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Preliminary Studies on Geological Fault Location Using Solid State Nuclear Track Detection

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Abstract: In this study, alpha track detectors have been used to develop a methodology to locate fault lines in Accra, Ghana. Alpha track (LR-115 type II) detectors were used for the soil radon gas measurement in forty two (42) sample pits on 70 m × 100 m of land behind National Radioactive Waste Management Centre (NRWMC), Ghana Atomic Energy Commission (GAEC) and fifteen (15) sample pits on about 300 m × 200 m of land at Dunkonah. Comparison method for the determination of uranium content of the soil with track-etch detectors was used in both studied areas. At Dunkonah, the average soil radon gas concentrations calculated ranged from 10.2±0.5 to 23.0±0.7 kBq/m^3 with seven (7) sample pits having very high concentration levels. The average soil radon gas concentrations obtained at NRWMC, GAEC ranged from 6.4±0.4 to 27.5±0.8 kBq/m^3 with 20 sample pits having very high concentration levels. The area of high soil radon gas concentration at NRWMC coincided with the fault lines discovered by G.S.D.

Key words: Alpha track (LR-115 type II) detector, fault lines, Ghana, radon, radium, soil, uranium

INTRODUCTION

Numerous geophysical Survey methods have been developed to locate fault lines. These fault lines are rock fractures which occur due to friction and rigidity of rocks, since rocks cannot simply glide pass each other. Rather stress builds up in the rocks and when it exceeds the strain threshold, the accumulated potential energy is released as strain. This is focused into a plane along which relative motion is accommodated forming fault (Ghislain and Petit, 2006; Collittini *et al*., 2005). Seismic (reflection or refraction), electrical, electromagnetic and potential methods are examples of geophysical techniques. None of these methods can be said to be perfect since each has its own scope and limitations because of susceptible physical, electrical and chemical properties of the earth (Beck, 1981; Parasins, 1966; Blyth and Fretis, 1984). In contrast to Radon (Rn-222), with the abundance of U-238 in soil and rocks; and its long half-life easily migrate through fractured rocks and soil overburdens (Al-Shereideh *et al*., 2006).

Radon-222 is an alpha emitter, has a half-life of 3.82 days and is the immediate daughter of Radium-226 produced in the decay series of U-238. During migration, it decays emitting alpha particles which can be detected by alpha sensitive detectors including solid state track detectors. These special characteristics make the Rn-222 isotope useful in earthquake prediction, geological and tectonic studies; the location of Uranium and oil deposits (Singh *et al*., 2006; Bossew, 2003).

The main objective of this study is to develop the methodology using solid state nuclear track detection for detecting faults.

MATERIALS AND METHODS

The study was carried out at the Physics Department of the National Nuclear Research Institute, Ghana Atomic Energy Commission from September, 2008 to January, 2009.

Study area: Two areas were selected for this study. Both areas are located in the Greater Accra Region of Ghana. The first study area is located behind NRWMC, GAEC at Kwabenya. Kwabenya geology is made up of the Togo formation and the Dahomeyan formation which forms

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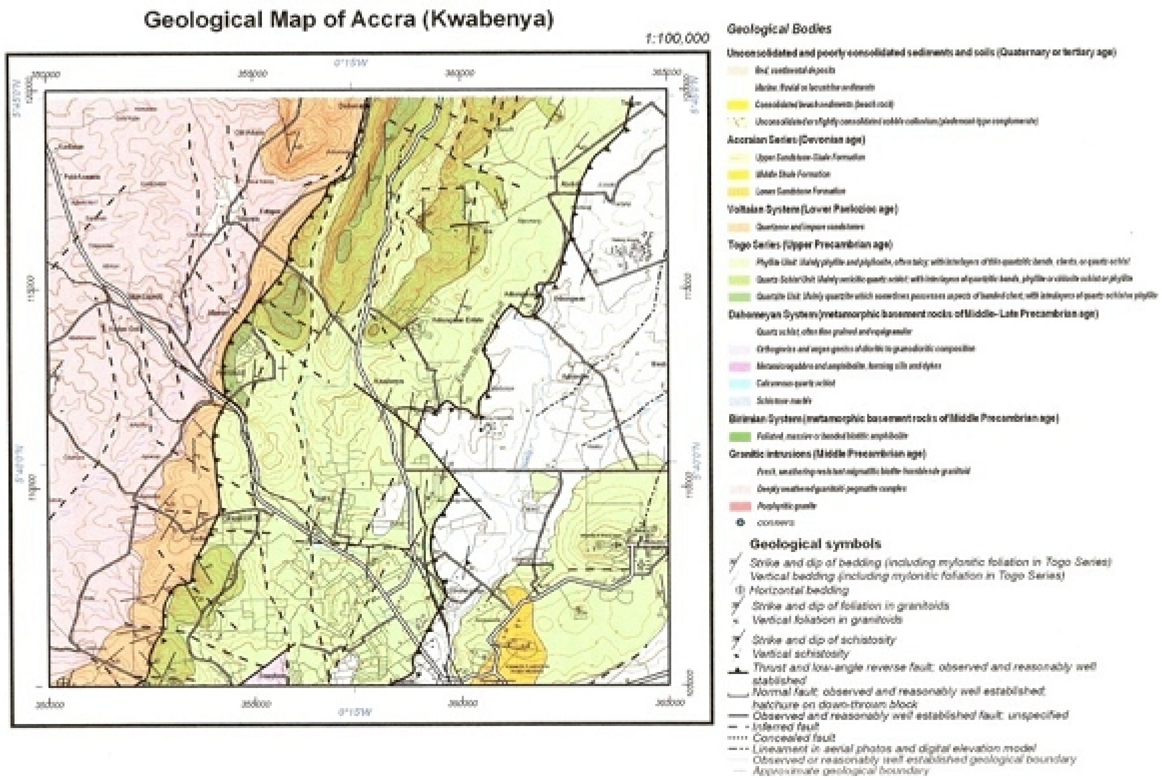

Fig. 1: Geological Map of Accra (Kwabenya), it specifically shows the geology of Kwabenya

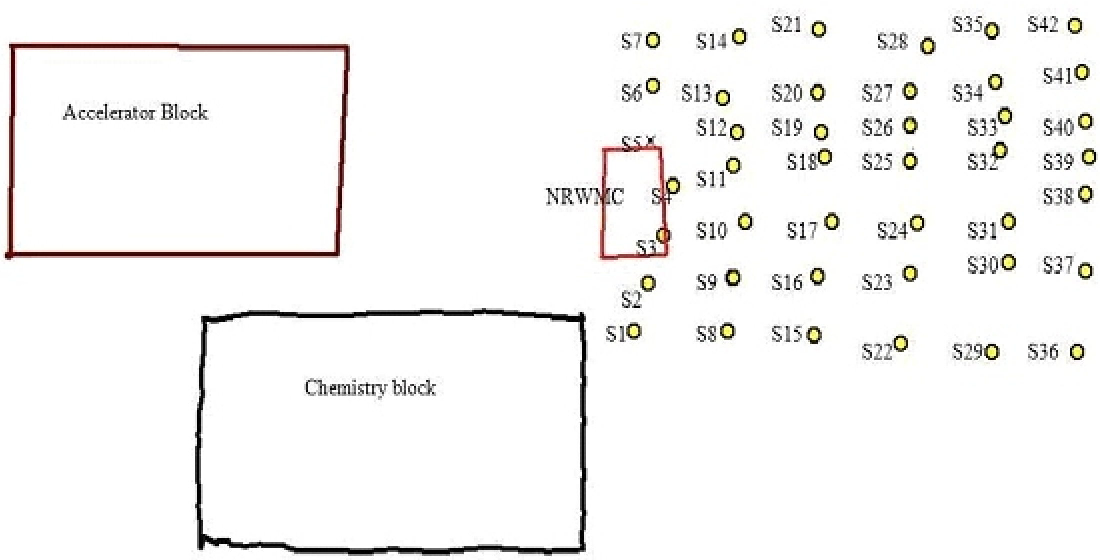

Fig. 2: Global positioning logging of the study area behind, NRWMC, GAEC, it describes the features of the study area and how this study area was prepared for the measurements

part of Precambrain Guinea Shield of West Africa where Ghana geology falls. The second study area is Dunkonah which is also a suburb of Weija District. Rocks here forms the Akwapim range of hill trending northeast wards from the coast west of Accra through Kpong, Anum into the Republic of Togo. The mostly found rocks are phyllites, schists and quartzite. The Dahomeyam formation occurs as four alternate belts of acid and basic gneisses trending

SSW to NNE from the coastal plains east of the Togo series. The area occupied by the basic gneisses are flat (Accra plains), while the area occupied by the acid gneiss gives rise to gently undulating topography. The most common rocks are quartz-schists, metamicrogabbros forming dykes and sills (Amedofu1 *et al.*, 2008; Kesse, 1985). Details of the above mention formations are shown in Fig. 1.

Soil radon gas measurement: Soil-radon gas measurement was performed for a period of three months during the dry season on about 70 m × 100 m of land at the study area behind the storage facility of the National Radioactive Waste Management Centre (NRWMC), Ghana Atomic Energy Commission (GAEC) where a fault has been located by GSD using the resistivity and seismic refraction geophysical methods. This served as a control for the study. The soil-radon gas measurement was done using radon samplers made up of LR-115 (II) cellulose nitrate detectors manufactured by Kodak Pathé in France and cut into sizes of 2×2.5 cm^2. This was attached to a wooden stopper with it's sensitive side facing downwards and fitted unto a 4 cm diameter poly vinyl chloride plastic tube of length 25 cm. The radon samplers were buried in holes of depth of about 75 cm created on forty two (42) grid points of distance of 10 m apart in the X- direction and 20 m apart in the Y- direction. The grid points were created with the help of survey tape measure, wooden pegs and a Trimble Geo 3 GPS receiver as shown in Fig. 2. The holes were then covered with plywood painted with creosote and soil to prevent rain and other material from entering. The radon samplers were exposed to soil radon gas for three months at two weekly intervals. The detectors after exposure were removed from the stoppers and etched in a 2.5 M NaOH solution at a temperature of 60ºC for 90 min. Due to the large number of detectors involved in monitoring of the soil-radon gas concentration, the spark counter technique in conjunction with a micro fiche reader was used where the detectors were stripped from their backing and were counted thrice for each detectors and the average was calculated. The track density was calculated using the formula:

Track density (ρ) = Average number of count/area of electrode for the spark counter and

Track density (ρ) = Average number of count/area of field of view for the optical microscope

The soil radon gas concentration was calculated using the formula:

$$\text{Concentration (kBq/m}^3\text{)} = \rho / \varepsilon T$$

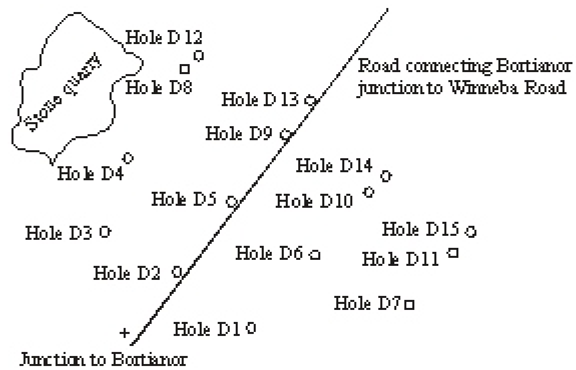

Fig. 3: Global positioning logging at Dunkonah, it describes the features of the study area and how this study area was prepared for the measurements

where,
ρ is the track density
ε is the calibration factor of the radon samplar
T (h) is the exposure time in hour

The procedures above were also carried out at the main project site at Dunkonah where about 300 m × 200 m of land was considered. Grid points of distance 100 m apart in X-direction and 50 m apart in Y-direction were randomly created due to logistics constraint as shown in Fig. 3.

Determination of uranium content: Six soil samples were randomly collected from both study areas. The samples were air dried for a period of one week, followed by oven drying at a temperature of 105ºC for 24 h. They were then allowed to cool to room temperature and grounded using a stone wear grinder. Soil samples were then sieved to remove debris.

LR-115 (II) cellulose nitrate alpha particle detectors cut to the size of 2×3 cm^2 were placed in rabbit capsules with its sensitive side facing inwards to establish contact with the soil sample. About 2.0 g of the soil samples and I.A.E.A uranium ore standard (Pitch Blende) S-13 were packed into the rabbit capsules, sealed and labelled. The packaging was done thrice for each sample to reduce error. The soil samples and the standard were neutron irradiated using the Miniature Neutron source reactor at GHARR-1 centre for a period of 10 seconds at a flux of 5×10^{11} n/cm^2s. The package was stored for three days for the activity to cool. The detectors were then removed and etched. Track evaluation was performed using the optical microscope at a magnification of 400 X. The uranium content was determined by the comparison method with track etch detectors where concentration of known sample is compared to the concentration of unknown sample assuming the matrix does not interfere as below:

$$C_x(U) = \rho_x / \rho_s * C_s(U)$$

Where C is the uranium concentration expressed in percentage fraction, s and x refer to the standard and the unknown, ρ is the track density calculated from the counts obtained (Fleischer *et al.*, 1975; Oppon and Aniagyei, 1988).

RESULTS AND DISCUSSION

Table 1 and 2 shows the average soil radon gas concentration obtained at both studied areas. The average soil radon gas concentrations are graphically represented in Fig. 4 and 5 which shows a 3-D surface graphs of average soil radon gas concentration versus hole numbers at the two studied areas.

The first batch of detectors at NRWMC, GAEC was not considered because they were destroyed during the etching process. The second batch of detectors had soil radon gas concentration ranging from 2.1 to 31.1 kBq/m^3, third set of detectors had concentration ranging from 3.8 to 29.4 kBq/m^3 and fourth batch had concentration ranging from 4.9 to 35.5 kBq/m^3. The average soil radon gas concentrations obtained for the study area behind NRWMC ranged from 6.4±0.4 to 27.5±0.8 kBq/m^3.

At Dunkonah the first batch of detectors had radon soil gas concentration ranging from 9.2 to 22.9 kBq/m^3, second batch of detectors had concentrations ranging from 8.2 to 25.6 kBq/m^3 and the third batch had concentrations ranging from 8.9 to 22.7 kBq/m^3. The average soil radon gas concentrations ranged from 10.2±0.5 to 23.0±0.7 kBq/m^3.

The soil radon gas values obtained are comparable to soil radon gas measurement made along some fault systems in parts of south eastern Ghana where the average soil radon gas concentration obtained was 25.92±0.01 kBq/m^3 (Amponsah *et al.*, 2008).

There are no international standards for soil radon gas concentration since the concentration depends on the geology of the area under investigation. There are numerous criteria for assessing soil radon concentration anomalies; these include the mean + 1, 2, or 3 × standard deviation (S.D.) of the data sets, above the mean or the mean of the data set as the background concentration and concentration values above the mean as abnormal (Price *et al.*, 1994; King *et al.*, 1996; Ghosh *et al.*, 2009; Cuff, 2001; Rannou, 1989). In this study the mean of the average soil radon gas concentration was used as the background levels. Concentration values higher than the background level were considered as anomalous.

The background value obtained at NRWMC, GAEC was 17.2 kBq/m^3 and that of Dunkonah was 16.2 kBq/m^3. The anomalies at both studied areas are graphically represented in Fig. 6 and 7. The anomaly at S26 verifies the location where G.S.D located the first fault with other anomalies clustering around it. Although the anomalies at S16, S30 and S39 are about 20-40 m away from the fault located, they had similar concentrations of 27.5, 27.0 and 27.0 kBq/m^3 representing hidden fault lines.

Table 1: Average soil radon gas concentrations at Dunkonah

Hole no.	Average radon gas concentration (kBq/m^3)
D1	22.6±0.7
D2	15.5±0.6
D3	14.3±0.5
D4	18.0±0.6
D5	17.1±0.6
D6	20.6±0.7
D7	12.3±0.5
D8	11.3±0.5
D9	23.0±0.7
D10	10.2±0.5
D11	22.6±0.7
D12	10.7±0.5
D13	15.0±0.6
D14	10.5±0.5
D15	18.7±0.6

Table 2: Average soil radon gas concentrations at the study area behind NRWMC, GAEC

Hole no.	Average concentration (kBq/m^3)
S1	11.5±0.5
S2	19.0±0.6
S3	12.7±0.5
S4	18.9±0.6
S5	18.4±0.6
S6	12.8±0.5
S7	12.6±0.5
S8	12.2±0.5
S9	20.9±0.7
S10	18.4±0.6
S11	18.3±0.6
S12	6.4±0.4
S13	19.1±0.6
S14	13.2±0.5
S15	18.7±0.6
S16	27.5±0.8
S17	15.8±0.6
S18	13.0±0.5
S19	17.1±0.6
S20	16.8±0.6
S21	16.8±0.6
S22	16.5±0.6
S23	16.4±0.6
S24	11.2±0.5
S25	20.0±0.6
S26	27.0±0.7
S27	20.0±0.6
S28	15.8±0.6
S29	9.2±0.4
S30	27.0±0.7
S31	24.6±0.7
S32	15.5±0.6
S33	15.5±0.6
S34	12.8±0.5
S35	21.6±0.7
S36	15.8±0.6
S37	21.0±0.7
S38	12.9±0.5
S39	27.0±0.7
S40	21.0±0.7
S41	12.5±0.5
S42	18.0±0.6

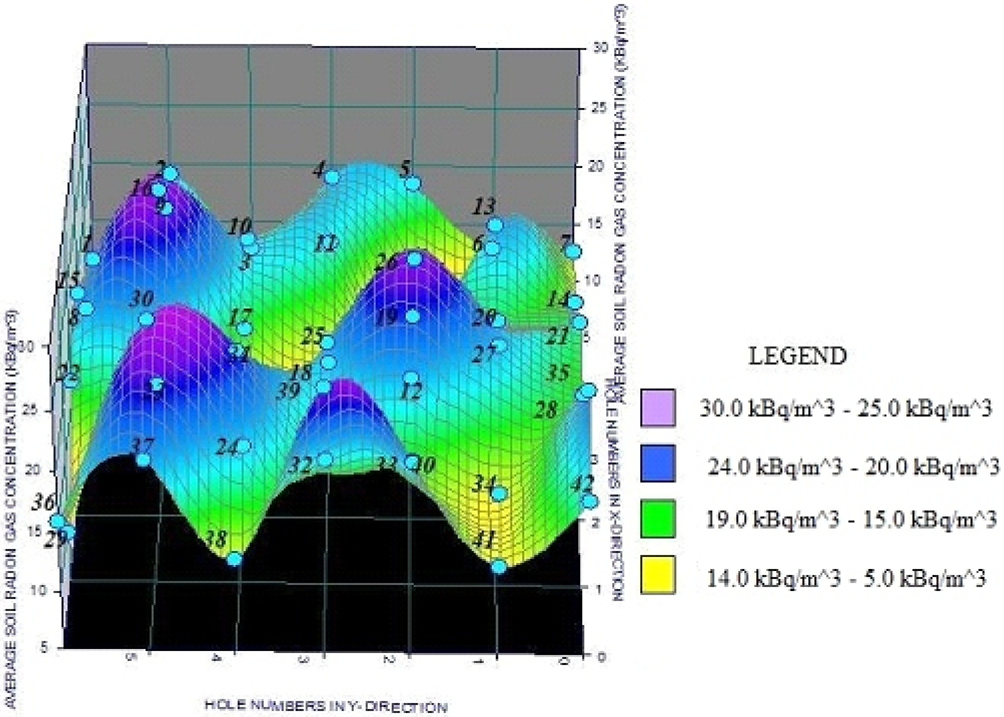

Fig. 4: A 3-D Surface graph of average soil radon concentrations versus hole numbers behind NRWMC, GAEC, this represents radon gas concentration (kBq/m^3) in each sample pit at this study area

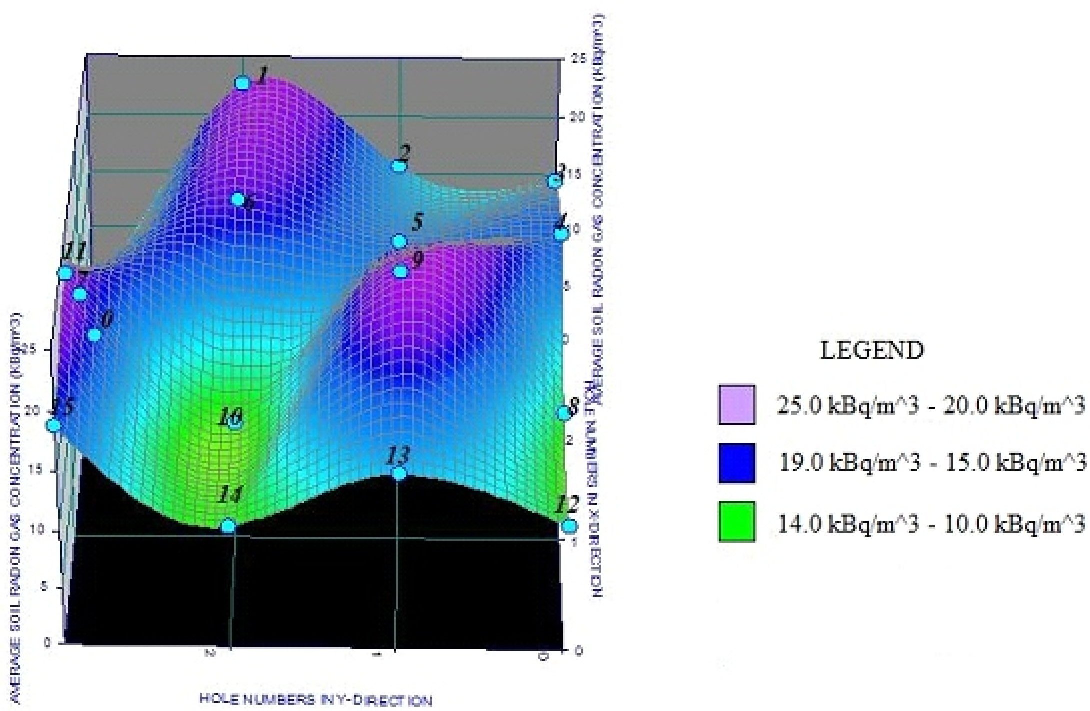

Fig. 5: A 3-D Surface graph of average soil radon concentrations versus hole numbers at Dunkonah, this represents radon gas concentration (kBq/m^3) in each sample pit at this study area

Table 3: Uranium content of soil at Dunkonah (D1, D2, D3) and behind NRWMC, GAEC (S1, S2, S3)

Soil code	Uranium-235 content (%)
D1	0.022
D2	0.023
D3	0.019
S1	0.021
S2	0.022
S3	0.023

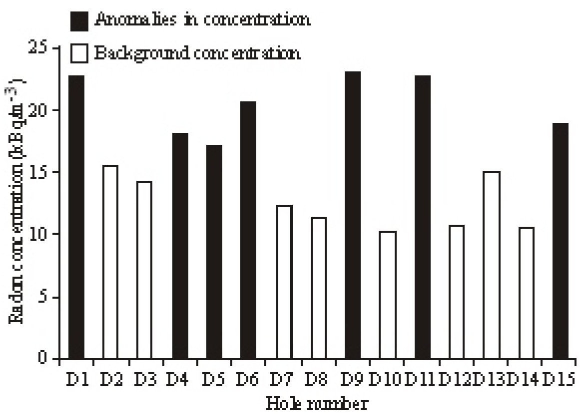

Fig. 6: A bar chart of average soil radon gas concentration versus hole numbers at Dunkonah, the bar chart illustrates the sample pits which registered anomalous concentration at Dunkonah

Table 3 shows the percentage fraction of uranium in the soil at both studied areas. The average value at both sites was 0.02%.

This average value does not fall within the low grade uranium of percentage 0.03-0.05% found in sedimentary formation that can be mined in Ghana (Kesse, 1985). Therefore the high anomalies obtained are due to presence of deep fractures which connects through the network of smaller fractures serving as vent for soil radon gas to the atmosphere.

The results obtained show that the located fault by G.S.D runs horizontally through S25, S26 and S27. Also this indicates that other fault lines as shown in Fig. 8 could not be located due to some limitations of the geophysical methods used.

With reference to the results obtained at the study area behind NRWMC, GAEC, the suspected fault lines at Dunkonah runs horizontally through D6, D5, D4 and vertically through D1, D6, D5, D9 and D11, D15 as shown in Fig. 9.

The difference in soil radon gas concentrations at the studied areas is due to difference in the underlying bedrocks and the geology of the studied areas. The high anomalies may be due to holes falling exactly on covered fault lines in the earth crust, since radon gas concentration in soil is taken as proportional to fracture opening. Large

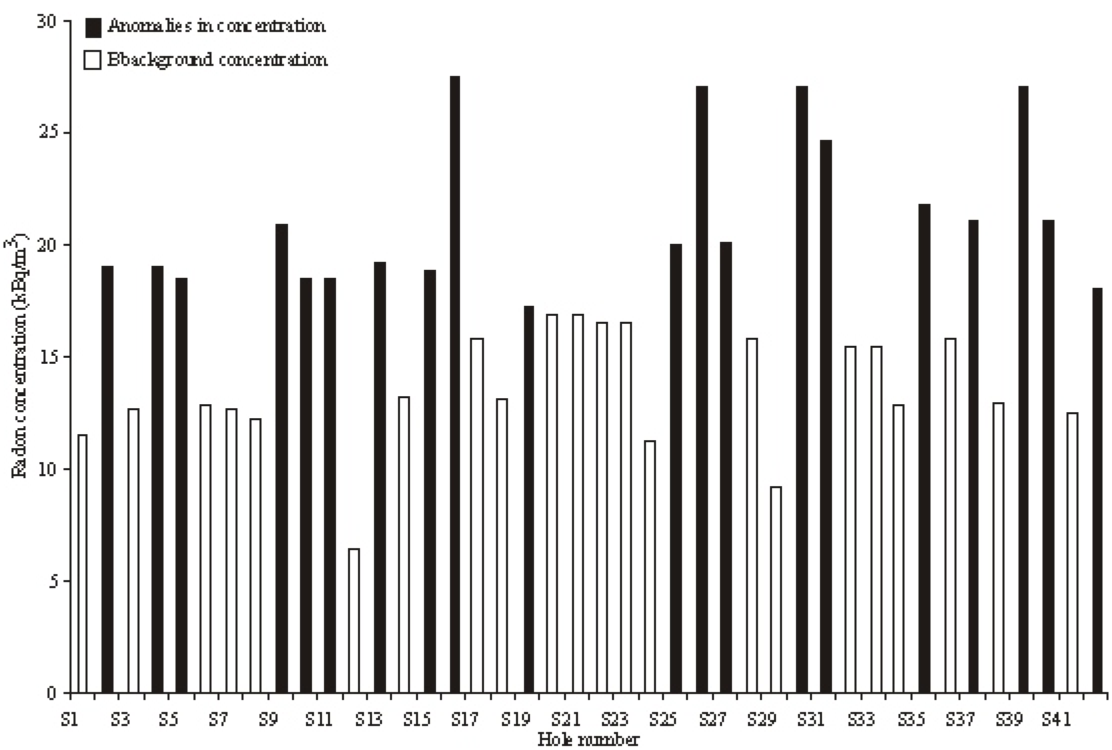

Fig. 7: A bar chart of average soil radon gas concentration versus hole numbers behind NRWMC, GAEC, the bar chart illustrates the sample pits which registered anomalous concentration at NRWMC, GAEC

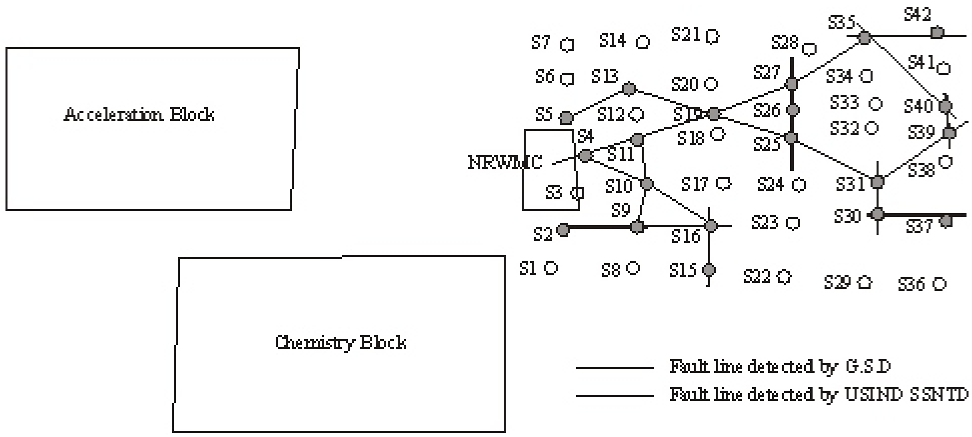

Fig. 8: Fault line located by G.S.D and fault lines located using SSNTD behind NRWMC, GAEC, it shows the fault line located by G.S.D and fault lines located using SSNTD at NRWMC, GAEC

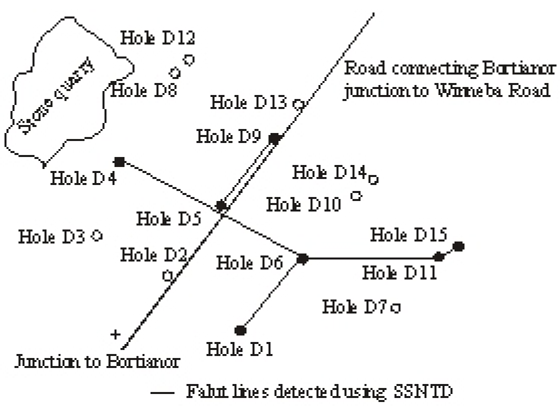

Fig. 9: Fault lines located at Dunkonah using SSNTD, it shows the fault lines at Dunkonah

size of the fault lines serve as routes for soil Rn-222 gas, porosity of sandstone which is normally found mainly under the Togo formation and high out gassing rate at faulted zones where the gas permeability is relatively high also contributes. Also it may be attributed to Rn-222 gas coming from the earth's deep interior but not from surrounding rocks because the rocks found at both studied areas do not fall under major rocks containing naturally occurring radioactive materials (NORMS) (Baubron *et al*., 2002; Toutain and Baubron, 1999).

CONCLUSION

The results from determination of uranium content of the soil delineates that, the anomalies obtained at the various fault lines detected is not due to abundance of local pockets of uranium in the soil but it is attributable to sample pits falling exactly on fault lines in the earth crust serving as route for Rn-222 gas. This confirms the fault lines which run horizontally through S25, S26 and S27 located by G.S.D behind NRWMC, GAEC and other fault lines which were not located due to some limitations of the geophysical methods used as shown in Fig. 8 and 9. It also confirms the feasibility of using solid state nuclear track detection for geological fault location. This method is preferable because it is less expensive and does not rely on true measurement but it averages the soil radon content for the area to locate the fault. The methodology developed had been used to locate two faults one at the control area which was undetected by the other geophysical method and the one in the study area.

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