prerequisite conditions. The higher durations of 29 ka ($S_3$–$S_5$), 24 ka ($S_5$–$S_6$) and 26 ka in the fluvial part of the section may be due to periodic non-deposition and at places due to erosion. Ideally, it would have been desirable to obtain ages on all eight seismites, but as indicated above, logistical problems restricted collection of only four seismite samples.

The present study provided luminescence chronology to four soft sediment deformation structures designated as seismites based on their lateral extension of deformation and similarity to other known occurrences of earthquake-induced deformation structures in soft sediments. The chronology of seismites $S_3$, $S_5$, $S_6$, $S_8$ are 90, 61, 37 and 26 ka respectively, indicating that $S_1$ and $S_2$ are significantly older than 90 ka, whereas the younger episodes would post-date 26 ka. This indicates that the Kaurik–Chango Fault and related seismicity has been active at least since the late Pleistocene.

1. Singhvi, A. K., Banerjee, D., Pande, K., Gogate, K. and Valdiya, K. S., *Quat. Geochronol.*, 1994, **13**, 595–600.
2. Mohindra, R. and Bagati, T. N., *Sediment. Geol.*, 1996, **101**, 69–83.
3. Anand, A. and Jain, A. K., *Tectonophysics*, 1987, **133**, 105–120.
4. Fort, M., Burbank, D. W. and Freytet, P., *Quat. Res.*, 1989, **31**, 332–350.
5. Allen, C. R., *Bull. Geol. Soc. Am.*, 1975, **86**, 1041–1057.
6. Sieh, K. E., *J. Geophys. Res.*, 1978, **83**(B8), 3907–3939.
7. Sims, J. D., *Science*, 1973, **182**, 161–163.
8. Sims, J. S., *Tectonophysics*, 1975, **29**, 141–152.
9. Weaver, J. D., *Geol. Mag.*, 1976, **113**, 535–543.
10. Vita-Finzi, C., *J. Geol. Soc. London*, 1992, **149**, 257–260.
11. Ikeya, M., Miki, T. and Tanaka, K., *Science*, 1982, **215**, 1392–1393.
12. Forman, S. L., Machette, M. N. and Jackson, M. E., *J. Geophys. Res.*, 1989, **94**, 1622–1630.
13. Buhay, W. M., Schwarcz, H., and Grun, R., *Quat. Sci. Rev.*, 1988, **7**, 515–522.
14. Vohra, S., M Tech dissertation, University of Roorkee, Roorkee, 1987.
15. Hutt, G., Jack, I. and Tchonka, J., *Quat. Sci. Rev.*, 1989, **7**, 381–385.
16. Aitken, M. J., *Thermoluminescence Dating*, Academic Press, London, 1985, pp. 359.
17. Berger, G., *Geol. Soc. Am., Spl. Paper*, 1988, **227**, 13–49.
18. Stokes, S., *Quat. Sci. Rev.*, 1992, **11**, 153–159.
19. Balescu, S. and Lamothe, M., *Quat. Geochronol.*, 1994, **13**, 437–444.
20. Gansser, A., *Geology of the Himalayas*, Interscience, New York, 1964, pp. 287.
21. Valdiya, K. S., *Ann. Tect.*, 1992, **VI**, 54–84.
22. Hayden, H. H., *Mem. Geol. Surv. India*, 1904, **6**, 1–121.
23. Gupta, J. and Virdi, N. S., *J. Geol. Soc. India*, 1975, **16**, 512–514.
24. Scott, B. and Price, S., *Tectonophysics*, 1988, **147**, 165–170.
25. Seed, H. B., *J. Soil Mech.*, 1968, **94**, 1055–1922.
26. Singhvi, A. K. and Aitken, M. J., *Ancient TL*, 1978, **3**, 2–9.
27. Aitken, M. J., *Thermoluminescence Dating*, John Wiley, NY, 1985.
28. Prescott, J. R., Huntley, D. J. and Hutton, J. T., *Ancient TL*, 1993, **11**, 1–5.
29. Chawla, S., Dhir, R. and Singhvi, A. K., *Quat. Sci. Rev.*, 1992, **11**, 25–32.

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# Tectonic settings of Indo-Gangetic basin revealed from magnetotelluric data

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**The Indo-Gangetic basin is one of the vast sedimentary basins of India. The knowledge of the subsurface tectonic structure of the basin and shield regions is important in understanding the dynamics of the lithosphere and for the knowledge of its hidden resources. Magnetotelluric (MT) data have been collected at 18 locations along two profiles north-south – Nepal border to Kanpur and east-west – Varanasi to Agra. MT parameters have been analysed at these locations. The pseudo-resistivity and phase plots have revealed resistivity structure and tectonic settings of the basin. The extension of the shield beneath the Indo-Gangetic basin has also been inferred from the MT data.**

INDO-Gangetic basin has an extensive coverage of 25,000 km$^2$ lying between Peninsular shield and Himalayan region (Figure 1). The region lies between the Himalayan mountains on northern side and Indian Peninsular shield on the southern side. The depression of the Indo-Gangetic plains is foredeep. In the north, this region is bounded by the Siwalik hills and in the south by the Bundelkhand granites/gneisses and Vindhyan sandstones. The Indo-Gangetic basin constitutes an asymmetrical prism of sediments with an axis of maximum deposition very close to the present foothills[1]. The basin continues to be a tectonic enigma despite its outward simplicity as a vast alluvial plain. Burrard[2] interpreted it as a rift filled with alluvium to a depth of nearly 16 km and as a trough at the advancing edge of the steeply subducting Indian plate. He further suggested on the basis of the geodetic observations that the Himalayan folds were the result of under thrusting of the Indian sub-crust below the land mass of the central Asia. Burrard believed that this observation explained mass deficiency of the Indo-Gangetic and Himalayan region.

The gravity and aeromagnetic measurements have been carried out in detail in the Indo-Gangetic basin[3-10]. On the basis of gravity and aeromagnetic data, the Indo-Gangetic basin has been divided into four different parts separated by basement. The basement high is the Bundelkhand–Faizabad ridge, which is found to be tectonically and seismologically inactive[9]. A number of traverse folds of mesoscopic and macroscopic dimensions have been mapped which are superposed on earlier folds of normal Himalayan trend and are parallel to great hidden ridge in the basement of the Indo-Gangetic plains. Surface wave data have been used to decipher a shield like upper mantle structure with thick sedimentary fills[11-12].

Efforts have been made to map the deeper structure of the Indo-Gangetic basin using various geophysical methods. The well-known seismic method which is commonly used for mapping deeper structure has not been used widely in the Indo-Gangetic basin due to high population. Recently, we have carried out magnetotelluric (MT) field work in the basin along two profiles AA′ from Kanpur to Nepal border and BB′ from Varanasi to Agra. The details about the MT equipment, data acquisition and data analysis have been given in detail by Singh *et al.*[13,14]. The locations of the MT soundings are shown in Figure 1. The deeper electrical resistivity structure has been mapped[13]. In the present communication, MT data have been analysed to study the subsurface geological settings of the basin. Singh *et al.*[13] found that the H-polarization MT data is affected by the distortion due to the sediments in the Indo-Gangetic basin and also due to the Himalayan range. Berdichevskiy and Dmitriev[15] reported that the determinant apparent resistivity and phase data are good indicators of average structure in two measurement directions. In view of the distortion of H-polarization apparent resistivity and phase data, we have analysed determinant apparent and phase data and have deduced the subsurface configuration beneath the Indo-Gangetic basin.

Figures 2 *a, b* show the pseudo-resistivity and phase plots from determinant data along profile Kanpur–Nepal border. The pseudo-resistivity plot (Figure 2 *a*) shows the presence of low-resistivity layer near the surface in Kanpur followed by high-resistivity layer. This high-resistivity layer corresponds to massive Bundelkhand Granite (represented by higher values of apparent resistivity contours) which is exposed near Jhansi. The apparent resistivity contours clearly show that the layers are dipping towards north and the Bundelkhand Granite

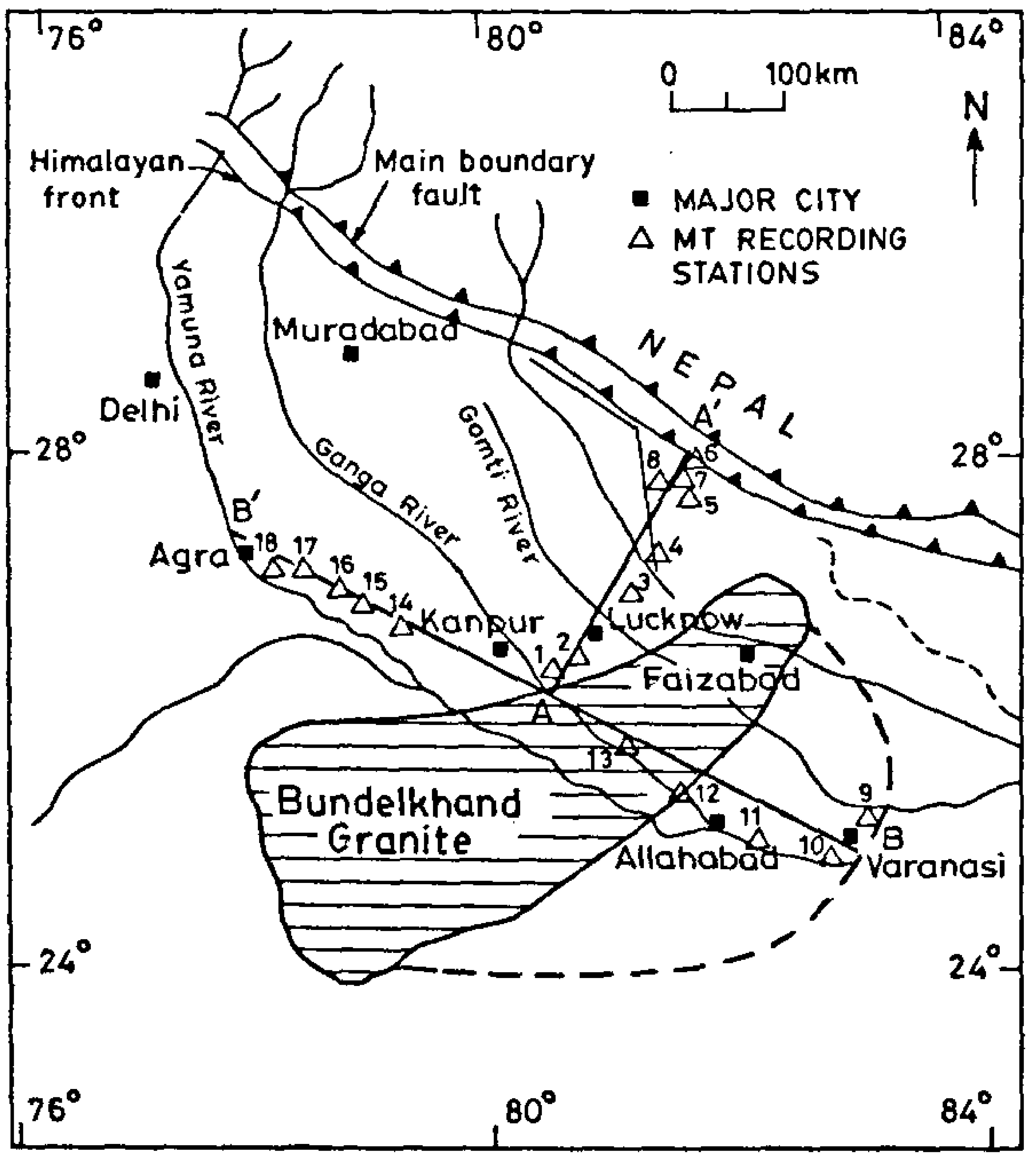


Figure 1. Location of magnetotelluric recording stations.

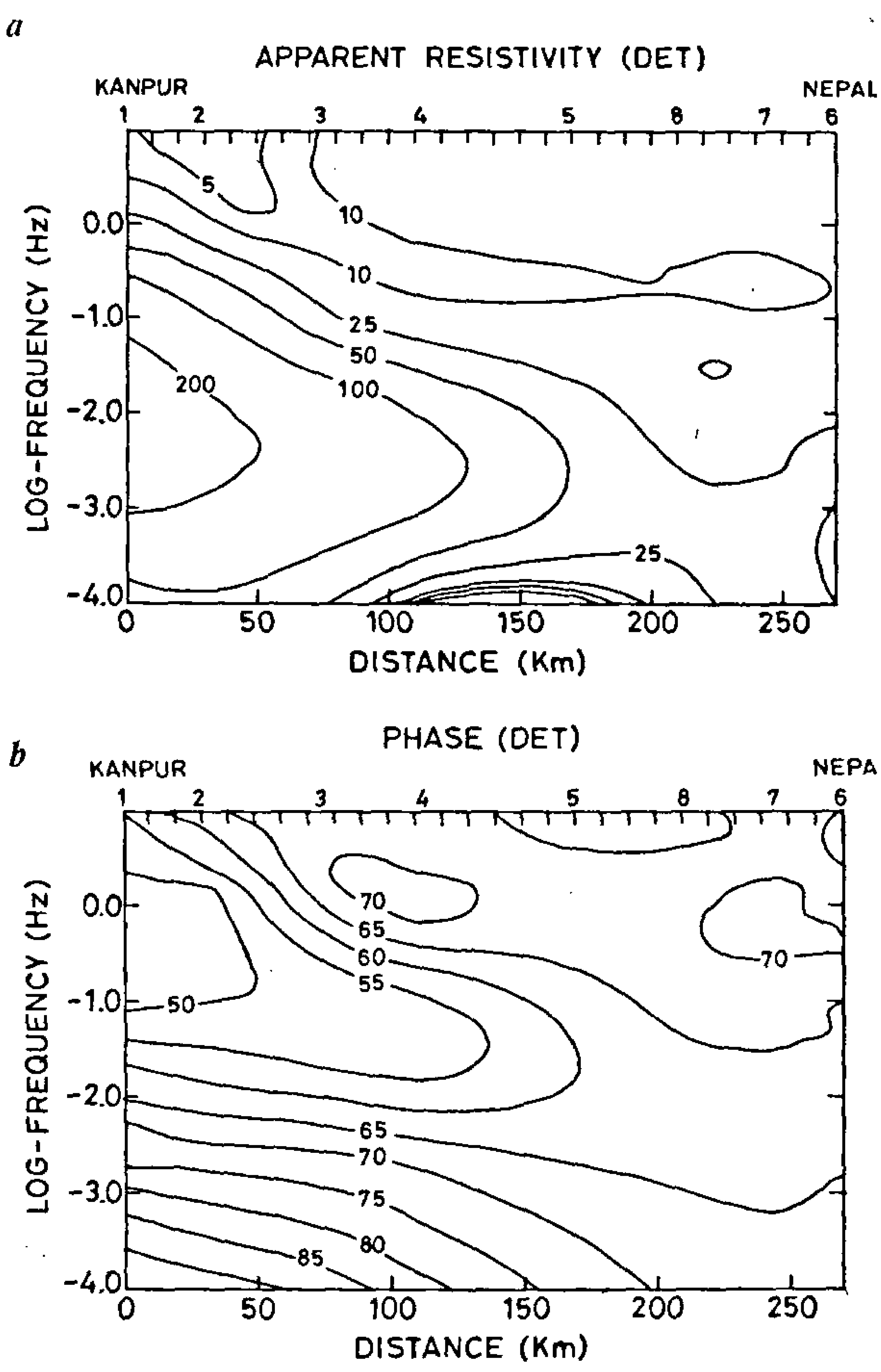


Figure 2. (*a*), Pseudo-resistivity plot and (*b*) pseudo-phase plot along profile Kanpur–Nepal border.

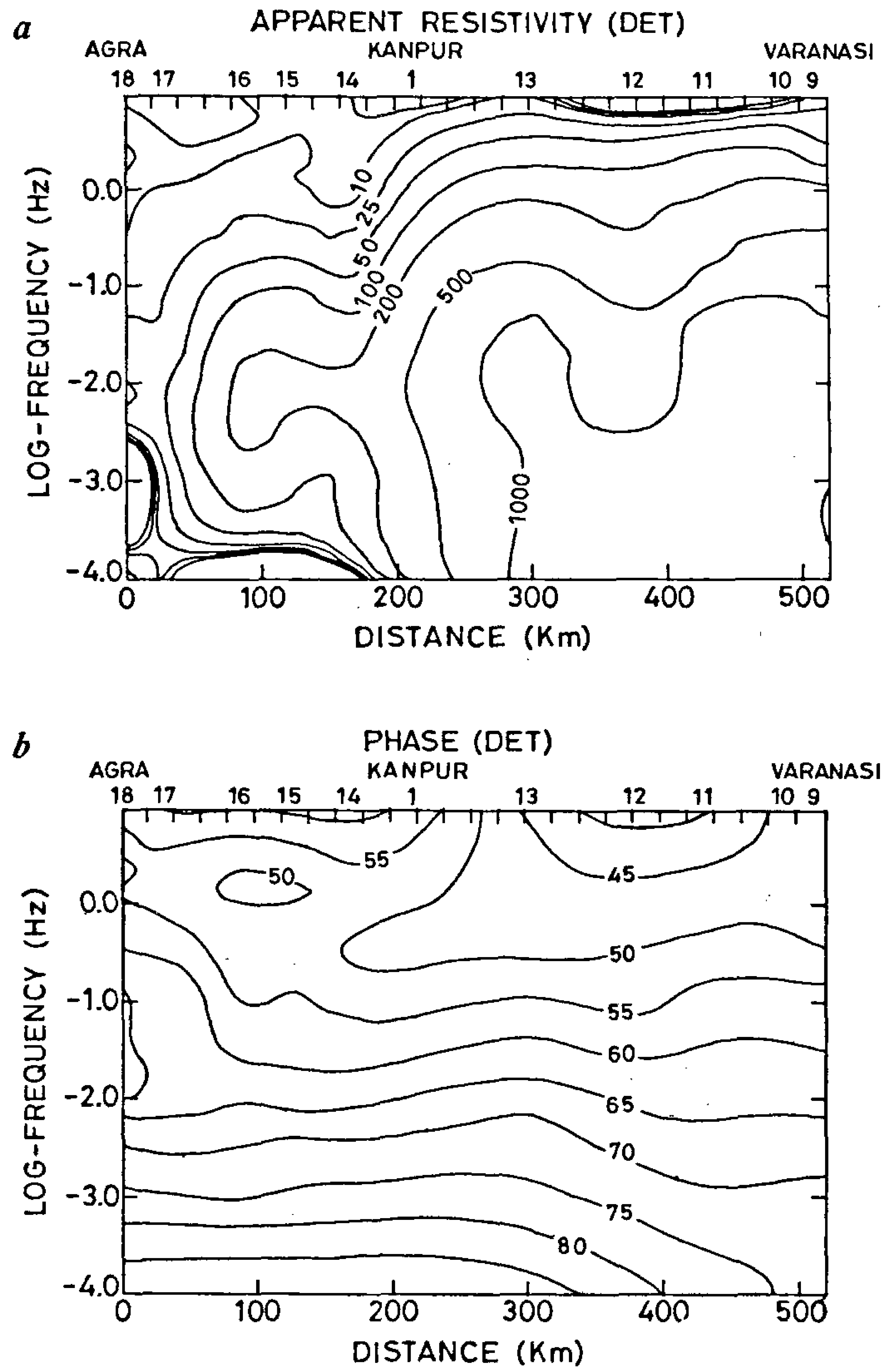


**Figure 3.** (*a*), Pseudo-resistivity plot and (*b*) pseudo-phase plot along Agra–Varanasi.

(represented by higher values of apparent resistivity contours) underlie the Indo-Gangetic basin up to stations 4 in north along Kanpur–Nepal border (profile AA′), which confirms the extension of the shield beneath the Indo-Gangetic basin. This is also supported by the pseudo-phase plot. The low phase values correspond to high-resistivity formations whereas higher phase values correspond to conductive formation. It is seen that beneath massive granite formation (represented by the phase value contours of 50–60 degrees contours) presence of higher conducting formation (represented by phase value contours of more than 60 degrees) is clearly seen. At the extreme north of the profile, beneath locations 7 and 6, presence of high conducting formation is seen which corresponds to low apparent resistivity of 10 ohm-m (Figure 2 *a*) and high phase value contour of 70 degree. The apparent resistivity and phase contours at low frequencies clearly show that the layers are dipping towards north, which confirms the northward dipping of Indian crust.

Figures 3 *a*, *b* show the pseudo-resistivity and phase plots along profile Agra to Varanasi. The higher apparent resistivity contours are seen from location 1 (Kanpur) to Varanasi which show the presence of higher resistivity formation corresponding to either extension of massive Bundelkhand Granite and/or extension of Vindhyan Formation beneath the Indo-Gangetic basin. The pseudo-apparent resistivity plot shows up warping of the basement which is also supported from aeromagnetic data[8–9]. Near locations 14 and 1, the pseudo-apparent resistivity plot shows the contact of low and high resistivity formations. It is seen that beneath Agra to Kanpur (beneath locations 17–14) near the surface of the earth the formation is conducting followed by high resistivity formation. At deeper level, the extension of Bundelkhand Granite is seen. The pseudo-resistivity plots show the high resistivity formations even up to very low frequencies. In pseudo-phase plots this formation is reflected by very high frequencies. The presence of low resistive formation beneath high resistivity formation below stations 16 and 17, is reflected by higher phase values at lower frequencies (Figures 3 *b*). The western extension of Bundelkhand Granite beneath the Indo-Gangetic basin is seen up to location between station numbers 16 and 17 (Figure 3 *b*).

The present study shows the tectonic settings of the Indo-Gangetic basin along two profiles. The pseudo-resistivity and phase contours confirm the extension of Bundelkhand Granite beneath the Indo-Gangetic basin. It is also found that the upper crust is dipping northward. The pseudo-resistivity and phase plots along east-west (Varanasi–Agra) profile show the contact point of hard and soft rock formations near Kanpur and extension of hard rock formation up to Varanasi in east and up to a station 17 in the west. This may be attributed to either extension of Bundelkhand Granite up to Varanasi or Vindhyan Formation from south beneath locations 11–9 (Allahabad–Varanasi). The apparent resistivity and phase values do not show any discontinuity in the contours, therefore it is concluded that the Bundelkhand Granite, which is identified as Faizabad ridge, extends up to Varanasi and beyond in the east and up to near Agra in the west. In the light of present study, the boundary of the Bundelkhand Granite is shown by the dotted line showing its extension up to Varanasi (Figure 1). Further, MT studies beyond Varanasi should be taken up to delineate the exact boundary of massive granitic formation.

1. Riverman, V., Kunte, S. V. and Mukherjee, A., *Petroliferous Basins of India*, Himanchal Times Group, Dehradun, 1983, pp. 67–92.
2. Burrard, S. G., *Proc. R. Soc. London*, 1915, **91A**, 220–238.
3. Sengupta, S. N., in *Geophysical Case Histories of India* (ed. Bhimasankaram, V. L. S.), AEG, Hyderabad, 1977, vol. 1, pp. 1–8.

4. Agarwal, R. K., in *Geophysical Case Histories of India* (ed. Bhimasankaram, V. L. S.), AEG, Hyderabad, 1977, vol. 1, pp. 27–46.
5. Rao, M. B. R., *J. Geol. Soc. India*, 1973, **14**, 217–242.
6. Sastri, V. V., Bhandari, L. L., Raju, A. T. R. and Datta, A. K., *J. Geol. Soc. India*, 1971, **12**, 222–233.
7. Sengupta, S. N., Proceedings of the 22nd International Geological Congress, 1964, vol. 11, pp. 334–352.
8. Qureshy, M. N., *Tectonophysics*, 1969, **7**, 137–157.
9. Qureshy, M. N., *J. Geophys. Res.*, 1971, **76**, 545–557.
10. Valdiya, K. S., *Tectonophysics*, 1976, **32**, 353–386.
11. Gupta, H. K., Nyman, D. C. and Landisman, M., *Earth Planet. Sci. Lett.*, 1977, **34**, 51–55.
12. Gupta, H. K. and Narain, H., *Bull. Seismol. Soc. Am.*, 1967, **97**, 235–248.
13. Singh, R. P., Kant, Y. and Vanyan, L., *Phys. Earth Planet. Int.*, 1995, **88**, 273–283.
14. Singh, R. P., Kant, Y. and Rastogi, A., *Indian J. Petroleum Geol.*, 1992, **1**, 258–271.
15. Berdichevskiy, M. N. and Dmitriev, V. I., *Acta. Geod. Geophys. Montan. Acad. Sci. Hung.*, 1976, **11**, 447–483.

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# Interaction of *Bacillus thuringiensis* with *Pythium ultimum* and *Fusarium oxysporum* f. sp. *lycopersici*: Possible role in biological control

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***Bacillus thuringiensis*** **(Bt) suppressed the growth of** ***Pythium ultimum*** **and** ***Fusarium oxysporum*** **f. sp.** ***lycopersci*** **and lysed the mycelium. Scanning electron micrographs showed the attachment of Bt cells to the hyphae of host pathogens. Bt cells attached to hyphae of** ***P. ultimum*** **polarly and externally, causing its deformation and lysis. In case of** ***F. oxysporum*** **f. sp.** ***lycopersici*****, the attachment was random and at a few places Bt cells entered the hyphae and caused lysis.**

In the search for new eco-friendly approaches to pest and pathogen management, use of biological control agents has been much studied. Researches on biological control of soil-borne plant pathogens have been making great strides since the first symposium 'Ecology of soil-borne plant pathogens – Prelude to biological control'[1].

*Bacillus thuringiensis*, which is unique in the bacterial world because of production of many chemical compounds designed for use in controlling economically and biomedically important insects, is being tested against fungal pathogens[2]. A nematode fungal disease complex of tomato was reported to be controlled by dipping seedlings in the suspension of *B. thuringiensis*[3]. Some bacteria like *Enterobacter cloacae* protect the plants against Pythium pre-emergence damping off caused by *P. ultimum* by binding to fungal hyphae[4]. However, the mechanism by which *B. thuringiensis* protects the plants/seedlings from soil-borne fungal pathogens is unknown. Therefore, a study was undertaken to investigate interaction between *B. thuringiensis* and *P. ultimum* and *Fusarium oxysporum* f. sp. *lycopersici*, causing wilting of seedlings of various crops[5], which could be utilized as a potential biocontrol agent.

A strain of *B. thuringiensis* obtained from Division of Entomology, Indian Agricultural Research Institute, New Delhi, was maintained on nutrient agar medium for the present studies.

Cultures of *P. ultimum* and *F. oxysporum* f. sp. *lycopersici* were isolated from soil by the dilution plate method and maintained on potato dextrose agar (PDA) slants. The cultures were identified by Indian Type Culture Collection (ITCC), New Delhi.

Potato dextrose agar plated petri plates were seeded at four corners with actively growing mycelial disc of *P. ultimum* and *F. oxysporum* f. sp. *lycopersici*. A loopful of 24 h growth of *B. thuringiensis* was seeded in the centre of each petri plate. The inoculated plates were incubated at 25°C for 4 days and mycelium from the interaction zone was processed for scanning electron microscopy.

The procedure given by Weidenborner *et al.*[6] was followed. Agar discs of 1 mm thickness were cut off from interaction zone and placed on cover glasses which were exposed to 2% osmium tetroxide for 24 h at 20°C. The samples were transferred to copper stubs over double adhesive tape, coated with gold in JEOL, JFC-1100E sputter coater and scanned in a SEM (JEOL-JSM 5200) at 25 kV and micrographs were taken.

In dual culture, the growth of *P. ultimum* and *F. oxysporum* f. sp. *lycopersici* was suppressed and mycelium was seen lysed. In case of *P. ultimum*, a narrow inhibition zone was also observed (Figure 1 *a*), while no clear inhibition zone was seen in *F. oxysporum* f. sp. *lycopersici* (Figure 1 *b*).

Scanning electron micrographs of the paired culture of *F. oxysporum* f. sp. *lycopersici* and *B. thuringiensis* showed attachment of around 9–10 bacterial cells to the hyphae of the fungal pathogen. The bacterial cells were attached more or less over the hyphal surface and at the site of attachment the hyphae were lysed (Figure 2 *a*, *b*). At a few places, bacterial cells seemed entering the mycelium as cracks in the wall were observed at