Radon precursory signals of Chamba earthquake

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Radon is recognized as a plausible precursor in earthquake prediction research. Radon monitoring in soil-gas and groundwater at Chamba and Dalhousie stations is carried out by using alpha-logger probes and emanometry. Radon anomalies are generally followed by seismic events in the grid (30–34°N, 74–78°E). The Chamba earthquake of 5.1 M, which occurred on 24 March 1995, had recorded its precursory signals.

Since the first observation of episodic changes in radon concentration in groundwater prior to the 1966 Tashkent earthquake[1], radon has been considered to be a plausible precursor for earthquake prediction. Observations of radon in soil-gas and groundwater have been recorded by various authors[2–10] and correlated with some of the earthquakes which occurred in USA, Japan, China, Mexico and India.

The physical basis of the radon anomalies prior to an impending earthquake have yet to be fully understood in terms of a comprehensive theoretical model. However, it is understood that the build-up of stresses prior to a seismic event induces strain fields in the crustal rocks; as a consequence, the radon emanation is enhanced. Model calculations indicate that a change in strain fields of at most 10^{-6}–10^{-8} caused the radon anomalies.

Radon monitoring work was started at Chamba and Dalhousie stations in Himachal Pradesh during March 1993 under the Himalayan Seismicity Programme of the Department of Science and Technology (DST), Government of India. Continuous radon monitoring is carried out in the soil-gas at Chamba and Dalhousie using the alpha-logger system, while radon is monitored daily at Dalhousie station in soil-gas and groundwater using the emanometry technique. The location of the monitoring stations is shown in the map (Figure 1), which shows major thrust faults in N–W Himalaya.

The alpha-logger probe (manufactured by Alpha-Nuclear Company in Toronto, Canada) is a portable battery-powered microprocessor-based data acquisition and control system. The detector probe consists of a silicon-diffused junction for the detection of alpha particles and can record radon alpha counts in 15 min increments over a period of 40 days non-stop. The detector unit is placed inside a covered auger hole about 60 cm in depth. The recorded data are retrieved with the aid of a laptop IBM-compatible PC by entering the proper commands. The software supplied with the system

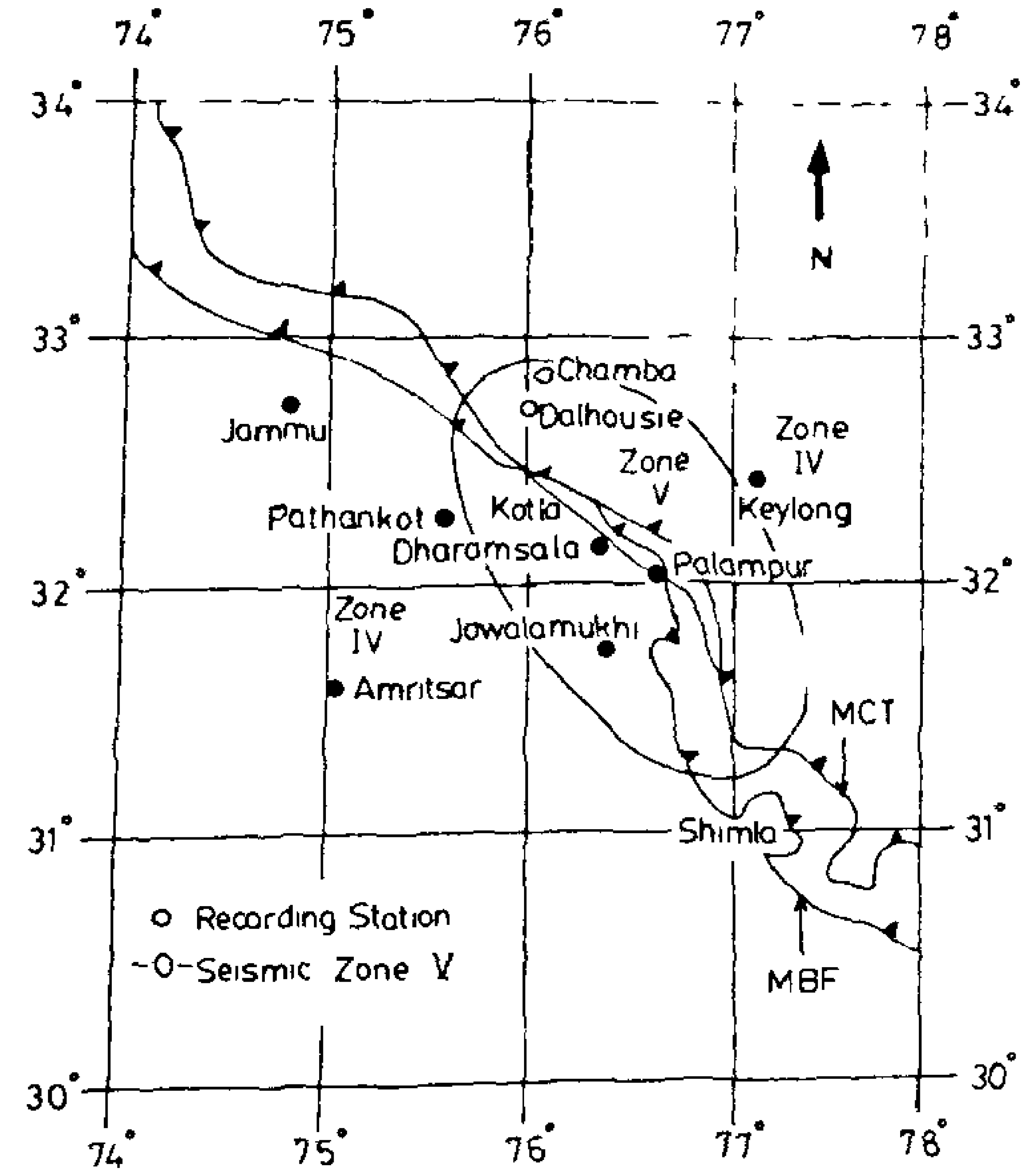

Figure 1. Map showing monitoring sites along with tectonic features in N–W Himalaya.

provides the facility to sum up any number of 15 min counting intervals for better counting statistics.

Radon monitoring in groundwater and soil-gas was carried out daily at Dalhousie station using the emanometry technique. The groundwater sample was collected from a 'bauli' (natural spring) at village Banikhet, 7 km from Dalhousie, in a sample bottle. A closed-circuit technique[11] was used to collect the gas that had passed through the water sample in the ZnS(Ag) detector cell as follows: The air was circulated in the closed circuit containing a hand-operated rubber pump, a water sample bottle, a drying chamber and a ZnS(Ag) detector cell for 10 min. Radon counts were recorded after 4 h, during which time the equilibrium between radon and its daughters gets established.

For measuring radon in soil-gas, auger-produced holes were left covered for 24 h, the same holes being used daily for radon monitoring. An emanometer was used to measure the alpha particle emission from radon in the gas fraction of a sample by pumping the soil-gas into a scintillation chamber using a closed-circuit technique. The alpha particles emitted from the decay of radon and its daughters impact the scintillator ZnS(Ag) creating an energy pulse in the form of photons. These photons were recorded by the scintillation assembly consisting of a photomultiplier tube and a scalar unit.

The Chamba and Dalhousie stations were set up as a part of radon network established in Himachal Pradesh to monitor the seismic activity of N–W Himalaya. Time series alpha-logger radon data for Dalhousie station are plotted in Figure 2 for the period October 1993 to March 1995. The first radon anomaly was recorded on 26 October, with a radon value of 18,873 counts/day, 191% above the average value. This was followed by a seismic event of magnitude 1.3 M on 28 October within an epicentral distance of 21 km. Similarly, there were other radon anomalies followed by seismic events as shown by arrows in Figure 2 and listed in Table 1. This clearly shows that radon precursory signals are recorded prior to seismic events in N–W Himalaya.

Radon monitoring at Chamba started in July 1993. Time series radon data are plotted in Figure 3 with radon anomalies followed by seismic events (shown by arrows) as listed in Table 2. During March 1995, the radon emanation registered an average value of 4010 counts/day (Figure 4 *a*). On 13 March the radon peak occurred with radon high of 7600 counts/day. It started decreasing thereafter and fell below the average value after the Chamba earthquake of magnitude 5.1 M, which occurred on 24 March 1995 with its epicentre at Pliure, nearly 7 km away from Chamba town.

Radon monitoring at Dalhousie station shows some interesting tiends (Figure 4 *b*): an enhancement till 16 March, then a fall, followed by a negative radon peak on 21 March, 3 days before the Chamba earthquake. Radon emanation showed a sudden rise after 21 March and this trend continued till 28 March; thereafter it started decreasing on 29 March. It reached its minimum value on 30 March after the seismic event of magnitude 3.0 M which occurred on 29 March. Chamba station became unoperational due to battery failure on 25 March and hence could not record the signal prior to 29 March event. The apparently different radon trends at both the stations may be explained on the basis of different geological conditions at the radon monitoring sites, their location from the main boundary fault (MBF) and the variation of the stress intensity factor[12].

Radon emanometry data (Figure 5) recorded the Chamba earthquake precursory signals more faithfully in both soil-gas and groundwater at Banikhet site near Dalhousie. The average radon values for March 1995 in soil-gas and groundwater were 71 and 98 counts/200 s, with a standard deviation of 97 and 103 counts, respectively. The radon anomaly was recorded simultaneously in both

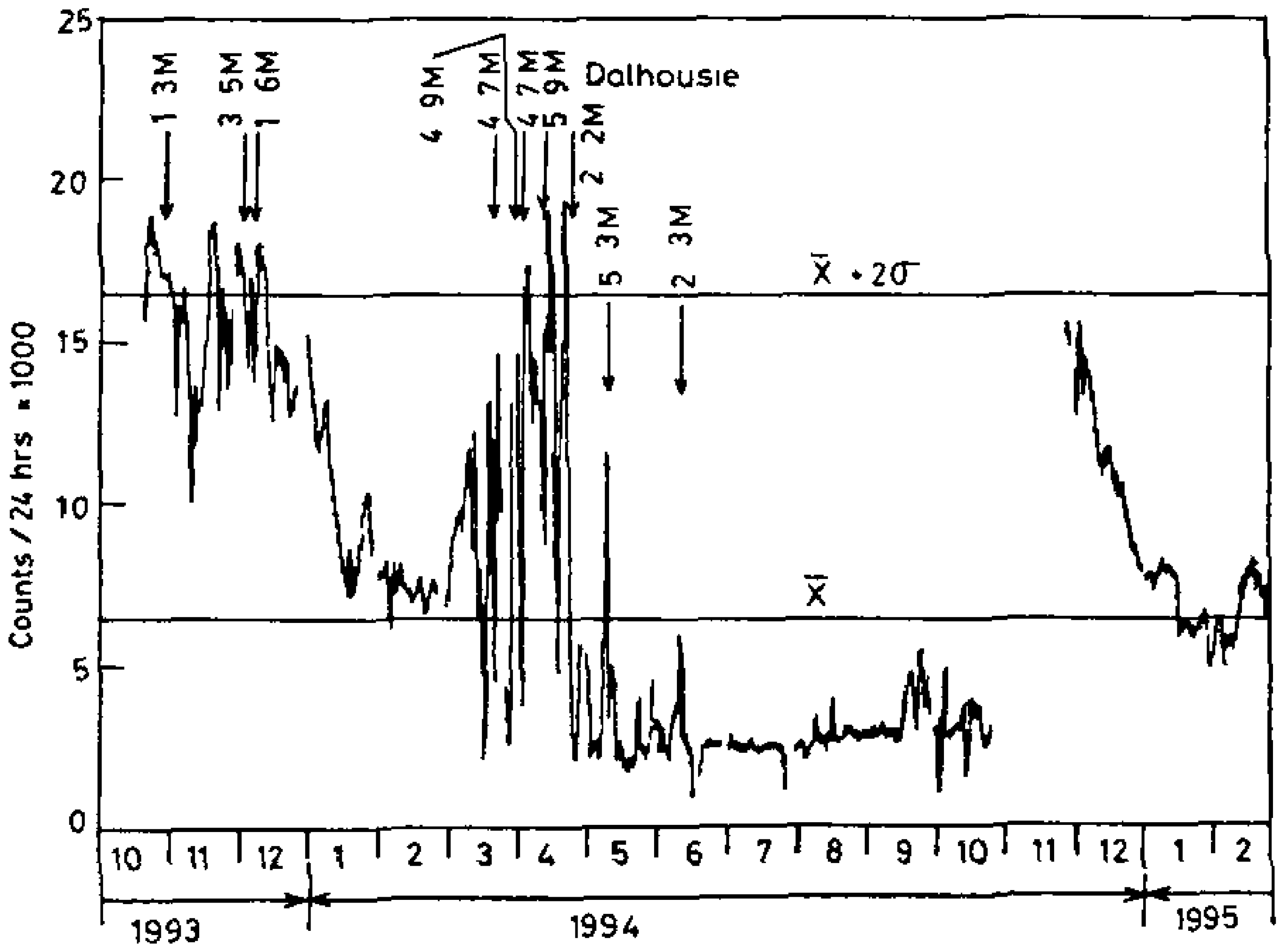

Figure 2. Time series alpha-logger data at the Dalhousie station.

Table 1. Correlation of radon anomalies at Dalhousie and the corresponding earthquake data

Date of radon anomaly	Date of the event	Magnitude	Alpha counts/day	Percentage increase above the mean value
26 10 93	28 10 93	1.3	18873	191
23.11 93	03 12.93	3 5	18625	187
02 12 93	05 12 93	1 6	18078	178
21 03 94	23 03 94	4 7	13166	103
24 03 94	30 03 94	4 9	14548	124
01 04 94	03 04 94	4.7	14575	124
06 04 94	09.04 94	5 9	17382	168
23 04.94	25 04.94	2 2	19343	198
10 05 94	10 05 94	5 3	11516	77
12 06 94	12 06 94	2 3	5846	-10

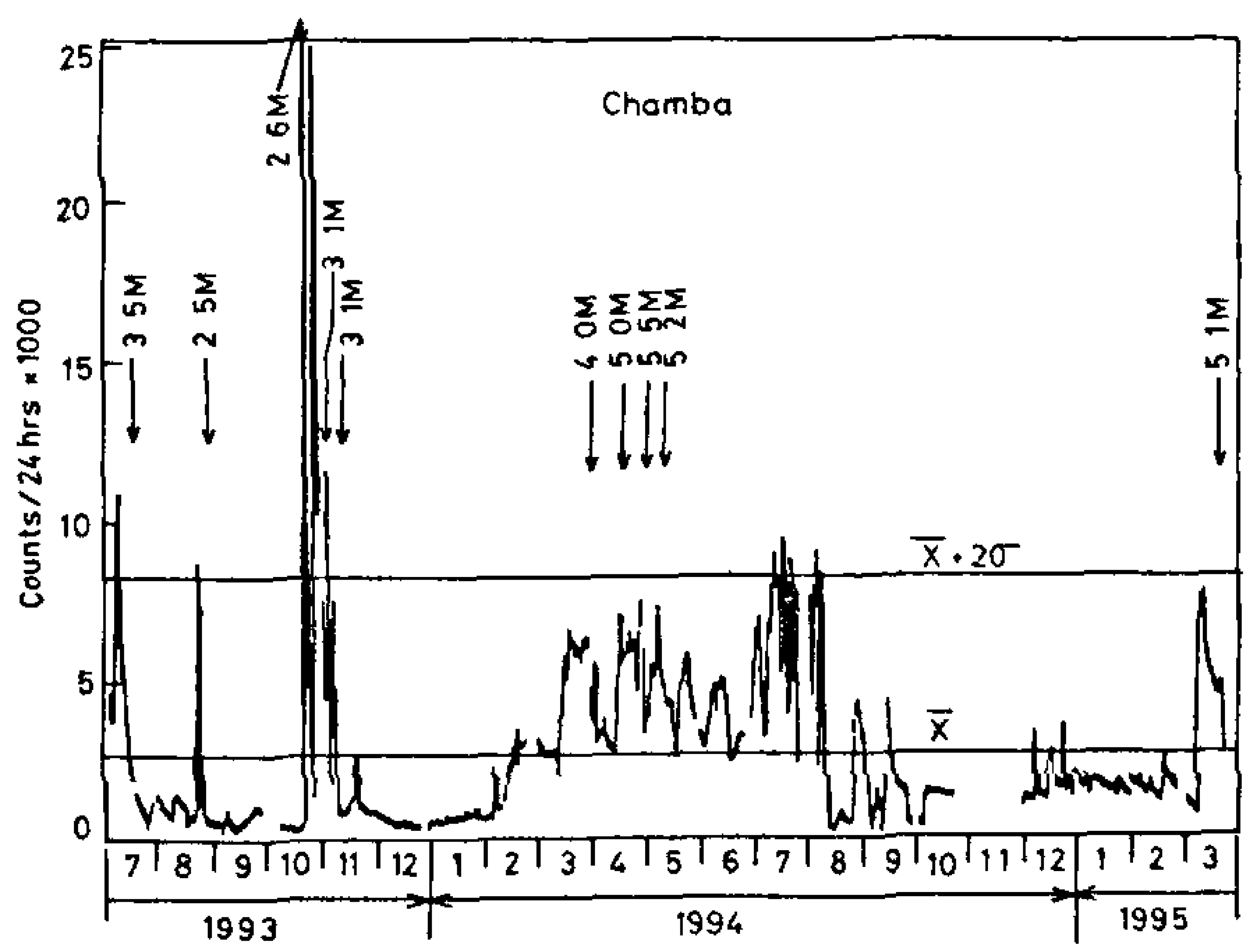

Figure 3. Time series alpha-logger radon data at the Chamba station.

Table 2. Correlation of the radon anomalies at Chamba and the corresponding earthquake data

Date of radon anomaly	Date of the event	Magnitude	Alpha counts/day	Percentage increase above the mean value
10 07 93	12 07.93	3 5	10906	309
26 08 93	28 08 93	2 5	8664	225
25 10 93	25 10 93	2 6	28837	982
04.11 93	10 11 93	3 1	11601	335
20 03 94	30 03 94	4 0	6611	148
18 04 94	18 04 94	5 0	7045	164
30 04 94	01 05 94	6 5	7536	182
09 05 94	09 05 94	5 2	7355	176

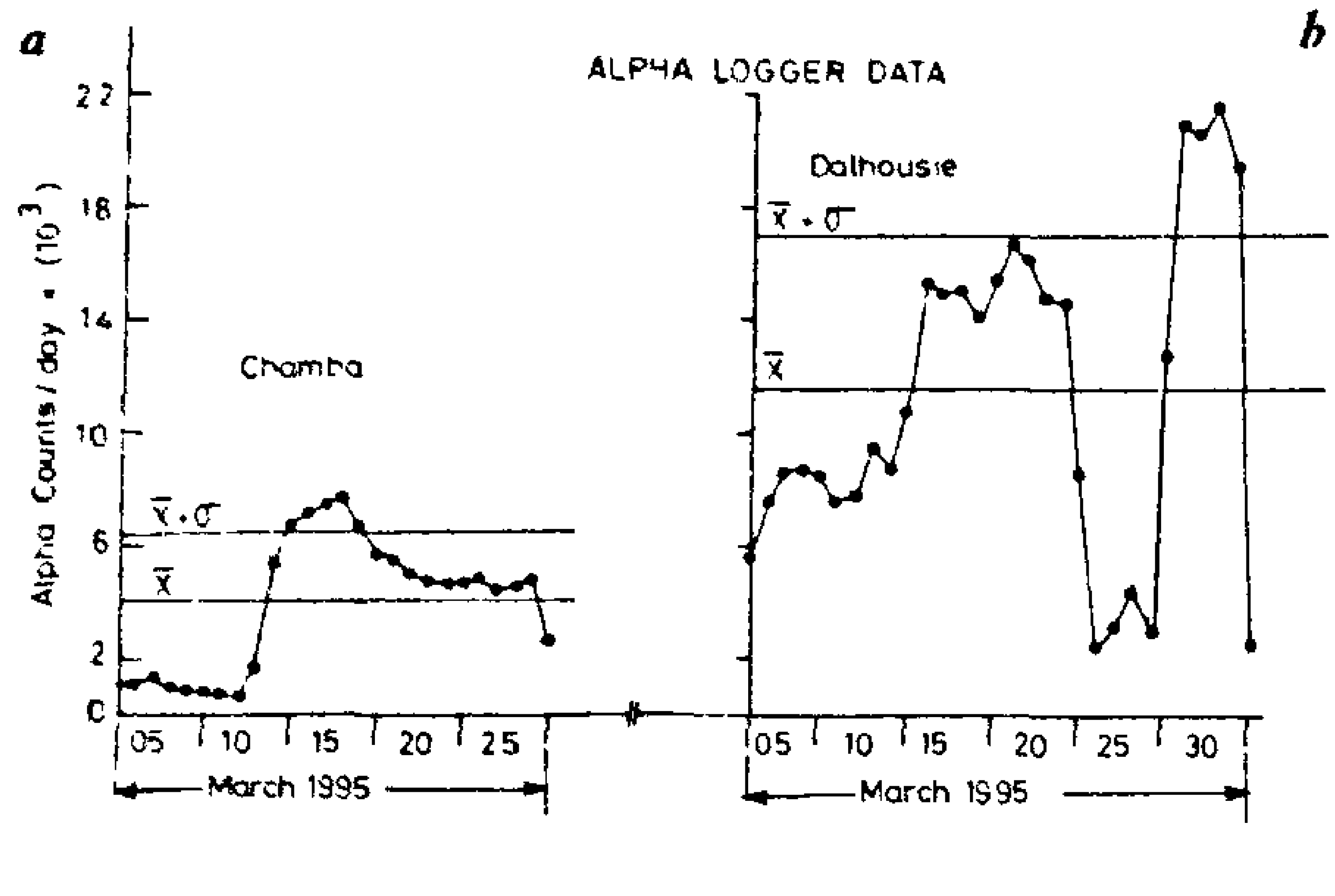

Figure 4. *a*, Alpha-logger radon data recorded at Chamba during March 1995. *b*, Alpha-logger radon data recorded at Dalhousie during March 1995.

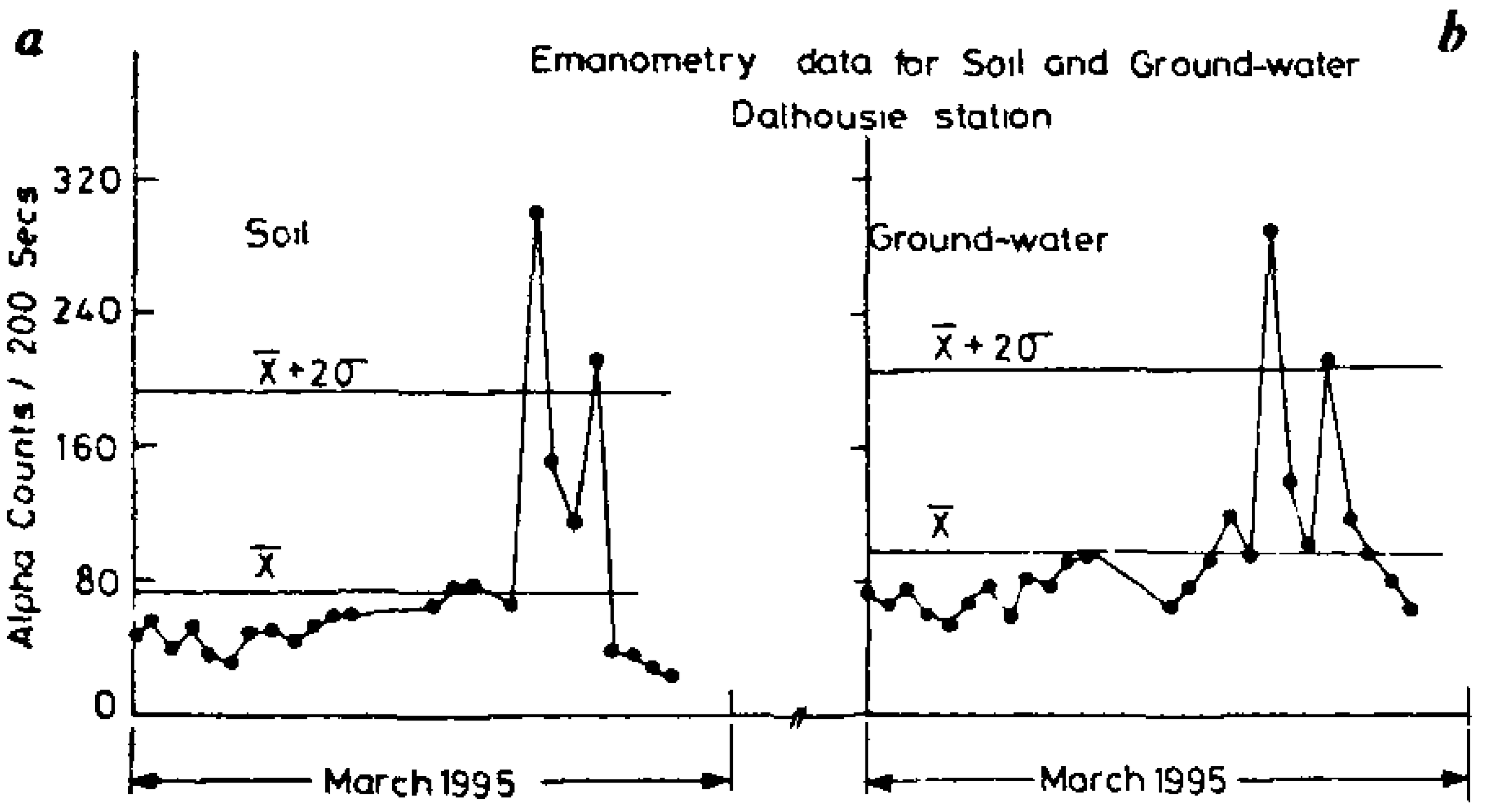

Figure 5. *a*, Radon emanometry data in soil-gas at Dalhousie during March 1995. *b*, Radon emanometry data in groundwater at Dalhousie during March 1995.

the media on 21 March, three days before the occurrence of Chamba earthquake and a day before a local event of magnitude 2.0 M, with peak values crossing the $x + 2\sigma$ level. There was another peak on 24 March and then a sudden fall in the radon emanation rate after the strain was released. The simultaneous recording of radon peaks in both soil-gas and groundwater at the same site and under similar meteorological conditions before the occurrence of Chamba earthquake on 24 March establishes the efficacy of radon as an earthquake precursor. It also augurs well for setting up radon monitoring networks in N–W, Central and N–E Himalaya for the purpose of earthquake prediction studies and delineation of hidden faults.

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Palaeogeographic evolution of the Akkulam lake and its geotechnical implications in the urban development of Thiruvananthapuram

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The palaeogeographic evolution of the Akkulam lake and its geotechnical significance based on field observations, mapping, lithological core sampling and geotechnical laboratory studies are highlighted. The findings have important implications in the future urban development of Thiruvananthapuram.

FROM a geological perspective all lakes are temporary features in the terrestrial landscape. Lakes originate, evolve and ultimately disappear. They differ from one another mostly in terms of their mode of formation, course of evolution, duration of existence and their ultimate disappearance.

The present investigation is concerned with the palaeogeographic evolution of the Akkulam lake and its geotechnical implications in the future development of the fast-growing urban area of the city of Thiruvananthapuram.

The Akkulam lake is one of the minor lakes located within the coastal plain immediately north of Thiruvananthapuram. The lake presently covers an area of 1.7 km^2 and is intermittently connected with the Lakshadweep