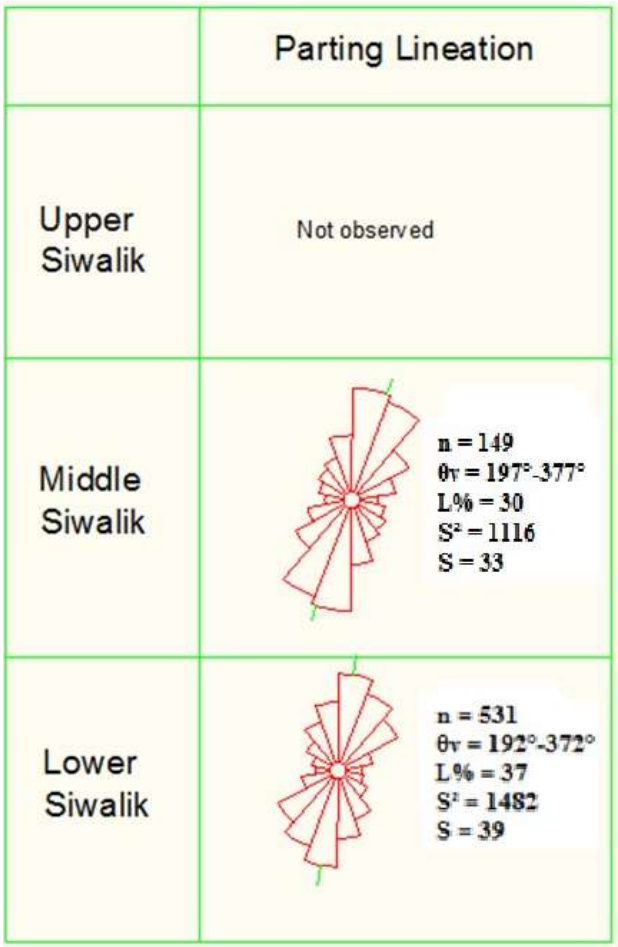

Fig. 4: Summary of sediment transport deduced from parting lineations in Lower and Middle Siwalik Subgroup, Ramnagar-Kaladungi area

Middle Siwalik Subgroup:

In contrast to the Lower Siwalik, the parting lineation is comparatively less abundant and confined to the lower part of the Middle Siwalik Subgroup. In the upper part of the succession the frequency of parting lineation is markedly decreased. The orientation of parting lineation exhibits unimodal distribution at locality as well as Subgroup level. The mean line of flow ranges between 10º -176º to 190º-356º (Table-1). The consistency ratio (L%) ranges from 13% to 97% at locality level showing scattering of parting lineation from between localities. At sector level it varies from 48% to 51% and at Subgroup level it is 30%, indicating the scattering decreases when data are lumped together. The variance ranges from 1010 to 1320 at sector level and at subgroup level it is 1116. Corresponding overall rose diagram of the Middle Siwalik Subgroup also showed that

its line of transport is north-northeast-south-southwest (Fig. 4).

Palaeocurrent and Palaeoslope:

The Middle Miocene to Pleistocene Siwalik Group is largely fluvial deposited in front of rising Himalaya by a network of streams of variable sinuosity and discharge which flowed from north-northeast to south-southwest (Tandon, 1976, 1991, Singh, 1996, Khan and Tewari, 2015). A detailed statistical analysis of parting lineation in study area suggests that Siwalik sediments were largely transported along north-northeast-south-southwest in this area through space and time. The outcrop level analysis suggests variation in mean orientation of parting lineation from 01^{o}-178^{o} to 181^{o}-358^{o} with moderate consistency ratio. It implies north-northeast/north-northwest—south-southwest / south-southeast line of transport throughout the Lower Siwalik sedimentation of Ramnagar-Kaladungi area. The grouped data in the three sectors, likewise, indicate similar trend. The pooled data for the entire exposed Lower Siwalik Subgroup of Ramnagar-Kaladungi area further show similar north-northwest to south-southeast line of sediment transport (Fig. 4). The statistical parameters of parting lineation so computed are suggestive of moderately sinuous to meandering stream pattern of Lower Siwalik Rivers corroborating the regional depositional models of Lower Siwalik by early workers (Tandon, 1991; Khan and Tewari, 2011, 2015). Thus, the present analysis evidently shows that the Lower Siwalik Subgroup of given area was deposited by meandering streams which flowed consistently from north-northwest to south-southeast through space and time.

The succeeding Middle Siwalik, exhibit an increase in proportion of sandstone bodies over mudstone. The analysis of parting lineation indicates north-northeast-south-southwest line of transport in space and time at individual outcrops, sectors and subgroup levels; corresponding vector strength and variance are 48% to 51% and 1085 to 1320. These parameters together with increased amount of sandstone bodies characterize braided (bed load) stream pattern for the deposition of Middle Siwalik subgroup. Elsewhere in other areas, the Middle Siwalik succession has been interpreted as low sinuous stream deposits (Tandon, 1991).

Thus the analysis of parting lineation suggests that the Lower, and Middle Sub-

groups of Ramnagar Kaladungi area of Uttrakhand, were deposited along north-northeast-south-southwest flowing network of streams through space and time. Moreover, the computed statistical attributes together with the increase of sandstone over mudstone are features corroborate a progressive increase in paleoslope and corresponding decrease in the sinuosity of depositing streams from meandering to braided through time from Lower to Middle Siwalik. The north-northest-south-southwest line of transport of Siwalik sediments here deduced is in general agreement with the southerly directed palaeocurrents in different sectors of Siwalik sediments of India (Parkash et al., 1974; Agrawal and Singh, 1983; Kumar and Nanda, 1989; Kumar et al. 2004; Deopa and Goswami, 2014; Khan and Tewari, 2015) Pakistan (Visser and Johnsson, 1978; Tauxe and Opdyke, 1982; Ullah et al., 2009; Abbasi and Friend, 2000) and Nepal (Ulak, 2009, Nakayama and Ulak, 1999; Syangbo and Tamrakar, 2013; Tamrakar and Syangbo, 2014). The similarity and consistency of southerly palaeocurrent direction, transverse to Himalayan orogen, through Siwalik sedimentation through space (east-west) and time (Lower to Upper) is significant and suggestive of corresponding Himalayan uplifts from the Lower to Middle Siwalik sedimentation in this area.

Conclusions

The Lower and Middle Siwalik Subgroups of Ramnagar-Kaladungi of Uttrakhand are characterized by interbedded mudstones and sandstones. The sandstone interbeds increase in number and thickness through time from Lower to Middle Siwalik. These Siwalik sandstones do not show a fair amount of cross-bedding and ripple marks throughout the area, though parting lineation is widely developed on the exposed bedding surfaces of sandstones. These linear structures are therefore used to deduce the line of sediment transport through space and time in the given Siwalik sandstones, which is compared with the palaeocurrents deduced from locally developed cross-bedding data.

Computed mean orientation of parting lineation from pooled data from 36 outcrops of Lower Siwalik shows north-northeast-south-southwest line of sediment transport with moderate consistency of depositing streams. Likewise the mean orientation from 14 outcrops of Middle Siwalik, through time, exhibits more or less

similar line of sediment transport (north-northeast-south-southwest) with greater consistency. The palaeocurrents based on locally developed cross bedding data in the given area suggests north-northeast to south-southwest palaeoflow in space and time. The closely comparable results of cross bedding orientation and parting lineation suggest that this linear structure should be used as an additional parameter in palaeoslope studies. It is further suggested that the plain bed transport producing parting lineation was the dominant mechanism of sediment dispersal during Lower and Middle Siwalik sedimentation.

Acknowledgements

One of the authors (SM) is grateful to faculty members of Geological Discipline, School of Sciences, Indira Gandhi National Open University for their constant encouragement. He is thankful to Shri Rangeet Kumar Srivastawa, Senior Manager (Civil), NHPC Limited who always remained helping in preparation of drawings. Thanks are also due to the anonymous reviewers of the JIAS for many useful suggestions.

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