the open sea and deposited in calm water bodies, such as lagoon/lake, where these shales were deposited and specimens got preserved.

Hofmann[1] proposed that the *Tawuia-Chuaria* assemblage zone can be considered as a potential chrono-biostratigraphic marker, and considered the period from 1.1–0.7 Ga as the Chuarian age. Although the OSF assemblage compares closely with the Mesoproterozoic Suket Shales assemblage, which predominantly comprises Chuarid and Grypanid remains, it shows closer similarity with the Rewa and Bhander assemblages which are Neoproterozoic in age. In the present assemblage, neither *Grypania spiralis* nor any other similar form has been noted. Hence on correlation, we presume that the Kurnool Formation is coeval to the Rewa and Bhander Groups of the Vindhyan Supergroup and the Halkal Formation of the Bhima Group. Thus, the present assemblage indicates a Neoproterozoic age for the OSF. Further search in the area may add to the diversity of palaeobiological remains of the Owk Shales Formation.

1. Hofmann, H. J., *Palaeontology*, 1985, **26**, 331–354.
2. Hoffman, H. J., in *The Proterozoic Biosphere* (eds Schopf, J. W. and Klein, C.), Cambridge Univ. Press, Cambridge, 1992, pp. 349–357.
3. Jones, H. J., *Rec. Geol. Surv. India*, 1909, **3**, 66.
4. Sanhi, M. R., *Rec. Geol. Surv. India*, 1936, **69**, 458–468.
5. Sanhi, M. R., *J. Pal. Soc. India*, 1977, **20**, 289–304.
6. Maithy, P. K. and Shukla, Manoj, *Palaeobotanist*, 1977, **23**, 176–188.
7. Kumar, S., *Precambrian Res.*, 1995, **73**, 291–298.
8. Rai, V., Shukla, M. and Gautam, R., *Curr. Sci.*, 1997, **73**, 783–788.
9. Kumar, S. and Srivastava, P., *J. Pal. Soc. India*, 1997, **42**, 141–146.
10. Gowda, S. S., Venugopal, S. K. and Sundara Raju, T. P., *Prof. Kurian's 60th Birthday Commemoration Vol.*, 1979, pp. 170–172.
11. Suresh, R. and Sundara Raju, T. P., *Precambrian Res.*, 1983, **23**, 79–85.
12. Das Sarma, D. C., Raha, P. K., Moitra, A. K., Ashok Kumar, P., Ananthraman, S., Rama Rao, U. and Sundram, V., *Curr. Sci.*, 1992, **63**, 140–142.
13. Sharma, Mukund and Shukla, Manoj, in *30th International Geological Congress*, Beijing, 1996, Abstract, vol. 2, p. 52.
14. Maithy, P. K. and Babu, Rupendra, *Palaeobotanist*, 1996, **45**, 1–6.
15. Rajurkar, S. T., *Indian Minerals*, 1963, **17**, 306–307.
16. King, W., *Mem. Geol. Surv. India*, 1872, **8**, 313.
17. Dutta, N. V. B. S., Ramesh Publications, Hyderabad, 1975, p. 205.
18. Nagaraja Rao, B. K., Rajurkar, S. T., Ramalingaswamy, G. and Ravindrababu, B., *Mem. Geol. Soc. India*, 1987, **6**, 32–36.
19. Ford, T. D. and Breed, W. J., *Palaeontology*, 1973, **16**, 535–550.
20. Vidal, G., *Fossil Strata*, 1976, **9**, 1–57.
21. Vidal, G. and Ford, T. D., *Precambrian Res.*, 1985, **28**, 349–389.
22. Maithy, P. K. and Shukla, M., *Palaeobotanist*, 1977, **23**, 176–188.
23. Sun, W., *Palaeontographica*, 1987, **B203**, 109–134.
24. Gussow, W. C., *J. Palaeontology*, 1973, **47**, 1108–1112.
25. Steiner, M., *Berliner Geowissenschaftliche Abhandlungen*, 1994, **E15**, 1–146.
26. Hofmann, H. J. and Aitken, J. D., *Can. J. Earth Sci.*, 1979, **16**, 150–166.
27. Duan, Chenghua, *Alcheringa*, 1982, **6**, 57–68.
28. Knoll, A. K., *Geol. Mag.*, 1982, **119**, 269–279.
29. Du Rulin and Tian, Lifu, *Precambrian Res.*, 1985, **29**, 5–14.
30. Walcott, C. D., *Smithsonian Misc. Coll.*, 1919, **67**, 217–260.
31. Tyler, S. A., Barghoorn, E. S. and Barret, L. P., *Bull. Geol. Soc. Am.*, 1957, **68**, 1293–1304.
32. Walcott, C. D., *Bull. Geol. Soc. Am.*, 1899, **10**, 199–244.
33. Han, T. and Runnegar, B., *Science*, 1996, **257**, 232–235.
34. Hofmann, H. J. and Chen, Jinbiao, *Can. J. Earth Sci.*, 1981, **18**, 443–447.
35. Brasier, M. D., Perejón, A. and De San José, M. A., *Estudios Geol.*, 1979, **35**, 379–383.
36. Nagaraja Rao, B. K., Rajurkar, S. T., Ramalingaswamy, G. and Ravindra Babu, B., *Mem. Geol. Soc. India*, 1987, **6**, 33–86.
37. Dutta, N. V. B. S., *Rec. Geol. Surv. India*, 1962, **87**, 549–694.

ACKNOWLEDGEMENTS. We are thankful to Dr Vibhuti Rai for going through the earlier version of the manuscript. Mukund is grateful to Mr Rajeshwar Tewari, Collector, Kurnool, who helped in our having access to several remote areas of the basin.

Received 31 October 1998; revised accepted 27 January 1999

Neotectonism – An offshore evidence from eastern continental shelf off Visakhapatnam

A. S. Subrahmanyam*, K. Venkateswarlu, K. S. R. Murthy, M. M. Malleswara Rao, K. Mohana Rao and Y. S. N. Raju

National Institute of Oceanography, Regional Centre, 176, Lawsons Bay Colony, Visakhapatnam 530 017, India

A minor tremor measuring 4.5 on the Richter scale occurred around 4.58 p.m. on 18 December 1995, with its epicentre located in the Bay of Bengal, nearly 30 km east of Vizianagaram on the Andhra Pradesh coast. The location of the epicentre is around 18°N and 83°42'E. It is significant that the epicentre falls in the innershelf off Vizianagaram, where a suite of rocks (Santapalle Rocks) outcrop at a water depth of around 30 m.

Bathymetry and magnetic data were collected over this region along closely spaced, coast parallel profiles covering the shelf regions. Observed magnetic anomalies are of short wavelength and high amplitude of the order of 600 to 700 nT. Two-dimensional modelling of these anomalies with conventional as

*For correspondence.

well as inversion methods indicates a severely faulted and folded basement of the order of 1 to 6 km. Three closely spaced river channels (Nagavali, Vamsadhara and Nellimarla) trending NW–SE are associated with the faulted and folded basement. Faulting associated with the Nellimarla river channel extending into the offshore zone may be the possible cause of the tremor.

Strong magnetic anomalies, complex basement structure, exposed rock outcrops in the innershelf (20 m) in the vicinity of the epicentre of Vizianagaram earth tremor provide evidence of Neo-tectonic activity in this region. The epicentral region falls in a shallow marine environment ideal for generating a geophysical database for stable continental region earthquakes.

THE plate tectonics theory assumes that a strong lithosphere overlies the weaker asthenosphere and lithospheric plates are undeformed except at their boundaries. Some observations that apparently violate these assumptions are recorded from the Central Indian Ocean Basin (CIOB) like intraplate seismicity, anomalous heat flow, deformed oceanic crust and overlying sediments which stand as the example of intraplate deformation of the oceanic lithosphere resulting from compressional forces in the equatorial Indian Ocean.

Southern peninsular India, bounded by passive margins, is so far considered stable being an intraplate zone. But this view is belied by the recent occurrences of earthquakes in Latur (Maharashtra) and Jabalpur (Madhya Pradesh).

Geophysical, geological and geomorphological studies of south India revealed neotectonic activity represented by:

(1) A basement upwarp along 13°N latitude acting as a water divide separating north flowing rivers from south flowing rivers[1].
(2) A lineament close to 13°N latitude identified as a new seismogenetic belt[2].
(3) A significant change in magnetic anomaly pattern off Chennai at 13°N latitude interpreted as a major structural discontinuity[3].
(4) Well-documented regional lineaments on Quaternary and recent sediments[4], deformation of south Indian shield into a series of E–W arches and depression due to stress-related activity[5] from remote sensing studies and occurrence of several faults in the surface and sub-surface sediments from high resolution shallow seismic data off Bhimunipatnam and Pudimadaka[6]. The present study deals with magnetic data in the offshore zone off Visakhapatnam–Kalingapatnam.

Total field magnetic data used in the present study were collected during the 245th cruise of *RV Gaveshani* along three coast parallel profiles (Figure 1) between 30

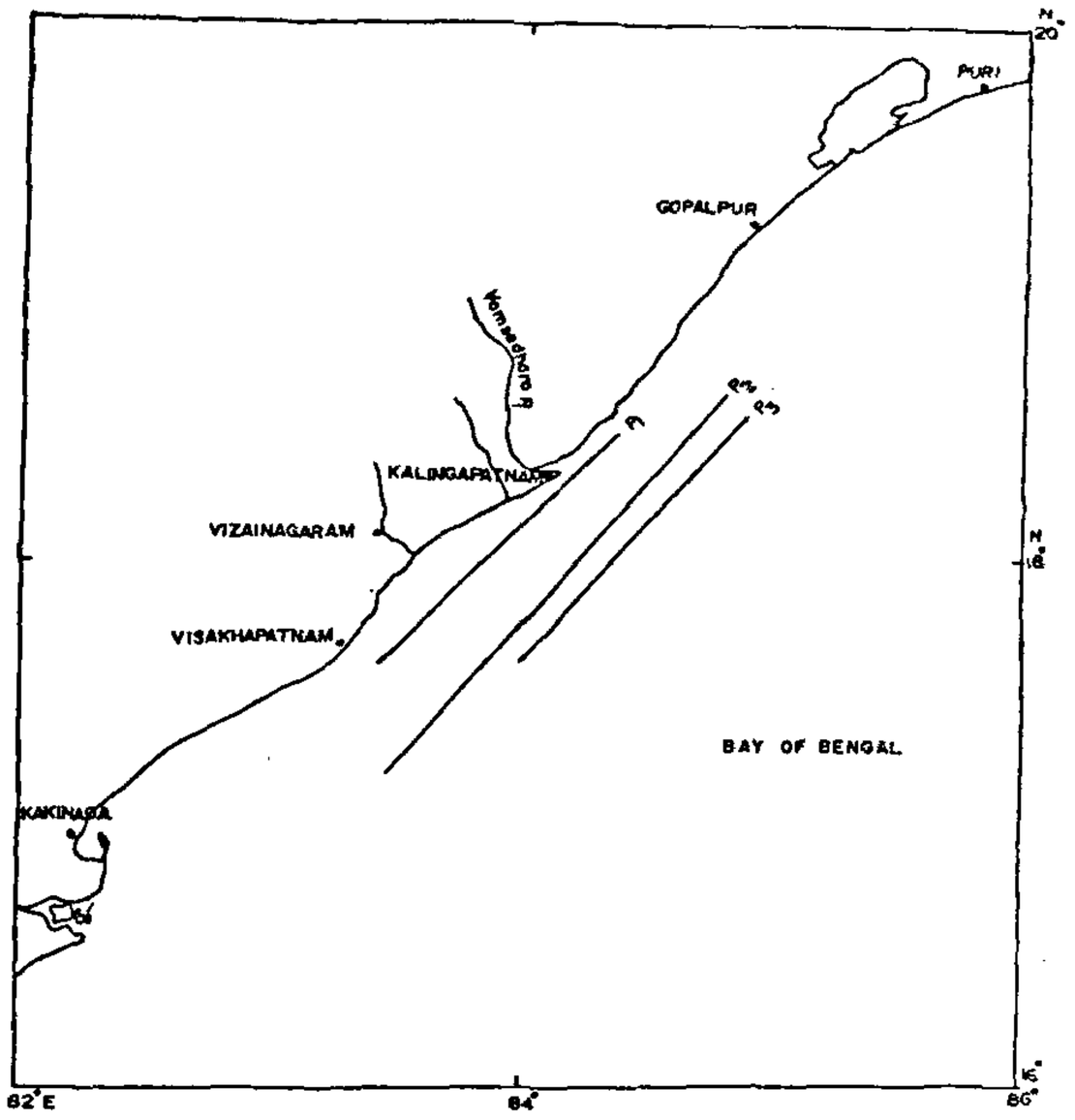

Figure 1. *Location* map showing 3 parallel profiles between Visakhapatnam and Kalingapatnam.

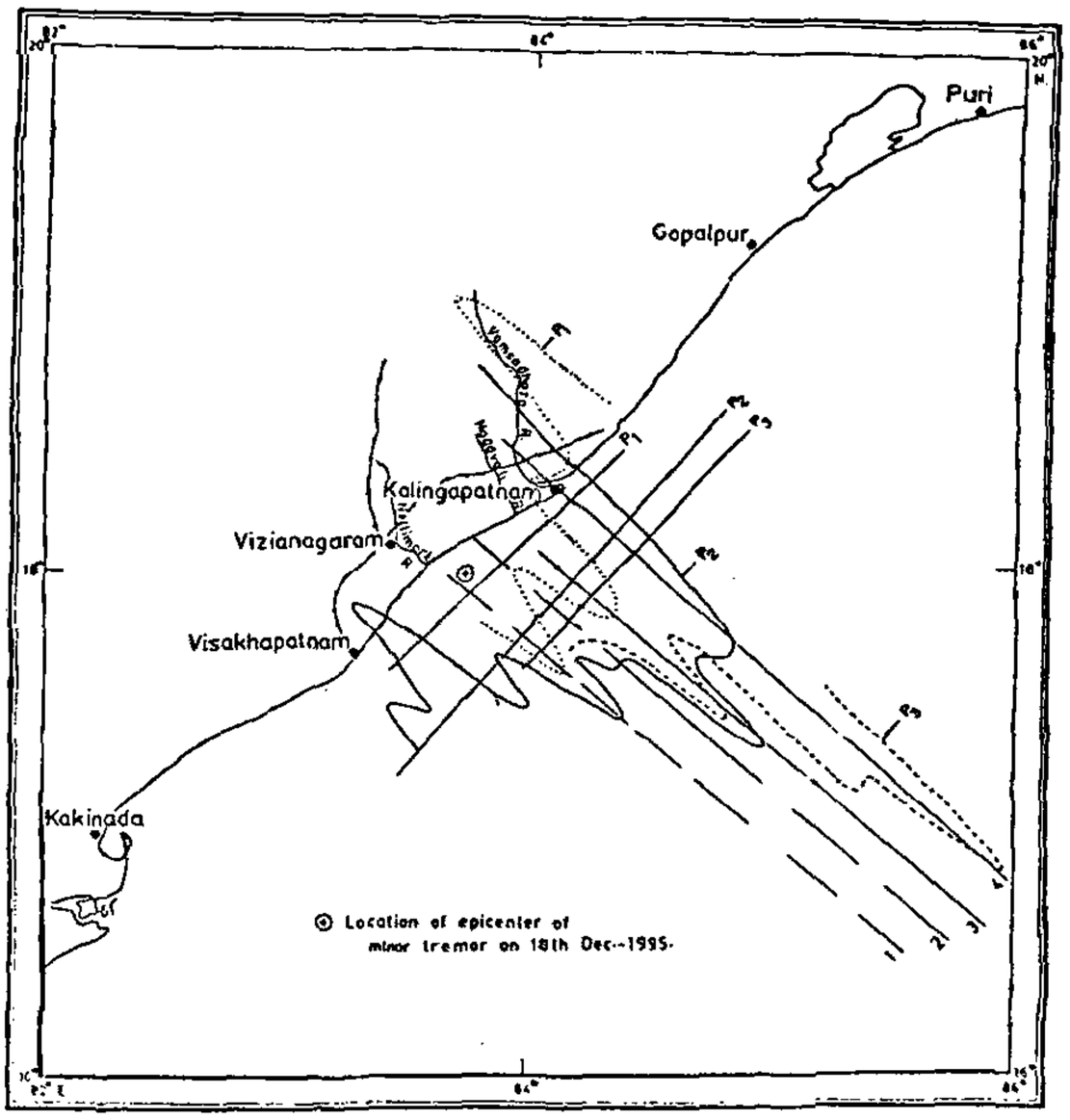

Figure 2. Magnetic anomalies along 3 parallel profiles.

and 100 m water depth over innershelf off Visakhapatnam. Each profile is 15 to 30 km long. Barringer proton precession magnetometer was used with a sensor towed nearly 150 m behind the vessel and the data were

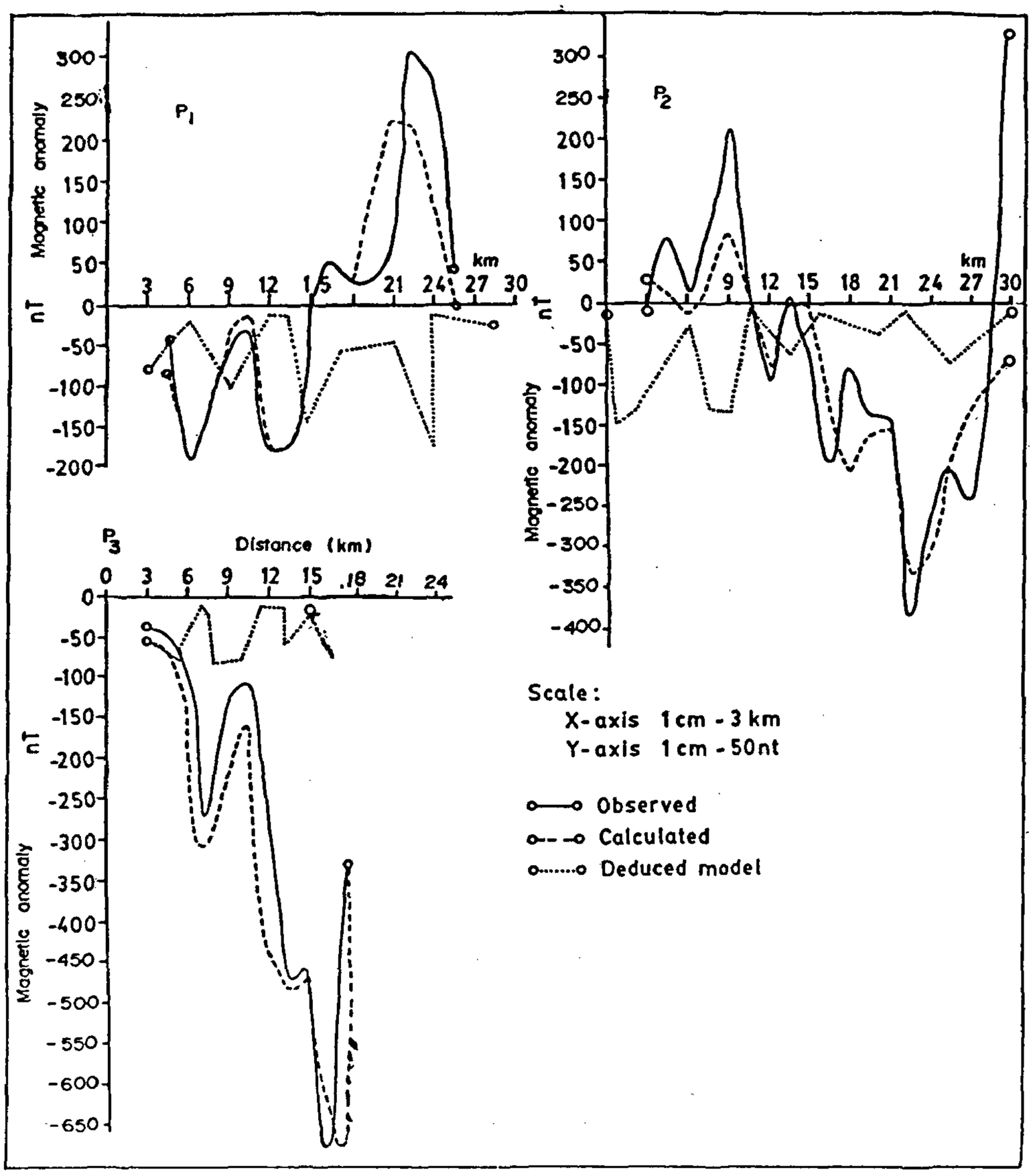

Figure 3. Two-dimensional models of 3 anomalies.

collected at 1 min polarization interval. Observed data were corrected applying IGRF corrections.

Magnetic anomalies are plotted along 3 profiles P1, P2 and P3 between Visakhapatnam and Kalingapatnam (Figure 2). Profile P1 close to the shore is associated with negative anomalies of the order of 200 nT at a water depth of 30 m. Profile P2 and P3 are characterized by short wavelength and high amplitude negative anomalies of 400 to 650 nT. Four major lineations (1, 2, 3 and 4) trending NW–SE are inferred from the anomalies (Figure 2). Two-dimensional modelling[7] of magnetic anomalies indicate a severely undulating basement with depth ranges between 200 m and 10 km. The basement topography inferred along profiles P1 and P2 is highly disturbed (Figure 4). The three trends 1, 3 and 4 appear to be the offshore continuation of 3 river channels inland. Geological studies of the inland region between Visakhapatnam and Kalingapatnam reveal that it is a relatively disturbed area, associated with severe folding and faulting in the shallow basement[8]. The Nellimarla river fault is a major one extending into offshore regions and spatially correlated to trend 1 inferred from our studies and to this particular trend only, the epicentre of the recent earth tremor (A in Figure 4) lies at nearly 20 m water depth about 30 km offshore from Vizianagaram in the Bay of Bengal. Two other river channels, like Nagavali and Vamsadhara, cutting across the coast are likely to extend offshore into the Bay of Bengal near Kalingapatnam which may be related to trends 3 and 4 inferred from geophysical data.

High resolution shallow seismic data along parallel profile off Bhimunipatnam indicate steep subsurface faulting (F in Figure 5) about 35 m below the seabed. Uniform and parallel bedding is observed in the left segment of the subsurface unit while another segment is inclined towards the fault plane suggesting deformation (Figure 5). In view of the several deformations noticed in the sedimentary units above and below the seabed at places off Visakhapatnam in the eastern continental

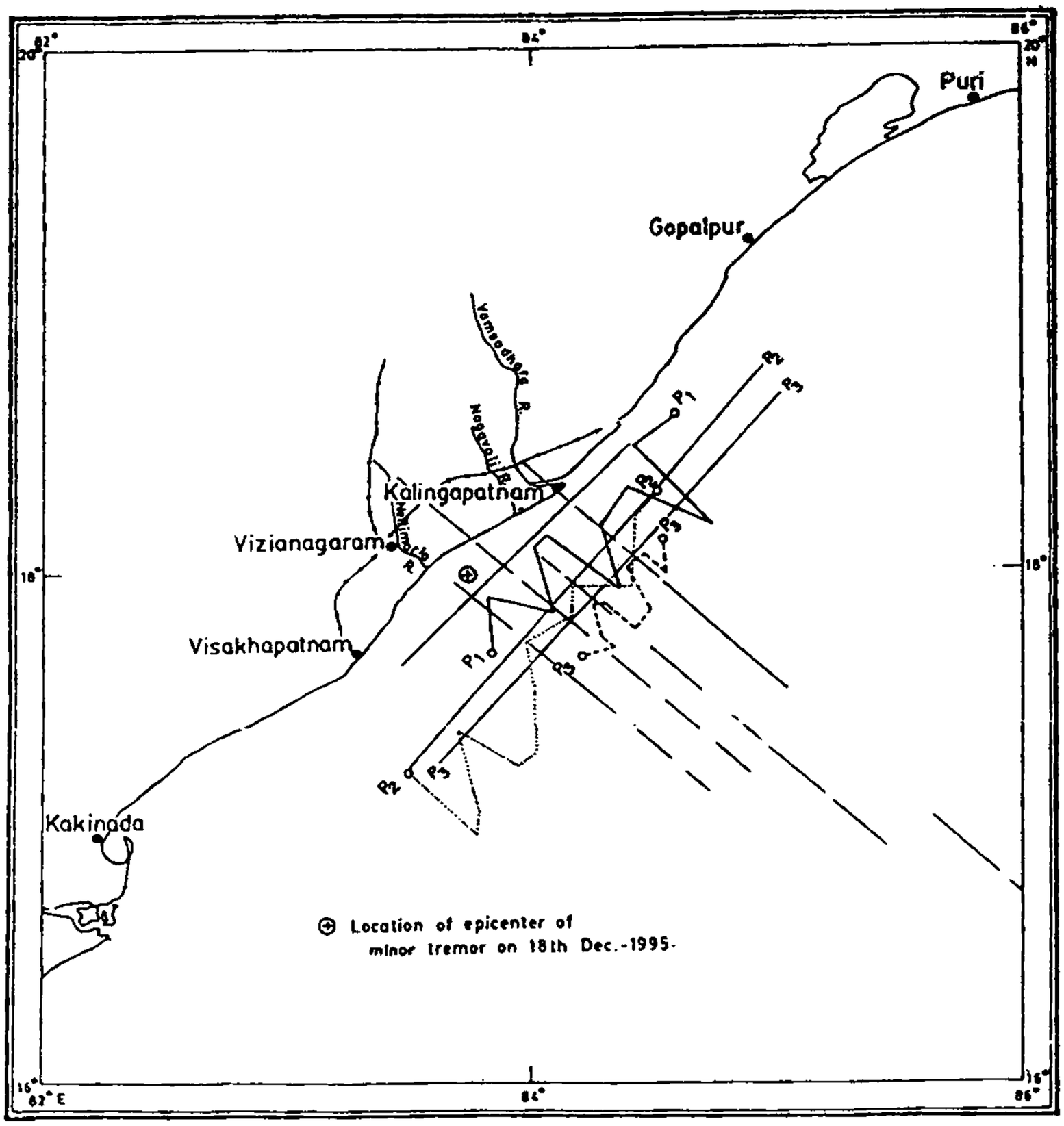

Figure 4. Magnetic basement inferred from model studies.

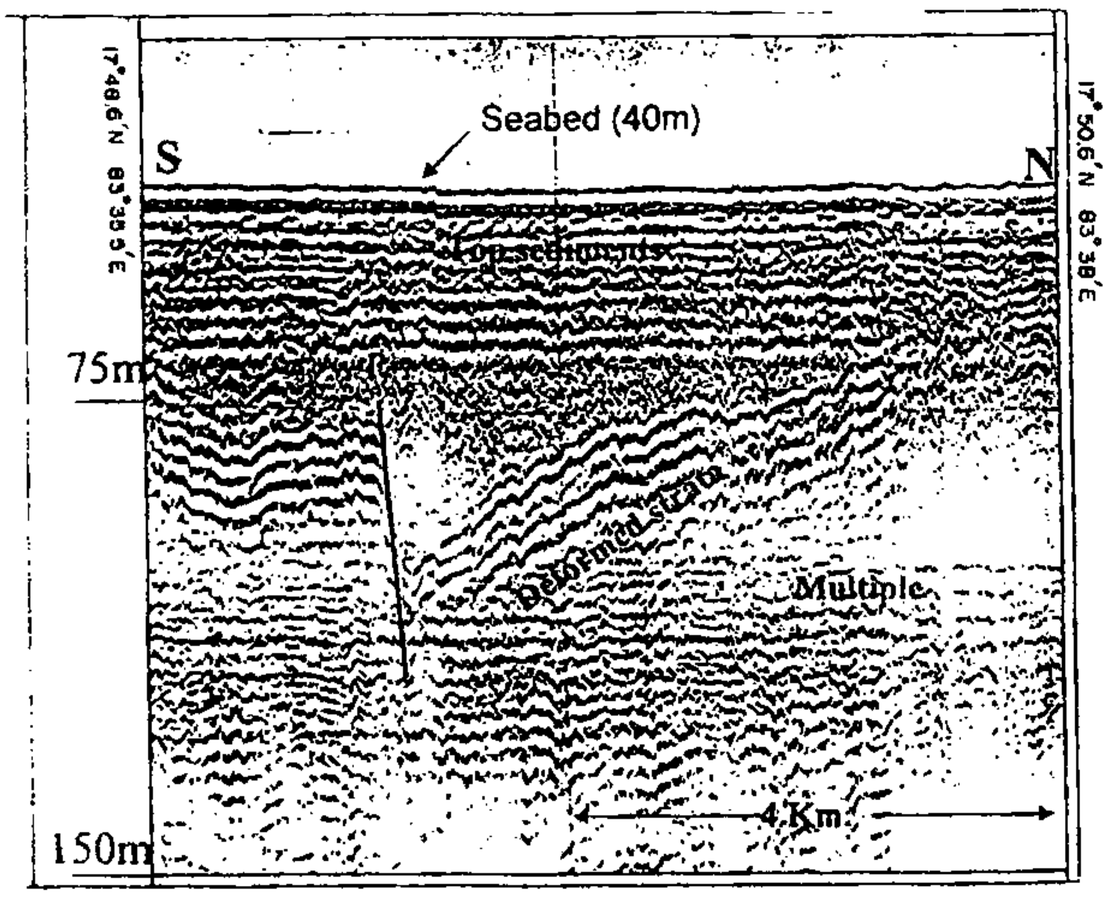

Figure 5. Shallow seismic record showing sub-bottom fault off Bhimunipatnam.

shelf, there is a possibility of recent tectonic movements in this region. Nearly 158 earthquakes were recorded within 30 km off Visakhapatnam during 1974 to 1976. Epicentres of 44 of these shocks are shallow with their foci between 0 and 30 km (ref. 9).

In the light of these observations and geophysical data interpretation and available geomorphological information, it may prove fruitful to establish the link between onland and offshore tectonic lineaments which would help one understand the factors responsible for the recent tectonic activity in the southern part of peninsular India.

1. Subrahmanya, K. R., *Curr. Sci.*, 1994, **67**, 327–330.
2. Ramalingeswara Rao, B., *Tectonophysics*, 1992, **201**, 175–185.
3. Murthy, K. S. R., Subrahmanyam, A. S. and Rao, C. V., 33rd Annual Convention of IGU at Hyderabad, 1996, pp. 56–57.
4. Anabarasu, K. and Rajamanickam Victor, International Symposium on Geology and Geophysics of Indian Ocean, 1996.
5. Ramasamy and Balaji, *Int. J. Remote Sensing*, 1995, **16**, 2325–2331.
6. Mohana Rao, K., Reddy, N. P. C., Raju, Y. S. N., Venkateswarulu, K. and Murthy, K. S. R., International Symposium on Late Quaternary Sea Level Changes at Tanjur, 1997

7. Talwani, M. and Heirtzer, J. R., in *Computers in Mineral Industry* (ed. Parks, G. A.), Stanford University Press, 1964, p. 464.
8. Kanungo, D. N. and Murthy, D. S. N., *Geophys. Res. Bull.*, 1981, **19**, 33–50.
9. Chaudhury, H. M. and Srivastava, H. N., Sixth Symposium on Earthquake Engineering, 1978, pp. 35–40.

ACKNOWLEDGEMENTS. The authors thank their colleagues for data acquisition and Dr E. Desa, Director, National Institute of Oceanography, for permission to publish this paper.

Received 25 January 1999; revised accepted 18 February 1999

In situ maturation of sediments within the weathering profiles: An evidence from REE behaviour during weathering of Delhi quartzites

Jayant K. Tripathi and V. Rajamani*

School of Environmental Sciences, Jawaharlal Nehru University, New Delhi 110 067, India

Orthoquartzites of Delhi Supergroup in Delhi region have low abundance of REE. There is a two-fold enrichment of REE in moderately weathered zones on the quartzites accompanied by increase in the amount of kaolinite. The REE patterns however are nearly identical to those of the unweathered core quartzite. In the strongly weathered outer zones both kaolinite and REE abundance decrease somewhat relative to the lower weak to moderately weathered zones. The weathering processes here involved are the formation of kaolinite possibly by the breakdown of a few grains of mica and the oxidation of pyrites present in the quartzite. During this process, the REE have been mobilized quantitatively by sulfate-bearing solutions without any fractionation. In the process the outermost zones have been made friable with lowered REE abundance. It is possible, that REE and Al depleted top friable zones may have been physically eroded away. Thus, although the REE are mobile in upper zones during weathering processes, they could be quantitatively retained in the lower weathering zones due to clay forming processes resulting in the production of silica-rich, REE depleted mature quartzite by stripping off the uppermost friable sediments of the rinds.

ALTHOUGH there have been many studies on the weathering of igneous rocks, there are few data concerning weathering of quartzite[1,2]. Quartz or its polymorphs form the end member oxides to the rock forming silicate minerals and this resistant mineral is a rate-limiting component in the weathering of rocks[3]. A study of weathering of quartzite which is composed mainly of quartz (~ 99%) will help us to understand between the weathering of this resistant mineral. REE geochemistry on fresh and weathered quartzite has been used to infer the mechanism and nature of solutions responsible for chemical weathering of quartzite. There have been studies showing that the rate of chemical weathering and erosion of weathering profiles are important in controlling the chemistry of sediments derived from them[4,5]. The sand derived from mature weathering profiles have less provenance information than the mud which contain better information[5]. Separation of sand and mud grade detritus by fluvial processes after the erosion of extremely weathered profiles has been suggested for the origin of first cycle quartz arenites[6,7]. Our present study provides a mechanism for the formation of supermature quartzite, with very low REE abundance, directly from the weathering arenaceous sediments without going through a long transportation and thereby differentiation into sand and mud grade sediments.

Middle to late Proterozoic metamorphozed quartzite of the Delhi System is exposed as a series of subparallel ridges in the Delhi and adjacent Haryana regions (Figure 1). The topographic depressions on the ridges have accumulated aeolian sediments transferred from the adjacent Thar desert of Rajasthan by the prevailing winds[8]. The quartzites have been intruded by pegmatite and quartz veins. The rocks have undergone extensive weathering in and around fracture zones through infiltration of meteoric water and dust. Occasionally massive quartzite bodies on top of the ridges (maximum elevation around 100 m relative to the local elevation) show development of a half to one meter thick, colour and texture zoned weathering rind (Figure 2). The region is semi arid with an annual rainfall of about 75 cm. We studied the chemical and mineralogical compositions of

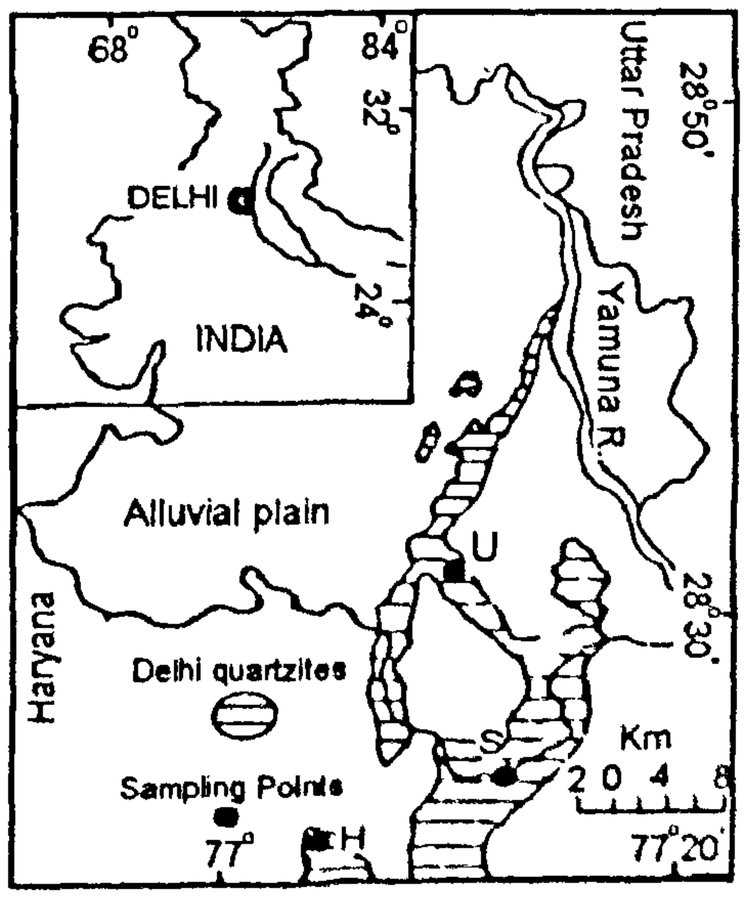

Figure 1. Geological map and sampling points of weathering rinds on Delhi quartzites. S, U and H represent Surajkund, Jawaharlal Nehru University and Sohna areas respectively.

*For correspondence. (e-mail: vrm@jnuniv.ernet.in)