IRS-1C Digital data interpretation of lithotectonic setting in northwestern part of the Eastern Ghats Mobile Belt, Orissa

T. K. Biswal and D. Sahoo

Department of Earth Sciences, Indian Institute of Technology, Mumbai 400 076, India

The lithotectonic setting of the northwestern part of Eastern Ghats Mobile Belt around Lathore, Lakhna and Turekela in Balangir and Kalahandi districts of Orissa has been interpreted on the basis of IRS-1C LISS-III digital data in conjunction with detailed structural mapping. The FCC (RGB = 532) is highly informative about the lithology in the above metamorphosed and deformed terrain and is conformable with the lithological map prepared through field mapping. The linearly stretched ratio image between B2 and B5 bands has clearly brought out the large scale structures. The result has confirmed the earlier study, that the area is part of fold-thrust belt in the Eastern Ghats and the individual lithotectonic groups namely Lathore Group and Turekela Group represent thrust sheets that have been successively thrust over craton.

WITH the development of remote sensing techniques, mapping and interpretation of large-scale structures in deformed and metamorphic terrains, have been speeded up. Systematic lithological classification has been achieved based on spectral signature of rocks and the tectonic setting can be visualized with the help of large scale lineaments, faults and folds. The effectiveness and consistency of this technique have been established in the studies of Proterozoic Eastern Ghats Mobile Belt[1,2].

In the present contribution, the IRS-1C LISS-III digital data along with the aerial photographs have been utilized in demarcating different lithologies and structural features in the northwestern part of Eastern Ghats Mobile Belt (EGMB) (Figure 1 *a*) in Balangir and Kalahandi districts of Orissa (Topo sheet No. 64 L/10 and 64 L/14). To avoid any biased conclusion, the above technique is applied subsequent to detailed mapping and conventional structural analysis of a few selected blocks like Lathore, Turekela, Lakhna[3–5]. The remote sensing data proves not only effective in substantiating the small scale observations but also helps in extrapolating the findings to larger areas.

The Proterozoic EGMB, which runs over 700 km across the coastal states of Orissa and Andhra Pradesh, is juxtaposed with the Archaean cratons to the west and to the north (Figure 1 *a*) along a crustal thrust which is referred to as terrain boundary shear zone. The craton, the EGMB[4–6] and the terrain boundary shear zone[2,4,7–9] have been studied by a number of authors. The study area encompasses all these three units (Figure 1 *b*). The EGMB is classified into two lithotectonic groups such as Turekela Group and Lathore Group based on their lithological and structural dissimilarities[4,5]. While the Turekela Group is dominated by khondalites with narrow bands of calc gneiss (not shown in the map), the Lathore Group comprises charnockitic gneiss and ferruginous calc gneiss with an elliptical outcrop of garnet-sillimanite gneiss. The garnet-sillimanite gneiss differs from khondalites with regard to little sillimanite and graphite content. The rocks of the Lathore Group are strongly marked by gneissic fabric defined by alternate bands of quartzo-feldspathic and garnet-hypersthene layers in charnockitic gneiss and calcite layer and diopside-sphene rich layer in calc gneiss. As the above fabric is axial planar to the isoclinal and reclined/recumbent LF_1 folds (Figure 2 *a*), granulite-facies metamorphism is interpreted as synkinematic to the LF_1 folding. The LF_1 folds are involved in coaxial refolding with the open to tight and northwesterly vergent LF_2 folds (Figure 2 *n*) resulting in type 3 interference pattern (Figure 2 *b*)[10]. The LF_2 folds, at many places, have been transformed into sheaths marked by planar axial planes and sharp curved hinges (Figure 2 *e*). The orientation of the LF_2 axial plane is reasonably stable in NNE–SSW

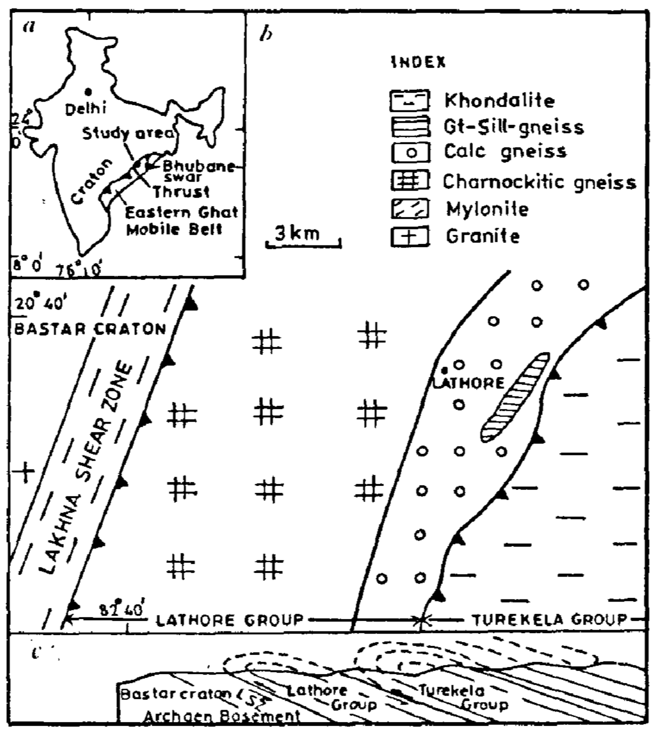

Figure 1. *a*, Location map of the EGMB; *b*, Geological map of the study area[4,5]; *c*, Schematic cross section showing fold-thrust nature of the belt.

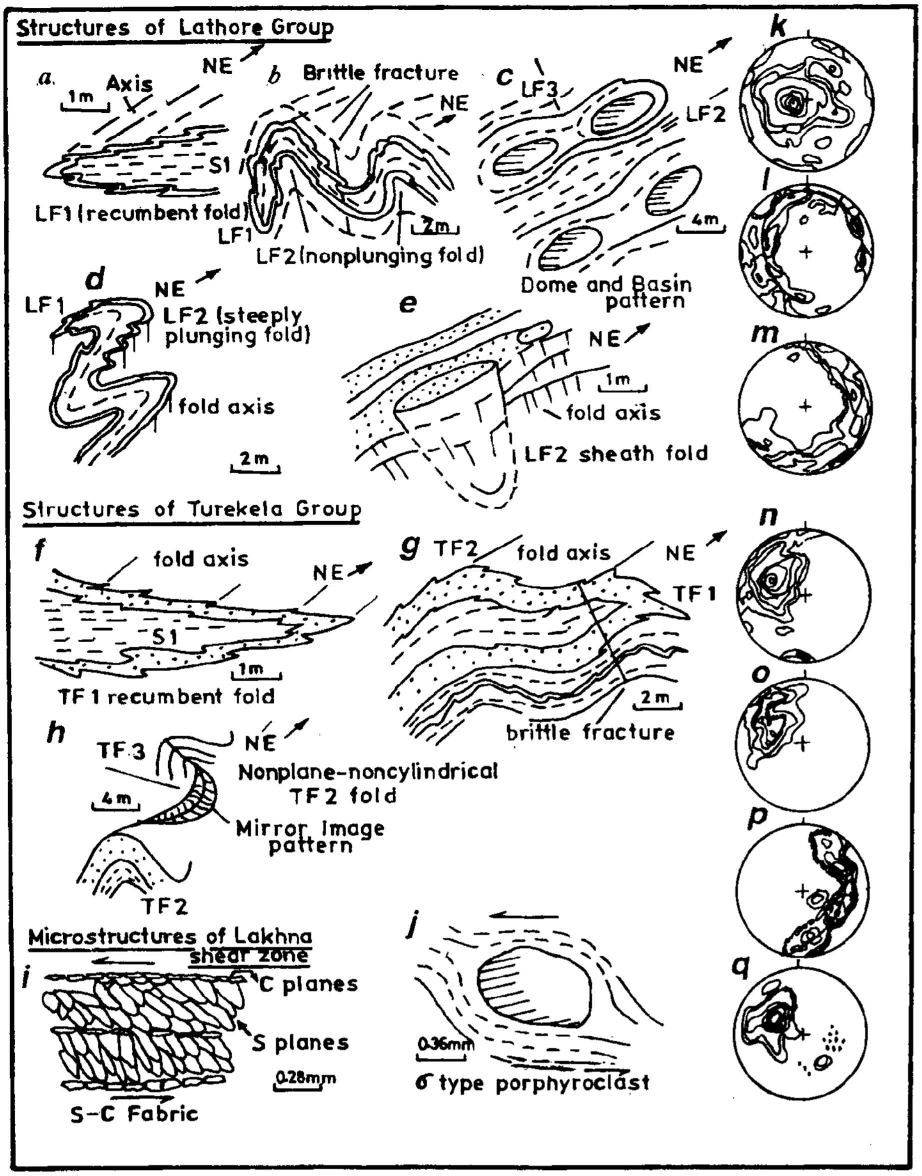

Figure 2. *Structures of Lathore Group* (*a–e*, Location: South of Dholmandal in calc gneiss). ***a***, LF_1 recumbent fold, on vertical surface, shows parasitic folding and horizontal fold axis in NE–SW direction; ***b***, Type 3 interference pattern between LF_1 and LF_2 fold seen on vertical face. LF_2 is nonplunging and northwesterly vergent. Brittle fractures are developed parallel to the axial plane of LF_2 fold in NE–SW direction; ***c***, Dome-and-basin pattern, seen on subhorizontal surface, due to superimposition of northwesterly trending LF_3 on northeasterly trending LF_2. This interference pattern is developed only where LF_2 is horizontal/subhorizontal; ***d***, Steeply plunging LF_2 fold, on subhorizontal surface, with axial plane striking NE–SW. LF_1 is refolded by this fold, resulting type 3 interference pattern. The steepness of the fold axis is ascribed to the transformation of LF_2 fold into sheath; ***e***, LF_2 sheath fold, on subhorizontal surface, shows sharply bent axis. The axial plane is planar in NE–SW direction. The transformation of LF_2 into sheath is attributed to inhomogeneous axial planar shearing. *Structures of Turekela Group* (*f–h*, Location: East of Turekela graphite mine in calc gneiss). ***f***, TF_1 recumbent fold, on vertical surface, shows parasitic folding and horizontal fold axis in NE–SW direction; ***g***, Type 3 interference pattern between TF_1 and TF_2 fold seen on vertical face; ***h***, Mirror image pattern due to interference pattern between TF_2 and TF_3. *Microstructures of Lakhna shear zone* (*i* and *j*, Location: Babupalli). ***i***, S–C fabric in the mylonites showing sinistral shear. Mica flakes are concentrated along C-planes. The dynamically recrystallized quartz grains define the S-planes; ***j***, σ-type porphyroclasts of plagioclase feldspar in mylonite showing sinistral shear. *Stereoplots of Turekela Group* (***k–m***). ***k***, S_1 planes (469 no. contours: 0.25-0.5-1.0-5.0-10%) are dominantly subhorizontal; ***l***, TF_2 axial planes (57 no. contours: 1.0-2.0-5.0%) is nonplanar due to TF_3 folding; ***m***, TF_1 and TF_2 axes (249 no. contours: 0.5-1.0-2.0-4.0%) are curvilinear due to TF_3 folding. *Stereoplots of Lathore Group* (***n–p***). ***n***, S_1 planes (211 no. contours: 0.5-1.0-2.0-5.0-8.0-10.0-16.0-20%) are steep to moderately dipping towards SE indicating overturned nature of LF_2; ***o***, TF_2 axial plane (61 no. contours: 1.0-4.0-6.0-8.0-10.0%) dip steep to moderately to SE; ***p***, TF_2 axes (27 no. contours: 0.5-1.0-4.0-8.0-12.0-16.0%) are curvilinear and distributed over a girdle because of sheath nature. *Stereoplots of Lakhna shear zone.* ***q***, Southeasterly dipping mylonitic foliation (136 no. contours: 0.5-1.0-5.0-10.0-20.0-30.0%). Dots represent the stretching lineation.

direction (Figure 2*o*). However due to sheath nature, majority of the LF_2 folds show steep plunge (Figure 2*d*) except in a few localities where gentle plunge corresponding to curved hinge zone of sheath is observed (Figure 2*p*). The above folds (LF_1 and LF_2) have resulted from continuous buckling along NW-SE axis. Inhomogeneous axial planar shearing subsequent to the development of the LF_2 fold had transformed them into sheath. The more localized NW–SE trending LF_3 folds, originated due to length parallel shortening[11] of the orogen, have developed dome-and-basin structure with the low plunging LF_2 folds (Figure 2*c*). The rocks of Turekela Group have also been deformed by three stages of folding. A set of isoclinal and reclined/recumbent folds define the TF_1 fold (Figure 2*f*) which have given rise to ubiquitous axial planar gneissosity in the rock. This is coaxially refolded by upright to NW vergent TF_2 folds along NNE–SSW axis producing type 3 interference pattern (Figure 2*g*). Unlike the Lathore group, the TF_1 and TF_2 fold axes are not steeped. On the other hand, their axial planes and axes have been refolded to various orientations by the NW–SE trending TF_3 fold giving rise to mirror image interference pattern (Figure 2*h*, *l* and *m*)[10]. The above variation is attributed to difference in flow direction during third stage folding in two Groups. While the LF_3 in Lathore Group is developed due to vertical flow, horizontal flow accounts for the TF_3 folding in Turekela Group. The two Groups do not represent a continuous sequence which is emphasized by the above variation in structural style and the contact is, therefore, interpreted to be a tectonic one. Observing the predominance of recumbent style of folding and subhorizontal gneissosity in the rocks of overlying Turekela Group (Figure 2*k*) the contact is inferred to be a thrust. Streams faithfully following the contact, occasional preservation of mylonitic rocks and sharp reversal of dip across the contact, further, underline its tectonic character. Farther west towards craton, the Lathore Group is underlain by the comparatively undeformed granites of Bastar craton with the distinct terrain boundary shear zone. The shear zone, which is named as Lakhna shear zone, is confined to the Archaean granites and is characterized by mylonitic foliation carrying down the dip stretching lineation (Figure 2*q*), S–C fabric (Figure 2*i*) and asymmetrical porphyroclasts (Figure 2*j*). Detailed petrofabric analysis of the mylonites of the shear zone underscores thrust slip nature of shearing, with northwesterly vergence from top, thus implying thrusting of the Eastern Ghats rocks over the Archaean craton[4]. Apart from ductile deformational structures, brittle structures are also common which include NE–SW ridge parallel strike slip shears and high angle Riedel shears[12] with the former hosting pseudotachylites in many instances. The high angle brittle shears show variable pattern. While NW–SE fractures are present in both the Groups, the ENE–WSW fractures are exclusive to Lathore Group and Lakhna shear zone. Secondly the ENE–WSW fractures are visibly shifted by NW–SE ones in a strike-slip manner pointing to its earlier origin. On the basis of this structural study the EGMB in the area has been interpreted analogous to fold-thrust belt[4] (Figure 1*c*) where individual lithotectonic group with distinctive structural style[13] serve a thrust sheet/nappe. Due to episodic exhumation, probably resulting from thrusting, different generations of brittle shears have developed superimposing one above the other.

The IRS-1C LISS-III digital data have been processed to get an FCC of RGB = 532 bands. Unlike standard FCC (RGB = 432), which failed to elicit variation in spectral signature of different rock types, the above FCC is conspicuous enough with regard to such variation and the lithocontacts that are mapped in the field remarkably coincide with the change of colour (Figure 3). The Archaean granites including the Lakhna shear zone are distinctly brown in colour which is followed, to the east, by blue coloured charnockitic gneiss. The above charnockitic gneiss with brownish-blue calc-gneiss and dull-brown garnet-sillimanite gneiss constitute the Lathore Group. To the east of Lathore, dark coloured hills are constituted by khondalites belonging to Turekela Group. The calc gneiss, which occurs as thin bands within khondalite, is obviously not prominent. But the eastern part of the Turekela Group, which is yet to be mapped in larger scale, shows bluish tinge mixed with brown, indicating association of different lithologies of which calc gneiss seems to constitute a major part. The above mentioned colour variation has guided in extending the lithocontacts further to north and south.

With regards to deformational structure, the linearly stretched ratio image between B2 and B5 bands proves to be more informative. Though the small scale ductile structures such as folds and their appendages are unlikely to be reflected on the imageries, large-scale fractures are well marked ripping across the area and prominently displacing the hill ridges (Figure 4). These fractures appear sympathetic to the small scale cross fractures. The ridge-parallel fractures are possibly masked by the strike of the hills as evident from the strong linearity of the ridge crests. The rectangular and diamond-shaped gaps along the strike continuity of the ridges possibly represent the pull-apart structures resulted from such ridge-parallel strike-slip shearing (Figures 3 and 4). The strike of the cross fractures and their sense of shearing vary within each group. While the ENE–WSW fractures are observed in Lakhna shear zone and Lathore Group, the NW–SE fractures are present in both the groups. This difference is so conspicuous that the ENE–WSW fractures while tracing eastward from Lathore Group, truncate against the Turekela Group. Further, while NW–SE fractures display dextral displacement (see the hill north of Turekela), the

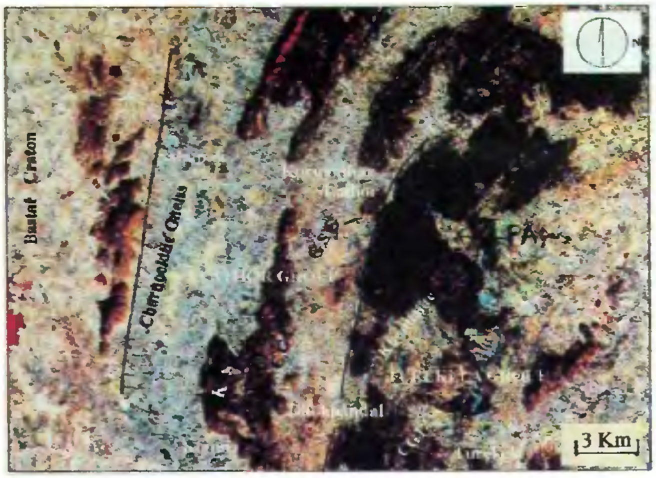

Figure 3. FCC (RGB = 532) from IRS-1C LISS-III digital data of the study area. The dark lines demarcate the boundary between Archaean and Lathore Group (west) and Turekela Group and Lathore Group (east). CG, calc gneiss, GSG, garnet–sillimanite–gneiss, PA, Pull apart structure.

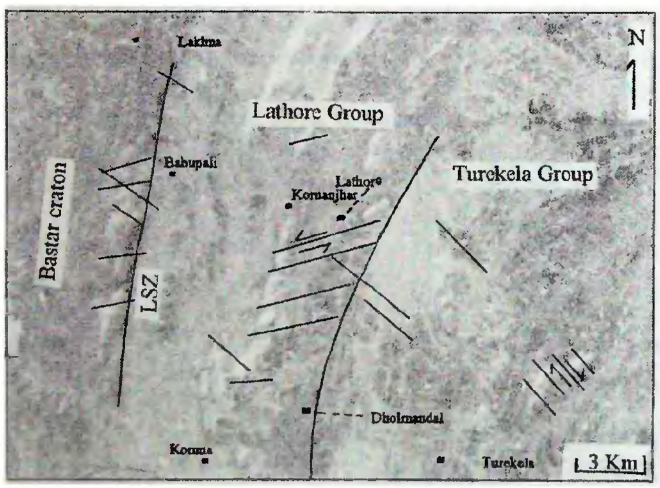

Figure 4. Linearly stretched ratio image of B2 and B5. LSZ, Lakhna shear zone.

ENE–WSW fractures are sinistral (hill southwest of Lathore). Inside Lathore Group and Lakhna shear zone where both sets are present, the ENE–WSW fractures are more abundant and are displaced by NW–SE fractures indicating its earlier origin. Hence these two sets indubitably belong to two different generations.

Based on small scale observation, the cross fractures are believed to be Riedel shears related to the ridge-parallel shear and indubitably developed subsequent to the exhumation of the terrain into the upper crust. The fact that they belong to two generations and each set is characteristic of a particular unit, the relative age of thrusting of these two lithotectonic units can be constrained. As ENE–WSW set is earlier and characteristic of Lathore Group, the later could therefore, be interpreted as older than Turekela Group in chronological order of thrusting. Subsequent to the thrusting of Lathore Group over the craton, the ridge-parallel shearing, similar to that of Cenozoic continent-collisional orogens like Himalayas[14,15], created NE–SW fractures. Pull-apart structures are the result of transtension[16] during such shearing. The ENE–WSW left lateral Riedel shears developed affecting the rocks of Lakhna shear zone and Lathore Group. Since Turekela Group was yet to be thrust up, it could not register these fractures. Later, when it was thrust up, ridge parallel strike-slip shearing induced NW–SE fractures which got superimposed over ENE–WSW ones in pre-existing Lathore Group. This episodic nature of thrusting is suggestive of fold-thrust nature of the belt where individual lithotectonic units act like a nappe sheet and thrusts over the craton episodically. Variation in sense of shearing along the Riedel fractures of the Groups could either be attributed to variation in sense of ridge-parallel strike slip shearing or strain variation[17].

This explanation takes an exception to the earlier views[18,19] which state that transform tectonic constitutes the major tectonic in the EGMB and transpression resulted from it eventually generated the folds. Rather a collisional tectonic with or followed by strike-slip shearing are more likely explanation for the evolution of the EGMB. This sort of tectonic matches with that of other granulite belts of East Gondwana[20].

1. Chetty, T. R. K. and Murty, D. S. N., *Terra Nova*, 1994, **6**, 72–81.
2. Nash, C. R., Rankin, L. R., Leeming, P. M. and Harris, L. B., *Tectonophysics*, 1996, **260**, 245–257.
3. Biswal, T. K., Sajeevan, G. and Nayak, B. P., *J. Geol. Soc. India*, 1998, **51**, 219–225.
4. Biswal, T. K., Sahoo, D., Haris, T. R. and Jena, S. K., *in The Indian Precambrian* (ed. Paliwal, B. S.), 1998, in press.
5. Biswal, T. K., *J. Afr. Earth Sci.*, 1998, **27**, 27–29.
6. Ramakrishnan, M., Nanda, J. K. and Augustine, P. F., *Geol. Surv. India Spl. Publ.*, 1998, **44**, 1–21.
7. Mahalik, N. H., *J. Geol. Soc. India*, 1994, **44**, 41–52.
8. Chetty, T. R. K., *Mem. Geol. Soc. India*, 1995, **34**, 205–220.
9. Chetty, T. R. K. and Murty, D. S. N., *J. Geol. Soc. India*, 1993, **42**, 37–39.
10. Ramsay, J. G., *Folding and Fracturing of the Rocks*, McGraw Hill, New York, 1967, p. 568.
11. Stubley, M. P., *Tectonophysics*, 1989, **158**, 75–92.
12. Bartlett, W. L., Friedman, M. and Logan, J. M., *Tectonophysics*, 1981, **79**, 255–277.
13. Meth, S. S., *Him. Geol.*, 1977, **7**, 26–42.
14. Molnar, P. and Tapponnier, P., *Science*, 1975, **189**, 419–426.
15. Valdiya, K. S., *Aspects of Tectonics. Focus on Southcentral Asia*, Tata McGraw Hill, 1984, p. 319.
16. Ramsay, J. G. and Huber, M. I., *The Techniques of Modern Structural Geology, Folds and Fractures*, Academic Press, London, 1987, vol. 2, p. 400.
17. Hancock, P. L. and Barka, A. A., *J. Struct. Geol.*, 1981, **3**, 383–392.

18. Aftalion, M., Bowes, D. R., Dash, B. and Dempster, T. J., *J. Geol.*, 1988, 96, 663–676.
19. Katz, M. B., *J. Geol.*, 1989, 97, 646–648.
20. Yoshida, M., *India and Antarctica during Precambrian*, Mem. Geol. Soc. India (eds Yoshida, M. and Santosh, M.), 1995, vol. 34, pp. 25–45.

ACKNOWLEDGEMENT. The above work is carried out under a DST-sponsored project. Dr S. V. Panikkar, Department of Earth Sciences, IIT, Bombay helped in processing the digital data. Suggestions made by an anonymous reviewer are duly acknowledged.

Received 20 February 1998; revised accepted 11 August 1998

Climate instability during last glacial stage: Evidence from varve deposits at Goting, district Chamoli, Garhwal Himalaya, India

R. K. Pant*[†], N. Juyal, Piyoosh Rautela*, M. G. Yadav** and S. J. Sangode***

*Wadia Institute of Himalayan Geology, 33 Gen. Mahadeo Singh Road, Dehra Dun 248 001, India
**Physical Research Laboratory, Ahmedabad 380 009, India

The varve deposits at Goting, district Chamoli, Garhwal Himalaya have recorded climate history of the Last Glacial Stage (LGS). ^{14}C chronology indicates that the deposition commenced around 40 ka BP and continued till the glacial maxima (about 20 ka). The magnetic susceptibility of the varve succession matches well with the lithological climate record. The varves are alternating dark and light grey bands of sub-millimeter scale separated by limonitic (pale yellow) bands and ice rafted dropstone debris. The mineral magnetic measurements show susceptibility enhancement corresponding to the limonitic beds. The enhancement of susceptibility has been attributed to accelerated weathering in the source area resulting from the temporary climatic shift from intense glacial cold to short-lived cool and wet periods. Such episodes were frequent during the LGS.

THE varve deposits at Goting (30°49′30″ N; 79°49′E), District Chamoli, were first reported by Sastri and others[1] between Malari and the Niti pass and stand out distinctly as ash grey columns against the lush green U-shaped valley floor. These workers have identified two levels of moraines intercalated with varve deposits and therefore, an interglacial stage has been assigned to the varves. This view is supported by the pollen analysis carried out on two samples that show a predominance of conifers over the pteridophytes and angiosperms, indicating a temperate climate comparable to horizon younger than the Middle Siwalik microflora[1]. However, our findings are at variance with the conclusions arrived at by these workers.

Geologically, the Goting basin is delimited by two fault planes, both trending NW–SE[2]. The southern fault line passes south of Goting along the Khal Kurans ridge, which is a subtle surface expression of the Tethyan Thrust that separates the Central Crystalline rocks from those of the Tethyan Group (Figures 1 and 2). Undifferentiated Pre-Cambrian gneisses and schists are exposed to the south of the thrust and towards the north these are juxtaposed against a succession of Maroli Group of rocks including rocks of Ralam and Garbyang formations of Cambrian age[2]. The Khal Kurans ridge rises abruptly above the surroundings and forms the southern limit of the Goting basin. Further towards NW this fault has generated a series of fault scarps and has created numerous rockfall debris in the basin (Figure 1). This rock debris has mixed with the Quaternary clays and has been wrongly identified as moraines by the earlier workers[1]. The Dhauliganga flows in N–S direction with a gentle gradient till Khal Kurans and cuts across it with a sharp bend in NW–SE direction following the fault line. The river has cut a 500 m deep gorge while emerging out of the basin at Khal Kurans (Figure 3). To the north of the basin, there exists a NW–SE trending fault in the Garbyang Formation marking the northern boundary of the basin.

Geomorphologically, the Goting is a north–south oriented basin with a narrow opening towards south through which the Dhauli drains out. The basin is bound by two ridges on either flank which form a crescentic rim (Khal Kurans ridge) towards south where it attains a general elevation of 3888 m. The valley floor has a gentle gradient (Figure 3) and has an average altitude of 3820 m but at the base of the Khal Kurans ridge it is 88 m deep. The western margin of the basin is very steep and abounds in extensive scree deposits (Figure 1). The Khal Kurans ridge acts as geomorphic barrier and has played an important role in controlling the advancement of the glacier. The narrow gorge of Dhaulingaga was blocked by the moraines dumped against this barrier, forming a proglacial lake in which the varves were laid down. Erosion has left behind a single outcrop of varves in the valley. However, the periphery of the basin has a thick veneer of ash coloured clays, indicating the extension of the proglacial like.

The precipitation regime in the Himalaya controls the spatial extent of the glaciers. In the Garhwal Himalaya, Nanda Devi massif acts as a geomorphic barrier and the precipitation regimes are different on its either side. The marked difference between the two areas is the density of ice or snow. The high density of lofty snow clad peaks along the Nanda Devi massif supports huge

[†]For correspondence. (e-mail: wihg@giasdl01.vsnl.net.in).