and *G. ruber* from the east Arabian Sea[5] and (ii) lack of evidence[6] for a comparable magnitude of negative $\delta^{18}O$ excursion from active monsoonal upwelling region of the Arabian Sea (core CD-17-30; where the amplitude of the observed negative $\delta^{18}O$ excursion at LGM is only half of that observed in SK-20-185). Therefore, while we cannot rule out the possibility suggested by Naqvi that the enigmatic $\delta^{18}O$ shift reflects local thermohaline changes in the surface water, we believe that this may not wholly account for the observed signal.

1. Gupta, S. K. and Sharma, P., *Curr. Sci.*, 1993, **64**, 107–110.
2. Sarkar, A., Ramesh, R., Bhattacharya, S. K. and Rajagopalan, G., *Nature*, 1990, **343**, 549–550.
3. Duplessy, J. C., *Nature*, 1982, **295**, 494–498.
4. Krishnamurthy, R. V., *Nature*, 1990, **348**, 118.
5. Guptha, M. V. S., Divakar Naidu, P. and Muralinath, A. S., *J. Geol. Soc. India*, 1990, **36**, 654–660.
6. Sarkar, A., Ph D Thesis, Gujarat University, Ahmedabad, 1989.

S. K. GUPTA
P. SHARMA

Physical Research Laboratory
Ahmedabad 380 009, India

OPINION

Latur earthquake of 30 September 1993: implications and planning for hazard-preparedness

K. S. Valdiya

The moderate earthquake (M 6.4; depth 7 km) of 30 September 1993 in the Latur area in Maharashtra (Figure 1) has once again demolished the thesis that the Peninsular India is a geodynamically stable shield. It has also strengthened my belief and postulation[1,2] that southern India did not and cannot escape the impact of northward drift of India and its collision with Asia. The resistance of the Indian plate to sliding under the Asian Plate is manifest in neotectonic movements and attendant seismicity in the Himalaya as well as in the Peninsular India. The earthquake-affected Latur belt has been exhibiting microseismicity for quite sometime – 1962, 1963, 1967, 1983, 1984 and in 1993 from 2 to 29 October. Obviously, internal strain has been progressively building up all through the time. Our inability to heed to the nature's loud signals is not only a sad commentary on our apathy, but also on the inexplicable failure of our seismological network to give timely warning of the uncommon occurrences (tremors) leading to a calamity of unimaginable proportions

Seismicity in southern India

The 1764 Mahabaleshwar and the 1843 Bellary earthquakes are among the many that have rocked southern India since time immemorial[3,4]. The seismicity is related to neotectonic movements on the NNW–SSE and E–W trending faults and fractures[5] (Figures 1 and 2). For example, the 8 February 1900 Coimbatore earthquake (M 6.0, hypocentral depth

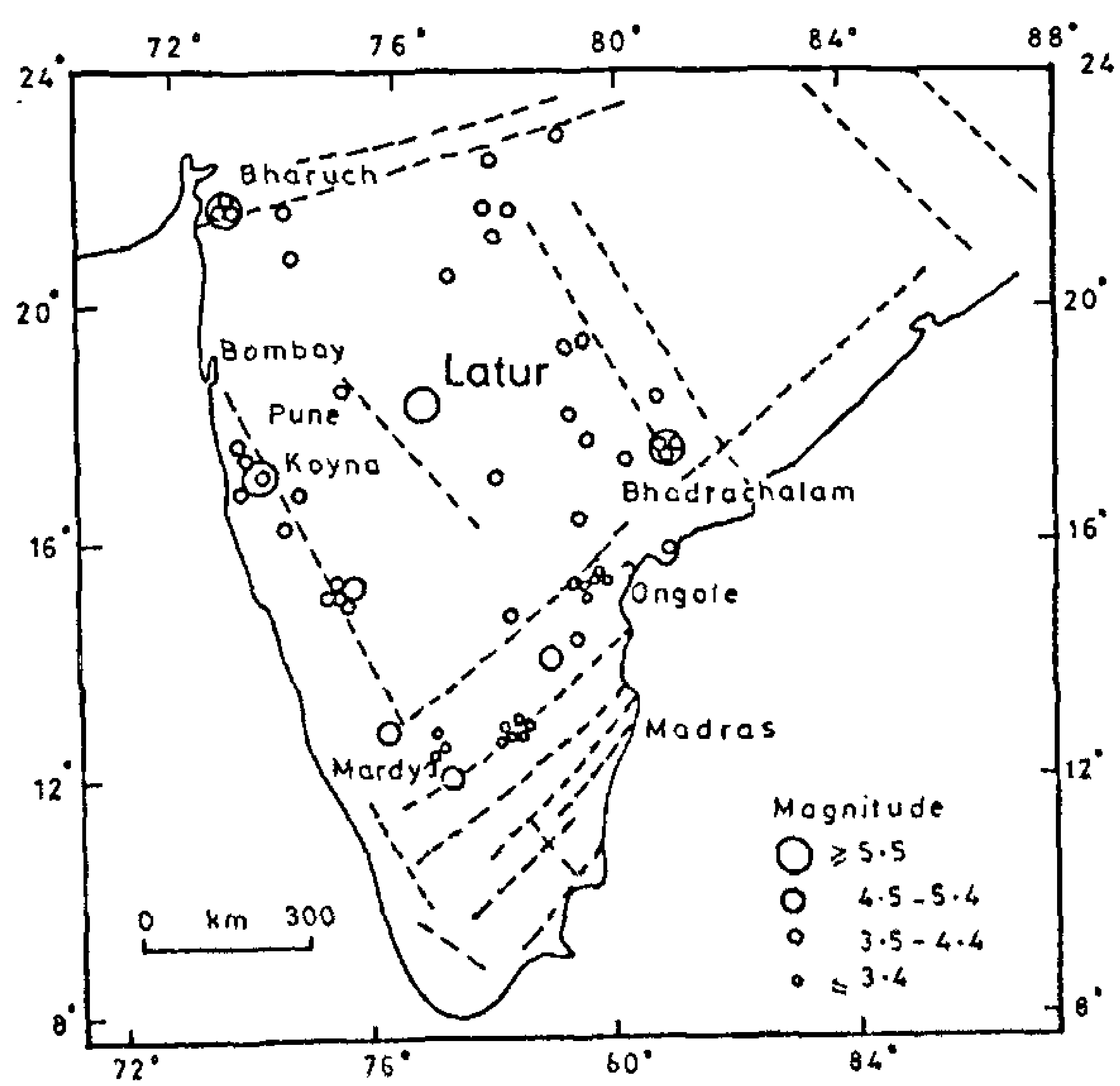

Figure 1. Seismicity in the Peninsular India is related to episodic movements on transcurrent faults (From Valdiya[5], based on the Annual Report of the NGRI, Hyderabad, 1977).

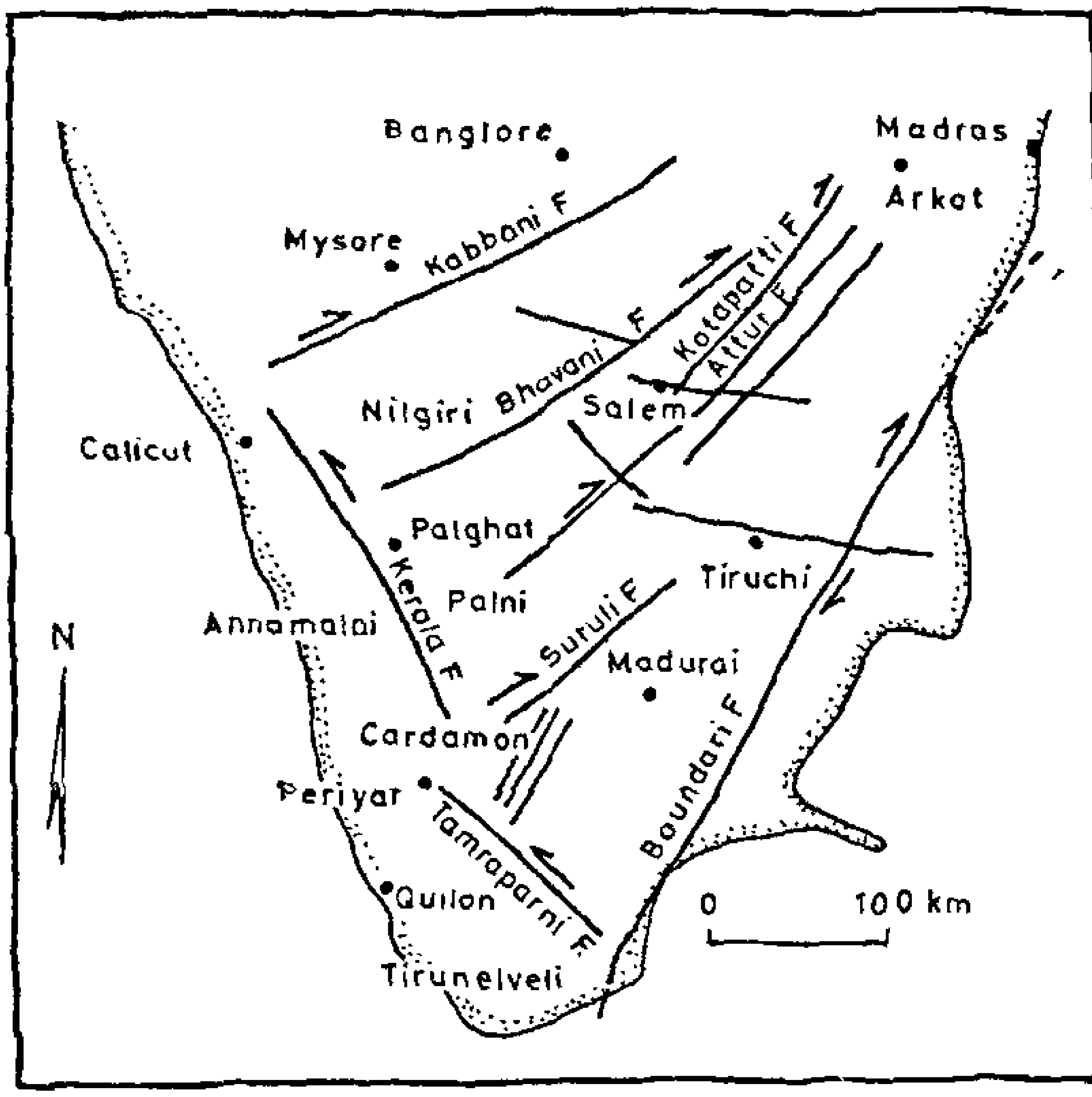

Figure 2. Much-faulted terrain of southern India Parts of the deep, long faults are active and seismogenic (From Valdiya[5] based on Borodin *et al.*[18] and Grady[19])

70 km) is related to a NNW–SSE trending fault in Kerala[6], the Bhadrachalam earthquake of 13 April 1969 (M 5.7, depth 10–15 km) originated in the NNW–SSE striking fault of the Godavari rift[7], the 10 December 1967 Koyna earthquake (M 6.4, depth 11–14 km) is related to the N10°E–S10°W trending fault[8,9], and the hypocentre of the Bharuch earthquake of 23 March 1970 (M 5.8, depth 25 km) was at the intersection of the faults of the Narmada and Sabarmati grabens[5].

It has been suggested that the Koyna tremors are the result of reactivation of the fault delimiting a 50-km wide rift valley recognized by Krishna Brahman and Negi[10] under the thick pile of the Deccan lavas (Figure 3). The recent Latur earthquake seems to be related to the fault of the other hidden rift valley – the Kurduwadi graben[10], which seems to be linked with the Koyna graben north of Pune. Although deep seismic soundings done by Kaila *et al.*[11] do not prove the existence of these grabens, the occurrence of recent earthquake and periodic tremors in the belt demonstrate that an active fault does cut the region. The strong NW–SE lineament, discernible in satellite imageries between Junnar in Maharashtra and Raichur in Karnataka controls the courses of the Ghod and Bhima rivers[12]. The lineament reflects influence of the Kurduvadi rift on the lava cover, and seem to be the result of slow vertical uplift, according to Powar[12].

As a matter of fact, the whole of Maharashtra, Karnataka and the adjoining regions have been in tectonic ferment throughout the Quaternary Period[5], as evident from the uplift in several pulses of the entire Western Ghat[13], the reactivation of the NE-SW oriented faults and resultant uplift of the parts of Karnataka craton[14], the drainage peculiarities in upland north-western Maharashtra[15], and geomorphic development in the East Coast[16].

Since the drift of the Indian subcontinent continues, the Peninsular region is likely to be rocked repeatedly by tremors and earthquakes originating in the faulted belts. In view of these facts, it would be desirable to establish/strengthen a network of closer seismological stations under an independent organization – carved out of the India Meteorological Department – to function in close collaboration with the National Geophysical Research Institute at Hyderabad, the Earthquake Engineering Research Institute at Roorkee and other institutions commanding requisite facilities.

Southern India, south of the Mysore–Madras line, the Koyna–Karad–Latur region in southern Maharashtra, the Godavari–Wardha valleys in Andhra

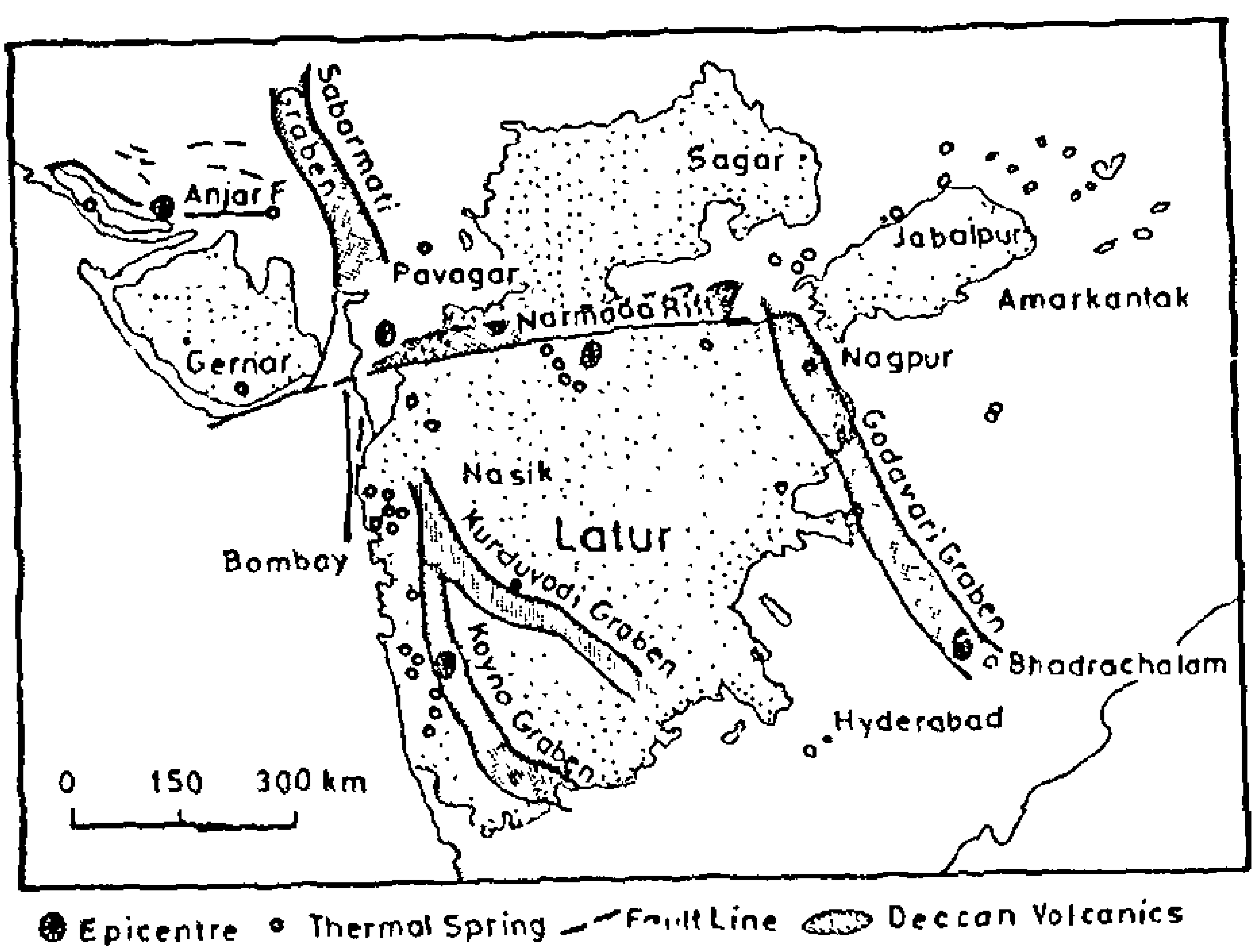

Figure 3. According to Krishna Brahmam and Negi[10], there are two rift valleys, possibly filled with Proterozoic (Purana) and Gondwana sediments underneath the thick pile of lavas of the Deccan Volcanic province (From Valdiya[5])

Pradesh and adjoining Vidarbha, the Bharuch–Kachchh belt in Gujarat, the Doda–Kangra sector in NW Himalaya, the Kaurik–Uttarkashi belt in north-eastern Himachal and adjoining Garhwal and the Dharchula–Bajang region in the Indo–Nepal border, besides the eastern Arunachal Pradesh and Assam need to be included in this network of close seismological stations.

In my perception the Dharchula–Bajang region in the central sector of the Himalaya is under critically stressed condition and must be taken up for intensive investigation without delay Likewise, the Palghat–Salem region south of the Nilgiri massif needs to be comprehensively studied.

Coping with natural hazards

Natural hazards (such as earthquakes, floods, cyclones, avalanches, landslides) cannot be prevented from occurring, but their impacts can be reduced and risks minimized if effective measures are taken in time. This calls for advance planning for disaster preparedness. For this purpose, a national agency – to be called the Natural Hazards Management Commission[17] – can be formed. Functioning in the manner the Election Commission does during elections, this agency would (i) make appraisals of the magnitudes of risks of varied hazards (earthquakes, floods, coastal storms, landslides) on the basis of past occurrences and monitoring of geological, geophysical and physiographic changes in the identified vulnerable zones or areas; (ii) prepare and publish hazard-zoning maps, (iii) disseminate relevant information through media and popular publications. The hazard-zone mapping can be pursued through academic institutions, and if need be, on contractual basis; and (iv) the Commission would mobilize personnels (drawn from different organizations, including voluntary agencies) and resources for coordinated operations related to evacuation, relief, sanitation, medicare, food, shelter, resettlement, loans for economic recovery, etc.

1. Valdiya, K. S., *Platinum Jubilee Lecture*, Pune Session, Indian Sci. Congress, Calcutta, 1988.
2. Valdiya, K. S., *Indian J. Geol*, 1989, **61**, 1–13.
3. Chandra, Umesh, *Bull. Seismol. Soc. Am.*, 1977, **67**, 1387–1413.
4. Mohan, Indra, Sitaram, M. V. D. and Gupta, H. K., *J. Geol. Soc. India*, 1981, **22**, 292–298
5. Valdiya, K. S., *Aspects of Tectonics. Focus on South-Central Asia*, Tata-McGraw Hill, New Delhi, 1984, pp. 319.
6. Krishna Brahmam, N. and Kanungo, D. N, *J. Geol Soc India*, 1976, **17**, 45–53.
7. Gupta, H. K., Mohan, Indra and Narain, H, *Bull. Seismol. Soc. Am.*, 1970, **60**, 601–615.
8. Guha, S. K, *Tectonophysics*, 1979, **52**, 549–559.
9. Gupta, H K, Rao, C U., Rastogi, B. K. and Bhatia, S C., *Bull. Seismol. Soc Am*, 1980, **70**, 1833–1847.
10. Krishna Brahmam, N. and Negi, J. G., *Geophys. Res. Bull.*, 1973, **2**, 207–237.
11. Kaila, K. L., Reddy, P. R, Dixit, M. M. and Lazarenko, M. A., *J. Geol. Soc. India*, 1981, **22**, 1–16.
12. Powar, K. B, *Mem Geol. Soc. India*, 1980, **3**, 45–56.
13. Powar, K. B., *Curr. Sci.*, 1993, **64**, 793–796.
14. Radhakrishna, B P., *Curr. Sci*, 1993, **64**, 789–793
15. Rajaguru, S N., Kale, V. S. and Badam, G. L., *Curr. Sci*, 1993, **64**, 817–822.
16. Vaidyanandhan, R and Ghosh, R. N., *Curr. Sci.*, 1993, **64**, 804–816.
17. Valdiya, K. S., *Environmental Geology: Indian Context*, Tata-McGraw Hill, New Delhi, 1987, pp. 227–239.
18. Borodin, L. S., Gopal, V, Moralev, V. M, Subramanium, U. and Ponikarov, V., *J. Geol. Soc. India*, 1971, **12**, 101–112.
19. Grady, S. A., *J. Geol. Soc. India*, 1971, **12**, 56–62.

K. S. Valdiya is in the Department of Geology, Kumaun University, Nainital 263 002, India

COMMENTARY

A quick look at the Latur earthquake of 30 September 1993

Harsh K. Gupta, Indra Mohan, B. K. Rastogi, M. N. Rao and C. V. Ramakrishna Rao

A majority of people in the western and central parts of Peninsular India were awakened in the early hours of 30 September 1993 by the shaking caused by the Latur earthquake. We, at the National Geophysical Research Institute (NGRI), Hyderabad, rushed to the Seismological Observatory on our campus. We were all worried that the earthquake might have occurred in the Koyna region as there was an enhanced seismic activity in that region and a couple of earthquakes[1] exceeding magnitude 5 occurred on 28 August and 3 September 1993. A quick analysis of the seismograms at the NGRI Seismic Station revealed that the epicentre was some 220 km west–north–west of Hyderabad in Latur district. The NGRI seismograph system having a high magnification, the seismograms were saturated and the magnitude of the earthquake could not be estimated immediately. However, it was clear that the earthquake must have a 6+ magnitude. Finally, the following earthquake parameters were estimated for this earthquake:

Origin time	03 h 55 m 46 68 s IST
Epicentre.	18°N76°32'E
Depth:	5–15 km
Magnitude:	MS = 6 4, m_b = 6 3
Seismic moment.	Mo = 1 8 × 10^{25} dyne cm

This earthquake was followed by a number of aftershocks. Table 1 gives details of these aftershocks and their magnitudes as estimated at the NGRI Observatory.