13. Radda, G. K., *FASEB J.*, 1992, **6**, 3032–3038.
14. Bachelard, H. and Badar-Goffer, R., *J. Neurochem.*, 1993, **61**, 412–429.
15. Cohen, J., *Mayo Clin. Proc.*, 1988, 1199–1207.
16. Foxall, D. L. and Cohen, J. S., *J. Magn. Reson.*, 1983, **52**, 346–349.
17. Lyon, R. C., Faustino, P. J. and Cohen, J. S., *Magnetic Reson. Med.*, 1986, **3**, 663–672.
18. Holtzmann, D., McFarland, E., Moerland, T., Koutcher, J., Kushmerick, M. J. and Neuringer, L. J., *Brain Res.*, 1989, **483**, 68–77.
19. Roots, B. I., in *Dynamic Properties of Glial Cells* (eds Schoffenils, E., Frank, G., Towers, D. B. and Hertz, L.), Pergamon Press, Oxford, 1978, p. 50.

ACKNOWLEDGEMENT. The NMR experiments were performed at the Sophisticated Instruments Facility, Indian Institute of Science, Bangalore.

Received 7 February 1996; revised accepted 14 May 1996

Anomalous helium emission: Precursor to earthquakes

Debasis Ghose, Nishith Kr. Das and Bikash Sinha

Variable Energy Cyclotron Centre, Department of Atomic Energy, I/AF Bidhan Nagar, Calcutta 700 064, India

Helium content at the thermal springs at Bakreswar, near Calcutta, was observed to vary. These variations appear correlated to seismic perturbations. The position and distance of epicentre cannot yet be predicted from such correlation.

THERE is adequate evidence that the variations in the relative abundance of the constituents of terrestrial gas have certain degree of correlation with the perturbations within the mantle as well as the crust of earth[1]. A recent report has indicated that there was a ten-fold increase in the radon content in bore hole gas prior to the earthquake at Kobe, Japan[2]. Anomalously high helium concentrations have also been reportedly observed in well waters and soil gases preceding an earthquake[3,4].

It is well established by now that noble gas such as helium and radon interact weakly with matter; thus, it is expected that there will be pronounced variations in their relative abundance for such perturbations just mentioned, compared to their chemically reactive counterparts, such as nitrogen and methane. In the case of radon on account of chemical non-equilibrium and short recoil length, the host rocks incorporating the parent Ra-226 migrates rather large distances in water and in soil[5]. However, its relatively short decay time (3.82 days) inhibits any substantial concentration, so that very marginal radon content contribute above background value[6]. Over the last several years, we have been observing large fluctuation in helium concentration in the natural gas emanating from thermal springs[7]. Three mechanisms have been suggested so far to account for the anomalies observed for the constituents of the soil gas in seismic-induced disturbances: (i) relative increase in heat flow that enhances gas concentrations near the surface[7,8], (ii) stress-induced pore collapse resulting in an upward flow of deep-seated gas[9]. (iii) stress-induced microfracturing leading to an increase in outgassing[10]. The collected sample of natural gas issuing from thermal springs was measured analytically by two separate techniques. A gas chromatograph operational at Bakreswar, the site of investigation (about 200 kms from Calcutta), of Variable Energy Cyclotron Centre was used to determine the relative abundances of helium and associated gases. Furthermore, the relative abundance of helium was determined by an absolute method based on the technique first developed by Frost[11].

We found the helium abundance at Bakreswar to be a variable quantity in general. The computed average of helium abundance, taken from recorded data of the diurnal readings for a five-year period, 1987–1991 was around 1.8%. We call this the characteristic 'helium index' for the spring. The normal value of the emanation rate during the quiescent state was close to the above figure with approximately ±0.2% variation. However it had been observed that the index began to fall very gradually two to three weeks prior to an impending seismic disturbance, known as earthquakes. The index tended to reach the minimum value four to five days before the triggering of the quake. This scenario was immediately followed by a sharp rise in the index, reaching its highest value two to three days prior to the occurrence of the quake, the peak value being two to three times the minimum value. Indeed, the helium content increased to 7.3% immediately prior to the volcanic eruption at Barren Island in July 1991 (ref. 12).

The measured magnitude of the helium concentration at Bakreswar for October in 1991 is plotted in Figure 1; corresponding data for January in 1992 is in Figure 2 and for the subsequent month of April 1992 is shown in Figure 3.

It was generally seen that the profiles had an irregular oscillatory pattern. This is expected since the helium contained in any underground environment is at best in a fragile state of equilibrium. It should also be mentioned that the presence of other diluting gases such as N_2 and CH_4 affected very feebly the outflow of helium as observed by Reimer[4] in soil gas. For large scale deviations ($d > 3\sigma$) one has to thus look for catastrophic causes such as earthquakes as suggested by Scholz *et al.*[13]. In order to judge the long term and background behaviour of helium changes, emission graphs for the period June 1991 to October 1991, January 1992 to July 1992 and January 1993 to October 1993 (Figures 4–6) are given. The spring gas was collected

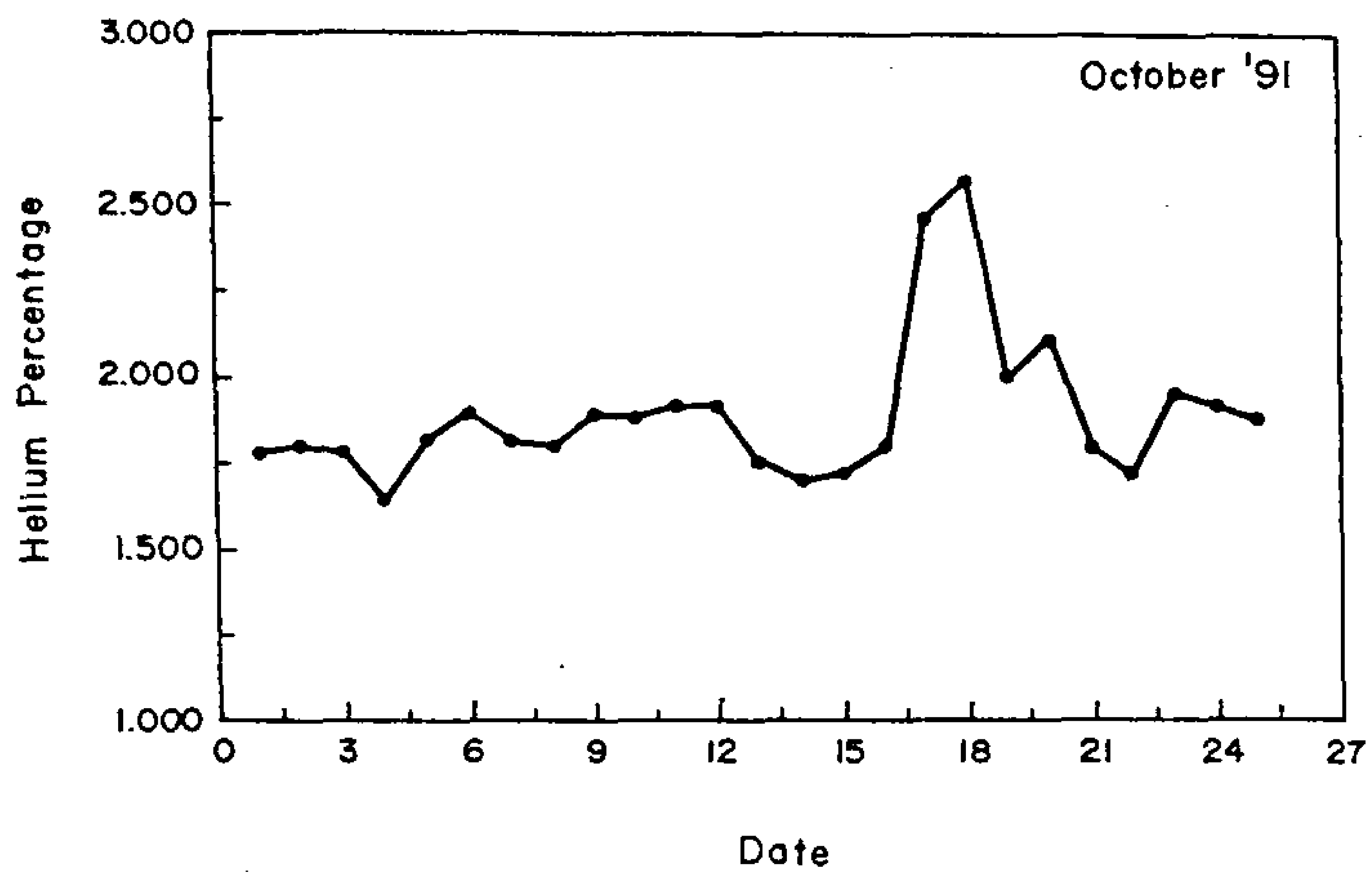

Figure 1. Variations of diurnal helium content during October 1991. The peak on 18 October precedes the Uttarkashi Earthquake on 20, 1991.

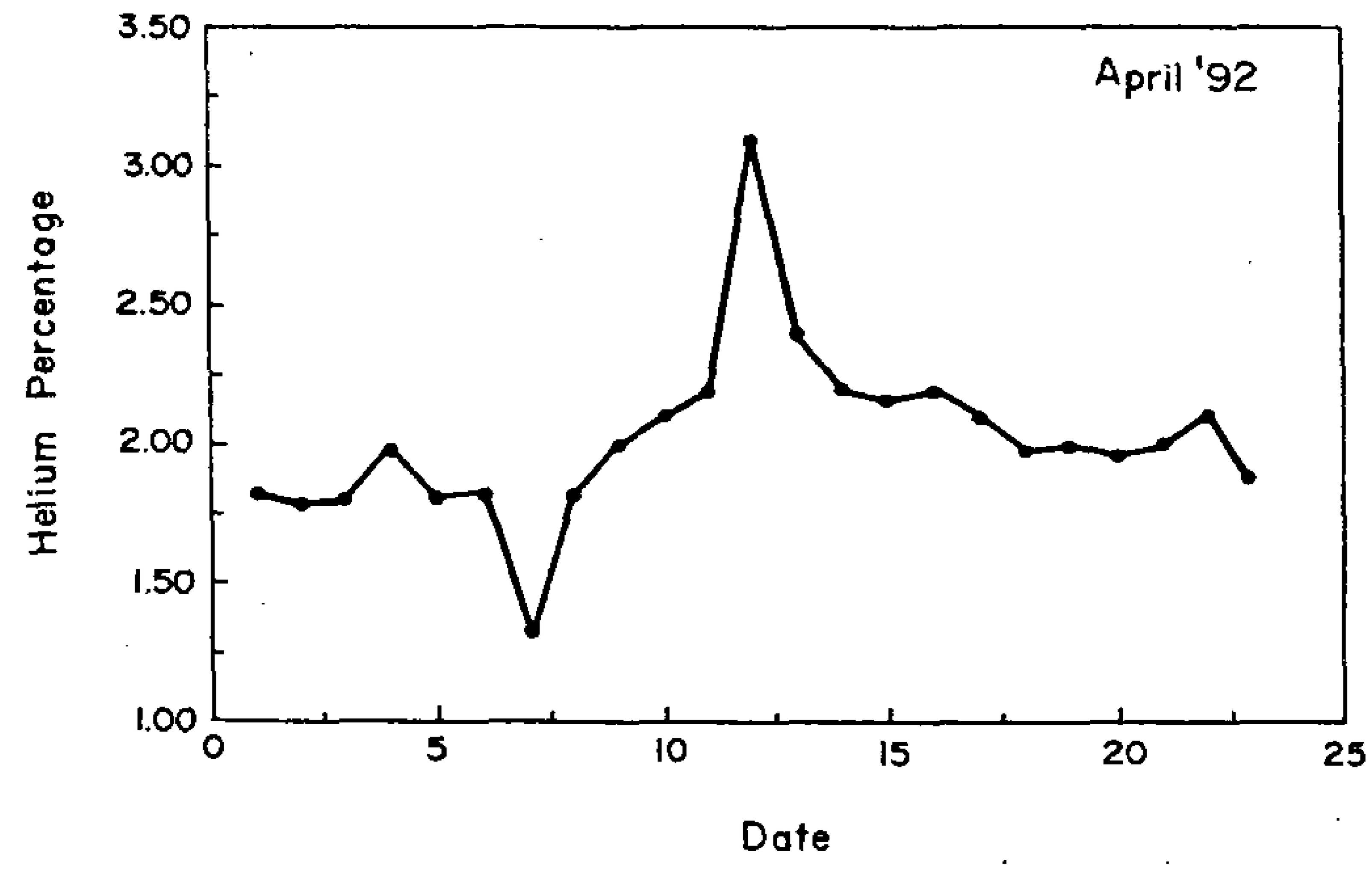

Figure 3. Helium variations for April 1992. The peak on 12 April corresponds to tremor at Shillong on 15 April 1992.

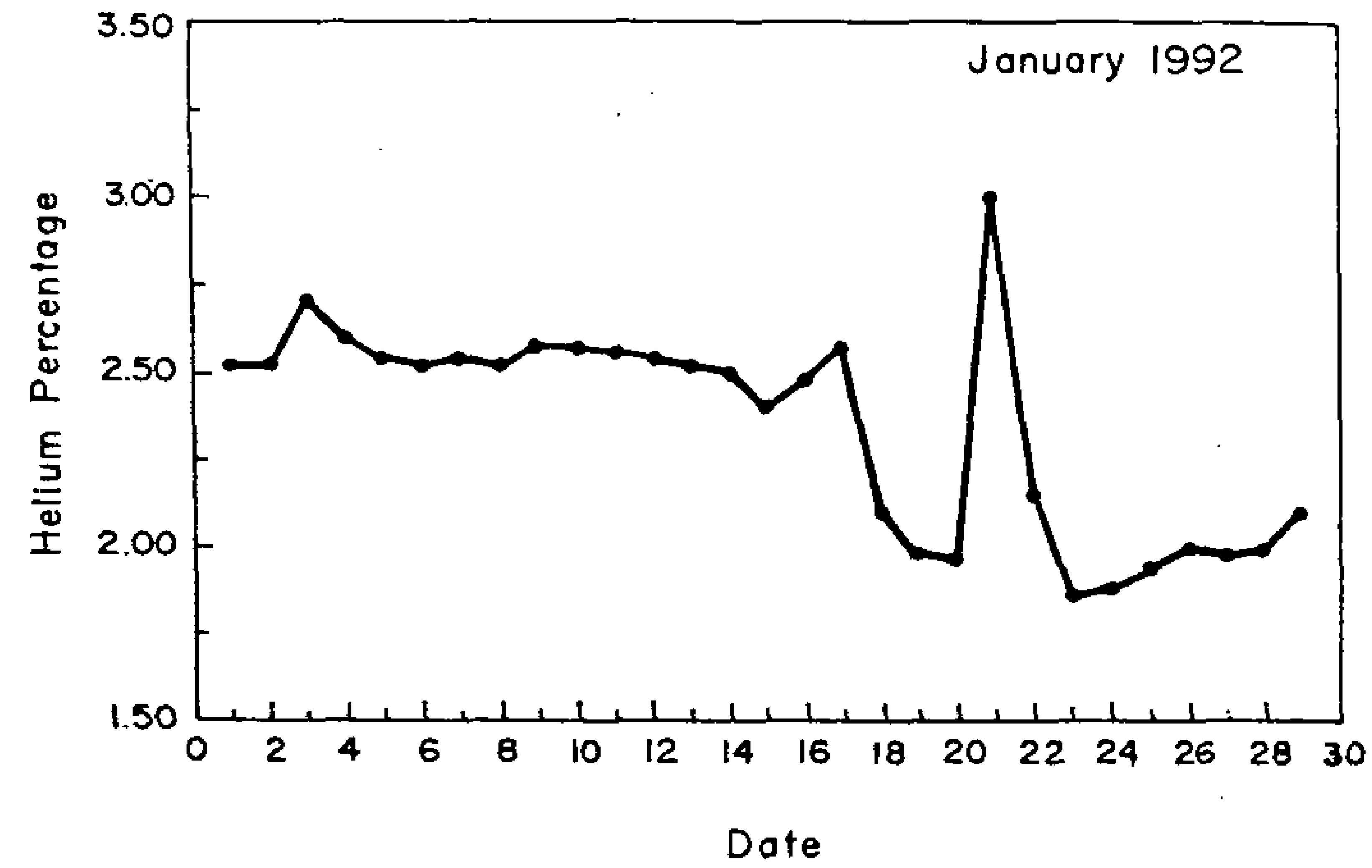

Figure 2. Helium variations for January 1992.

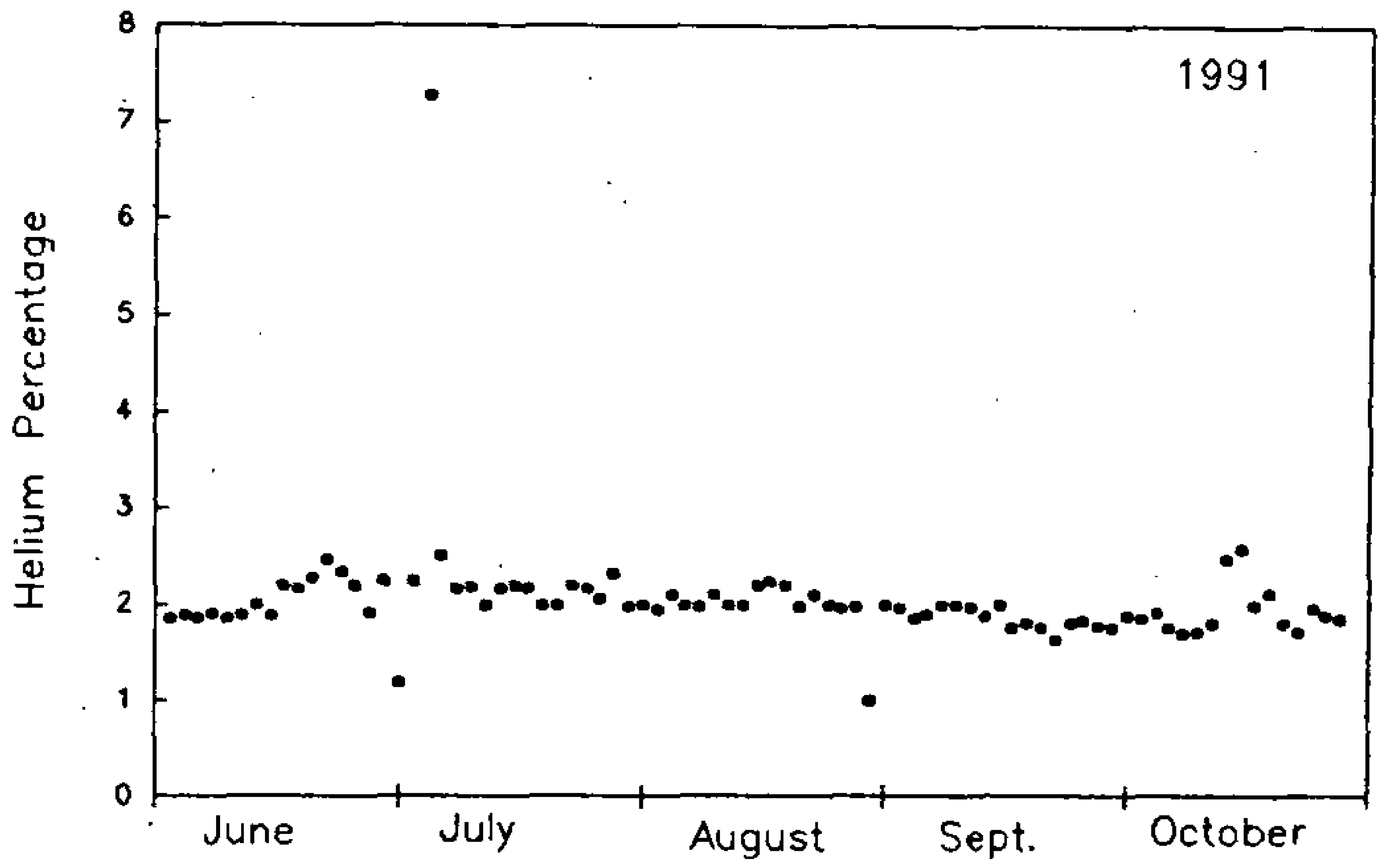

Figure 4. Temporal variations of helium in 1991 from June to October.

beneath a water column about 1.2 m. One can therefore preclude effects caused by meteorological conditions such as atmospheric pressure, wind speed, precipitation and temperature variations. As the springs lie in a relatively secluded area, influence of other non-tectonic factors such as mining, industrial activity, dam building or even water pumping is unlikely.

Our observations tend to indicate that the gas anomalies are reflected even at large distance from the centre of the quake. However, we could not correlate the observed increase in helium on January 21, 1992 to any specific tremor. Nonetheless, the peak may well be a manifestation of the reported seismic disturbances in Ionian sea; the Kamchatka peninsula and Japan's Honsu Island around January 23–25, 1992. It is also known that a change in strain associated with an earthquake by only 10^{-8} will lead to a change in the helium content[14]. Such gas anomalies and seismic disturbances are possible incidental results of the same cause, the strain changes that take place within the earth's crust. Because of the large disparity in the magnitude of the energies involved, gas anomalies show up much earlier.

In some cases fluctuations as high as six to seven times the standard deviations have been noticed. It has not been possible so far, as mentioned, to predict with reasonable precision the distance of the epicentre of the quake or its location with relation to the thermal spring. One can only predict two or three days prior to the triggering of an earthquake somewhere! Work is in progress to estimate the radial distance of the epicentre from the spring site through multiple observation points. Although, as yet, there is no total one to one correspondence between earthquake and anomaly occurrences, we would venture to predict the following about the possible increase in the relative abundance of helium scenario just before the earthquake, admittedly rather

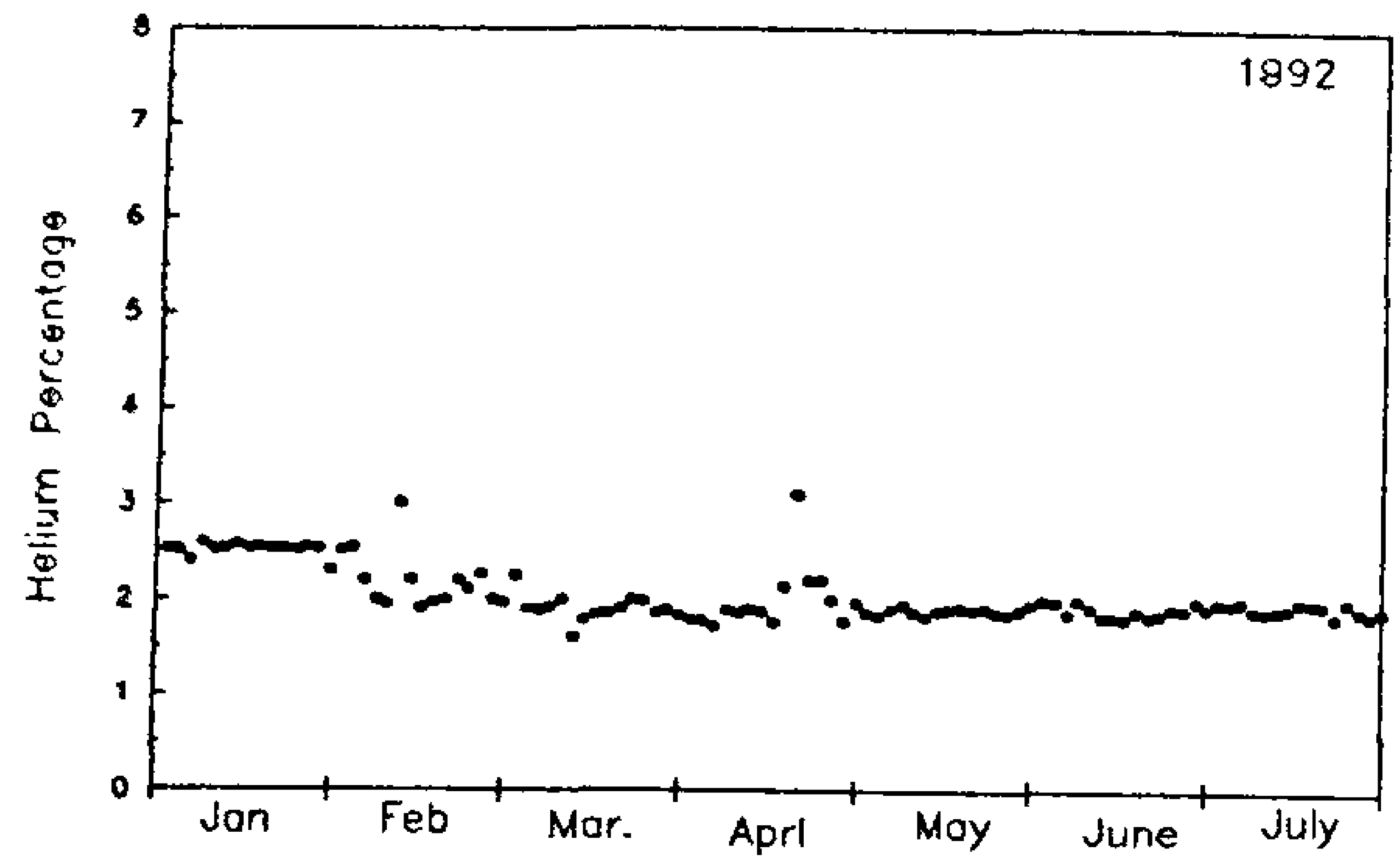

Figure 5. Temporal variations of helium in 1992 from January to July.

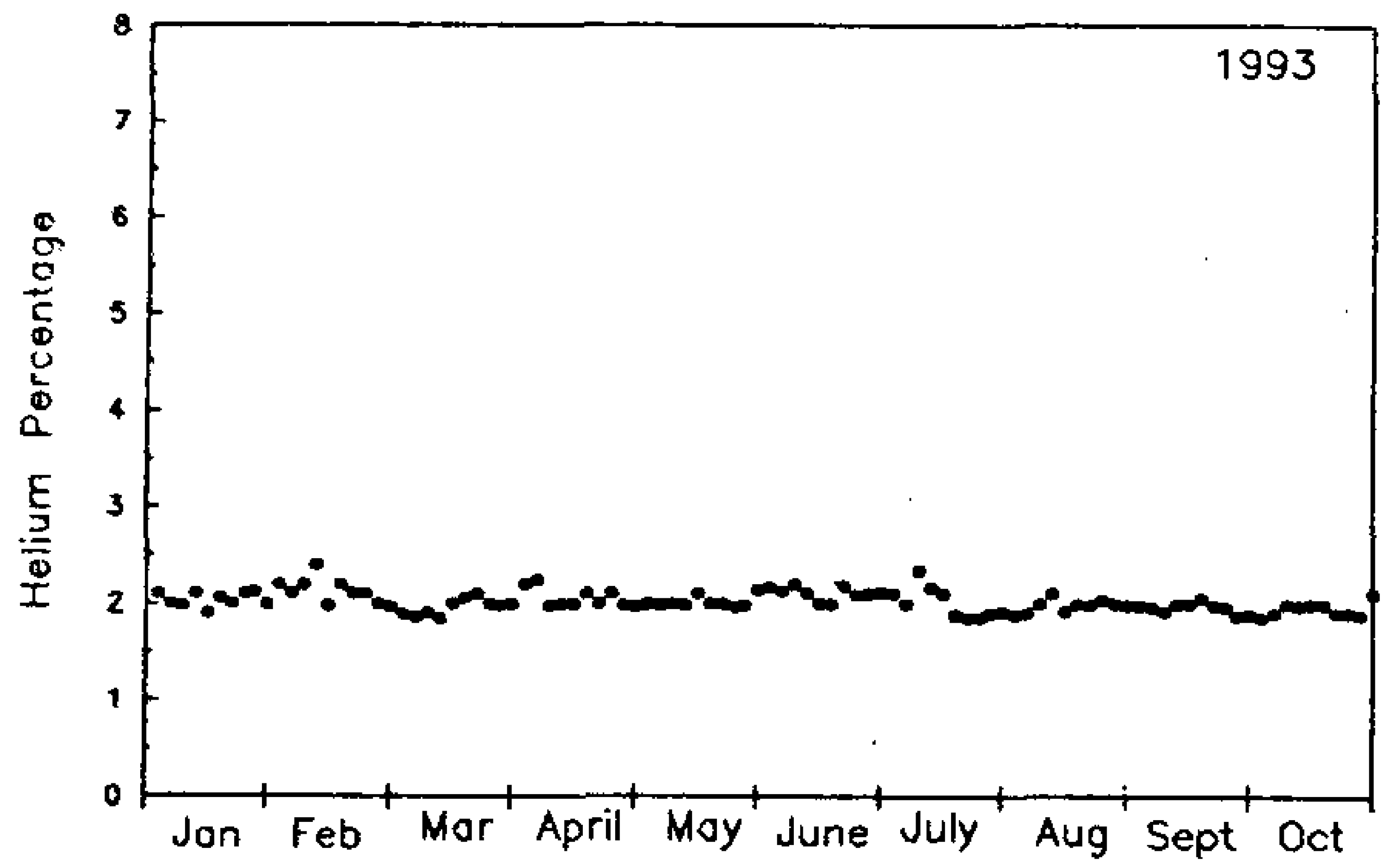

Figure 6. Temporal variations of helium in 1993 from January to October.

speculative, but interesting. Gradual accumulation of stress within the rock structure results in rise of pore pressure. The typical precursor of earthquakes, in general, is a steady rise in the pressure around the epicentre of the quake, at or around a yet unknown critical pressure of the system. Rather like more familiar phase transition of the system at a critical pressure essentially gives in with a sudden release of the pressure. With the rise of pressure the amplitude of the elastic shocks propagating around the centre increases as it approaches towards the triggering point. The shock waves, associated with the pressure release is the quake. With release of the pressure the helium stored in the rock matrix, aquifer or produced *in situ* tends to escape in larger volume as observed. The shocks travel a fairly large distance indeed, the very characteristic of helium is such that sources of helium turn out rather sensitive even at a very large distance. The speculative scenario, just prescribed has analogies with the bounce of supernova explosion or even head shocks or slide splash in nuclear physics[15,16]; a geological analogue in large scale is yet to be worked out.

1. Hooker, P. J., Bertrami, R., Lombardi, S., Onions, R. K. and Oxburgh, E. R., *Geochim. Cosmochim. Acta*, 1985, **49**, 2505–2513.
2. Igarsi, G., Saeki, S., Takahata, N., Sumikawa, K., Tasaka, S., Sasaki, Y., Takahasi, M. and Sano, Y., *Science*, 1995, 269.
3. Gorbushina, L. V., Tyminskiy, V. G. and Spiridonov, A. I., *Int. Geol. Rev.*, 1973, **15**, 380–383.
4. Reimer, G. M., *Pure Appl. Geophys.*, 1985, **122**, 369–375.
5. Mogro-Campero, A. and Fleischer, R. L., *Earth Planet. Sci. Lett.*, 1977, **34**, 321–325.
6. Tanner, A. B., *The Natural Radiation Environment III*, Symposium Proceedings 1978, Houston, Texas, April, 23–28, Rep. CONF-780 US Dept of Energy, Washington DC, 1980, **422**, pp. 5–56.
7. Ghose, D., Das, N. K., Sinha, B., Das, S. K. and Chatterjee, S. D., *Proc. Indian Natl. Sci. Acad.*, 1994, **A60**, 481–486.
8. Sultankhodzhayev, A. N., Proceedings International Earthquake Prediction, UNESCO, Paris, 1979, pp. 181–191.
9. Nur, A., *Bull. Seismol. Soc. Am.*, 1972, **62**, 1217–1222.
10. Varshal, G. M., Sobolev, G. A., Barsukov, V. L., Koltsov, A. V., Kostin, B. I., Kudinova, T. F., Yu. Stakheyev I. and Tretyakova, S. P., *Pure Appl. Geophys.*, 1985, **122**, 463–477.
11. Frost, J. M., *Bull. US Bureau of Mines*, 1951, **486**, 141.
12. Ghose, D., Das, N. K., Sinha, B., Das, S. K. and Chatterjee, S. D., *Proc. Int. Sci. Acad.*, 1994, *Ibid.*
13. Scholz, C. H., Sykes, L. R. and Aggarwal, Y. P., *Science*, 1973, **181**, 803–810.
14. King, C. Y., *J. Geophys. Res.*, 1986, **91**, 12,269–12,281.
15. Stuart, Shapiro, L. and Saul A. Teukolsky, *Black Holes, White Dwarfs and Neutron Stars: The Physics of Compact Objects*, John Wiley and Sons, New York, 1983.
16. Gustafsson, H. A., Gutbrod, H. H., Kolb, B., Lohner, H., Ludewigt, B., Poskanzor, A. M. *et al.*, *Phys. Rev. Lett.*, 1984, **52**, 1590–1593.

Received 27 December 1995; revised accepted 14 May 1996

Modelling of aeromagnetic anomaly and its implication on age of emplacement of ultramafic–mafic–alkaline complex at Jasra, Assam

D. Atchuta Rao, G. D. J. Sivakumar Sinha and H. V. Ram Babu

National Geophysical Research Institute, Hyderabad 500 007, India

The aeromagnetic anomaly around Jasra in Assam, based on which the Atomic Minerals Division had discovered an ultramafic–mafic–alkaline carbonatite complex[1] has been modelled. Inferred direction of magnetization of the source body suggested the age of emplacement of the source to be around Jurassic period which is correlated with the time of breaking up of the Gondawanaland and the northward drift of the Indian plate and crustal upheavals.

THE aeromagnetic survey carried out by the National Geophysical Research Institute (NGRI), over an area of about 14000 km^2, covering parts of Garo hills, Shillong plateau, and Khasi hills region of Meghalaya and Assam