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Monitoring of soil radon by SSNTD in Eastern India in search of possible earthquake precursor

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ABSTRACT

The present paper deals with monitoring soil radon-222 concentration at two different locations, designated Site A and Site B, 200 m apart at Jadavpur University campus, Kolkata, India, with a view to find possible precursors for the earthquakes that occurred within a few hundred kilometers from the monitoring site. The solid state nuclear track detector CR-39 has been used for detection of radon gas coming out from soil. Radon-222 time series at both locations during the period August 2012–December 2013 have been analysed. Distinct anomalies in the soil radon time series have been observed for seven earthquakes of magnitude greater than 4.0 M that occurred during this time. Of these, radon anomalies for two earthquakes have been observed at both locations A and B. Absence of anomalies for some other earthquakes has been discussed, and the observations have been compared with some earthquake precursor models.

1. Introduction

Earthquake is a natural disaster that has long been a threat to human society. Such catastrophic events cause great devastation and loss of life. To minimise such huge losses, researchers all over the world have been trying to determine possible precursors of impending earthquakes for the last several decades. Various seismic and non-seismic precursors including seismicity trends, lithospheric, geophysical and geochemical precursors, animal behavior, ground water variations, and electromagnetic changes in ionosphere have been studied globally by various researchers (Fleischer and Mogro-Campero, 1978, 1985; Lott et al., 1981; Kagan and Jackson, 1991; Pulinets et al., 2006; Pérez et al., 2008; Singh et al., 2010; Freund and Stoic, 2013; Ergintav et al., 2014; Jin et al., 2014). Geochemical signals (radon, helium, methane, etc.), especially radon-222 gas emanated from soils and hydrothermal systems, have drawn much attention as promising seismic precursors. Continuous monitoring of radon-222 concentration in hydrothermal systems (Mogro-Campero et al., 1980; Mil'kis 1984; Yu and Mitchell, 1988; King et al., 2000; Chaudhuri et al., 2011, 2013; Barbosa et al., 2015) or sub-surface soil gas (Toutain and Baubron, 1999; Hartmann and Levy, 2005; Weinlich et al., 2006; Ramola et al., 2008; Georgy et al., 2015) is an interesting method for determination of precursory signals of an earthquake. Large variations in radon concentrations in soil gas and gases coming out from dead volcanoes as well as in groundwater and hot springs and atmosphere have been reported in many studies (Ulomov and Mavashev, 1968, 1971; Sadowsky et al., 1972; Sultankhodzhayev et al., 1976; King, 1978, 1980; Teng et al., 1981; Friedmann, 1985; Rastogi et al., 1986, 1987; Igarashi and Wakita, 1990; Igarashi et al., 1995; Segovia et al., 1995; Pulinets et al., 1997; Yasuoka and Shinogi, 1997; Planinić et al., 2000; Reddy et al., 2006; Yang et al., 2005; Das et al., 2006; Yalim et al., 2007; Tuccimei et al., 2010; Cigolini et al., 2015; Nevinsky et al., 2015; Petraki et al., 2015; Oh and Kim, 2015). Such variations, called 'anomalies', are manifested as large deviations from the normal radon emanation rates at the sites of observation. The anomalies which occur due to earthquake-related stress–strain changes underneath the earth crust may provide suitable earthquake precursory signal.

A part of the radon gas generated in rocks remains in the solid matrix of the earth crust, while the rest moves to pore-fluids and migrates away through interconnected pores and aquifers by the methods of diffusion and fluid flow. Tectonic deformation during earthquake preparation phase causes changes in rock pressures and fluid convective flows, which lead to changes in the strain field of rock mass. The strain developed within the earth crust before an earthquake causes transportation of gases from deep inside the earth to the surface (Fleischer and Mogro-Campero, 1978; Thomas, 1988; Walia et al., 2005; Kumar et al., 2012). Several in-situ and laboratory experiments have been performed and mathematical models have been proposed by Clements (1974); Schery et al. (1984); Schery and Siegel (1986); Holford et al. (1993); and Reddy et al. (2006). However, the origin and mechanism of

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soil radon anomalies and their relationship to earthquakes are not completely understood yet. According to the compression mechanism proposed by King (1978), anomalous radon emission from soil may be induced due to an increase in crustal compression that squeezes out the soil gas into the atmosphere at an increased rate before an earthquake. Radon anomalies have been observed at large distances from the earthquake epicentre, resulting from the earthquake-induced changes in the physical parameters of the soil matrix near the monitoring station. Hence, it may be considered that the changes in stress or strain propagate from the rupture zone to the monitoring station, leading to variations in porosity and permeability of soil and the rate of groundwater flow at the radon monitoring station (King, 1978). Hauksson (1981) reported that radon anomalies may occur at greater epicentral distances for earthquakes of larger magnitude, and precursor time may increase with the magnitude of the earthquake and decrease with the distance from the epicentre to the radon monitoring station.

The first mathematical formulation connecting the magnitude of an earthquake with the maximum distance from its epicenter where radon anomalies are likely to be observed was by Dobrovolsky et al. in 1979. Their proposed relation gives the maximum epicentral distance, D_m (in km) for an earthquake of magnitude M as

$$D_m = 10^{0.43M}, \ M \geq 3 \tag{1}$$

Fleischer (1981) and Fleischer and Mogro-Campero (1985) modified this empirical relation and proposed the following

$$\begin{aligned} D_{Fl} &= 10^{0.48M}, \ \text{for} \ \ M \geq 3 \\ D_{Fl} &= 10^{0.813M}/16.6, \ \ \text{for} \ \ M < 3 \end{aligned} \tag{2}$$

In 1980 Sultankhodzhayev et al. proposed an empirical relation between earthquake magnitude (M), precursor time and epicentral distance (D) which gives the maximum precursor time (in days) before an earthquake as

$$\begin{aligned} T_{sul} &= 10^{(0.63M+0.15)}/D, \ \text{for} \ \ M \geq 3 \\ T_{sul} &= 10^{(0.63M-0.15)}/D, \ \text{for} \ \ M < 3 \end{aligned} \tag{3}$$

However, many physicochemical features of the earth crust like soil density, grain size, porosity, permeability, presence of radioactive elements (like uranium) underneath the soil, etc., and geophysical factors like local geology and movement of ground water and nature of aquifers may affect the normal radon emanation from soil in a region and hence conceal the genuine precursory anomalies (Virk and Singh, 1993; Pinault and Baubron, 1996; Walia et al., 2005; Das et al., 2006; Ramola et al., 2008; Cigolini et al., 2009; Koike et al., 2014; Silva et al., 2015). Moreover, the emanation process is influenced by various meteorological parameters such as temperature, atmospheric pressure, rainfall and humidity of both sub-surface soil layers and atmosphere (Tanner, 1964; Shapiro et al., 1985; Fujiyoshi et al., 2006; Laiolo et al., 2012; Barman et al., 2016). Another important factor is the tidal effects of sun and moon that cause diurnal, semi-diurnal and semi-monthly variations in soil radon emanation in a region (Baykut et al., 2011; Chaudhuri et al., 2011, 2013).

In the present work, the soil radon-222 data monitored at Jadavpur University premises (22.4999°N, 88.3715°E) during the period August 2012–December 2013 has been analysed in order to determine possible correlations between radon anomalies with seismic events of magnitude > 4.0 M that occurred within a radial distance of 500 km from the monitoring site.

2. Geology of the region

Jadavpur is a southern neighbourhood of Kolkata metropolis located on the east bank of river Hooghly, in the lower Gangetic Delta of eastern India. The entire region is positioned over the Bengal Basin which is one of the most extensive sediment reservoirs in the world and constitutes the lower floodplain and delta plain deposits of India and Bangladesh, at the mouth of the Ganga–Brahmaputra–Meghna River systems (Roy et al., 2010; Alam et al., 2003). Due to the location of the basin at the juncture of three interacting plates, viz., the Indian, Burma and Tibetan (Eurasian) Plates, the basin-fill history of these geotectonic provinces varied considerably. The hinge zone and the shelf area are traversed by many faults, some which may be tectonically active at present. The hinge zone is about 25 km wide and occurs at a depth of about 45000 m below Kolkata (Nandi, 2007). The major fault systems in this region are Garhomoyana-Khandaghosh Fault (GKF), Jangipur-Gaibandha Fault (GGF), Pingla Fault, Eocene Hinge Zone (EHZ), Debagram Bogra Fault (DBF), Rajmahal Fault (RF), Dauki Fault (DF), Sylhet Fault (SF), Sainthia Bahmani Fault (SBF), and Dhubri Fault (DHF) (Shiuly and Narayan, 2012). This tectonic setting is shown in the geological map (Fig. 1). The total sedimentary thickness below Kolkata is of the order of 7500 m above the crystalline basement. Of this the top 350–450 m is Quaternary, followed by 4500–5500 m of Tertiary sediments (Bhattacharya et al., 2012).

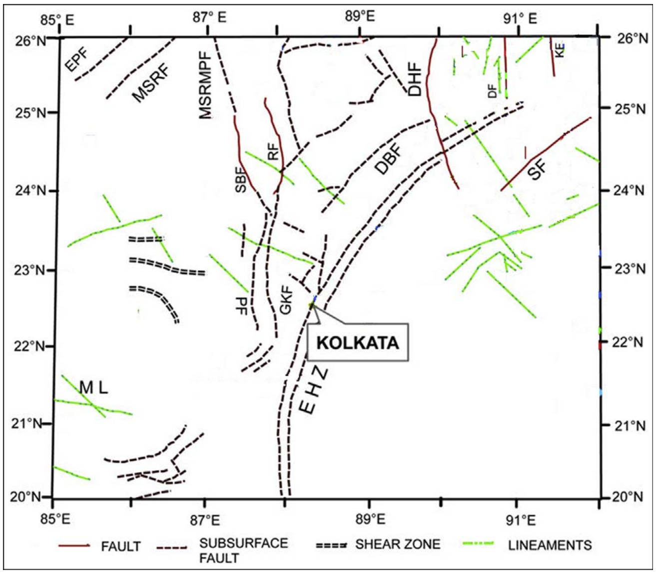

Fig. 1. Seismotectonic map of Kolkata city and surrounding region (modified after Shiuly and Narayan, 2012).

3. Experimental method

In the present work track etch technique method has been adopted utilizing the solid state nuclear track detector (SSNTD) CR-39 plastic plate for registering tracks of α-particles emitted by Rn-222 from soil. A small square CR-39 plate of size 1 cm × 1 cm was attached with double sided tape on the inner bottom surface of a plastic cup of height 4.7 cm and diameter 6.3 cm at the open end and 5.9 cm at the closed base. The open end of the cup was covered with a stretched latex membrane of thickness 20 μm. This membrane is permeable to radon while other elements like short-lived radon progeny are stopped by it along with dust and water vapour whose sizes are greater than 20 μm. A 70 cm long steel cylinder open at both ends was placed permanently inside a hole in the ground at the spot selected for soil radon monitoring so that the top of the cylinder was at the ground level. The plastic cup along with the detector was placed within the cylinder in such a way that its membrane-covered face remained towards the ground. The separation between the soil surface and the membrane was kept nearly 1 cm with the help of two supports which were also useful for preventing any damage to the membrane. An adequate quantity of anhydrous silica gel adsorbent was placed within the cylinder to reduce moisture within the enclosed volume. The upper end of the cylinder was covered with a lid in order to reduce the effect of external air turbulences on soil radon. A schematic diagram of the experimental setup is shown in Fig. 2.