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Recognition and characterization of a tectonically active Karak Thrust using radon measurement technique in the Southern Kohat Plateau, Pakistan

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Abstract

The technique of radon gas measurement can successfully be employed as a very useful geological tool in the prediction of earthquakes, authentication of active fault zones and exploration of hidden uranium deposits. This study was designed to declare appropriateness of this technique in the study of an active thrust fault in District Karak, Khyber Pakhtunkhwa. RAD7, a radon-in-air monitor of Durridge Company (USA) was used for the onsite soil air radon levels measurement in traverses made across the thrust fault on its either side. In this survey 21 measurement points were selected along four traverse lines across the fault. High levels of radon were observed in the soil air at points on or adjacent to the fault trace as compared to the points away from the fault line on its either side. The values were high by a factor of 5-12 times above the background values. This clearly indicates that the technique of soil air radon measurement can effectively be used as a realistic tool in the detection, characterization and mapping of the on surface and buried active geological faults. An earthquake occurred along the thrust two years after the conduction of this study in on September 28, 2014 confirming our conclusion that the fault is tectonically active.

Keywords: Radon; Soil air; Active faults demarcation; Active technique; Karak Thrust; Pakistan.

1. Introduction

Radon is a naturally occurring, noble, alpha particles discharging radioactive gas found ubiquitously in our environment. It is the decay product of a radioactive metal, radium, which in succession has been produced from the radioactive decay of its precursor element, uranium. Uranium metal is found unanimously in trace amounts in the soils and rocks of the Earth's crust. Radon (222Rn), thoron (220Rn) and actinon (219Rn) are the three commonly occurring natural isotopes of radon gas. Creation of radon (222Rn), the most stable and abundant isotope, takes place from the disintegration of 238U which has a natural abundance of about 99.3% of the total uranium found within the Earth's crust. Thoron (220Rn) is formed in nature during the decay of 232Th, while, actinon (219Rn) is produced during the decay of 235U (Canadian Nuclear Safety Commission, 2011). Half-life of the most abundant isotope of radon (222Rn) is 3.82 days. It disintegrates by emitting an alpha particle of 5.49 meV and creates a radioactive daughter polonium (218Po).

Migration and transport of 222Rn gas from its point of creation at particulate level in the rocks and soils to the point of its ultimate release at the surface of the earth take place through two mechanisms, namely, the diffusion and convection, respectively. The short half-life of radon gas restricts its diffusion for long distances through soils and rocks in the subsurface. Therefore, high levels of radon gas monitored at the surface of the earth cannot be from a deeper source unless there may prevail a swiftly transporting mechanism other than simple diffusion. For explaining transportation of radon gas over long distances several models have been proposed. It has now been widely accepted that underground water and carrier gases including methane, carbon dioxide, helium and nitrogen can cause transportation of radon gas over large distances from its point of origin (Kristianson and Malmqvist, 1982; Rogers and Nielson, 1991; Etiope and Martinelli, 2002).

Radon plays a dual role in human life. Being radioactive, it poses a major health hazard to mankind. The radon progenies are well-known for their contributory role in causing lung and gastrointestinal cancers (ICRP, 1994; UNSCEAR, 2000). To safeguard community from the effects of excessive exposure to harmful radiation from radon gas and its progenies it is obligatory to get awareness about the levels of radon in the indoor environment of houses or in the underground water and soil gas (Nero, 1990).

On the contrary, it serves as a very powerful exploratory tool in the field of geosciences (Khan, 1991). Normally, emission of radon from the earth crust into the atmosphere is in infinitesimal amount. However, incredible quantities of radon could be emitted above geothermal energy sources, volcanoes, underground uranium deposits and geological faults. High levels of radon emissions over these sites depend upon the releasing ability of soils and rocks, mechanisms of subsurface migration and the climatic factors (Magro-Campero and Fleischer, 1977). Therefore, radon monitoring technique can be used as an excellent geological tool in exploration for subsurface uranium deposits, earthquake prediction and confirmation of fault zones (King, 1980; Gingrich, 1984).

Very limited data is available on the proper demarcation and activeness of the Karak Thrust. The aim of the presently conducted research work was to study the possibility of using soil gas radon measurements technique as a geological tracer for exploring and properly delineating a tectonically active Karak Thrust in the vicinity of a tectonically active area of Siwalik Group of rocks in District Karak, Southern Kohat Plateau, Pakistan.

2. Location and extent of the study area

The study region is located on the northern side of the Karak-Sabir Abad road, extending from Karak city in the west up to Sabir Abad village in the east in Tehsil Karak. It is situated on the southern side of the Kohat Plateau. Karak City is the District Headquarter of the region. The plateau itself is located between 70° - 74° E and 32° - 34° N and is spread over an area of about 10,000 km^2. The Plateau constitutes the westernmost deformed part of the Himalayan Foreland Fold and Thrust Belt (Ullah et al., 2006). The entire Plateau is characterized by a series of roughly east-west trending anticlines and synclines formed due to the continuous collision between the Indian and Eurasian plates and contains some of the beautiful exposures of Cenozoic sedimentary rocks (Khan et al., 1986). The Kohat Plateau is surrounded by the Surghar Range Thrust (SRT) in the south, Main Boundary Thrust (MBT) in the north, Kurram Fault in the west and Kalabagh Fault (and Indus River) in the east (Jaume and Lillie, 1988; Meissner et al., 1974). The first detailed geological map of the Plateau was published by the United States Geological Survey (Ahmad et al., 2005).

The present study was conducted on Karak Thrust, a recently active geological fault located on the northern side of Karak Trough, a part of the Tehsil Karak of District Karak, Khyber Pakhtunkhwa Province. Karak Trough is located at the southern edge of the Kohat Plateau between 71° 01' 20" - 71° 23' 17" E and 33° 1' 12" - 33° 7' 12" N (Fig. 1). It is located on the southern side of the Karak Thrust and is bounded toward west by the Bannu Basin toward east by the Shakardara hills and toward south by the Shinghar-Surghar ranges. It covers about 80% of Tehsil Karak and includes Karak City and its adjoining villages located in its north, south, west and east. The Karak Trough is occupied by the Siwalik Group of rocks of Miocene age which are gently folded into a series of east west trending folds along with associated thrust faults (Ali, 2010). Karak Thrust, a northeast southwest trending and roughly north dipping geological fault juxtaposes younger Siwalik Group of sedimentary rocks of Miocene age on the south against older Bahadur Khel Salt and Jatta Gypsum of Eocene age on the north.

3. Brief geology of the Karak Trough and adjoining region

Along the east-west stretching Karak Trough a thick sequence of molasse sediments of the Siwalik Group is exposed. Stratigraphically the Siwalik Group within the region is divisible into the Lower, Middle and Upper Siwaliks, respectively (Abbasi et al., 1983). As a whole the Siwalik Group within the region comprises of sandstones, shales and conglomerates. Karak Thrust is a major roughly

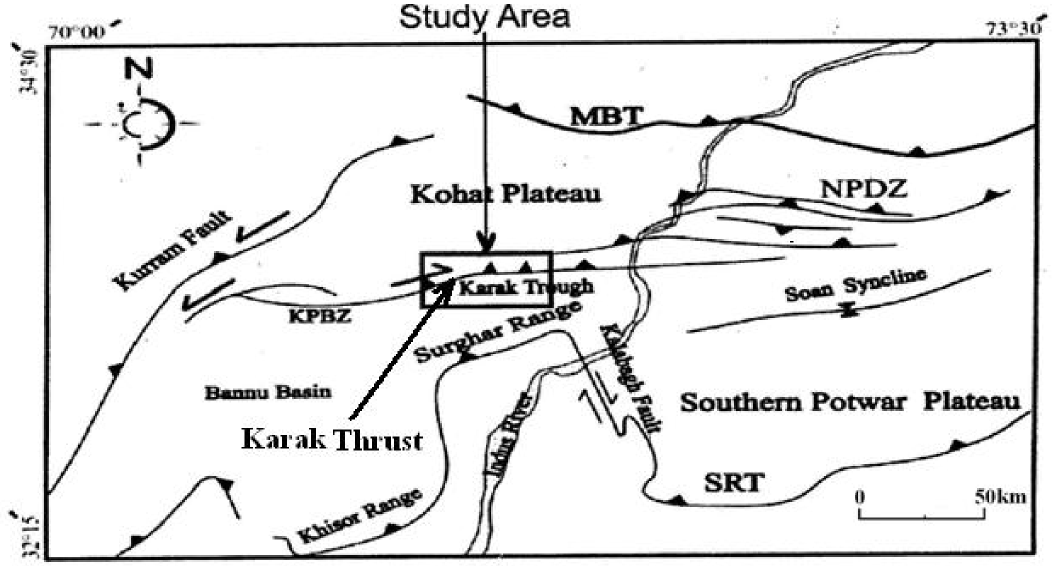

Fig. 3. Digitized streams and contours from the topographic sheet.

northeast-southwest striking thrust fault in the north of the Karak City along which gypsum beds of Eocene age have been brought southward over the Lower Siwalik sandstones and shales of Miocene age (Ali, 2010). A major roughly NE-SW striking anticline known as Karak Anticline occupies southern part of the Karak Trough on the southern side of the Karak Thrust.

4. Experimental procedure

The current study was carried out with the RAD7, an electronic detector from Durridge Company (USA). This equipment makes use of an air pump and a solid state alpha detector which consists of a semiconductor material (generally silicon) that transforms alpha radiation directly to an electrical signal. The internal sample cell of RAD7 is a 0.7 liter hemisphere, coated in the interior with an electrical conductor. A silicon made alpha detector is located at the centre of the hemisphere. The radon chamber is described in detail in Amgarou (2002). One key advantage of the solid state devices is roughness. Another benefit is the capability to instantly differentiate radon from thoron by the energy of the alpha particle liberated. The technique is known as alpha spectrometry. The standard units of picocuries per litre (pCi/l) were used for measuring the radioactivity in this study. One pCi is equivalent to the decay of about two radioactive atoms per minute. RAD7 was configured to sniff mode, which permits detecting rapid changes in radon concentration.

Soil-gas radon can be measured in three different modes with Rad7 equipment, namely, by the grab sample mode, another by continuous monitoring in the standard protocol and the third in the THORON mode, with the pump running continuously. In our case we used the grab sample mode. For GRAB protocol, it is mandatory first to purge the RAD7 for a duration of ten minutes or more with fresh, dry air, before connecting the probe.

A total of four traverses were completed across the hitherto poorly investigated and delineated Karak Thrust. In each traverse radon measurements were taken at five different locations (except traverse No. II′ in which measurements were taken at six location). A stainless steel soil-gas probe supplied by Durridge Company (USA) was used to measure radon activity in soil-gas. A 50 cm deep and 2 cm wide hole was made by inserting the probe, with a hollow tube through the soil with the help of a hammer. Sometimes the depth of the hole was less than 50 cm due to poor development of soil above the parent rock or the pebbly nature of the soil that did not allow the rod to reach at 50 cm depth. The probe was connected to RAD7 by pushing the plug-in hose connector into the probe, for preventing any water entrance to the detector. After the water trap, the air passed through a desiccant tube, then to a filter and finally to the RAD7 (Fig. 2). Before the counting process started the hole was properly sealed in order to prevent mixing of soil-gas with air from the atmosphere.

After giving test start command to the RAD7, its pump started to run for five minutes. During this time air was drawn up the tube, into the RAD7. The instrument then started to wait another five minutes and then counted for four five-minute cycles. At the end of the half-hour period, the RAD7 printed out a summary of the measurement, including an average radon concentration in the soil gas from the four 5-minute cycle measurements. In this method soil gas radon measurements were obtained quickly (in half hour) and the least amount of soil gas was used. Radon concentration was obtained in the units of pCi/l.

The beauty of this technique is that after the five minutes pumping at the start of the GRAB protocol, the RAD7 may be detached from the probe and the whole lot moved to a new site for the next measurement while the RAD7 continues to scan the grab sample just taken that is still in the measurement chamber. After completion of the test the RAD7 was purged again in order to prepare it for the conduction of the next test.

5. Soil gas radon survey across Karak Thrust

The so far poorly explored roughly north dipping Karak Thrust is located on the northern extremity of the Karak Trough and is trending in the northeast-southwest direction (Khattak et al., 2014). The fault is emplacing the rocks of Jatta Gypsum and Bahadur Khel Salt of Eocence age in the north over the younger Chinji Formation of Miocene age in the south (Fig. 3). The Karak Thrust marks the southern most extension of the evaporate facies exposed at the surface in the Kohat Plateau (Ahmad, 2003).

Soil gas radon concentration was measured along four different traverses each being across the strike of the fault. From east to west these were (1) the traverse of Banda Spina along FF′, (2) the traverse of Tarkha Koi along GG′, (3) the traverse of Lakki Ghundaki along HH′ and (4) the traverse of Gandao Village along II′, respectively. The aim was to determine the radon concentration in soil gas at a specified depth within the soil.

In the three traverses (FF′, GG′ and HH′) radon concentrations were measured at five different locations, while, along the fourth traverse (II′) radon measurements were made at six different locations.

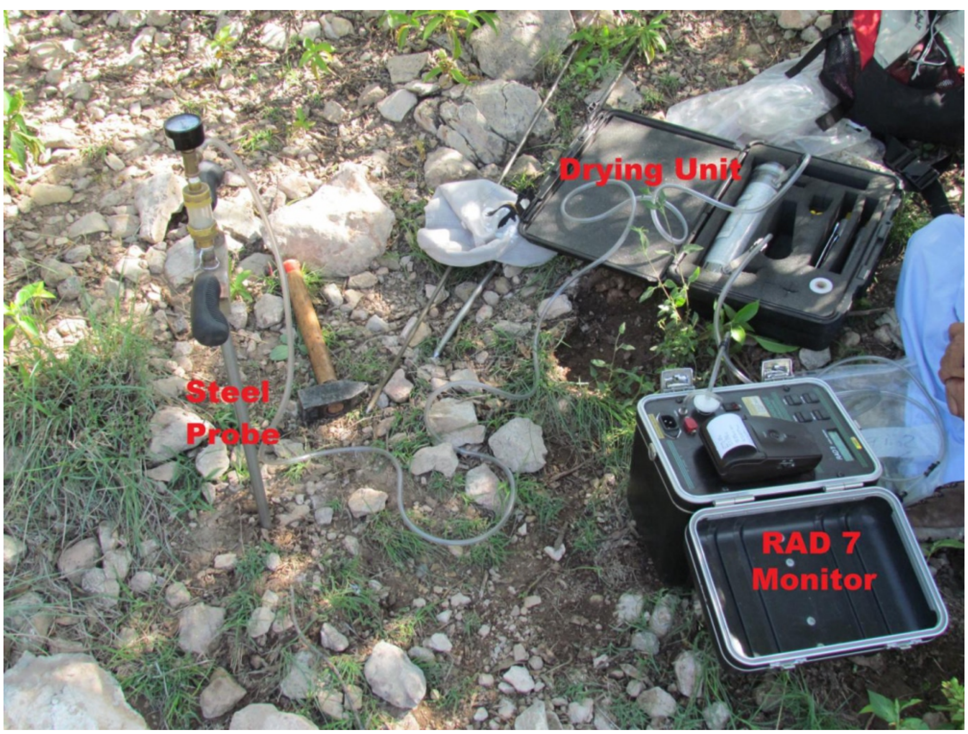

Fig. 2. Photograph showing RAD7 (Radon detector) setup for the measurement of radon concentration in soil-gas.

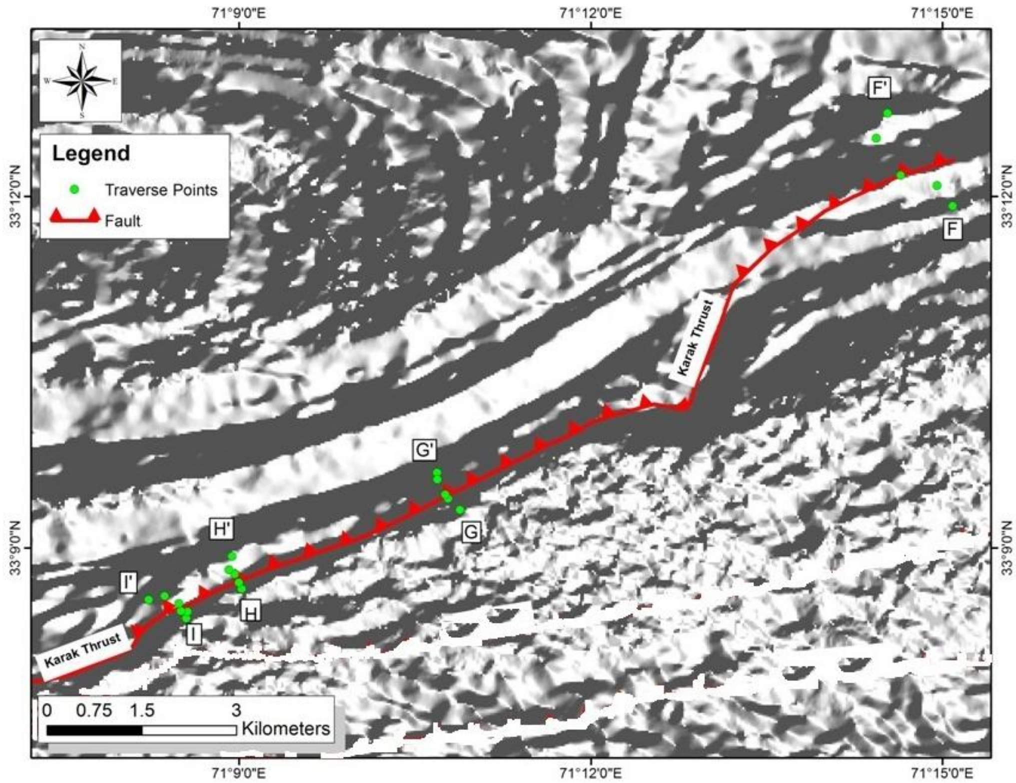

Fig. 3. DEM image showing different traverses completed across Karak Thrust for the measurement of radon gas in the soil.

6. Results and discussion

Geological faults can be defined as planar fractures within rocks, across which relative displacement of one side with respect to the other has taken place as a result of movement of the rock mass. Within the earth's crust large faults have usually resulted from the action of tectonic forces at or near the plate boundaries like subduction zones, mid-oceanic ridges or transform faults. Majority of the earthquakes occurring over the globe are the result of release of energy on active geological faults.

Faults may be either active or passive in nature. Active faults are those in which the blocks on either side of the fault plain move across each other in due course. On contrary inactive faults are those in which there had been movement along them in the geologic past, but are presently not moving actively. Active faults favor leakage of gases including radon because they result in increase in the permeability of soil which facilitates the gases to travel up easily.

Provided that the bed rock geology of a study area is uniform, the nature of its soil is homogenous and the depth of the air gas samples taken is consistent, the values of radon concentration should be alike (Al-Tamimi and Abumurad, 2001). Radon can travel through soil and bed rock by diffusion, by the flow of the moving soil gases (convection) or by combination of both the mechanisms (Ioannides et al. 2003). Gases from depth are usually coming from the faults where advection is generally responsible for the upward migration of these gases (Walia et al., 2005). Diffusion may explain for radon transfer over small distances usually only of few meters in arid soils of normal porosity and may be much shorter in soils of high moisture contents and low porosity (Tanner, 1964). Transportation of radon over long distances may, on the other hand, occur through the process of convection when radon is carried upwards by a rising flux of other soil gases, such as underground water, CO_2, N_2 or CH_4 (Fleischer et al., 1980; Kristianson and Malmqvist, 1982). This mechanism can as a result cause considerable increase of radon activities at the land surface. Strong degassing fluxes are, hence, encountered in the areas of crustal discontinuities like fractures and faults, because of the elevated permeability of the soil and bed rock.

In the currently conducted research the aim was to study the possibility of employing soil gas radon measurements technique as a useful tool for exploring the Karak Thrust for its proper delineation and classification with the radon measurement technique and to see if it is likely to become the source of any potentially dangerous seismic activity sometime in the future.

A total of 21 radon measurements were carried out over an area of about 12.5 km × 0.4 km which almost covers the region from Banda Spina in the NE up to Gandao Village in the SW. The locations of radon traverses were selected according to our observations of soil and some available geological data and the probable trace of the thrust fault. Results of the soil gas radon survey along the four different traverse across Karak Thrust have been presented in the Fig 4 and Table 1, respectively. In the studied profiles, the radon concentration has a wide range from (0.66) to (464) pCi/l. The range has two extremities for each profile and the region on or adjacent to the fault is showing maximum radon concentration.

Table 3. Number of pixels with corresponding area from the ASTER, SRTM DEM, and Toposheet.

Sr. No.	Traverse Line	Location Name (Traverse)	Geographic Co - Ordinates	Mean Radon Concentration (pCi/L ± 1σ)
1	F-F	BandaSpina	N 33° 11′ 55.0″, E 71° 15′ 05.2″	145 ± 10.10
2	"	BandaSpina	N 33° 12′ 05.5″, E 71° 14′ 57.1″	191 ± 10.50
3	"	BandaSpina	N 33° 12′ 10.7″, E 71° 14′ 38.5″	66.8 ± 8.92
4	"	BandaSpina	N 33° 12′ 29.6″, E 71° 14′ 26.0″	3.55 ± 2.51
5	"	BandaSpina	N 33° 12′ 42.5″, E 71° 14′ 31.9″	0.66 ± 0.44
1	G-G	Tarha Koi	N 33° 09′ 19.4″, E 71° 10′ 52.9″	143 ± 15.20
2	"	Tarha Koi	N 33° 09′ 25.2″, E 71° 10′ 46.9″	38.0 ± 3.68
3	"	Tarha Koi	N 33° 09′ 38.5″, E 71° 10′ 41.3″	95.6 ± 9.35
4	"	Tarha Koi	N 33° 09′ 35.1″, E 71° 10′ 41.4″	171 ± 16.80
5	"	Tarha Koi	N 33° 09′ 27.3″, E 71° 10′ 45.4″	95.6 ± 9.35
1	H-H	Laki Ghundaki	N 33° 08′ 39.1″, E 71° 09′ 01.2″	12.9 ± 4.64
2	"	Laki Ghundaki	N 33° 08′ 42.3″, E 71° 08′ 59.7″	29.9 ± 7.49
3	"	Laki Ghundaki	N 33° 08′ 46.6″, E 71° 08′ 57.6″	464 ± 25.60
4	"	Laki Ghundaki	N 33° 08′ 48.9″, E 71° 08′ 54.6″	203 ± 9.89
5	"	Laki Ghundaki	N 33° 08′ 55.7″, E 71° 08′ 56.2″	198 ± 14.90
1	I-I	Gandao	N 33° 08′ 24.0″, E 71° 08′ 32.8″	36.2 ± 3.19
2	"	Gandao	N 33° 08′ 27.3″, E 71° 08′ 33.4″	51.3 ± 4.25
3	"	Gandao	N 33° 08′ 27.6″, E 71° 08′ 30.1″	403 ± 11.80
4	"	Gandao	N 33° 08′ 31.5″, E 71° 08′ 29.0″	458 ± 8.59
5	"	Gandao	N 33° 08′ 33.4″, E 71° 08′ 13.6″	114 ± 14.00
6	"	Gandao	N 33° 08′ 35.3″, E 71° 08′ 21.7″	90.7 ± 3.80

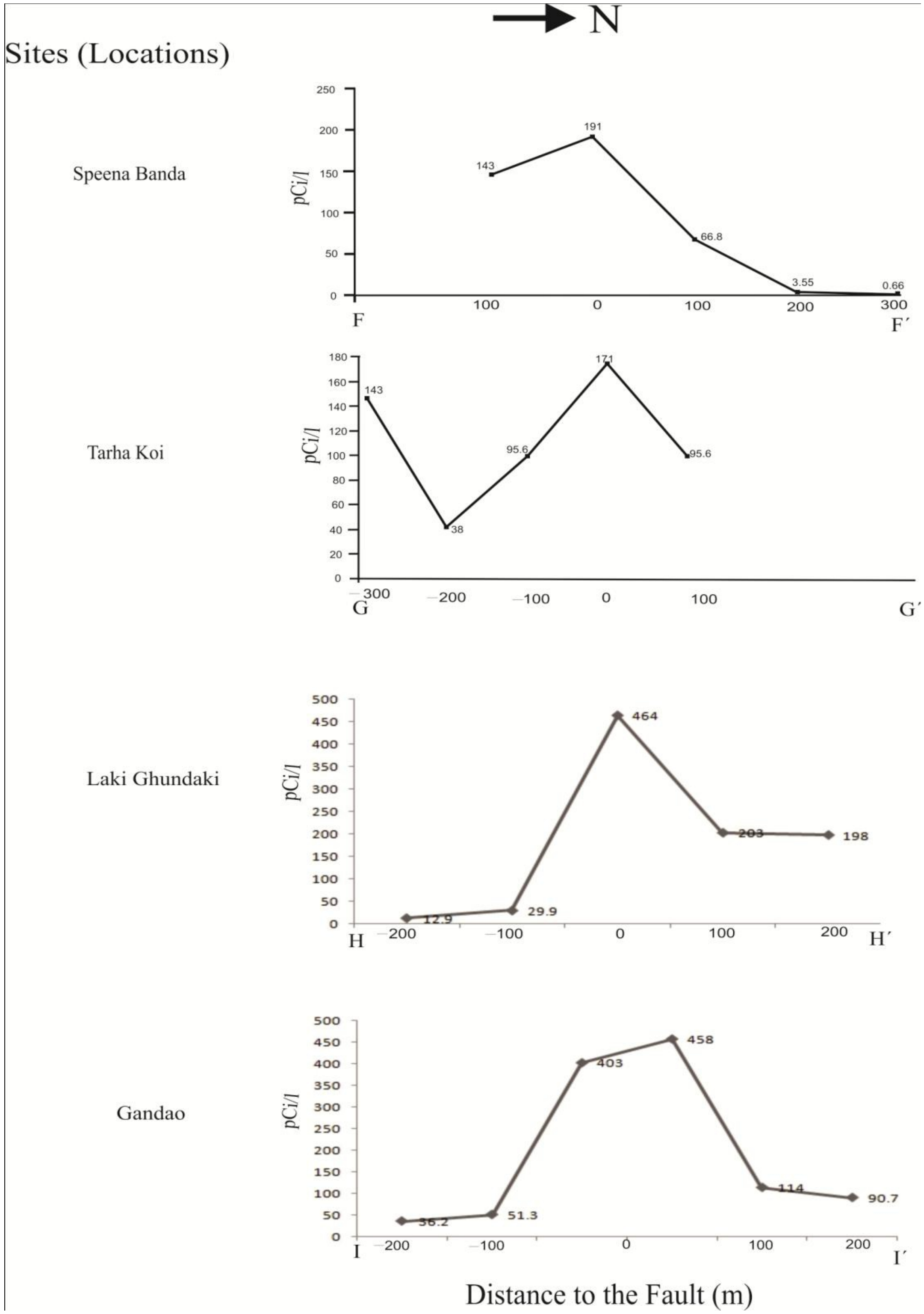

Fig. 4. Soil-gas radon concentrations vs. distance from the fault (0 point) along the survey profiles (a) F-F′, (b) G-G′, (c) H-H′ and (d) I-I′ lines of Fig. 3 crossing the Karak Thrust located in the extreme north of the study area.

As the geology of the region does not contain any significant source of natural radioactive elements such as radium or uranium, so the average level of radon activity within the region was quite low. The minimum radon concentration measured along each traverse can be considered as background for it.

Along traverse FF′ on the north eastern side of the studied area near Banda Spina (Fig. 4) a major peak nearly 191 times the background value has been recorded in the hole no. 2 above the fault trace showing radon concentration of 191 pCi/L. Along traverse GG′ near Tarha Koi highest concentration of 171 pCi/L of radon is found in the hole no. 4 above the fault trace the major peak being nearly 5 times the background value. Along traverse HH′ near Laki Gundaki highest value was recorded in the central sample (i.e. hole No.3), which is located almost over the fault zone. Here radon peak is about 36 times the background value for that traverse. Near Gandao Village along traverse II′ elevated values of radon concentration of 403 and 458 pCi/L have been encountered in the two central holes (hole no. 3 and 4, respectively). Average of these two central holes is about 431 pCi/L which is about 12 times the background value.

Along fault zones a huge increase in the permeability and porosity can result from crumpling and crushing of the deformed rocks. Radon can travel up through this porous and permeable material more efficiently than the surrounding intact rocks. (King, 1980; Kresl et al., 1993 a, b). Also larger grains along fault zone may be broken-down into many smaller grains thereby liberating more radon into the pore spaces formed as a result of the movement along fault. This may cause an increase in the radon concentration. (Gundersen and Linda, 1991).

Radon values several order of magnitudes higher than the background values have been noticed on or in the vicinity of Karak Thrust in all the traverses. There is no any geological formation showing significant enrichment in either uranium or radium metals. The high levels of radon concentration above or in the vicinity of the trace of the fault can, therefore, be attributed to its upward migration from considerable depth along the fault plane. This suggests that Karak Thrust can be classified as a tectonically active feature which can cause a potential hazard of earthquake in the region at some time in future. The key tectonic element responsible for making Karak Thrust active may be the diapric uprise of Eocene rock salt found ubiquitously within the region.

An earthquake occurred along the Karak Thrust two years after the conduction of this study on September 28, 2014 October confirming our conclusion that the fault is tectonically active. The earthquake activity and its effects along the fault were noticed by several people in the area.

7. Conclusion

- This study is the first of its kind to employ radon gas monitoring as a tool in properly exploring and delineating the hitherto poorly explored Karak Thrust in District Karak. Increase of radon concentration several order of magnitude higher than the background value were noted above or in the immediate vicinity of the fault in all the four traverses completed.
- This study indicates that the width of the fault zone can also be properly estimated with this technique if the radon gas is monitored in closely spaced monitoring stations across the fault along the traverses made.
- The study indicates that the technique can successively be applied for discovering and demarcating active geological faults in other areas of the country as well.
- Monitoring of radon can serve as a tool to identify regions in which there is possibility of activation of faults in future.
- This method can be successfully applied in discovering and delineating blind active faults beneath the ground which are not yet revealed by any other method. The nominal cost and swiftness of the radon gas survey technique, make it a potent tool for geological exploration.
- Radon gas survey can be successfully applied in earthquake hazard assessment and in earthquake prediction if continuous monitoring is carried out.

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