The buoyancy control in one ammonite genus *Buchiceras* (Hyatt, 1875) came into light through the study of epizoic oysters on it[11]. Previously, Seilacher[12] had shown this overgrowth of oysters took place when the ammonite was alive and capable of remaining afloat with the increasing weight of the oysters. In another example from Cretaceous Bagh-beds (MP), many specimens of *Placenticeras* (Meek, 1870) ammonites have oyster attachments on their internal moulds. Ammonite shells, being originally aragonitic, are very unstable during diagenesis and original shells are mostly recrystallized to calcite or undergo dissolution leaving only internal moulds. Now, overgrowth of oysters on internal moulds clearly implies that the timing of attachment must have involved some complex taphonomic processes. Organisms were buried, the original shell was dissolved during early diagenesis, leaving only indurated internal mould Specimens are reported from a hard-ground horizon which facilitates early lithification (pers commun.). These internal moulds were subsequently reworked and provided hard substrate for oyster attachment.

Raup and Stanley[13] described the Devonian bivalve, *Modiomorpha concentrica* (Conrad) with epibionts encrusting in the posterior part. Because of this preferential encrustation they concluded that the host bivalve species was alive and the animal had semi-infaunal life mode. While the present author fully agrees with their interpretation with regard to the way of life of the host animal on the basis of the evidence of epibiont attachment, the timing of attachment may not, however, be always the same.

In the present study of *G. sculpta*, it has been demonstrated that infestation was a post-mortal event since organisms show ecologic incompatibility and time-averaging. No wonder that telescoping of organisms of different environments in a single horizon has also been observed in fossil records. Fursich and Kauffman[14] for example, described freshwater unionids in life position amidst brackish water molluscs from the Albian sequence of Wyoming

Barnea is a highly variable pholadid genus belonging to the family Pholadiadae. It is usually described as a boring organism into different substrata such as stiff clay, weathered rocks, etc. and to our knowledge not a single species is known to have semi-infaunal life mode. *B. candida*, the common Indian species, is axiomatically considered as deep burrowing organism[5]. But evidence such as preferential encrustation of different epibionts along the posterior region suggests that the Indian species perhaps evolved to adapt a semi-infaunal life within stiff clay sediments without sacrificing its streamlined shape and other features which may otherwise indicate deep boring form when considered in isolation.

1. Niyogi, D., *Bull. Geol. Min. Met. Soc. India*, 1970, **43**, 1–36.
2. Pascoe, E. H., Govt. of India Publ., Calcutta, 1964, vol. 3, pp. 1–2130.
3. Cox, L. R. *et al.*, *Bivalvia-Heterodonta: Treatise on Invertebrate Palaeontology* (ed. Moore, R. C.), Geol. Soc. Am. Univ Kansas, 1969, vol. 2, p. 952.
4. Abbott, R. T., Golden Press, New York, 1986, p. 280.
5. Rao, N. V. S. (ed.), *Fauna of West Bengal*, Zool. Surv. India 1992, p. 268.
6. Chakraborti, P., *Mem. Geol. Soc. India*, 1991, pp. 25–30.
7. Chakraborti, P., *Mem. Geol. Soc. India*, 1991, pp. 165–181.
8. Bardhan, S., Ghosh, T. and Bose, S., *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1995, communicated.
9. Frey, R. W. and Basan, P. B., *Sen. Mar.*, 1981, **13**, 111–155.
10. Fursich, F. T. and Aberhan, M., *Lethaia*, 1990, **23**, 143–152.
11. Heptionstall, W. B., *Lethaia*, 1970, **3**, 317–328.
12. Seilacher, A., *J. Paleontol.*, 1960, **34**, 189–193.
13. Raup, D. M. and Stanley, S. M., *Principles of Palaeontology* CBS Publishers, New Delhi, 1985, p. 481
14. Fursich, F. T. and Kauffman, E. G., *Palaeontology*, 1984, **27** 501–536.

ACKNOWLEDGEMENT. I thank S. Bardhan, Jadavpur University for kindly reviewing the manuscript, P. K. Bose, S. K. Chanda and T Ganguly for suggesting improvements on the earlier version of this work. I am indebted to Jadavpur University for providing all infrastructural facilities.

Received 26 February 1996; revised accepted 3 September 1997

Evidence of Middle to Late Holocene neotectonic activity in the Ganga Plain

I. B. Singh*, G. Rajagopalan†, K. K. Agarwal*, P. Srivastava*, M. Sharma* and S. Sharma*

*Department of Geology, Lucknow University, Lucknow 226 007, India

†Birbal Sahni Institute of Palaeobotany, Lucknow 226 007, India

We report here the development of fracture planes, bending and tilting of the beds, and block movement in cliff section of the Sengar river, a tributary of the Yamuna river.

FORELAND basins are characterized by syndepositional activity, which is more pronounced along the orogenward as well as cratonward margins. The Ganga Plain is an active foreland basin where effects of active tectonics are evident[1]. Lately, several studies have documented evidences of active tectonics which has controlled the development of geomorphic features and the alignment of river courses in the Ganga Plain[2–10]. Based on the pattern of tectonic activity, three major zones are identified in the Ganga Plain, namely the Piedmont zone, Central alluvial plain, and Marginal alluvial plain[7,11].

The Marginal alluvial plain and the southern part of the Central alluvial plain show evidences of vertical upliftment causing deep incision of the river system[1,11,12]. In this paper, we report development of fracture planes, bending and tilting of the beds, and block movement in cliff section of the Sengar river, a tributary

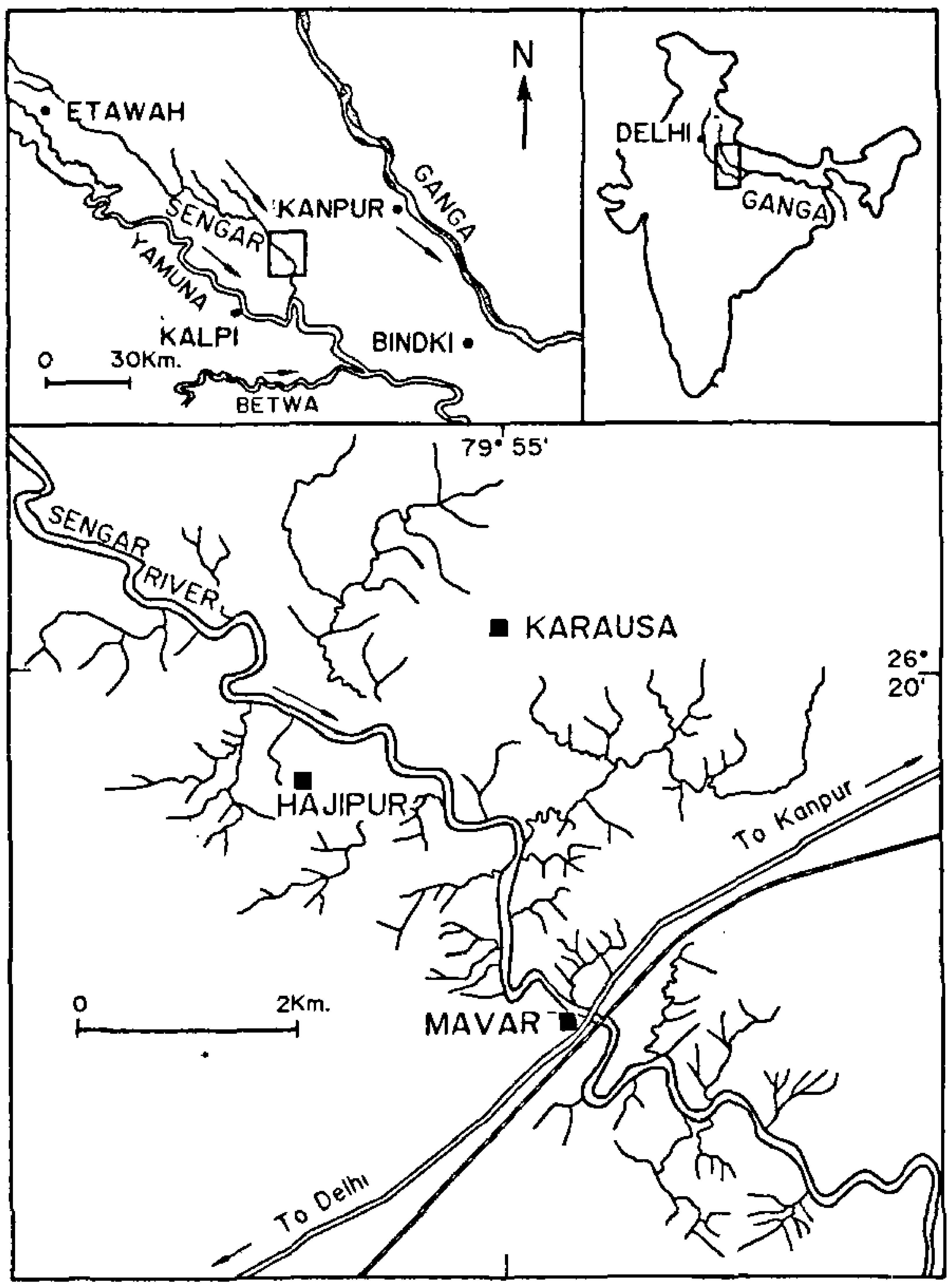

Figure 1. Location map showing area of study.

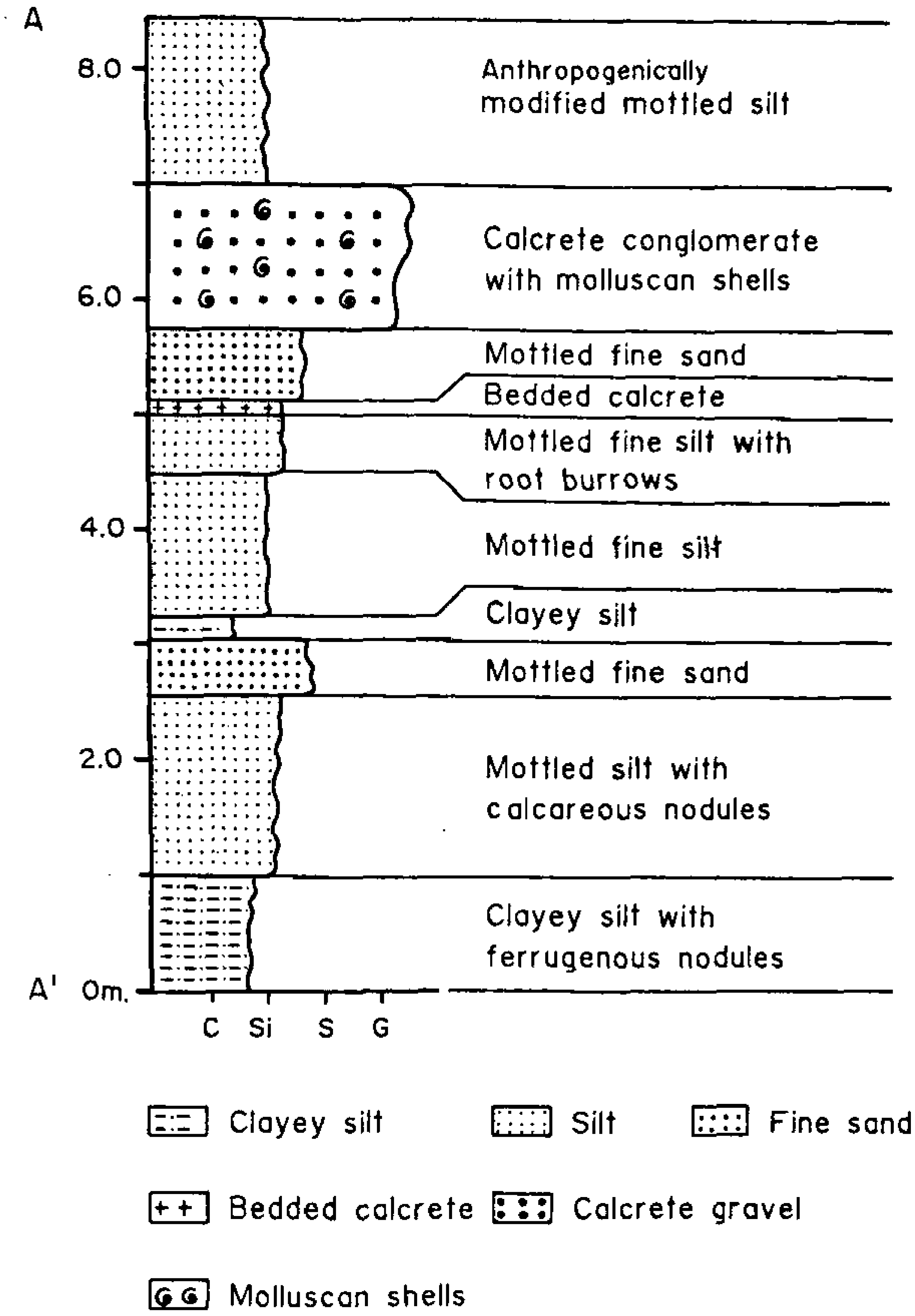

Figure 2. Litholog along the A–A′ section. The topmost lithounit of mottled silt is not developed along the section line.

of the Yamuna river in the Ganga–Yamuna Doab (Upland Interfluve) (Figure 1). The tectonic features have affected a well-developed calcrete conglomerate horizon containing shells, dated 9960 ± 80 yr BP, suggesting an episode of neotectonic activity in the Middle to Late Holocene. For the ^{14}C-dating, the bivalve shells were thoroughly cleaned, and treated with 1% HCl for 5 min to dissolve the surface material which might have got contaminated due to isotopic exchange. The sample was processed for ^{14}C assay, using the procedure described by Rajagopalan *et al.*[13]. The ^{14}C age of the shell was found to be 9020 yr ($T^{1/2}$ = 5730 ± 40 yr). Using the age calibration computer program Ver. 3.0.3 (ref. 14), and based on the dataset of the Kromer and Becker[15], the calibrated age of the sample (BS-1324) was determined as 9960 ± 80 yr.

In the generalized models proposed for the foreland basins, it is often argued that period of thrust-sheet loading in the orogen is followed by a relaxation phase, when there is increased tectonic activity in the peripheral bulge[16,17]. It has been emphasized that during relaxation phase the axial river system shifts towards orogen, and the sediments of the peripheral bulge are eroded[17,18]. However, in the case of Ganga Plain the tectonic activity in the peripheral bulge led to the vertical upliftment where the axial river system responded by making deep incision, without shifting their position[11]. The areas between two major rivers make depositional upland interfluve surfaces (doab), which are beyond the reach of the floods in the channels[11].

The stratigraphy of the upland interfluve deposits is made up of sloping surfaces, flat areas, small channels, ponds and lakes, which are exposed in the cliff sections and the ravines of the rivers[11]. A well-developed 10 m thick cliff section is exposed on the southern bank of the Sengar river near the road bridge of the NH 2 near the Mavar village (Figure 1). A generalized lithological succession is given in Figure 2. A characteristic lithology of this succession is 1.0 m thick horizon of calcrete conglomerate, rich in molluscan shells showing prominent trough cross-bedding. The clasts of the conglomerate are made up of mm to several cm size calcrete nodules; the matrix is composed of medium to coarse-grained quartz sand. It is a lensoid body showing channelized character. The bivalve shells of this horizon give an age of 9960 ± 80 yr (BS-1324) by ^{14}C-method.

The origin of this calcrete conglomerate horizon is probably due to reworking of calcrete-bearing silty sediments by rain water; winnowing away the fine-grained fraction and concentrating the coarse fraction (mainly the calcrete nodules). Concentration of this material took place in small channels, where during intense rain strong current velocities were generated to form large bedforms, which produced trough cross-bedding[19,20]. The molluscan population lived in small pools within the channel. During flood events, the molluscs were washed and deposited along with the sediments. Majority of the lamellibranchs are double-valved, suggesting their burial, while still living. This excludes the possibility of long-distance post-mortal transportation of the molluscan fauna. The horizon of calcrete conglomerate is followed by a 1.5 m thick deposit of silty clay, not present in the measured section (A–A′), but towards east of the cliff. A number of shell beds which occur several metres below the surface in the Ganga–Yamuna doab have been dated by ^{14}C-method; and a rate of sediment accumulation of 2–3 cm/100 yr has been calculated for the Holocene (unpublished data). Thus, the 1.5 m thick silty clay horizon above the calcrete conglomerate may represent deposition during time span of 9–5 ka. The topmost part is anthropogenically disturbed.

The cliff section along the Sengar river is exposed for about 200 m, with maximum elevation of 10 m above the river bed. The cliff shows prominent fractures which belong to the two sets with orientations of NNE–SSW and NNW–SSE (Figures 3 and 4), affecting the entire succession of the cliff. There are also evidences of bending of beds, which show dips of about 2° (Figure 5). One may argue that can the fractures observed be related to the compaction of the sediments? The fractures produced due to compaction show random orientations in different lithologies. The fractures described above cut across the lithological boundaries and maintain consistent geometry and orientation throughout the area of study. Hence, these fractures are product of extensional processes in response to consistent tectonic stress conditions.

Figure 3. Field photograph of the cliff along Sengar river showing two sets of fracture planes.

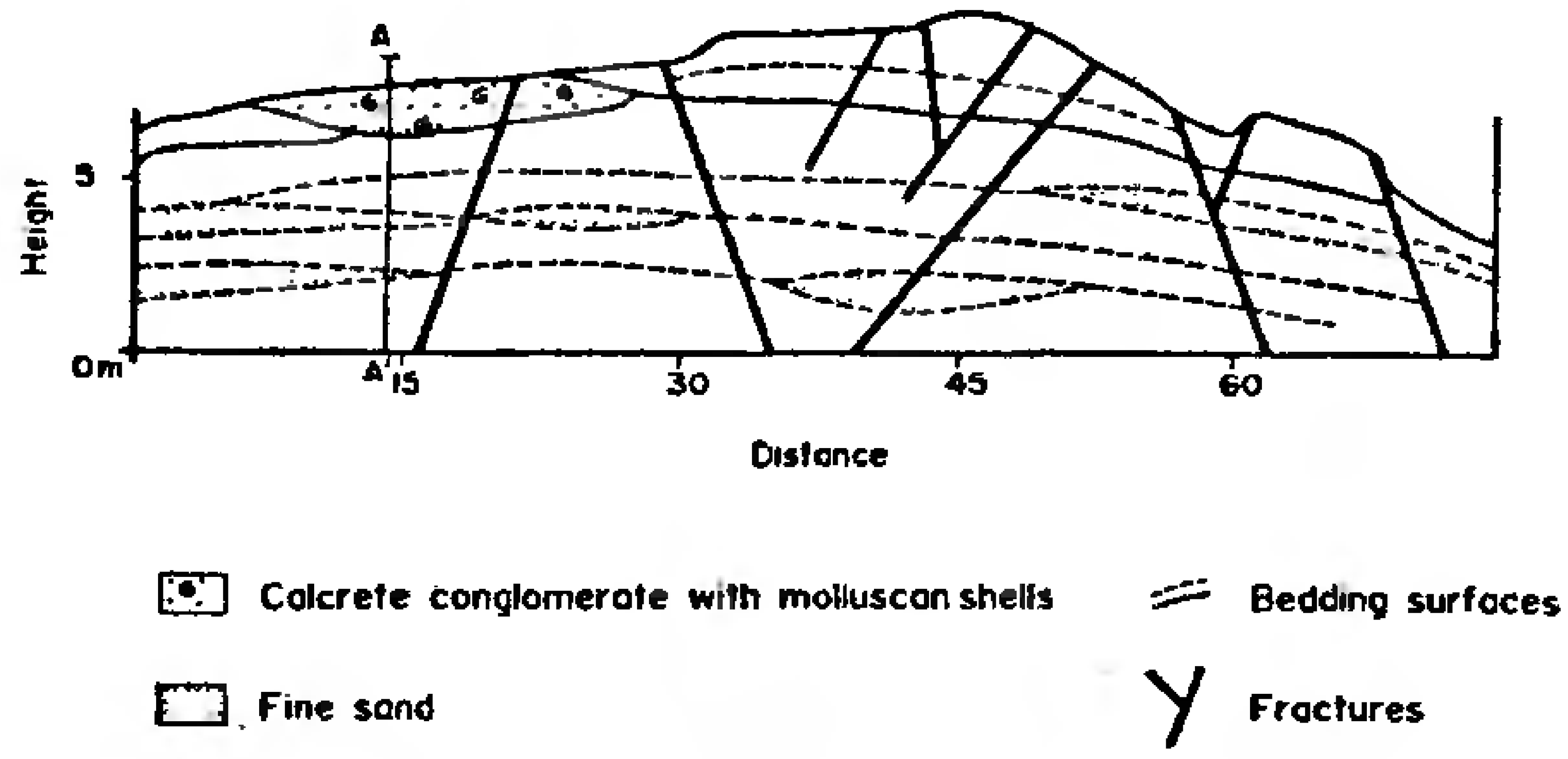

Figure 4. Sketch of the cliff along Sengar river. The major fracture planes are emphasized.

Figure 5. Field photograph showing open fracture cutting the calcrete conglomerate horizon (C). There is slight dip away from the observer.

A general survey along the Yamuna, Chambal and Sengar rivers and in the ravines of Kanpur Dehat, Jalaun and Etawah districts demonstrates that the major rivers flow mainly in the E–W direction showing cliffs of 10–30 m height. The area shows evidences of tilted blocks, domal upwarping of the sedimentary cover attaining dips of 8–10° on the flanks. The entire surveyed area shows prominent conjugate system of fractures oriented in the NNE–SSW and NNW–SSE directions. The conjugate system has controlled the breaking of the cliffs in characteristic triangular shapes, which are rotated backwards.

The continued northward push of the Indian lithosphere and the overloading in the Himalaya caused downbending of the lithosphere in the central and proximal parts of the Ganga Plain foreland basin, and upliftment in the peripheral bulge near the cratonward margin. To accommodate the sediments, there is extensional tectonics[21] to create the space near the cratonward margin of the foreland basin. Evidences of such extensional tectonics in the Ganga Plain are in the form of W–E trending faults which have affected the basement as well as the sediment cover and are mostly sites of the important rivers[1,2]. They are developed as step faults[1], similar to the half-graben structures. The conjugate fracture sets make acute angles to the W–E tectonic trend and represents accommodation zones[22] in this part of the basin. We propose here that an intense tectonic activity in the southern part of the Ganga Plain took place after 9 ka as the fractures cut across the datable calcrete conglomerate. The same fractures have also affected the overlying silty clay horizon which may have been deposited until about 5 ka. Thus the tectonic activity producing open fracture in this area may be younger than 5 ka.

Some attempts have been made to put age constraints on the geomorphic changes and soil evolution related to the neotectonic activity in the northern part of the Ganga plain[23,8]; and activity along the faults in the northwestern part of the Ganga plain[24]. However, the present study provides date to a fracture system affecting a datable horizon in the southern part of the Ganga plain. More detailed studies of the neotectonic activity in the Ganga plain are required to understand the regional tectonic framework.

1. Singh, I. B. and Rastogi, S. P., *Curr. Sci.*, 1973, **42**, 305–307.
2. Singh, I. B. and Bajpai, V. N., *J. Geol. Soc. India*, 1989, **31**, 61–66.
3. Singh, I. B. and Ghosh, D. K., Proceedings of the National Symposium on Remote Sensing for Sustainable Development, Lucknow, 1992, pp. 273–278.
4. Singh, I. B., *Indian J. Earth Sci.*, 1987, **14**, 272–282.
5. Singh, I. B. and Ghosh, D. K., in *India: Geomorphological Diversity* (eds Dikshit, K. R., Kale, V. S. and Kaul, M. N.), Rawat Publications, New Delhi, 1994, pp. 270–286.
6. Singh, I. B., in *Gangetic Plain: Terra Incognita* (ed. Singh, I. B.), Geology Department, Lucknow University, 1992, pp. 1–14.
7. Singh, I. B., Ansari, A. A., Chandel, R. S. and Misra, A., *J. Geol. Soc. India*, 1996, **47**, 599–609.
8. Srivastava, P., Parkash, B., Sehgal, J. L. and Kumar, S., *Sediment. Geol.*, 1994, **94**, 129–151.
9. Mohindra, R. and Parkash, B., *J. Geol. Soc. India*, 1994, **43**, 149–157.
10. Bajpai, V. N., *J. Indian Soc. Remote Sens.*, 1989, **17**, 47–53.
11. Singh, I. B., *J. Palaentol. Soc. India*, 1996, **41**, 99–137.
12. Misra, M. N., Srivastava, R. N., Upadhyaya, M. C. and Srivastava, M. P., *J. Geol. Soc. India*, 1994, **43**, 677–684.
13. Rajagopalan, G., Vishnu-Mitre and Sekar, B., *Radiocarbon*, 1978, **20**, 398–404.
14. Stuiver, M. and Reimer, P. J., *Radiocarbon*, 1993, **35**, 215–230.
15. Kromer, B. and Becker, B., *Radiocarbon*, 1993, **35**, 125–135.
16. Hellar, P. L., Angevine, C. L., Winslow, N. S. and Paola, C., *Geology*, 1988, **16**, 501–504.
17. Tankard, A. J., *Spl. Publ. Int. Assoc. Sedimentol.*, 1986, **8**, 369–392.
18. Burbank, D. W. and Beck, R. A., *Geol. Rundsch.*, 1991, **80**, 623–638.
19. Reineck, H. E. and Singh, I. B., *Depositional Sedimentary Environments*, Springer-Verlag, Berlin, 1982.
20. Allen, J. R. L., *Sedimentary Structures, Their Character and Physical Basis*, Elsevier, Amsterdam, 1984.
21. Laubscher, H. P., *Tectonophysics*, 1978, **47**, 325–337.
22. McClay, K. R., *Spl. Publ. Geol. Soc. London*, **99**, 201–225.
23. Mohindra, R., Parkash, B. and Prasad, J., *Earth Surface Processes and Landforms*, 1992, **17**, 643–662.
24. Kumar, S., Parkash, B., Manchanda, M. L., Singhvi, A. K. and Srivastava, P., *Z. Geomorphol. N.F.*, 1996, **40**, 283–312.

ACKNOWLEDGEMENTS. We thank UGC and CSIR for providing financial support to undertake this study. We are highly indebted to Mr Lal Hem Rudra Singh of Etawah and Shri Prakash Agarwal of Auraiya for providing the logistic support and to the technical staff of ^{14}C laboratory in the Birbal Sahni Institute for carrying out the age measurements.

Received 9 June 1997; revised accepted 20 October 1997

Landslide hazard analysis of the area around Dehra Dun and Mussoorie, Uttar Pradesh

Sambhu V. Panikkar and V. Subramanyan

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

Landslides are a common natural hazard in mountainous terrain like the Himalaya. In the present study, an area of 445 sq km around Dehra Dun and Mussoorie in Uttar Pradesh has been considered for landslide hazard analysis on a geomorphological basis. The analysis involves classification of the terrain into homogeneous units (terrain mapping subunits) based on relevant geomorphic parameters, and consequently the geomorphic processes including occurrence of landslides. The hazard in these units is evaluated on the basis of field settings. Decision rules for the allotment of a hazard score to a unit have also been framed. The data on geomorphological complexes, lithology, drainage density, relief and landslide distribution were used in a geographical information system (GIS) for the analysis. A final landslide hazard map with four classes – very high, high, low and very low has been prepared. Such a map proves extremely useful as a first generation map for planning detailed surveys in the high hazard areas. The effect of human interference on the environment, particularly depletion of the forest cover has been studied. The landuse/land cover data for a period of 60 years were analysed in a GIS to study the changes in the forest cover. The forested areas account only for 9% of the landslide occurrence. About 60% of the landslides are in non-forested areas that were forested in 1930.

LANDSLIDES are one of the many natural hazards that can affect human population adversely. They may range in size from small slides causing only minor problems to gigantic ones resulting in destruction of life and property. Landslide studies have traditionally been carried