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LITHOFACIES ANALYSIS OF THE LARIAKANTHA QUARTZITE AND ITS IMPLICATION ON THE GENESIS OF THE BLAINI FORMATION, KUMAUN LESSER HIMALAYA

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ABSTRACT

The Lariakantha Quartzite Member of the Blaini Formation around Nainital region comprises mainly fine to coarse grained quartz arenite with subordinate siltstone, shale and pebbly sandstone. Four major lithofacies are identified and assigned to specific depositional environments. These are fine to medium grained cross-bedded quartz wacke interbedded with silty shale (Lithofacies A), cross-bedded pebbly quartz arenite (Lithofacies B), massive to parallel laminated quartz arenite (Lithofacies C), ripple cross-laminated quartz arenite interbedded with silty shale (Lithofacies D).

The vertical and lateral association of the lithofacies and dispersal pattern of these rocks suggest that the Lariakantha Quartzite represents a progradational sequence. The sedimentation took place in high energy environments; storm dominated lower to middle shoreface (Lithofacies A), subtidal longshore bars (Lithofacies B), tide-wave dominated beachface (Lithofacies C) and intertidal mixed flat and tidal channel environment (Lithofacies D).

Key words : Sedimentation, Blaini Formation, Tide-storm setting, Lesser Himalaya.

INTRODUCTION

The sedimentary rocks of the Nainital area represent southeastern extremity of the Krol Belt. Extending from Solan in Himachal Pradesh to Nainital these rocks are exposed in the form of a string of five *en echelon* synforms. In the Nainital syncline, the Nagthat Formation of the Jaunsar Group (Auden, 1934) is the oldest lithounit. It consists of quartz arenites and associated penecontemporaneous basic lava flows. The Nagthat Formation is overlain by diamictite–bearing Blaini Formation of the Mussoorie Group (Valdiya, 1980) with a sharp contact. The Blaini Formation, in turn, is transitionally succeeded by thick carbonate horizons of the Krol-Tal Formations of the Mussoorie Group (fig. 1).

The Blaini Formation in the Nainital area is classified into four members (Valdiya, 1980) (Table-1). It begins with quartz wacke, quartz arenite, diamictite, siltstone and shale succession of the Bhumiadhar Member, followed up by a thick quartz arenite, quartz wacke, siltstone and shale sequence of the Lariakantha Quartzite (Member). The Lariakantha Quartzite, in turn, is succeeded by diamictites, purple-grey slates, siltstones and lenticular pink siliceous dolomitic limestone of the Pangot Member. The grey carbonaceous-pyritous slates and siltstones of the Kailakhan Member cap the Pangot Member.

The depositional environment of the Blaini Formation has been studied by a number of workers and models ranging from glacial (Oldham, 1888; Auden 1934; Bhargava, 1972; Srikantia, 1975), glaciomarine (Bhatia 1975, Jain and Vardaraj, 1978), turbidite (Ghosh *et al.*, 1966; Rupke 1968; Valdiya 1970) to shallow marine (Tangri and Singh, 1982) have been proposed. However, the models proposed by these workers, except Tangri and Singh (1982), are based on the sedimentology of the two pebbly horizons without considering their association with the other lithounits of the Blaini. As a matter of fact, the diamictites constitute a very small fraction (<3%) of the whole stratigraphic thickness of the Blaini Formation and, therefore, models based solely on pebbly horizons cannot be depended upon.

The glacial and glaciomarine models were greatly influenced by, and stemmed from, correlation of the Blaini Formation with the Permo-Carboniferous glaciogenic Talchir Formation of the Peninsular India. The recent fossil finds (Singh, 1981; Azmi and Pancholi, 1983; Bhatt and Mathur, 1990), however, necessitated the revision of the lithostratigraphic set-up of the Krol Belt and such

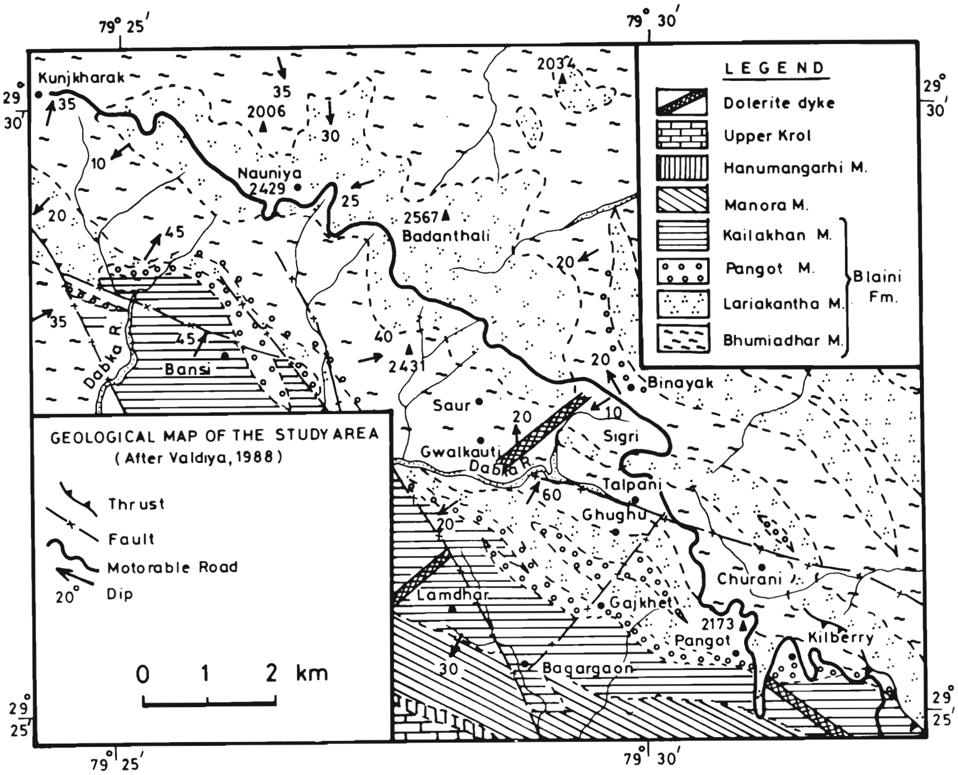

Fig. 1. Geological map of the northwestern part of Nainital (after Valdiya, 1988).

Table 1: Stratigraphic subdivisions of the Blaini Formation in Nainital Area (after Valdiya, 1980).

Group	Formation	Member	Lithology
	Krol		
		Transitional	
MUSSOORIE GROUP	Blaini	Kailakhan	Variegated, ash grey, brownish grey to black grey carbonaceous slates.
		Pangot	Diamictite, purple-green slates capped with pink siliceous dolomitic limestone.
		Lariakantha Quartzite	White, pink, grey, purple, brown and fawn quartzarenite and sublitharenite often pebbly with purple-olive green slates.
		Bhumiadhar	Greyish brown to grey quartzarenite, litharenite, lithicwacke with siltstone and shale
		Sharp contact	
Jaunsar Group		Nagthal Formation	

assumptions are no more tenable. Nevertheless, the Blaini succession of the Nainital Hills do not provide any evidence of glacial activity, viz., presence of varvites, slickensides, dropstone structures, textural immatuarity of the succession and melange of exogenic (exotic) clasts etc. as also noticed by Valdiya (1970) and Tangri and Singh (1982). The turbidity models, likewise, fail to explain the association of ±1000m thick quartz arenites (Lariakantha Quartzites) showing bed forms, sedimentary structures and dispersal pattern very chacteristic of the shallow marine setting. Moreover, so far none of the typical turbidite succession/ associations (Dzulyinski and Walton, 1965; Walker, 1973; Caron *et al.*, 1989) are reported from the Blaini Formation. Valdiya (1970) has also subtly commented regarding the genesis of the Blaini Formation as "it is not established beyond doubt that the conglomerates are slide deposits, nor can be claimed that evidence for glacial origin is unambiguous".

The Lariakantha Quartzite, which is intimately associated with the diamictites in the Nainital syncline, provides an excellent opportunity to study the hydrodynamics, dispersal pattern and reconstruction of depositional environment. Therefore, the present work was taken up with the hope that it would provide new insight into the mechanism of sedimentation during the Blaini times.

The present work deals with the lithofacies analysis of ± 1000m thick Lariakantha Quartzite of the Blaini Formation, exposed along the Kilberry-Ghughukan and Binayak-Badhanthali-Kunjakharak ridges, northwest of Nainital (figs. 2, 3).

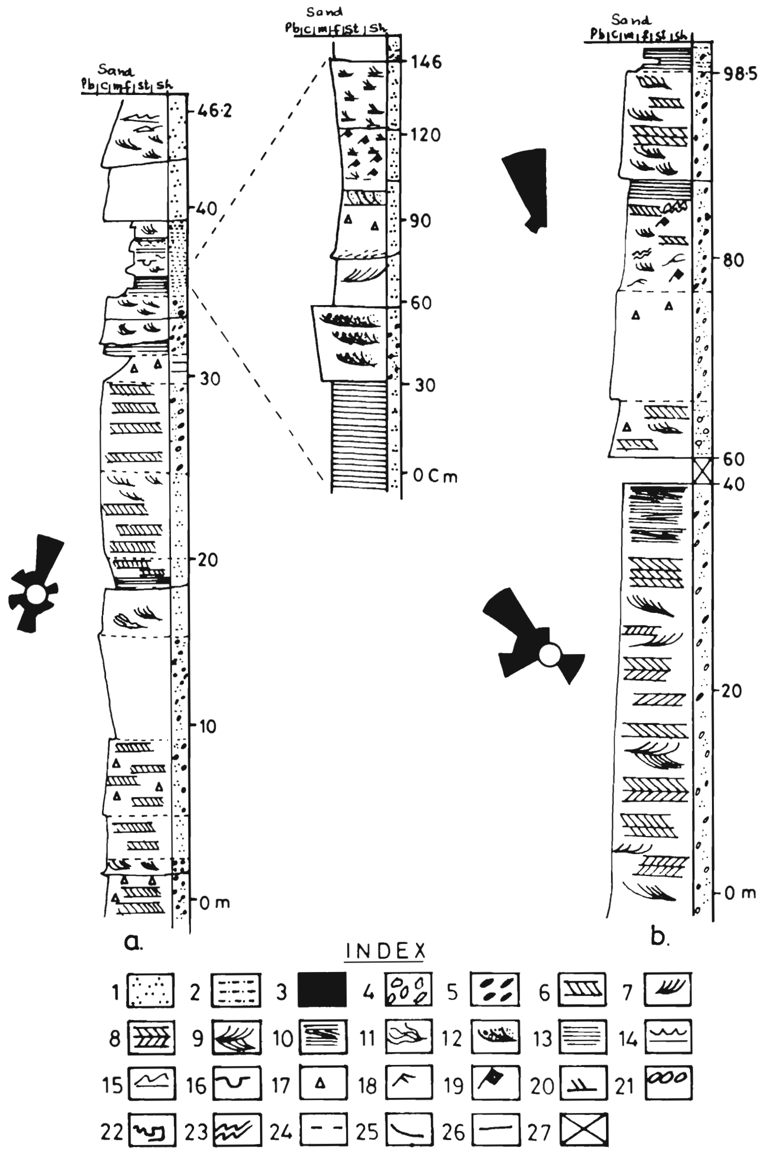

Fig.2. Lithologs of the Lariakantha Quartzites along (a) Nauniya Binayak-Binayak road (b) Binayak to Badanthali ridge, showing lithofacies variation, distribution of sedimentary structures and palaeocurrent directions. Index : 1. Quartzite, 2. Silty shale, 3. Shale, 4. Pebbles, 5. Mud flakes, 6.Planar cross-beds 7. Trough cross-beds, 8. Herringbone cross-beds (Planar), 9. Herringbone cross-beds (trough), 10. Low angle discordance surfaces, 11. Deformed cross-bed foresets, 12. Graded cross-bed foresets, 13. Parallel laminations, 14. Wave ripples, 15. Current ripples, 16. Small channels, 17. Graded beds, 18. Lenticular bedding, 19. Flaser bedding, 20. Climbing ripple cross laminations. 21. Pebble imbrications, 22. Load structures, 23. Convolute bedding, 24. Gradational contact, 25. Erosional contact, 26. Sharp contact, 27. Unexposed sequence.

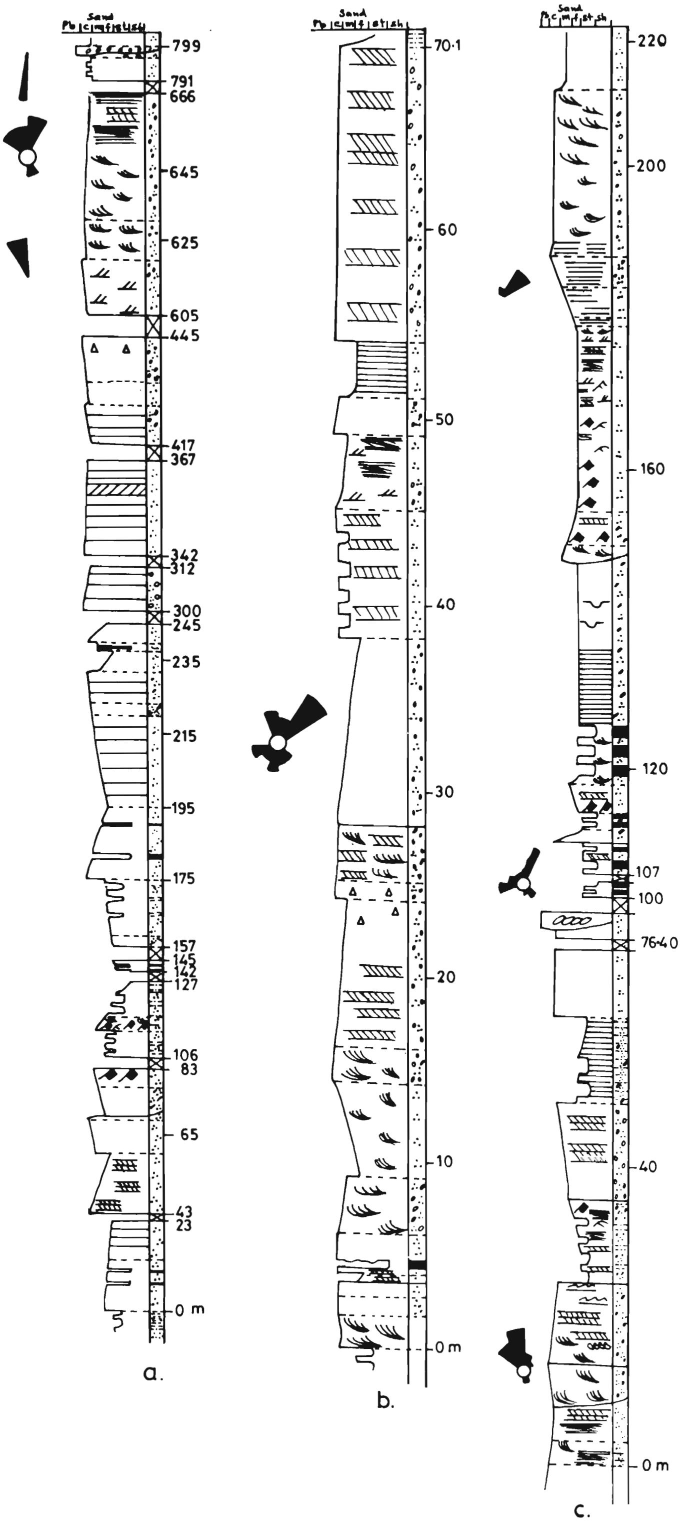

Fig. 3. Lithofacies of the Lariakantha Quartzite along Kilberry-Kunjakharak road sections (a) Binayak-Badanthali, (b) Kunjakhark-Nauniya Binayak, (c) Badanthali-Nauniya Binayak, showing Lithofacies vartiations, sedimentary structures and palaeocurrent pattern.The index is same as in fig. 2.

FACIES ANALYSIS

Four distinct lithofacies are identified in the Lariakantha Quartzite (cf. Ginsburg, 1975; Walker, 1984; Miall, 1990) on the basis of lithology, grain size and associated sedimentary structures. The general terminology and inferences have been drawn from Davis (1978), Reineck and Singh (1980), Reading (1986), Selley (1988) and Miall (1990).

After establishing the general trend of palaeoshore as NW-SE, on the basis of trend of the lithofacies, channel axes and palaeoflow pattern, etc., the northerly oriented modes are considered to represent the offshore palaeocurrent and southerly oriented ones to indicate onshore palaeocurrent as also pointed out by Singh (1979, 1985), Valdiya (1980), Ghosh (1991) and Shukla and Pant (1996).

The description of the lithofacies and tentative interpretation of the depositional environment is given below.

LITHOFACIES A : FINE TO MEDIUM GRAINED CROSS-BEDDED QUARTZ WACKE INTERBEDDED WITH SILTY SHALE.

Lithological Attributes : The lithounits are 6 to 16m thick and comprise fine to medium grained, poorly sorted, grey to purple quartz wacke interbedded with silty shale. The quartz wacke beds range between 15 cm to 1.5m in thickness and generally show lateral pinching and swelling and have sharp/erosional bases (fig. 4a). Silty shales vary in thickness from 5 to 15 cm. Showing lateral variation in thickness, the lithofacies comprises few papery thin mud clasts (fig. 4b) and abundant micaceous minerals associated with quartz wacke horizons.

The lithofacies shows characteristic developm-ent of small to large scale (2-25cm thick) planar and trough cross-bedding with graded foreset laminae and ubiquitous load casts on the underside of the arenaceous beds. The sandy units are characterized by parallel laminations, low angle discordance surfaces, lensoid morphology and internally show normal graded units, isolated flutes and groove casts often accentuated by loading. Significantly, at some places the cross-beds manifest down dip size gradation as well. The lithofacies display a NNW-NNE directed palaeocurrent.

The lithofacies generally shows gradational lower and upper contacts with the bounding lithofacies and an upward coarsening character.

Interpretation : On the basis of fine to medium grain size, poor sorting, large scale cross-beds with mud clasts and extensive graded units, the lithofacies is inferred to have been deposited in the lower to middle shoreface subenvironment of deposition.

The repetitive sand and silty shale alternations on varying scales showing erosional bases, and graded character might have been related to the operation of cyclic processes with varying periodicities related to storm and fairweather conditions (cf. Bhattacharya *et al.*, 1980). During storms, much sand is eroded from the upper shoreface and foreshore regions, taken into suspension by turbulent water and, subsequently, deposited in the lower to middle shoreface (Reineck and Singh, 1972). The presence of abundant mud clasts, erosional bases of the sandy units, flute casts accentuated by loading and load casts suggests sudden deposition of sand onto water-saturated mud in response to waning phases of storm activity.

The occurrence of cross-beds with seaward directed palaeocurrent may be attributed either to the storm enhanced rip currents or to the storm generated geostrophic currents (Walker, 1984; Duke, 1990; Cruszczynski *et al.*, 1993) which cause the bottom currents to move offshore. The mud clasts are considered to have generated at the height of storms when the semi-consolidated muddy sediments were ripped up and redeposited.

The rocks of the lithofacies are devoid of the characteristic hummocky cross-stratification (HCS) in the sense of Harms *et al.* (1975). However, it may be emphasized that the parallel laminations, low angle discordance surfaces and graded units so frequently recorded in the lithofacies, characterize many storm generated deposits (Howard, 1971; Kumar and Sanders, 1976; Howard and Reineck, 1981; Duke *et al.*, 1991). Kreisa (1981) interprets that such laminations form during waning phases of storm when storm suspended sand and silt rapidly drop from suspension, in very slowly moving water.

LITHOFACIES B : CROSS-BEDDED PEBBLY QUARTZ ARENITE

Lithological Attributes : The lithofacies comprises 6 to 46m thick lensoid units of medium to coarse grained, well sorted, grey to purple grey, thickly bedded, pebbly quartz arenite. The lithofacies abounds in mud pebbles and mud flakes.

The lithofacies units generally show erosional lower and gradational upper contact with the bounding lithofacies. The basal part of the lithofacies is conglomeratic and the grain size in the lithofacies decreases upwards.

The upper part of the lithofacies is characterized by large scale, high angle (up to 30°), planar and trough cross-beds (30-70cm thick), with a lot of reactivation surfaces (fig 4c,d), mud pebbles and synsedimentary deformation (fig. 4e). The foresets internally manifest normal down dip direction size grading and vary in thickness from 0.4 to 5cm. Many of the foresets show concentration of mud pebbles along their surfaces (fig. 4f). The lithofacies also manifests low angle discordance surfaces, very thin graded beds and crude pebble imbrication. The lithofacies is characterized by polymodal palaeocurrent prominently directed towards NNE-NNW and SSW-SSE.

At some places the lithofacies shows development of symmetrical mega ripples of 70 cm wavelength and 10 cm amplitude, superimposed by washed current ripples. The mega ripples indicate ENE-WSW directed wave action, whereas the current ripples indicate SW directed palaeocurrent.

Interpretation : On the basis of medium to coarse grain size, well sorted grain texture and steep angles of foresets this lithofacies is interpreted to be of subtidal (Upper shoreface) bar origin. Such type of foresets from upper shoreface are also reported by McCubbin (1982) and DeCelles and Cavazza (1992) from Cretaceous Gallup Sandstones of New Mexico and Pliocene succession of southern Italy respectively. The morphology and dimensions of the cross-beds suggest that bars are of sandwave origin (Allen, 1980). The deformed foresets with mud clasts indicate rapid sedimentation under high energy conditions.

The polymodal palaeocurrent may be attributed to interaction of storm enhanced rip and longshore currents and storm generated geostrophic currents. The prominent seaward and landward directed palaeocurrents positively indicate conclusive role of storm generated geostrophic currents (cf. Shepard and Inman, 1950; Morton, 1981). Significantly, the mega ripples recorded in the units show shore parallel (ENE-WSW) palaeoflow direction which could be the result of storm enhanced longshore currents (McCubbin, 1982).

The conglomeratic horizons lying at the basal part of the units may indicate peak of storm erosion and the overlying cross-bedded horizons may indicate wave activity during the waning phases of storms. The mud flakes and mud pebble conglomerates in the lithofacies are considered to represent the storm lag deposits (cf. Bhattacharya *et al.*, 1980).

LITHOFACIES C : MASSIVE TO PARALLEL LAMINATED QUARTZ ARENITE

Lithological Attributes : The lithofacies comprises 10 to 42m thick units, composed of medium to coarse grained, thickly bedded, moderate to well sorted, white grey or purple quartz arenite. The quartz arenite is occasionally pebbly and also contains few mud flakes and shale partings. The beds (25cm to 1m thick) of the lithofacies are generally massive (structureless) or show parallel laminations in the upper part with low angle discordance and parting lineations. The thick beds of the lithofacies in general are stacked one over the other.

The lithofacies abounds in segregated layers of heavy minerals. The lithofacies generally shows an upward coarsening character and erosional or sharp lower and gradational upper contact with the bounding lithofacies.

Interpretation : On the basis of medium to coarse grain size, moderate to well sorting, concentration of heavies and low angle discordance, this lithofacies is interpreted to have been deposited in a high energy beachface setting.

The presence of mud flakes, pebbles and parallel laminations and discordances together suggest high energy conditions during the deposition of the lithofacies. The thin interbedded shale partings might have formed during relatively slack water conditions.

The parallel laminations with discordances suggest sedimentation due to swash and backwash processes on the beachface (Reineck, 1963). Such type of parallel laminations are known to form from sediment charged flows driven by vigorous currents that buried the pre-existing sandwaves (cf. Chakraborty and Bose, 1990).

The general absence of the storm generated structures in these beachface deposits may be attributed to extensive reworking by dominant tidal currents (Soegaard and Erikson, 1985).

LITHOFACIES D : RIPPLE CROSS-LAMINATED QUARTZ ARENITE INTERBEDDED WITH SILTY SHALE

Lithological Attributes : The 5 to 30m thick lithounits consist of fine to medium grained, moderately sorted, purple, purple grey or pink pebbly quartz arenite interbedded with subordinate grey to purple silty shale. The silty shale, at places, is highly micaceous. The lithofacies shows 4 to 7cm deep and 20 to 40cm wide, NNE to SSW trending channels filled with mud clasts at the base, becoming fine sandy upwards (fig.5a).

The lithofacies abounds in flaser and lenticular bedding, climbing ripple cross-laminations, trough and planar cross-beds (fig. 5b) and herringbone cross-beds in the quartz arenites. The set thickness of the cross-beds range between 5 to 40cm having steep angles (up to 23°), 2mm to 1 cm thick foresets showing size gradation in the down current direction. The flat mud pebbles are seen resting parallel to the foresets. The lithofacies also shows thin graded bedding, convolute bedding, low angle discordance surfaces, parallel laminations and many erosional surfaces of localized nature.

The upper part of the quartz arenite units manifest prolific development of wave, current, wave modified current ripples and interference ripples (fig. 5c). The ripple index (1.1-1.5), rounded sinuous crest and their extensive bifurcation indicate the wave origin for most of the ripples (Tanner, 1967).

The lithofacies generally shows polymodal with prominent NNE-NNW, and SSW directed palaeocurrent. The lithofacies has gradational lower and erosional upper contact with the bounding units, and displays an upward decrease in grain size.

Interpretation : On the basis of moderate sorting, fine to medium grained quartz arenites and silty shale alternations showing presence of flaser and lenticular bedding, and climbing ripple cross-laminations, the lithofacies is considered to have been deposited in intertidal zone (cf. Straaten, 1954; Reineck and Singh, 1980).

The presence of small scale channels with lag pebbles at the base and overall upward decrease in grain size and occurrence of herringbone cross-beds may be attributed to the tide-storm activity in the intertidal zone, most probably in the mixed flat and along the tidal channels.

The prominent landward and seaward directed palaeocurrents probably indicate pronounced effect of tidal currents. The size gradation along the foreset laminae has been attributed to the wave swash and backwash in intertidal zone (Clifton, 1969; Reineck and Singh, 1980; Reinson, 1984; Cudzil and Driese, 1987). The preservation of current and wave modified current ripples in the upper part of the units indicate variations in the velocities, and reworking is considered to be related to emergence and superimposition of wave processes (Reineck and Singh, 1980). The high sinuosity of the ripples may be attributed to relatively high energy and decreasing depths (Tanner, 1967; Allen, 1980; Collinson and Thompson, 1989).

FACIES ASSOCIATION

It is apparent from the facies' description that all the four lithofacies identified in the Lariakantha Quartzite are exclusive in their character and show marked lateral as well as vertical variation. The vertical association of lithofacies is: Lithofacies A → Lithofacies B → Lithofacies C → Lithofacies D.

The unit cycles constituting the Lariakantha sequence show upward fining character. The shoreface sediments (Lithofacies A and B) are followed up by beachface (Lithofacies C) and mixed flat and tidal channel (Lithofacies D) sediments. However, the overall sequence of the Lariakantha Quartzite manifests an upward coarsening as evident by marked increase in grain size in the stratigraphically upper level.

DISCUSSION

The existing models of the Blaini Formation are based mainly on the sedimentological investigations of the pebbly horizons (diamictites) without any emphasis to the associated arenaceous lithounits. A critical perusal of the evidences put forward by the advocates of different hypotheses reveals that none of them could be taken as finally established. The Lariakantha Quartzite which is intimately associated and constitutes an integral part of the Blaini Formation in the Nainital syncline provides an excellent opportunity to study the bed forms, sedimentary structures their dispersal pattern and understanding of the hydrodynamics.

The present study demonstrates that the Lariakantha Quartzite Member represents a progradational (regressive) sequence and has developed in a high energy setting. The deposition milieu ranged from storm dominated lower to middle shoreface (Lithofacies A), subtidal longshore bars (Lithofacies B), beachface (Lithofacies C) to the intertidal mixed flats and tidal channels (Lihtofacies D).

The lower to middle shoreface depositional units (Lithofacies A) showing repetitive sand and silty shale in varying scales have been related to operations of cyclic processes with varying periodicities, probably alternating storm and fairweather conditions. The sandy beds show thick cross-bed sets, sharp/erosional, load, flute casted lower surface and gradational upper contact with the silty shale units. Internally the beds show extensive size gradation. The repetetion of load casted sandy beds and argillaceous alternations probably suggest alternations of high energy episodic events and low energy conditions.

The subtidal bar units show erosional base, mud pebble conglomerates as lag deposits, steep cross-beds, thin graded units and low angle discordances/ parallel laminations and an overall fining upward (Lithofacies B). Such a package suggests marked role of storms during the sedimentation (cf. DeCelles and Cavazza, 1992). Additionally, abundance of mud flakes, pebbles and graded units further corroborate such deductions.

The overlying moderate to well-sorted quartz arenite (Lithofacies C) showing parallel laminations, discordances and segregation of heavy minerals suggest sedimentation due to swash and backwash condition in the beachface.

The intertidal mixed flat zone (Lithofacies D) in the sequence generally lack strong evidence of storm activity owing to extensive reworking of sediments by strong tidal currents and waves. The occurrence of large scale cross-beds, flaser and lenticular beds, climbing ripple cross-laminations, small scale channels and many erosional surfaces of localized nature suggest sedimentation in the intertidal zone. The bipolar cross-beds, currrent, wave and interference ripples recorded in the lithofacies are strong evidences of strong tide-wave activity.

The various lines of evidences suggest that the rocks of the Lariakantha Quartzite were deposited in a regressive high energy continental shelf that was affected by frequent storms. These storm features have, perhaps, led some workers to postulate a deep turbidite environment for these rocks. However, these rocks differ from the typical deep water turbidites in being strongly lenticular rather than laterally continuous and lacking consistantly developed Bouma sequence or their recognised variations (cf. Kelling and Mullin, 1975; Cudzil and Driese, 1987; Kressay, 1994).

The Lariakantha Quartzite is intimately associated with the diamictites (Valdiya, 1980; Tangri and Singh, 1982). The upper diamictite horizon, capped by pink siliceous dolomitic limestone comprising cryptalgal laminations, as such cannot be the product of glacial, glaciomarine or turbidite processes. The genesis of the Blaini Formation, therefore, is closely linked with the depositional set-up of the Lariakantha Quartzite which has provided an excellent oppoutunity to study hydrodynamics and bed form association in response to changing hydraulic regimes.

To sum up, the occurrence of large scale cross-bedding, extensive reactivation surfaces, flaser and lenticular bedding, current and wave ripples, mud pebble conglomerates, strong palaeocurrent variability, textural and mineralogical maturity (Pant and Goswami, 1996) and channeling in the Lariakantha Quartzite manifest deposition by traction currents in a shallow coastal realm rather than in deep environments by turbidity currents, or by glacial processes.

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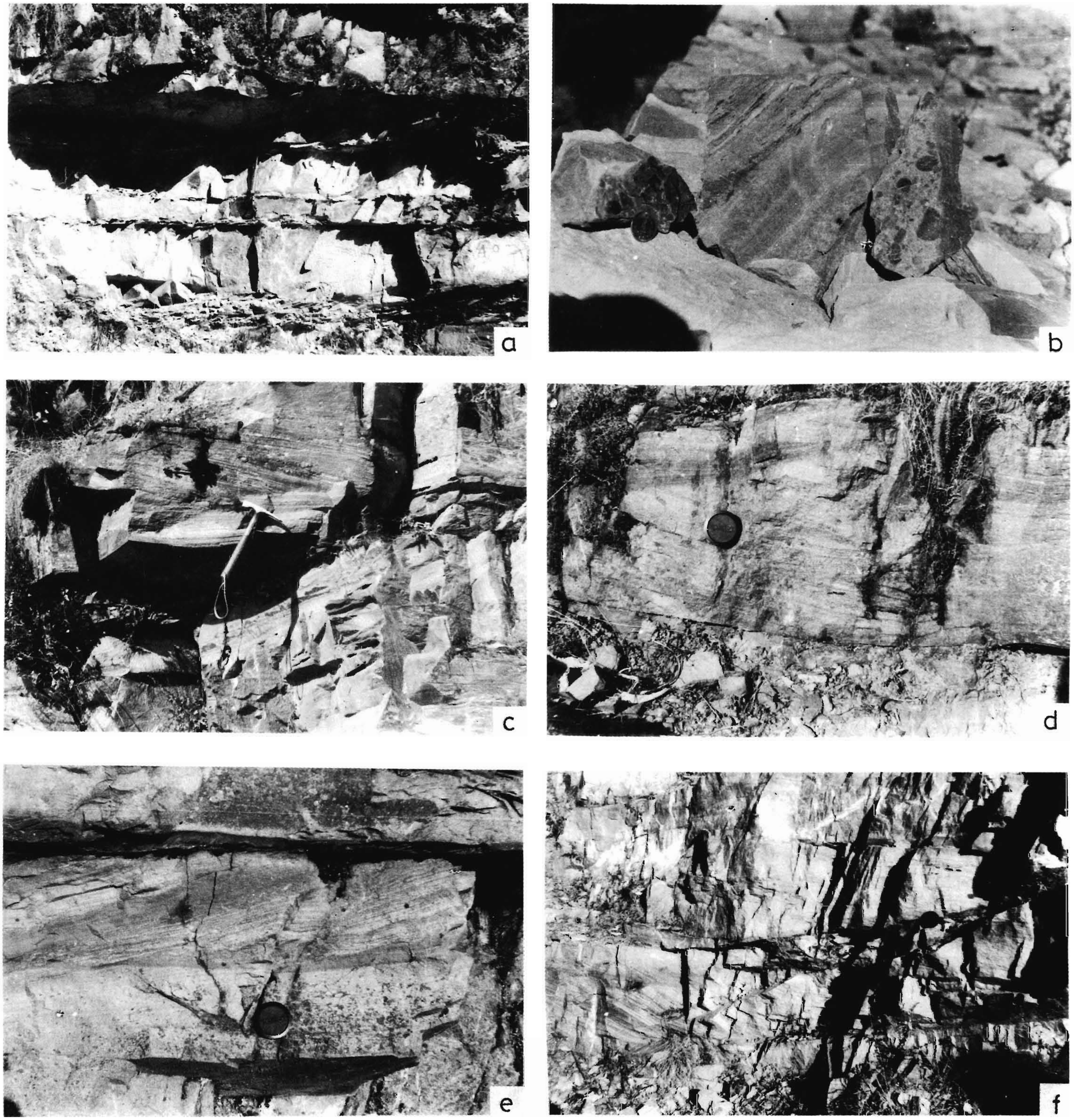

Fig. 4 : (a) Lithofacies-A showing sandstone and shale interbedding. Note the load casted undersuface of the sandy units Location : South of Nauniya. (b) Mud flake conglomerate developed in lithofacies-A showing angular to subrounded mud pebbles along the bedding plane. Internally the units display graded bedding. Location : between Binayak - Nauniya Binayak along the motor road. (c) Lithofacies-B showing large scale planar cross bedding (bar type). Also seen mud flakes along the foresets. Location : south of Nauniya Binayak. (d) Large scale trough cross bedding in the Lithofacies-B showing size gradation along the foresets and ripples towards top of the units. Location : North of Binayak. (e) Deformed cross-bed foresets seen in Lithofacies B, developed in the western face of Badhanthali ridge. (f) Lensoid bed forms showing high angle cross-bedding and erosional mutual contacts as seen in Lithofacies-B developed four Kilometers north of Binayak along the motor road.

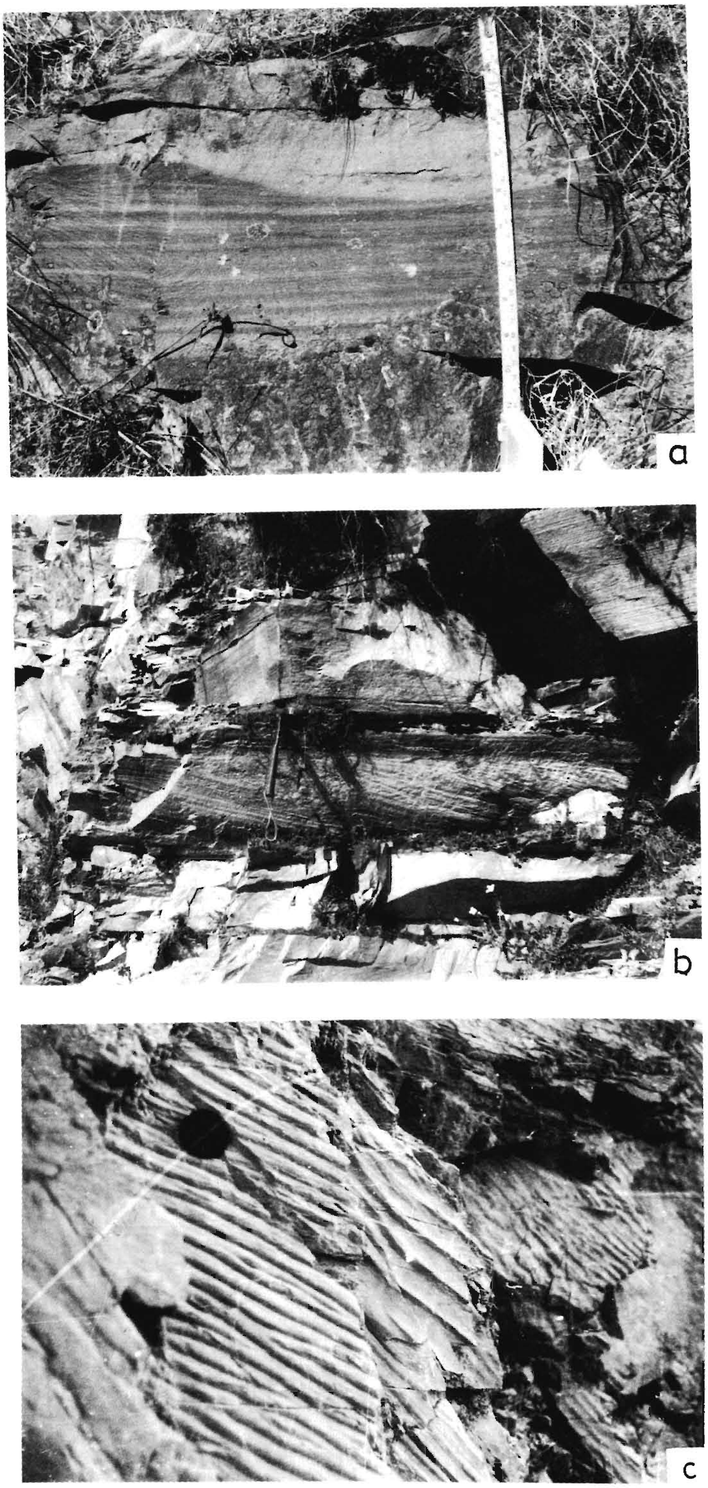

Fig. 5 : (a) Small scale channelised sandstone body developed in thinly laminated siltstone and quartzites incised in Lithofacies D Location : Near Nauniya Binayak. (b) Planar cross-bedded sandstone developed in Lithofacies-D Location : about 3 km. north of Binayak along the motor road. (c) Prolific development of wave and wave modified current ripples in Lithofacies-D developed near Kilberry.