

Correlation Between Underground Radon Gas and Dormant Geological Faults

J. A. LÓPEZ^{1*}, O. DENA ORNELAS², L. SAJO-BOHUS³, G. RODRÍGUEZ¹,
I. CHAVARRÍA¹

¹Department of Physics, University of Texas at El Paso, El Paso, Texas 79968, U.S.A.

²Universidad Autónoma de Ciudad Juárez, Ciudad Juárez, Chihuahua, México

³Universidad Simón Bolívar, Caracas, YV-1080^a Venezuela

*Email: jorgelopez@utep.edu

Published online: August 08, 2016,

The Author(s) 2016. This article is published with open access at www.chitkara.edu.in/publications

Abstract This work studies the concentration of radon in soil around a fault in the East Franklin Mountains in the El Paso area in West Texas. It is found that the in-soil production of radon is correlated to the existence of a fault even if it has not had any recorded activity in recent geological times. This adds to previous observations that link the production of radon to seismic activity, and seems to indicate that in non-active faults the radon production is due mainly to the radioactivity of the top soil and to the transport properties of the medium and not to deeper seismic activity. These results open the possibility of using in-soil radon gas concentrations as an examination tool of dormant faults.

Keywords: radon; faults; dilatancy-diffusion theory

1. INTRODUCTION

Radon is a gas that is produced as part of the radioactive decay of ^{238}U , which includes $^{230,234}\text{Th}$, ^{234}Pa and ^{234}U and other elements that exist abundantly in most types of rocks and sediments; radon is thus present in all types of soil. The concentration of underground radon near the surface depends solely on the presence of its parent nucleus, ^{226}Ra , and the transport properties of the medium. As the medium transport properties vary drastically near geological faults, it is expected that in-soil radon gas concentration will increase near faults [5].

The increase of radon concentrations in the neighborhood of active faults, has been explained in terms of the dilatancy-diffusion model of earthquake

Journal of Nuclear
Physics, Material
Sciences, Radiation and
Applications
Vol-4, No-1,
August 2016
pp. 265–275

López, J.A.
Dena Ornelas, O.
Sajo-Bohus, L.
Rodríguez, G.
Chavarría, I.

occurrence [21], and has even been used to predict tectonic activity. In a nutshell, changes of elastic strain before earthquakes cause rocks to dilate forming open fractures and facilitating rupture, which in turn allows the flux of gases including radon. Since radon has a very poor intrinsic mobility in soil and a very short half-life (3.8 d), it would not be expected to propagate upwards long distances, however, the enhanced upward speed of the radon gas is explained by the existence of rising fluids such as underground water, carbon dioxide, nitrogen and methane produced and liberated by the tectonic activity [4]. Such condition of increased flow is expected to exist for as long the fault continues being active.

Due to wide variation of conditions, no precise world averages exist for in-soil concentrations of radon nor for its variation around fractures and faults. Increments ranging up to 3.233% over the mean background radon level have been reported at the Bad Nauheim fault in Germany [12], where a peak radon signal of over 1,000 kBq/m³ was observed around a region where the mean background level is 30 kBq/m³. On the other hand, since similar increments of radon concentration have also been reported around less active faults [4, 14, 22], it is possible to think that enhanced radon exhalations can occur in even in faults without any recent tectonic activity.

2. HYPOTHESIS

In this article we test a complementary hypothesis, namely, that once a fracture or fault has been created, the enlarged path for gas flow remains and facilitates the flow of radon gas even in the absence of any tectonic activity. That is, in-soil radon concentrations should increase near faults as compared to the immediate background concentration of the neighborhood.

It is clear that, without the help of tectonic gases, the underground radon gas found near the surface could not have been produced at greater depths. Radon, at a difference from tectonic gases, is produced at all depths, but due to its slow diffusion and short half-life, it can only migrate short distances.

To understand this it is necessary to remember that ²²²Rn is generated through the ²³⁸U decay series which produces several long half-life isotopes (²³⁴U, ²³⁰Th and ²²⁶Ra) which are commonly found in granite, igneous rocks, sedimentary rocks, metamorphic rocks, etc. It is this abundance that permits the production of ²²²Rn by practically all types of rocks and soils at all depths.

Furthermore, the radon ascent velocity in soils is relatively slow, and its mean distance displacement is relatively short due to its brief half-life. For example, taking into account the ²²²Rn half-life of 3.82 d and the diffusion coefficient of radon in dry soil (5×10^{-6} m²/s), the average diffusion length is

found to be 1.6 m [15]. Without tectonic gases, radon gas produced at much larger depths would not live long enough as to reach the surface through dry soil. The existence of fractures and faults, however, could increase the diffusion length of gas produced near the surface allowing a much larger concentration of gas around faults.

As a proof of principle, we test whether radon concentration increases noticeable near dormant faults, i.e. around faults that have not had any recorded activity in recent geological times. In this article we present a preliminary study of ^{222}Rn measurements along a dormant fault in the Franklin Mountains in the El Paso Area in West Texas, and contrast it with studies that identify fractures and faults through the general area. If proven correct, this hypothesis would open the possibility of using in-soil radon gas concentrations as an examination tool of dormant faults.

3. GEOLOGICAL SETTING AND FAULT TRACE LOCATION

Measurements of radon concentrations were taken on the east side of the Franklin Mountain in El Paso, Texas in the United States of America. These are tilted block-fault mountains formed by fractures of the Earth's crust produced by near-vertical faults which thrust and tilted the landmass upward producing diagonal rock layers which expose layers of Precambrian rock 1.25 billion years old. The area of study (see Figure 1) is located at the east flank of the Franklin Mountains, which constitutes a small range trending north-south between south New Mexico and the western tip of Texas. Although the Franklin Mountains are mainly composed of Cretaceous sedimentary rock units formed when the region was covered by water, there are also tertiary igneous intrusions and Precambrian crystalline rocks.

Tectonically, two major pulses, the Laramide orogeny (85-45 My) and the Cenozoic Rio Grande Rift, have shaped the geological landscape around the area of study. However, the major structural control on the uplift and tilting of this range is the Late Cenozoic crustal extension process associated with the Rio Grande Rift, which has resulted on a well-defined horst and graben classic rift architecture. The Bolson del Hueco, located at the eastern upskirts of the Franklin Mountains is an extensional basin developed as consequence of the Neotectonic displacement of the basement by more than 2,700 m in depth along a series of quaternary age of the Late Miocene [13]; there are normal faults bounding the basin between the Franklin Mountains and the Hueco Tanks [6].

The main fault evidenced by surface geology is the East Franklin Mountain Fault (EFMF), which has been dated as 8-12 ky [16], with scarps ranging

López, J.A.
Dena Ornelas, O.
Sajo-Bohus, L.
Rodríguez, G.
Chavarría, I.

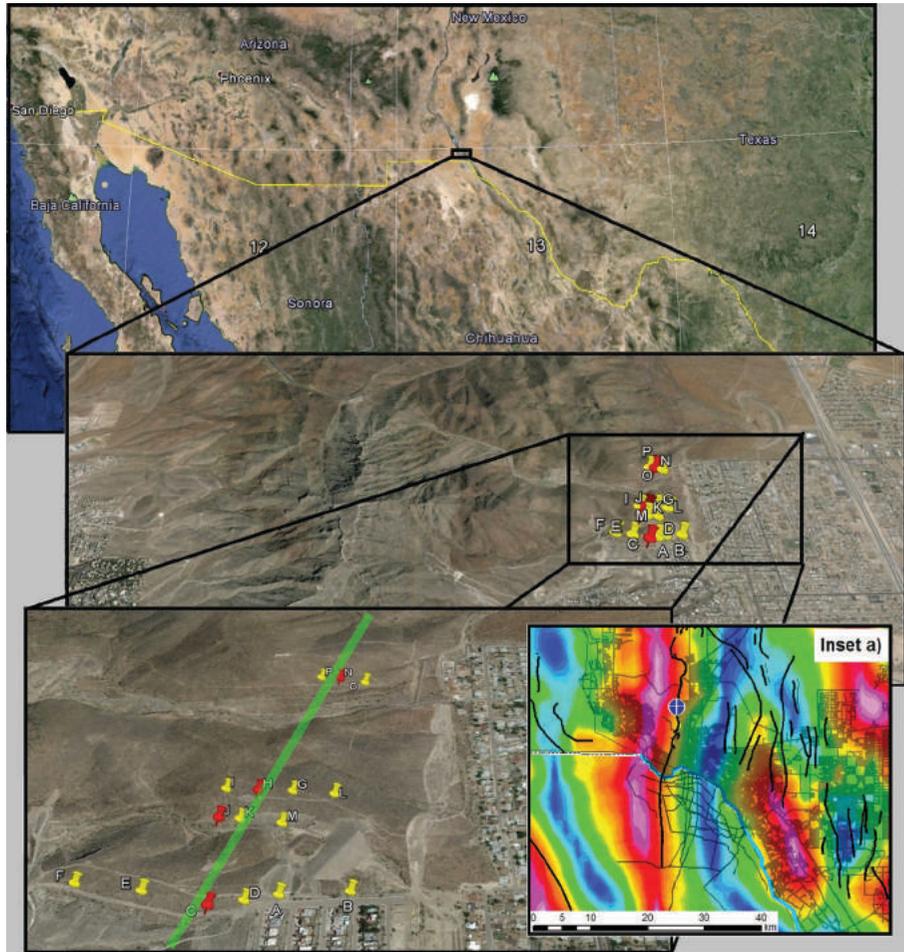


Figure 1: Location of the Franklin Mountains, the area of study, collected points and approximate location of the East Franklin Mountain Fault (EFMF). The inset (a) shows the tilt derivative map derived from the Corrected Bouguer Anomaly to infer the trace of the EFMF.

between 2 m and 60 m [16, 6], and with average displacements of 0.18 mm/yr [17]. This 52.7 km length fault [17] is considered, assuming an equivalent surface rupture, with potential to trigger a 7.1 Richter scale earthquake ([23], normal fault data). The EFMF is also clearly evidenced by the strong gradient on the tilt derivative map of the gravity corrected Bouguer anomaly (Figure 1, inset a), derived from the gravity data base of the University of Texas at El Paso.

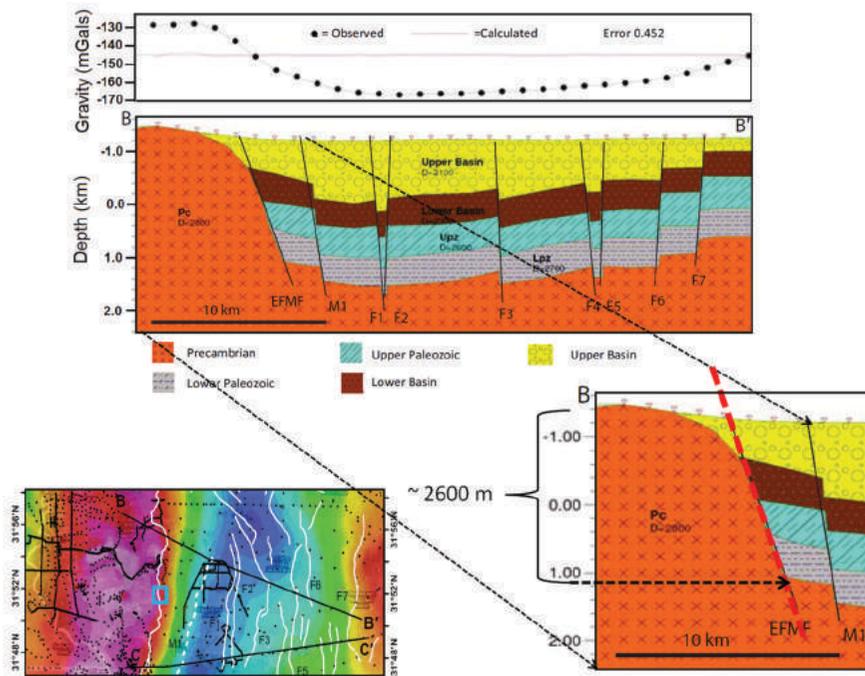


Figure 2: Fault trace location and 2D profiling. Modified from [3].

Although the East Franklin Mountain Fault surface location is mapped and available through the USGS quaternary fault database [13], the fault attributes are not detailed. Fault anatomy can be found on more recent studies which have not only mapped the quaternary faults in the El Paso Texas - Ciudad Juarez metroplex area, but also modeled gravity 2D profiles [2, 3, 18, 7]. The study of Ávila [3] shows two profiles located nearby the study area of this research. Figure 2, modified from such study, shows the fault trace location and 2D profiling of the zone. In particular profile B-B', located 6 km north to the radon field collection area, shows how the gravimetric signature can be properly fitted with a 2000 m heave, and a trough of nearly 2600 m. This quasivertical displacement of the Precambrian basement is associated with the EFMF. Avila et al. also shows the gravity forward modeling correlated to a north located seismic reflection section [8] providing both geophysical and geological constraints that support the normal fault controlled horst-and-graben basin architecture. The gravity forward model also reveals the outcropping Precambrian basement that might be acting as radioactive source.

In this study we connected the EFMF along Ávila's profiles BB and CC. Since the radon decay products are expected to occur across faults and nearby

López, J.A.
 Dena Ornelas, O.
 Sajo-Bohus, L.
 Rodríguez, G.
 Chavarría, I.

presence of crystalline rock units, the fault trace was mapped and identified on the terrain to collect a series of radon concentration readings on the field as shown in Figure 1.

4. RADON MEASUREMENTS

Although the natural radon family has among their members the isotopes 222, 220 and 219, the most often measured is the radioactive inert gas ^{222}Rn that has a half-life of 3.82 days and belongs to the ^{238}U chain. The world average exhalation flux at the soil surface is 22 mBq/m²s which corresponds to about 40 Bq/m³ indoors; however depending on the subsurface gas permeability, the flux can be much larger.

Measurements of radon content in ground air were carried out using a Markus 10 portable instrument manufactured by Gammadata in Sweden. The instrument operates by pumping out gas from the ground through a probe inserted in the soil at a relaxation depth of ~35cm during 30s. The Rn gas is stored for 10 min. in a measuring cell, time during which it decays into its progeny (^{218}Po and ^{214}Po) through alpha radiation detected with a silicon surface barrier detector operating under an strong electric field (~600 VDC). The readings are converted by the device into volume concentrations (i.e. an average radon concentration in the air-filled part of soil-pores) in kBq/m³. Table 1 shows the radon measurements obtained at the 16 points selected.

The nominal measuring error established by the factory calibration is of 1.7% of the measurement, but the readings are additionally rounded off by the LED readout of the device to tenths of kBq/m³; this sets the average uncertainty

Table 1. Location of points and radon concentrations obtained.

Point	Easting (m)	Northing (m)	Radon Concentration (kBq/m ³)	Point	Easting (m)	Northing (m)	Radon Concentration (kBq/m ³)
A	361731	3525816	1.05 ± 0.05	I	361553	3526166	2.75 ± 0.05
B	361883	3525823	8.05 ± 0.137	J	361555	3526062	3.75 ± 0.064
C	361586	3525789	8.75 ± 0.149	K	361606	3526056	1.35 ± 0.05
D	361660	3525801	4.05 ± 0.069	L	361819	3526143	4.35 ± 0.074
E	361436	3525831	4.35 ± 0.074	M	361706	3526041	1.75 ± 0.05
F	361286	3525855	5.75 ± 0.098	N	361787	3526655	7.75 ± 0.132
G	361716	3526156	5.75 ± 0.098	O	361830	3526632	6.05 ± 0.103
H	361632	3526159	9.35 ± 0.159	P	361733	3526659	7.05 ± 0.120

to a minimum of 50 Bq/m³ and as high as 1.7% of the measurement. For this reason we take all readings as being in the middle of each 100 Bq/m³ bin and list the uncertainty as the maximum of 1.7% or 50 Bq/m³. For instance, the reading at point C, which was recorded by the Makus 10 as 8.7 kBq/m³, could indeed correspond to any value between 8.700 and 8.799 kBq/m³, thus in Table 1 it is listed as 8.75 kBq/m³ with a 1.7% error of 0.149 kBq/m³.

The first observation is that the overall scale of measurements is in the same range as observed in many active faults as reported, for instance, by [19] (see Table 1); indeed these readings are higher than those obtained near the active fault of Dead Sea Transform in Jordan (1.8 – 3 kBq/m³) [1] and the Johnson Valley Fault in Landers, California (4 kBq/m³) [19], similar to those on the North Anatolian Fault in Turkey (9.8 kBq/m³) [10], and not too distant to those measured on the North and Northwestern Greece Fault (13 kBq/m³) [11]. This immediately appears to support the hypothesis that radon production is not related to seismic activity.

Overlaying the values of concentration of Table 1 over the geographic map of the EFMF it is possible to obtain a contour map of the concentration levels of the inspected area; Figure 3 shows such contour map using a color scale ranging from 1.1 kBq/m³ to 9.1 kBq/m³. Although the lack of information at the far edges of the map distorts a bit the information presented, the map clearly shows that the highest concentration levels, namely points C (8.7 kBq/m³), H (9.3 kBq/m³) and N (7.7 kBq/m³), coincide with the expected location of the EFMF. Furthermore, the concentrations are observed to die down very rapidly for points merely meters away from the fault.

The noticeable exceptions are the points J, K and M which show much lower levels of radon concentration: 3.7, 1.3 and 1.7 kBq/m³ respectively. These points, fortuitously, are located on a dirt road that was excavated next to a wash which, undoubtedly, removed and eroded soil and deposited extraneous debris of several feet of depth, that affected both the radon production (compared to neighboring terrains) and the structure of the uppermost soil and its gas transport properties. Seen from the positive side, the low readings obtained at the dirt road and wash seem to confirm that the in-soil radon concentration is produced mostly by the top soil and not by the deeper undergrounds which, in this case, were covered by dirt and debris of the erosion.

[A second possible conclusion, not explored in this article, is that the reduction of radon gas could indicate a segmentation of the fault. This would be welcome news for the El Paso Area population as a 52.7 km fault carries a risk of 7 in the Richter scale while two faults of 26 km would reduce the risk to 5 in the same scale; further analysis would be needed to test this possibility.]

López, J.A.
Dena Ornelas, O.
Sajo-Bohus, L.
Rodríguez, G.
Chavarría, I.

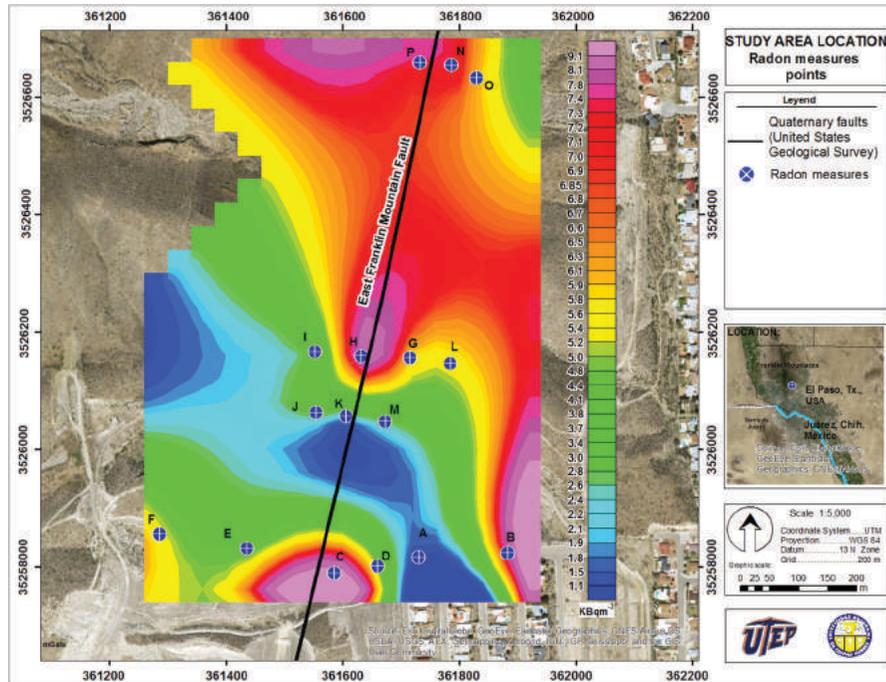


Figure 3: Concentration of radon gas measured on the area studied; the color scale varies from 1.1 kBq/m³ (blue) to 9.1 kBq/m³ (pink). The solid line approximates the location of the EFMF.

As pointed in other studies [9], the soil-gas concentrations of radon are expected to vary in time due to several factors (temperature, precipitation, humidity, pressure, tectonic activity), thus, to fully substantiate the hypothesis presented in this article a continuous long time monitoring of this and other faults is necessary. It must be pointed out that, to support the hypothesis, the levels at the fault would only have to peak with respect to the background of the immediate neighborhood and not attain specific levels. Such spatiotemporal study is currently underway [20].

5. CONCLUSIONS

By studying the production of radon in soil around the East Franklin Mountain Fault in El Paso, Texas, we determine a strong correlation between the in-soil concentration of radon gas and the location of the fault. The fact that the fault has not had any activity in recent geological times serves as a proof

of principle that enhancement of radon production near a fault is not due to seismic activity as predicted by the dilatancy-diffusion model of earthquake occurrence, but to the inherent radioactivity of the soil and to the enhanced gaseous transport properties of the soil due to the existence of the fault. Since the in-soil radon concentration is observed to decrease where extraneous dirt and debris have been deposited on top of the fault, this supports the idea that the in-soil radon concentration is produced mostly near the top soil and not deeper in the ground.

We conclude that the use of non-invasive measurements of radon gas concentrations to detect non-active faults appears as a real possibility that deserves further study. If proven correct by further studies, this method of fault detection has distinct advantages when used in populated areas. For instance, it does not rely on the production of shear and compressional waves, such as the method of seismic tomography, nor needs to produce electrical signals which can interfere with the urban electrical network as does the method of electrical resistivity tomography. These advantages are especially useful in determining the location of faults inside cities.

ACKNOWLEDGEMENTS

Part of this study was supported by the Wiemer Family Student Endowment for Excellence, and the UTEP MARC program.

REFERENCES

- [1] Al-Bataina, B.A., Al-Taj, M.M., Atallah, M.Y. Relation between radon concentrations and mor-photectonics of the Dead Sea transform in Wadi Araba, Jordan. *Radiat. Meas.* **40(2-6)**, 539-543 (2005).
<http://dx.doi.org/10.1016/j.radmeas.2005.06.023>
- [2] Ávila, V. M. An investigation of the Seismic Hazards of the El Paso-Juarez region: The nature and extent of the southern east Franklin Mountains Fault Zone. M.S. Thesis. University of Texas at El Paso. 75 pp (2011).
<http://digitalcommons.utep.edu/dissertations/AAI1494329>. Accessed 26 May 2016.
- [3] Avila, V.M., Doser, D.I., Dena, O.S., Moncada, M., and Marrufo-Cannos, S.S. Using geophysical techniques to trace active faults in the urbanized northern Hueco Bolson, West Texas, USA, and northern Chihuahua, Mexico. *Geosphere* **11(6)**, 1-17 (2015).
- [4] Baubron, J.-C., Rigo, A., Toutain, J.-P. Soil gas profiles as a tool to characterize active tectonic areas: the Jaut Pass example (Pyrenees, France). *Earth Planet. Sci. Lett.* **196(1-2)**, 69-81 (2002). [http://dx.doi.org/10.1016/S0012-821X\(01\)00596-9](http://dx.doi.org/10.1016/S0012-821X(01)00596-9)

-
- López, J.A.
Dena Ornelas, O.
Sajo-Bohus, L.
Rodríguez, G.
Chavarría, I.
- [5] Burton M., Neri, M., Condarelli, D. High spatial resolution radon measurements reveal hidden active faults on Mt. Etna. *Geophys. Res. Lett.* **31(7)**, 1–4 (2004). <http://dx.doi.org/10.1029/2003gl019181>
- [6] Collins, E.W., and Raney, J.A. Tertiary and Quaternary structure and paleotectonics of the Hueco basin, trans-Pecos Texas and Chihuahua, Mexico. The University of Texas at Austin, Texas Bureau of Economic Geology Geological Circular **91(2)**, 44 (1991).
- [7] Dena, O.S. Estudios geofísicos de gravedad, magnetometría y zonación de Riesgo Sísmico por el método de ondas superficiales en la región norte del estado de Chihuahua. Final Internal Report. Universidad Autónoma de Ciudad Juárez. 199 pp (2012).
- [8] Figuers, R.H. Structural geology and geophysics of the Pipeline Complex, Northern Franklin Mountains, El Paso, Texas. M.S. Thesis, University of Texas at El Paso. 185 pp (1987). <http://digitalcommons.utep.edu/dissertations/AAI8729914/>. Accessed 26 May 2016.
- [9] Han, X., Li, Y., Du, J., Zhou, X., Xie, C., et al. Soil gas Rn and CO₂ geochemistry in the capital area of China. *Nat. Hazards Earth Syst. Sci.*, **14**, 2803–2815 (2014). <http://dx.doi.org/10.5194/nhess-14-2803-2014>
- [10] Inceoz, M., Baykara, O., Aksoy, E., Dogru, M. Measurements of soil gas radon in active fault systems: a case study along the North and East Anatolian fault systems in Turkey. *Radiat. Meas.* **41(3)**, 349–353 (2006). <http://dx.doi.org/10.1016/j.radmeas.2005.07.024>
- [11] Ioannides, K., Papachristodoulou, C., Stamoulis, K., Karamanis, D., Pavlides, S. et al. Soil gas radon: a tool for exploring active fault zones. *Appl. Radiat. Isot.* **59**, 205–213 (2003). [http://dx.doi.org/10.1016/S0969-8043\(03\)00164-7](http://dx.doi.org/10.1016/S0969-8043(03)00164-7)
- [12] Israël, H., Björnsson, S. Radon ²²²Rn and thoron ²²⁰Rn in soil air over faults. *Zeit. Geophysik.* **33**, 48–64, (1966).
- [13] Keaton, J. R., and Barnes, J. R. Paleoseismic evaluation of the East Franklin Mountains fault, El Paso, Texas. Technical report to U. S. Geological Survey, contract 1434-94G-2389 (1995).
- [14] Kemski, J., Klingel, R., Schneiders, H., Siehl, A., Wiegand, J. Geological structure and geo-chemistry controlling radon in soil gas. *Radiat. Prot. Dosim.* **45(1/4)**, 235–239 (1992).
- [15] Koike, K., Yoshinaga, T., Ueyama, T. and Asaue, H. Increased radon-222 in soil gas because of cumulative seismicity at active faults, *Earth. Planets and Space* **66**, 57 (2014). <http://dx.doi.org/10.1186/1880-5981-66-57>
- [16] Machette, M.N. Preliminary assessment of paleoseismicity at White Sands Missile Range, southern New Mexico—Evidence for recency of faulting, fault segmentation, and repeat intervals for major earthquakes in the region. U.S. Geological Survey Open-File Report 87(444), 46. (1987).
-

-
- [17] McCalpin, J.P. (2006). Quaternary faulting and seismic source characterization in the El Paso-Juarez metropolitan area; Collaborative research with the University of Texas at El Paso, Program Element II: Evaluate Urban Hazard and Risk. Unpublished Final Technical Report submitted to U.S. Geological Survey by GEO-HAZ Consulting, Inc., Contract 03HQGR0056. 68 pp.
<http://earthquake.usgs.gov/research/external/reports/03HQGR0056.pdf>. Accessed 26 May 2016.
- [18] Moncada, M. G. Estudios geofísicos y geológicos para recarga de acuíferos en la zona norte del estado de Chihuahua. B.S. Thesis. Universidad Autónoma de Ciudad Juárez, 150 pp (2011).
- [19] Richon, P., Klinger Y., Tapponnier, P., Li, C.X., Van Der Woerd, et al.. Measuring radon flux across active faults: Relevance of excavating and possibility of satellite discharges. *Rad. Meas.* **45**, 211-218 (2010).
<http://dx.doi.org/10.1016/j.radmeas.2010.01.019>
- [20] Rodriguez, G. A study of radon emission around an East Franklin Mountain Fault in El Paso, Texas. M.S. Thesis, University of Texas at El Paso. In preparation.
- [21] Scholz C. H., Sykes, L. R. and Aggarwal Y. P. Earthquake prediction: A physical basis. *Science*, **181**, 803–810, 1973.
<http://dx.doi.org/10.1126/science.181.4102.803>
- [22] Tansi, C., Tallarico, A., Iovine, G., Folino Gallo, M. and Falcone, G. Interpretation of radon anomalies in seismotectonic and tectonic-gravitational settings: the south-eastern Crati Graben (Northern Calabria, Italy). *Tectonophysics* **396** (3–4), 181–193 (2005). <http://dx.doi.org/10.1016/j.tecto.2004.11.008>
- [23] Wells, D.L. and Coppersmith, K.J. Empirical relationships among magnitude, rupture length, rupture area, and surface displacement. *Bulletin of the Seismological Society of America*, **84**, 974-1002 (1994).

Correlation
Between
Underground
Radon Gas
and Dormant
Geological Faults
