Relation between radon concentrations and morphotectonics of the Dead Sea transform in Wadi Araba, Jordan

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Abstract

Radon concentrations were measured along six profiles crossing three morphotectonic features of the Dead Sea transform fault in Wadi Araba. Two profiles of detectors were placed across a fault scarp, a sag pond and a pressure ridge formed along the active Wadi Araba strike-slip fault. The maximum radon peak was measured in the pressure ridges ($1.8 \pm 0.07$ kBq m$^{-3}$). This high concentration may be due to the up squeezing and heterogeneous fracturing of the Cretaceous and the Pleistocene Lisan beds beneath the pressure ridges. The minimum radon readings were measured in the sag pond floor ($0.4 \pm 0.06$ kBq m$^{-3}$), the fractures are concentrated at the pond borders and not in the pond floor. The sag ponds are filled with fine sediments, which decreases the porosity and hence the upward radon migration. The fault scarp has intermediate radon radiation, with concentration values ranging between 1.1 and 1.2 kBq m$^{-3}$.

Keywords: Transform fault; Sag pond; Pressure ridge; Fault scarp; Radon

1. Introduction

Radon as a geological tracer has been used for uranium prospecting, environmental research, earthquake and volcanic prediction, and fault zone confirmation (King, 1980; Gingrich, 1984; Igarashi et al., 1995; Toutain and Baubron, 1999; Segovia et al., 2001; Virk et al., 2001). Radon emanation is strongly affected by geological and geophysical conditions. Movement of radon through the earth is strongly influenced among other factors by permeability of soil, porosity and degree of fracturing in rocks, and carrier gases (Abumurad et al., 1994; Etiope and Lombardi, 1995; King et al., 1996; Toutain and Baubron, 1999; Yang et al., 2003). In the active Dead Sea transform, radon concentration was measured in Wadi Araba, the Dead Sea and Jordan Valley (Steinitz et al., 1992; Atallah et al., 2001; Al-Taj et al., 2004). Radon was also measured along inactive faults in northern Jordan (Al-Tamimi and Abumurad, 2001).

The aim of this study is to measure the radon concentration across a pull apart basin, a pressure ridge, and a fault scarp formed along the northern Wadi Araba fault, in order to compare radon concentration in areas of compression (push-ups) and tension (pull-aparts). The reason for choosing this particular area is because of the excavation of three trenches across the Northern Wadi Araba fault, one across the fault scarp, the second across the pull apart basin and the third across the pressure ridge (Niemi et al., 2001). The presence of the trenches gives a constraint on the rock type...
in the radon sampling areas. The study area is covered by alluvial fan deposits, mostly consisting of limestone gravels intercalated with sand and silt size deposits. The alluvial fans cover the Pleistocene Lisan lake sediments, which are composed in the study area of oolitic sandstone (Niemi et al., 2001). In this arid area, a well developed soil horizon was not formed and the dosimeters were placed in an unconsolidated, fractured and highly porous gravelly-sandy beds. These sediments do not contain any significant source of radiogenic elements like U, Th, Ra or K (Rashdan, 1988).

2. Experiments

2.1. Geological background

The Dead Sea transform (DST) is an active left lateral strike slip fault. It consists of three morphotectonic segments, the Jordan Valley in the north, the Dead Sea basin in the middle and the Wadi Araba fault in the south. Geological and geomorphological evidences in addition to historical and recent earthquakes prove that the DST is active (Garfunkel et al., 1981; Galli, 1999; Al-Taj, 2000; Atallah and Al-Taj, 2004). Many authors have described the formation of the transform (Quennell, 1959; Bender, 1968; Freund et al., 1970; Garfunkel, 1981; Atallah, 1992). Its formation began in the Tertiary (15 million years ago), in association with the opening of the Red Sea, and is still going on.

Many morphotectonic features were formed as a result of this activity including pull apart basins (sag ponds), pressure ridges, fault scarps, offset of streams and alluvial fan surfaces (Garfunkel, 1981; Galli, 1999; Al-Taj, 2000; Klinger et al., 2000; Niemi et al., 2001; Atallah and Al-Taj, 2004). Pressure ridges and pull apart basins are formed due to the bending or stepping of the strike slip faults. In left lateral strike slip fault, pull apart basins are formed due to left-bend or step of the fault plane, while pressure ridges are formed due to right-bend or step (Sylvester, 1988). Cross-section across a pressure ridge shows positive flower structure (Wilcox et al., 1973) or palm tree structure (Sylvester, 1988), while across a pull apart basin negative flower structure is formed (Wilcox et al., 1973). Pressure ridges are characterized by compression manifested by high topography, squeezing of rocks, folding and reverse faulting, while pull apart basins are resulted from tensional stresses manifested by stretching of rocks, normal faulting and formation of basins. The ridges and basins, associated with strike slip faults vary in dimensions, range from few meters to kilometers.

2.2. Sampling

Six sampling profiles were chosen across the Northern Wadi Araba segment of the DST. Two profiles across the fault scarp close to trench number 1 (Fig. 1), two profiles across the pull apart basin, close to trench number 2, and two profiles across the pressure ridge, close to trench number 3.
The length of these profiles, which ranges from 45 to 60 m, depends on the extent of the morphotectonic feature (Fig. 1). The average distance between the dosimeters in each profile, ranges between 2 and 6 m, depending on the complexity of the topography of the different features.

The sampling took place in the summer of 2003. In previous works (Atallah et al., 2001), winter measurements showed lower radon concentrations than summer measurements on the fault planes. So, winter sampling was not performed.

2.3. Methodology

Square pieces (1.5 × 1.5 cm²) of solid state nuclear track detectors (CR-39) were mounted in the internal bottom of cylindrical plastic cans. The lid of each can is punched with few holes and these holes are then covered with (0.5 cm) pieces of sponge to filter out ²²⁰Rn. The resulted dosimeters were previously calibrated in the school of Physics and Space Research at the University of Birmingham, England. The activity concentration of the calibrated chamber was 90 kBq m⁻³ and the exposure time 48 h (Al-Bataina et al., 1997). The sensitivity of the dosimeter was found to be (7.64 ± 0.04) tr cm⁻²/kBq m⁻³ h. Moreover, a background measurement was performed using the same procedure and it was found to be (0.66 ± 0.16) tr cm⁻²/h, and the net number of z tracks was computed. The uncertainty in the counting system has been estimated to be about 10%. Each dosimeter was put upside down in a hole dug at 50 cm depth in each sampling site. Sampling was repeated three times to get both the average radon concentration and the standard deviation. Also, to eliminate the daily variations of radon and to obtain a time integrating measurement. The dosimeters were placed in each hole for 3 weeks (about 5 times the half-life time of ²²³Rn). Then, they are extracted and a new one put instead. The time interval took about two months.

3. Results

Three pairs of traverses were chosen across the three different morphotectonic features of the northern Wadi Araba fault. They are the fault scarp, the sag pond and the pressure ridge, respectively. The mean, standard deviation and the range of the radon concentrations at each site are presented in Table 1.

3.1. Fault scarp

The active Wadi Araba fault forms 2 m height scarp in the study area. A 25 m long and 5 m deep trench was excavated across this scarp to study the paleoearthquakes of the area (Niemi et al., 2001). Along the trench walls, different generations of alluvial fan sediments were exposed. At deeper point of the trench sand and marl of the Lisan Formation are exposed. The fault zone is represented by a 9 m wide-flower structure (Niemi et al., 2001). Pulverized rock in a fault gouge indicates repeated motion along two main strands of the fault (Niemi et al., 2001). In the two sampling profiles (L1 and L2, Fig. 2a and b), one sample is placed at the bottom of the scarp, one at the top of the scarp and one at the middle of the scarp face. Two other samples were placed on both sides of the scarp, with a distance of 15 m (Fig. 2a and b). West of the fault scarp radon concentration is relatively low (0.7–0.8 kBq m⁻³). At the fault scarp itself, the concentration increases to a maximum of (1.2 ± 0.07) kBq m⁻³ in L1 and to (1.1 ± 0.07) kBq m⁻³ in L2. At the scarp top, the concentration values decreases (0.9 ± 0.07) kBq m⁻³ and further to the east it increases again to the values of 1.2 and 1.3 kBq m⁻³ in L1 and L2, respectively.

3.2. Sag pond

To the north of the previous trench, another one was excavated across a sag pond. The sag pond extends N–S for 30 m long and 10 m wide, it is filled with fine sediments, it is bounded by fault scarps on the east and a pressure ridge on the west (Niemi et al., 2001; Fig. 1). Along the trench wall, Lisan Formation is composed of oolitic sand, clay, silt and gravel. They are overlain by Holocene silt, sand and gravel of both the alluvial fan deposits and the sag pond filling. The trench walls show also a multiple fault strands concentrated in two areas bordering the sag pond. Two sampling profiles crossing this structures L3 and L4 are placed. The samples were distributed on the two opposite scarps and on the floor of the sag pond. Two other samples were placed 15 m west and east of the structure (Fig. 2c and d). The distance between the samples within the structure ranges from 2–6 m according to the topographic changes, they were placed at the top, middle and at bottom of the two scarps and at the center of the sag pond (Fig. 2c and d). L3 shows low radon concentrations outside the sag pond (0.8±0.08) kBq m⁻³, high concentration at the scarp bordering the pond (maximum of 1.5 and 1.7 kBq m⁻³ on the eastern and western scarps respectively). The sag pond floor shows lower concentrations (1.1–1.2 kBq m⁻³). L4 shows more irregular pattern. East of the pressure ridge radon concentration is low (0.7 ± 0.08) kBq m⁻³, but west of it, where a pressure ridge was formed, the concentration

<table>
<thead>
<tr>
<th>Site</th>
<th>No. of samples</th>
<th>Mean (kBq m⁻³)</th>
<th>Standard deviation</th>
<th>Range (kBq m⁻³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>8</td>
<td>1.02</td>
<td>0.16</td>
<td>0.78–1.22</td>
</tr>
<tr>
<td>L2</td>
<td>7</td>
<td>0.96</td>
<td>0.22</td>
<td>0.75–1.32</td>
</tr>
<tr>
<td>L3</td>
<td>10</td>
<td>1.10</td>
<td>0.26</td>
<td>0.79–1.62</td>
</tr>
<tr>
<td>L4</td>
<td>10</td>
<td>1.07</td>
<td>0.22</td>
<td>0.72–1.49</td>
</tr>
<tr>
<td>L5</td>
<td>13</td>
<td>1.16</td>
<td>0.30</td>
<td>0.46–1.43</td>
</tr>
<tr>
<td>L6</td>
<td>11</td>
<td>1.08</td>
<td>0.33</td>
<td>0.48–1.75</td>
</tr>
</tbody>
</table>
is relatively high \( (1.2 \pm 0.07) \text{ kBq m}^{-3} \). The base of the eastern scarp shows a high peak \( (1.5 \pm 0.08) \text{ kBq m}^{-3} \). One sample at the center of the sag pond floor shows a low value of \( (0.9 \pm 0.07) \text{ kBq m}^{-3} \). Because of the trend is not similar in L3 and L4, the fractures in L4 seem to have more heterogeneous distribution than L3.

3.3. Pressure ridge

At the northern edge of the above mentioned sag pond, a pressure ridge was formed due to the right step of the Wadi Araba fault. East of the pressure ridge a small scale N–S elongated sag pond was formed (Fig. 1). At the northern edge of the ridge a trench was excavated for gravel supply. A well-developed, positive flower structure is exposed in the trench. The rocks exposed in the trench are mainly Upper Cretaceous limestone and sand, marl and conglomerate of the Lisan Formation. The sample profiles crossing the pressure ridge are L5 and L6 (Figs. 1 and 2). The samples were placed at every subtle change in the topography within the structure and 15 m distance on both sides of the structure (Fig. 2e and f). L5 shows low radon concentration east and west of the pressure ridge \( (0.5 \text{ and } 0.7 \text{ kBq m}^{-3} \), respectively). Along the pressure ridge higher radon concentrations were recorded, the values range between 1.2 and 1.4 \text{ kBq m}^{-3} \). A low value of \( (0.8 \pm 0.07) \text{ kBq m}^{-3} \) was recorded on a small sag pond east of the pressure ridge (Fig. 2e and f). This sag pond is getting wider in L6, where it shows also very low radon concentration \( (0.4 \pm 0.08) \text{ kBq m}^{-3} \). A maximum value of \( (1.8 \pm 0.08) \text{ kBq m}^{-3} \) was measured in the pressure ridge of L6 (Fig. 2e and f). East of the sag pond, radon concentrations increase to \( (1.2 \pm 0.07) \text{ kBq m}^{-3} \) (on a fault trace east of the pressure ridge, Fig. 1) and then decreases to \( (0.9 \pm 0.08) \text{ kBq m}^{-3} \). West of the pressure ridge, the values decrease to \( (0.9 \pm 0.07) \text{ kBq m}^{-3} \) and then increase to \( (1.1 \pm 0.08) \text{ kBq m}^{-3} \).

4. Conclusions

Six profiles of radon detectors are placed across three morphotectonic features of the active Dead Sea transform in Wadi Araba. The fault zone has higher radon concentration than the surrounding alluvial sediments, but based on previous works (Atallah et al., 2001; Al-Taj et al., 2004), the difference is less than expected. This may be due to the high porosity and permeability of both the fault zone and the alluvium. Consequently, an air leakage is expected. The higher radon peaks are measured in the pressure ridges, because below the ridges the Cretaceous and the Lisan beds are squeezed up and are highly fractured as seen in the trench 3. The lower radon readings are measured in the floor of the sag ponds, the ponds have no fractures and filled with fine sediments, which decreases the porosity and hence the upward radon migration. The fault scarps have generally intermediate radon concentrations.
References