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Bank material characteristics and its impact on river bank erosion, West Tripura district, Tripura, North-East India

Moujuri Bhowmik[1,*], Nibedita Das (Pan)[1], Champakali Das[2], Istak Ahmed[1] and Jatan Debnath[1]

[1]Department of Geography and Disaster Management, Tripura University, Suryamaninagar 799 022, India
[2]Department of Civil Engineering, Indian Institute of Engineering Science and Technology, Shibpur, Haora 711 103, India

In West Tripura district, river bank erosion becomes very common during monsoons along the Haora River and the Sonai Gang. Erosion occurs across 45.39 km (96% of the total length) of the Haora River and 20.12 km (90% of the total length) along the Sonai Gang. The main cause of river bank erosion in the district is the nature of bank material with respect to its erodibility factor (resisting force). The objectives of this study were to identify the nature of bank material of the rivers in West Tripura district and to analyse the shear strength of these materials. Samples were collected from twelve sites at various depths from top of the river bank up to the water level. Hydrometer test and grain size were also analysed. Uniformity coefficient (C_u) and coefficient of curvature (C_c) were calculated to identify the shear strength of bank soil. Tests revealed that the bank soils contain more than 90% sand and less percentage of silt and clay. This makes the soil non-cohesive and leads to maximum erosion.

Keywords: Bank erosion, bank material, grain size, shear strength, West Tripura district.

RIVER bank erosion is a dynamic process which affects the concave side of the bank, while the eroded materials are dropped on its opposite side[1]. It is usual for a river to meander in its middle course, however, in many places the rate of erosion is amplified owing to hydraulic processes[2]. This is common in the mature stage when the river becomes sluggish and wanders[3]. Lateral shifting is evident from asymmetric shape of the river valley which also represents its spatio-temporal change[4].

In the West Tripura district, river bank erosion becomes very common during monsoons along the Haora River and the Sonai Gang (a stream). Here erosion occurs along 45.39 km (96% of the total length) of the Haora River and 20.12 km (90% of the total length) along the Sonai Gang. The main causes of river bank erosion are erodibility and erosivity that are considered the resisting and driving forces respectively. The variables of

*For correspondence. (e-mail: moujurigeo14@gmail.com)

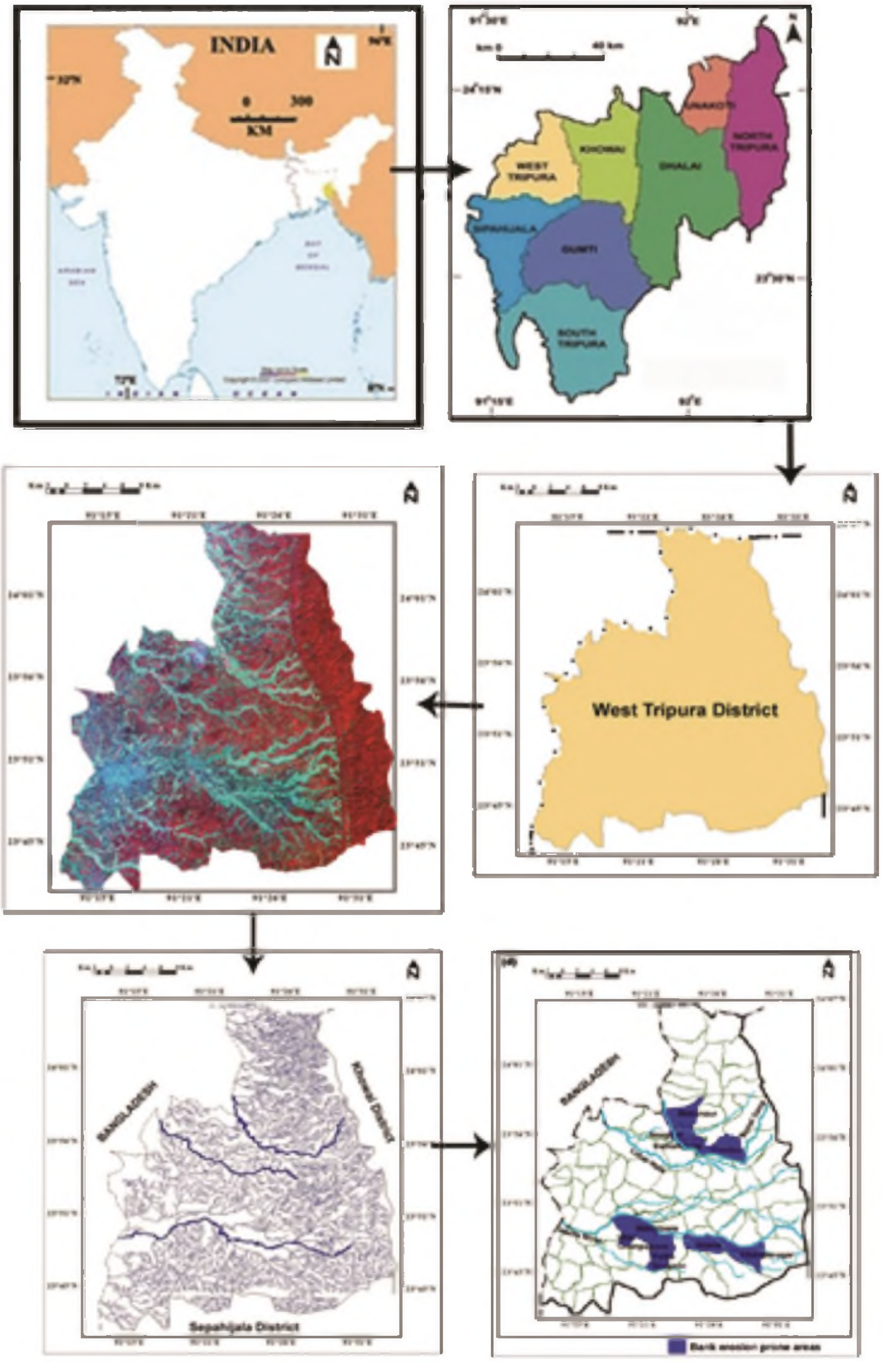

Figure 1. Location map of the study area.

erodibility are the ratio of root depth, bank angle, weighted root density, ratio of bank height, bank area (%) protected by vegetal cover, bank material composition, etc. And the variables of erosivity are channel pattern, presence of channel bar, radius of curvature, ratio of radius of curvature and bank-full width, ratio of pool depth to bank-full mean depth, velocity gradient, etc. which are the causes of bank erosion. All the variables of erodibility and erosivity have been measured and calculated, but here we only discuss bank material erodibility. Among all variables, the nature of bank material is mainly responsible for erosion at almost all sites selected for this study.

West Tripura District extends from 23°40′N to 24°07′N lat and 91°12′E to 91°32′E long (Figure 1). The study area falls under Dupitilla Series and Tipam Group of rocks of tertiary age and primarily characterized by sandstones. Surma Group and alluvium deposition are also found in this district. The area experiences tropical

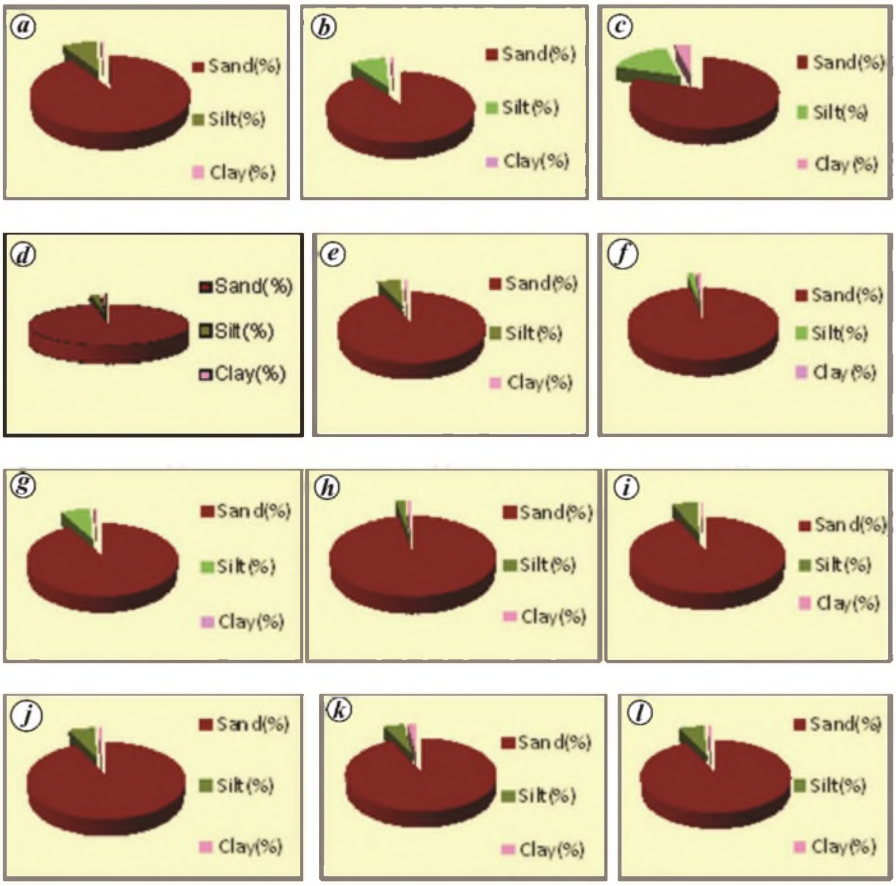

Figure 2. Analytical results of samples collected from the banks of the rivers at: ***a***, Champanagar Market; ***b***, Champanagar Causeway; ***c***, Rabicharan Thakur Para; ***d***, Golak Thakur Para; ***e***, Purba Noagaon; ***f***, Mekhlipara; ***g***, Uttar Champamura; ***h***, Chandpur; ***i***, Barkanthalia; ***j***, Ailaghat; ***k***, Trishghar; ***l***, Mohanpur Bazar.

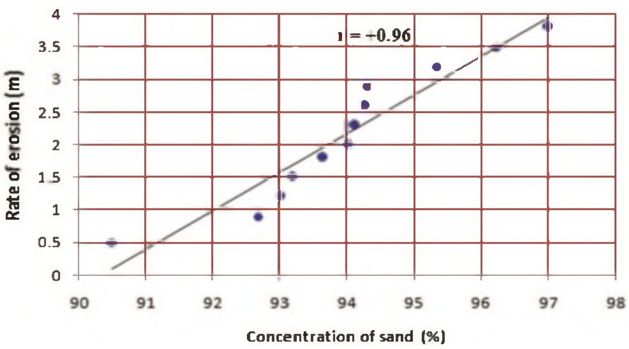

Figure 3. Positive correlation between sandy bank materials and rate of erosion of the Haora River and the Sonai Gang.

monsoon climate. Hill range, piedmont plateaus, terraces and tillas (isolated hillocks) and flood plains are the major physiographic divisions. Red soil, alluvial soil and lateritic soil are found in this district.

Our aim was to study the nature of bank material and its impact on river bank erosion in West Tripura district. The following objectives were selected to fulfil this aim. (1) To identify the nature of river bank material in West Tripura district. (2) To analyse the shear strength of the bank materials.

Table 1. Bank material analysis

Sites	Sand (%)	Silt (%)	Clay (%)
Champanagar Market	92.67	6.56	0.82
Champanagar Causeway	93	6.18	0.82
Rabicharan Thakur Para	90.5	7.5	2
Golak Thakur Para	97	2	1
Purba Noagaon	94.29	4.14	1.57
Mekhlipara	93.64	5.59	0.77
Uttar Champamura	94.25	4.98	0.78
Chandpur	96.24	3.2	0.56
Barkanthalia	95.33	4.04	0.62
Ailaghat	94.12	5.16	0.71
Trishghar	93.17	5.5	1.33
Mohanpur Bazar	94	5.26	0.74

Source: Measured by the researcher through hydrometer test.

For this study Geomatica V 10.1 GIS software, MS Excel, Adobe Photoshop, GPS tool, SOI topographical maps (79M/1, 2, 5, 6, 9, 10, 78 P/8 and 12) of 1 : 63360 scale were used.

Intensive field survey and observations were the bases of this study. Twelve sites along the rivers of West Tripura district namely, Champanagar Market (site 1), Champanagar Causeway (site 2), Rabicharan Thakur Para (site 3),

Table 2. Grain size of soils collected from the river banks of various sites

	Grain size (mm) with the value of phi (ϕ)					
Sites	2 (–1 ϕ)	2–1 (0 ϕ)	1–0.5 (1 ϕ)	0.5–0.25 (2 ϕ)	0.25–0.125 (3 ϕ)	0.125–0.06 (4 ϕ)
Sites along the bank of the Haora River	0.41%	2.31%	15.23%	29.94%	50.65%	1.46%
Sites along the bank of the Sonai Gang	0.25%	1.51%	8.57%	33.82%	54.26%	1.59%

Source: Measured and calculated by the researcher.

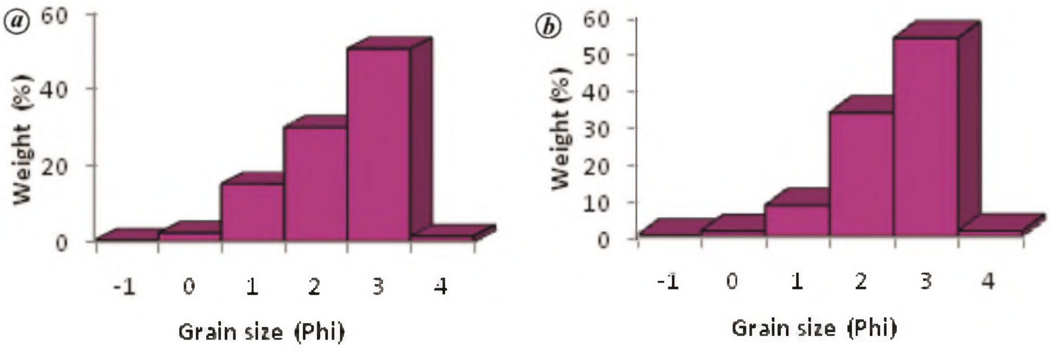

Figure 4. Analytical results of sample grain size from the banks of (***a***) the Haora River and (***b***) the Sonai Gang.

Golak Thakur Para (site 4), Purba Noagaon (site 5), Mekhlipara (site 6) and Uttar Champamura (site 7) along the bank of the Haora River and Chandpur (site 8), Barkanthalia (site 9), Ailaghat (site 10), Trishghar (site 11) and Mohanpur Bazar (site 12) along the bank of the Sonai Gang were identified, as most vulnerable to bank erosion. At these sites, annual land loss due to river bank erosion is a common phenomenon which has a strong impact on floodplain dwellers, agricultural lands on the margins of rivers, tea garden and also on the National Highway 8. In order to identify the characteristics, samples were collected from 12 sites at various depths from top of the river bank up to the water level and hydrometer test and grain size analysis were done. Hydrometer test was used for analysis of particle size and for calculation of weight percentages of sand, silt and clay. For grain size analysis, samples were dried in an oven at 60°C for 24 h. Initially, 100 g of each sample taken from river bed were treated with 10% dilute HCl for removing of carbonate. The samples were further dried and sieved in table sieve shaker (vibration type) for 15 min using ASTM sieve at one phi interval. Samples retained in each sieve were collected and weighed. Uniformity coefficient (C_u) and coefficient of curvature (C_c) were also calculated to identify the gradation of these samples. Soil gradation is an indicator of engineering property of samples such as shear strength. The formula of C_u is D_{60}/D_{10} and of C_c is $(D_{30})^2/D_{60}*D_{10}$. D is the diameter of particle and D_{10}, D_{30} and D_{60} are particle lengths in mm at 10th, 30th and 60th percentiles of cumulative mass distribution respectively. If $C_u > 6$ and $1 < C_c < 3$ then the samples are well graded and have more shear strength (ASTM-D2487-11)[5].

River bank reflects the result of interactions between the river's hydraulic action and the nature of bank materials in the form of erosion. It involves mass failure of bank soil and its removal[6]. Erodibility is a function of bank material, bank morphology and bank vegetation. The tractive force to carry load increases with channel slope, flow velocity and water depth. Therefore, the erosive power of the river increases with higher flow velocity[7]. Bank erosion normally widens the river channel or may lead to meandering, without change in river size. This happens when erosion on one bank is compensated by deposition on the opposite bank to retain the same width of the channel.

Hydrometer test was carried out to obtain the percentage of materials in samples collected from banks, which revealed high erodibility of bank materials at all sites under study. In this district, river banks are composed of non-cohesive materials, i.e. bank soil with high percentage of sand, which leads to high erosion and eventually widening of the channel, as it cannot resist stress produced by the force of river water (Figure 2 and Table 1). Due to the absence of interstitial spaces clay particles stick together and so are difficult to displace[8]. At Golak Thakur Para and Trishghar, due to high depth and density of vegetation roots and moderate bank angle, the amount of bank erosion is comparatively less. But high concentration of sandy materials makes these banks erosion-prone. A very high positive correlation (+0.96) between sandy bank materials and rate of erosion of rivers has been established (Figure 3).

Bank stability is influenced by factors such as temperature regimes, composition of bank materials, hydraulic forces, presence or absence of permafrost and vegetation[9]. Strength of materials depends on the balance of forces acting on grain surface[10]. All samples were tested using sieve to determine the particle size distribution.

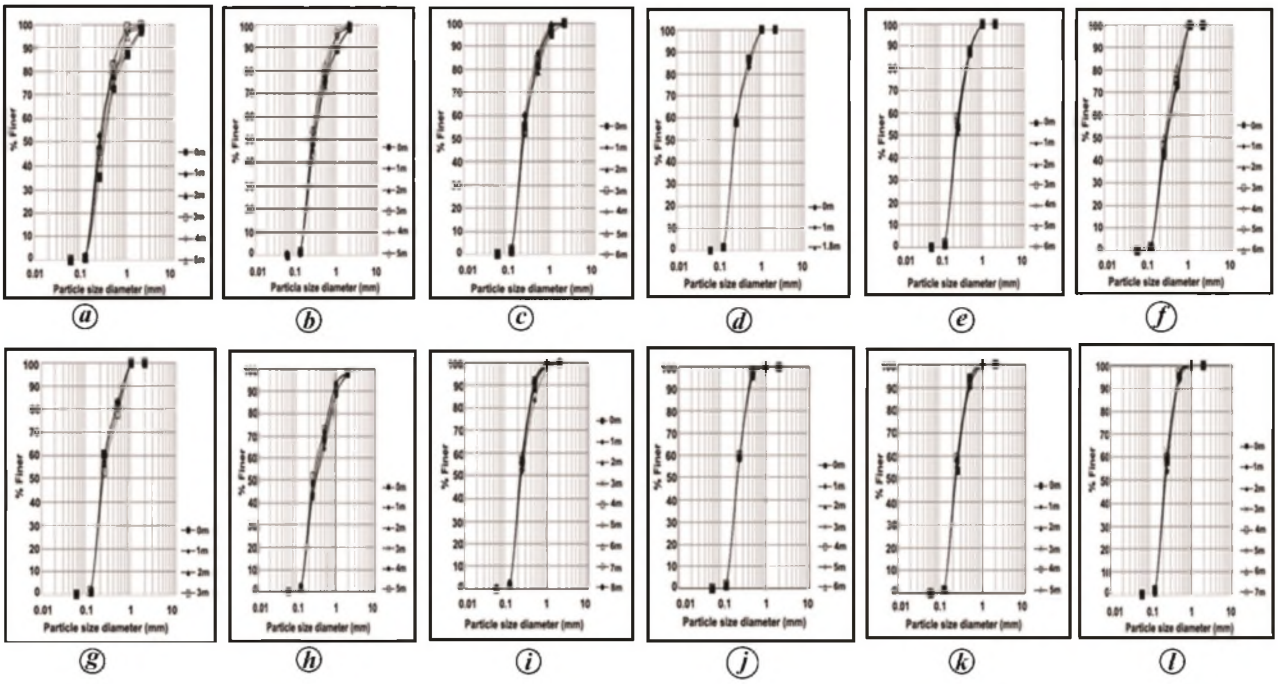

Figure 5. Grain size analysis curves at (***a***) Champanagar Market, (***b***) Champanagar Causeway, (***c***) Rabicharan Thakur Para, (***d***) Golak Thakur Para, (***e***) Purba Noagaon, (***f***) Mekhlipara, (***g***) Uttar Champamura along the bank of the Haora River and (***h***) Chandpur, (***i***) Barkanthalia, (***j***) Ailaghat, (***k***) Trishghar and (***l***) Mohanpur Bazar along the bank of the Sonai Gang.

Table 3. Calculation of uniformity coefficient and coefficient of curvature

Sites	C_u (uniformity coefficient)	C_c (coefficient of curvature)
Champanagar Market	2.33	0.92
Champanagar Causeway	2.13	0.75
Rabicharan Thakur Para	1.80	0.89
Golak Thakur Para	1.80	0.80
Purba Noagaon	1.93	0.82
Mekhlipara	2.33	0.76
Uttar Champamura	1.80	0.80
Chandpur	2.33	0.76
Barkanthalia	1.80	0.80
Ailaghat	1.73	0.83
Trishghar	1.80	0.80
Mohanpur Bazar	1.66	0.86

Source: Calculated in the Civil Engineering Department, Adamas Institute of Technology, West Bengal, on the basis of sieve analysis of grain size.

From grain size analysis it was found that the samples were poorly graded (SP) fine sand as the diameter size ranges from 2.0 to 0.06 mm (–1 to 4 ϕ) at all sites (as per ASTM-D422-63 (2007))[11] and least percentage of silt is present in the samples (Table 2 and Figure 4). The test result reveals the group name of the sample as Silty Sand (SM). According to ASTM code for soil classification (ASTM-D2487-11), the samples were under the group symbol SP-SM which indicates poorly graded silty sand. As the samples are of sandy composition they are under cohesion-less category; shear strength of cohesion less soil (sand) is less with respect to cohesive soil (clay). Therefore, this type of soil is easily erodible.

Shear strength of soil illustrates the maximum shear stress that a soil can sustain in its incipient failure condition[12]. Bank erosion is a function of the nature of channel flow and the properties of bank materials. Shear failure in the upper bank is the most common form of bank collapse in rivers[13]. Shear strength of a soil is the capacity of the soil to resist shearing stress[14]. All samples subjected to sieve analysis (Figure 5) were utilized to determine the C_u (uniformity coefficient) and C_c (coefficient of curvature), presented in Table 3. From results, it can be concluded that the points closer to the river have lower values of C_c and C_u with respect to the other points. Any soil to be considered well graded, when $C_u > 6$ and $1 < C_c < 3$.

Here, C_u value ranges between 1.66 and 2.33 and C_c value between 0.75 and 0.92. Thus, the soils of all the sites are poorly graded sandy soil, i.e. under cohesion-less category. Shear strength parameter C of cohesion less soil becomes less with respect to cohesive soil. In case of cohesion-less soil the angle of friction (ϕ) is more owing to very poor cohesion; the bank particles cannot resist thrust of river flow during monsoons leading to bank failure.

It can be concluded that the nature of bank material is the main causative factor behind bank erosion at all sites selected for this study. Bank material containing more than 90% sand and less percentage of silt and clay makes the soil non-cohesive which leads to maximum erosion and ultimately widens the channel. C_u (1.66 to 2.33) and

C_c (0.75 to 0.92) of the samples indicate that the soil is poorly graded and falls under cohesion-less category. Therefore, shear strength becomes less; angle of friction (ϕ) becomes more due to which inter-granular attraction is less and ultimately, bank erosion takes place. Therefore, bank erosion hazard at these sites need proper attention for providing effective policy decision and execution of appropriate protection measures.

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Garnetiferous metamorphic rocks in Jaspa granite, Himachal Pradesh, India: implication of Tethyan Himalayan metamorphism and tectonics

S. S. Thakur*, A. K. Singh, D. Rameshwar Rao, Rajesh Sharma, Subhajit Pandey and Aliba Ao

Wadia Institute of Himalayan Geology, 33 GMS Road,
Dehradun 248 001, India

Studies on the magmatic enclaves, pelitic xenoliths and host Jaspa granite pluton outcropped in the Lahaul area, NW Himalaya, India illustrate that the rocks have undergone garnet-grade metamorphism. The *P–T* pseudosection modelling shows that the metamorphic mineral assemblage is stable in the *P–T* range ~4.5–7.3 kbar and ~440–500°C, matching quite well with the results obtained from the conventional geothermobarometers (5.7–8.6 kbar and 409–531°C). The observed garnet-grade metamorphism in and around the Jaspa pluton is proposed to be due to localized perturbation of high-temperature isotherms in the Tethys Himalaya, as a consequence of the Cenozoic tectono-thermal event during Himalayan orogeny. Further, the Haimanta group of Tethys Himalayan rocks in the Lahaul area has been interpreted to have attained right-way-up metamorphic field gradient.

Keywords: Garnet-grade metamorphism, granite pluton, magmatic enclaves, pelitic xenoliths.

THE Tethys Himalaya Sequence (THS) forms an important lithotectonic unit of the Himalayan orogenic belt. It got transformed into an extensive fold-thrust belt as a result of the continental collision between Indian and Asian plate during the Cenozoic Himalayan orogeny[1–5]. The basal part of the Tethys Himalaya is commonly known as the Haimanta Group of rocks, whereas the upper part of the THS remains unmetamorphosed, and is commonly designated as Tethys Sedimentary Sequence (TSS). Studies show that the Haimanta Group of rocks has attained Cenozoic greenschist- to amphibolite-facies metamorphism[3,4,6–11]. The THS has also witnessed two major tectonic events: (i) the intrusion of Lower Palaeozoic granites of ~480–520 Ma often correlated with Pan-African orogeny and (ii) the tourmaline-bearing leucogranite emplacement during the Himalayan orogenic event at ~20–22 Ma.

Despite the occurrence of low-grade nature of metamorphic rocks in the Lahaul area, the chlorite–biotite grade Haimanta Group of rocks of the THS is important to understand the tectono-metamorphic evolution of the

*For correspondence. (e-mail: satya_edu1974@yahoo.co.in)