The influence of different types of granite on indoor radon concentrations of dwellings in the South African West Coast Peninsula

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ABSTRACT

Granite commonly contains high concentrations of uranium, with subsequent high exhalation of radon gas. The geology of the West Coast Peninsula of South Africa is dominated by granite. No measurements of radon gas has, however, been undertaken in, or near the towns of the peninsula and a recent article predicted potentially high indoor radon concentrations in the town of Saldanha. This article sets out to validate the predicted results by measuring the indoor radon concentration for the two largest settlements on the West Coast Peninsula: Vredenburg and Saldanha. Measurements were conducted during the summer months with houses typically being more open due to the warm weather. The data was found to exhibit lognormal behavior, with the I-type granite formation of Vredenburg yielding a higher indoor radon concentration than the ignimbrite formation of Saldanha. The average indoor radon concentration of Vredenburg was 34% higher than that of Saldanha, with 58.7 Bq/m$^3$ and 38.6 Bq/m$^3$ respectively.

1. Introduction

Granite is of igneous origin and typically has elevated levels of radionuclides which includes uranium and its progeny. The progeny of uranium contains radium that decays into hazardous radon gas, which can have health implications on inhabitants of dwellings if indoor buildup occurs (Clement et al., 2010). Houses that are built on or between granite rocks, or on granitic soils, therefore have a higher potential to accumulate high indoor radon concentrations. The International Commission for Radiological Protection (ICRP) and the International Atomic Energy Agency (IAEA) recommends that radon concentrations for dwellings should be below 300 Bq/m$^3$ (IAEA, 2015), while the World Health Organization (WHO) recommends that homeowners should take action when radon exceeds 100 Bq/m$^3$. It is also important to note that finer grained particles, like the weathered granitic soils, would more readily support radon exhalation due to its larger exposed active areas (Nguyen, Nguyen, Vu, Nguyen, & Cong, 2018).

The towns of Vredenburg and Saldanha are the two largest settlements on the West Coast Peninsula and is situated about 100 km north of Cape Town, South Africa. Vredenburg is situated inland about 10 km from the coast and has a bigger population and larger area than Saldanha. Saldanha is 15 km from Vredenburg and is situated on Saldanha Bay. The Peninsula is around 40 km in length and 20 km in width and is mainly dominated by granite geology. The towns are both built on granite hills with exposed granite rock structures evident amongst the houses. This is clearly visible in aerial photographs of the towns that are shown in Figure 1. Bezuidenhout (2012) also showed that the sandy slopes of these granite hills mostly consists of granitic soils, probably due to the weathering of the parent rock of the hills and subsequent eolian and alluvial deposition in its proximity. Based on the granite geology, Bezuidenhout (2019) estimated that the indoor radon concentrations of about 5.7% of the dwellings in Saldanha would exceed 300 Bq/m$^3$. The estimation was, however, not based on measurements of indoor radon concentrations, something that this study aims to address.

The estimated radon hazard in towns or suburbs is typically determined by sampling a selected or representative number of dwellings. The indoor radon concentrations relates well to geology and soil, but other factor such as building characteristics, lifestyle and climate also plays a role (Schubert, Musolff & Weiss, 2018). The granite in the towns of Saldanha and Vredenburg will consequently have an impact on the indoor radon concentrations of houses. The geology of the West Coast Peninsula is, however, complex and geological differences between the towns should be taken into account when indoor radon measurements are used for general radon estimations. This article relates indoor radon measurements that were conducted in the beginning of 2019 to the geology of Saldanha and Vredenburg.
Figure 1. Some aerial photographs of the granite hills with the houses on them in Saldanha and Vredenburg. The first two photos show houses that are built on Malgaskop and Hoedjieskop in the town of Saldanha. The last photo shows the houses on the summit of the granite hill in Vredenburg.

Figure 2. Geological map of the western part of the Saldania orogenic belt, including the Cape granite suite. Modified from Belcher and Kisters (2003), Theron, Gresse, Siegfried, and Rogers (1992) and Villaros (2010).
2. The geology of the West Coast Peninsula

The geology of the West Coast Peninsula forms part of the larger Cape Granite Suite (e.g. Scheepers & Schoch, 2006), which outcrops amongst older Malmesbury shales and younger Cape Supergroup sandstones, from the West Coast Peninsula in the west and into the Cape Fold Belt to the east (Figure 2).

These granitic rocks were emplaced between 560–520 Ma as part of a greater Saldania belt, during a global Pan-African orogenic event, leading to the amalgamation of Pangea. The western part of the Cape Granite Suite (Figure 2) was emplaced within three northwest-southeast trending terranes, separated by tectonic fault zones, one of which is the Colenso fault zone that transect the West Coast Peninsula and runs to Franschhoek in the southeast. The Colenso fault zone also acts as a boundary between two different sub-types of granitic rocks, referred to as I-types and S-types on the basis of their assumed derivation through the partial melting of either an igneous or sedimentary crustal source rock, respectively (Chappel & White, 1974). The S-types tend to be more peraluminous than I-types and that is also consistent with a more clay-rich source, such as the Malmesbury shales that the granites are hosted in.

S-type granite plutons consequently dominate the coastal Tygerberg Terrane, south-west of the Colenso fault zone. The seaward part of the Tygerberg Terrane around the Saldanha Bay area is, however, dominated by a special igneous unit, known as Saldanha-Postberg ignimbrite (Clemens and Stevens (2016), and references therein and Bezuidenhout and Potgieter (2018)). Ignimbrites have a volcanic origin and represent hot pyroclastic material that was deposited within topographical depressions as density currents. These welded Saldanha ignimbrites are very competent and give rise to some prominent hills in the area, including Baviaansberg, Malgaskop, Hoedjieskop and Saldanhakop, in and around the town of Saldanha (Figure 3; Bezuidenhout and Potgieter (2018)).

The Colenso fault zone – separating S-type and I-type granites – runs in between the towns of Saldanha and Vredenburg and thereby give rise to very different underlying basement geology (Figure 3). The large Vredenburg I-type granite pluton (G3 in Figure 3) consequently underlies

Figure 3. A geological map of the southern part of the West Coast Peninsula that demonstrates how the towns of Saldanha and Vredenburg are located on Saldanha ‘ignimbrites’ and Vredenburg I-type granites, respectively (Roberts & Siegfried, 2014).
most of the Vredenburg area; whereas, Saldanha is underlain by ignimbrite hills (G2) and older S-type granites (G1) across flatter inland parts. The difference in origin and characteristics of the ignimbrites and S-type granites to the south-west and I-type granites to the north-east most likely give rise to uniquely different radionuclide concentrations, measured by Bezuidenhout (2013; Table 1). Most notably, higher concentrations of thorium and uranium exists in the Vredenburg I-type granite; whereas, ignimbrites exhibit marginally higher concentrations of potassium.

3. Methods

Indoor radon measurements were conducted in 19 houses in Saldanha and 33 houses in Vredenburg.

Table 1. Average measured activity concentrations of the K, U and Th for samples from I-type granites and ignimbrites around the towns of Vredenburg and Saldanha, respectively. This table is taken from Bezuidenhout (2013).

| Site                        | K (Bq/kg) | U (Bq/kg) | Th (Bq/kg) |
|-----------------------------|-----------|-----------|------------|
| Gravel Saldanha Quarry A    | 1181.7    | 119.6     | 170.3      |
| Gravel Saldanha Quarry B    | 1253.0    | 107.8     | 192.7      |
| Gravel Saldanha Quarry C    | 1148.0    | 120.6     | 174.2      |
| Granite Vredenburg Hill     | 1287.2    | 84.5      | 158.2      |
| Average (I-types Granite)   | 1217.5    | 108.1     | 173.2      |
| Granite Malgaskop Hill      | 1313.9    | 61.7      | 100.8      |
| Granite Hoedjieskop Hill    | 1270.6    | 59.1      | 63.8       |
| Average (ignimbrites)       | 1292.2    | 60.4      | 82.2       |

The measured areas are indicated in Figures 4 and 5 for Saldanha and Vredenburg respectively.

Sample selection was done by first identifying areas in both towns where houses were situated on, or in close proximity to Granite outcrops. Houses in these

Figure 4. Geological map indicating the area of measurement for Saldanha.

Figure 5. Geological map indicating the area of measurement for Vredenburg.
areas were then randomly selected and the owners approached to obtain permission for measurement. The purpose of the study was explained to each possible respondent, the placing and functioning of the electret ion chambers were explained, and each homeowner was asked to complete a form indicating that they voluntarily take part in the study.

Airborne radon concentrations were measured by placing electret ion chambers (E-PERM\textsuperscript{TM}) from Rad-Elec Inc. in the living areas of each house. The chambers were placed more than 1 m above the floor and 1 m clear of any windows, doors or walls. All the measurements were done for a minimum of three days, while the inhabitants continued with their normal routine. A surface potential electret voltage reader (SPER) that is also produced by Rad-Elec Inc. was used to measure the initial and final voltage of each electret. The difference in voltage potential was then determined and a standard background correction made. This is the typical background gamma radiation, and was assumed to be around 32 Bq/m\textsuperscript{3} (Shahbazi-Gahrouei, Setayandeh, & Gholami, 2013). The final indoor radon concentration was then calculated.

Even though many surveys of radon in homes in different countries have found the results to follow a lognormal distribution, or close to lognormal (Daraktchieva, Miles, & McColl, 2014), Tondeur and Cinelli (2014) stated that the 3-component nature of indoor radon (radon from outdoor air, from building materials and from subsoil) can generate deviations from the log-normal trend on the low- and high-concentration sides.

To determine whether the results from the Vredenburg and Saldanha measurements exhibit lognormal characteristics, the natural logarithm of the data was obtained and plotted. Next, the mean and standard deviation of the values were calculated, and a normal distribution generated using these values. In order to obtain a smooth plot, 30 000 random variables were used for the normal distribution. This distribution was then plotted against the calculated indoor radon concentration to compare the data trends and characteristics. To compensate for scaling differences between the two plots, the amplitudes were normalized according to the maximum occurrence of the mean values.

4. Results and discussion

The results from the indoor radon calculations are given in Figures 6 and 7. As can be seen, the average radon concentration found in Vredenburg homes are 34% higher than those found in Saldanha, with averages of 58.7 Bq/m\textsuperscript{3} and 38.6 Bq/m\textsuperscript{3} respectively.

The extremity found between 190 and 200 Bq/m\textsuperscript{3} in the Vredenburg results is due to a large, protruding granite rock found in the living area of a particular residence. The occupants are also living a ‘closed’ lifestyle, implying very little airflow through the house to mitigate the buildup of radon gas. Comparing this to radon concentrations found in Saldanha (Figure 7), an opposite effect can be observed in the lower extremity of the data between 0 and 10 Bq/m\textsuperscript{3}. This calculation comes from a house situated in an area with a mild microclimate, which allows the occupants to have an ‘open’ lifestyle. This implies consistent airflow which minimizes radon gas buildup. The radon concentration for this residence

\[ \text{Figure 6. The calculated indoor summer radon concentration for Vredenburg.} \]
was calculated to be approximately 2.5 Bq/m³. It is thus evident that an occupant’s lifestyle can greatly affect the buildup of radon.

The construction and location of the residence also affects the emanation and buildup of radon gas. The highest measured concentration in Saldanha was measured to be 86 Bq/m³. This was in a confined flat on the ground floor with few windows and a concrete ceiling. As a result, the restricted airflow increased the radon concentration.

The average indoor radon concentrations of both towns are below the IAEA’s recommended level of 300 Bq/m³. It is comparable with countries with warmer climates, such as the Israel (Epstein, Koch, Riemer, Orion, & Haquin, 2013) and some Arab countries (Al-Azmi et al., 2012).

A characteristic of a lognormal distribution is that the natural logarithm of the data will exhibit a normal distribution (Limpert, Stahel, & Abbt, 2001). As can be seen from Figures 8 and 9, both datasets exhibit this characteristic. The mean of the Vredenburg dataset was calculated as 3.93, with a standard deviation of 0.48. The Saldanha dataset, on the other hand, has a mean of 3.5 with a standard deviation of 0.72. This suggests a higher radon potential in the Vredenburg region, due to the I-type granite that occurs.

Figure 7. The calculated indoor summer radon concentration for Saldanha.

Figure 8. The calculated indoor radon concentration of Vredenburg compared to a normal distribution with a mean of 3.93 and a standard deviation of 0.48.
5. Conclusion

Measurements done by Bezuidenhout (2013) found higher concentrations of uranium in the Vredenburg I-type granite. This suggests a higher radon potential in the Vredenburg region, due to the I-type granite that underlies the town.

Using E-PERM™ electret chambers, it was found that the indoor radon concentration of the Vredenburg region is indeed 34% higher than those found in Saldanha. The average values of the two regions are 58.7 Bq/m³ and 38.6 Bq/m³ respectively. This supports Bezuidenhout’s hypothesis, but there are also indications that the construction and location of the home, as well as the lifestyle of the occupants, could play a role in the concentration of indoor radon found in the study area.

Also notable is that the data exhibit a lognormal distribution, as is commonly reported in the literature. The Vredenburg data has a mean of 3.93 and a standard deviation of 0.48. As expected, the Saldanha data has a lower mean of 3.5 and a standard deviation of 0.72.

Disclosure statement

No potential conflict of interest was reported by the authors.

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