# A desktop study of radon gas concentration levels for the Isle of Man, with respect to the underlying geology

A report for the Public Health Directorate, Isle of Man Government

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## Scope

In this report we collate evidence of radon levels on the Isle of Man from publicly accessible data through a desk-based study. We link this data to the geology of the island, and spatially consider how geology, radon level and population overlap. We draw on more extensive UK datasets of radon levels and geology, comparing these to the Isle of Man and discuss possible inferences. The report outlines the limitations of the data available and provides recommendations for potential future data collection and analysis.

## Radon and public health

Radon levels are measured in becquerels per cubic metre of air (Bq $m^{-3}$). The UK Health Security Agency reports that the average level in UK homes is 20 Bq $m^{-3}$ and that for levels below 100 Bq $m^{-3}$ individual risk remains relatively low and not a cause for concern (UK Health Security Agency UKradon - What is radon?). However as radon levels increase so does risk to health. Ionizing radiation is linked to cancers, with exposure to radon in homes the second leading cause of lung cancer in the UK after cigarette smoking (AGIR, 2009). In industrial settings where workers are exposed to increased levels of ionizing radiation (e.g. the nuclear industry) exposure to and dosage of ionizing radiation are both well regulated and monitored (Lopez et al. 2004). In contrast, home exposure to naturally occurring radon is unregulated and unmonitored. This is despite the fact that home radon, on average, contributes to 50% of a person's ionizing radiation exposure (Hughes, 1999), see also Figure 1 from the UK Health Security Agency which breaks down exposure by source. Further, studies in Europe and the US have shown that home exposure can exceed whole body exposure level recommendations set out by the International Commission for Radiological Protection (ICPR) (Report No. 60, 1990) (Henshaw, 1993).

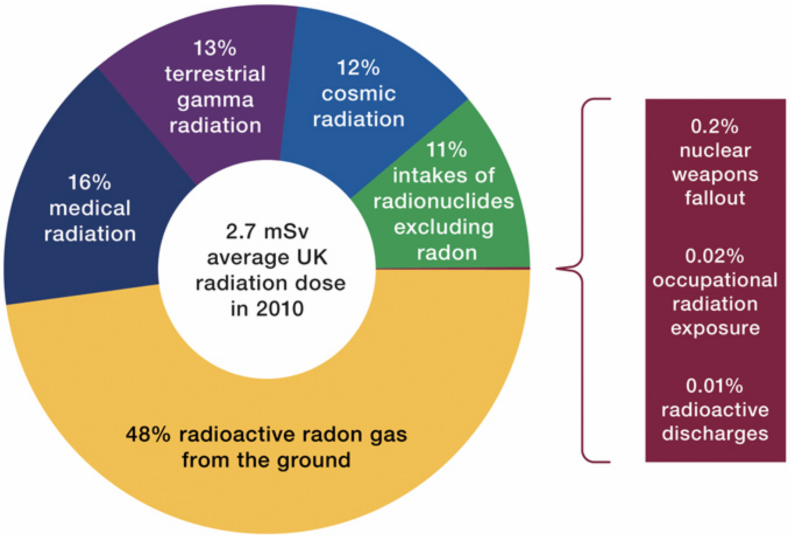

*Figure 1. Average UK radiation dose in 2010 by source, from the UK Health Security Agency https://www.ukradon.org*

## Radon generation and containment

Radon is a naturally occurring colourless and odourless radioactive gas. It forms from the decay of radioactive elements that occur in rocks and soils. It is possible to directly measure radon levels in a single place or as a dosage to an individual. Radon level can be related to geology: rocks such as granites, limestones and organic rich sediments contain higher amounts of radioactive elements (e.g. Uranium, Thorium and Potassium) that will decay to form radon (Scheib et al. 2013), than other rocks. However, geology is not the only factor in determining radon level. Radon level is also affected by the ability for radon gas to escape from its source (e.g. through fractures) to the surface (Schery et al. 1982) and the extent of dispersion at the surface (de Lurdes and Fiuza, 2005). So built infrastructure, including ventilation (Chao et al. 1997) and building materials and design (Burghele et al. 2021), also play a part in determining radon levels in the home and other built environments.

## Geology of the Isle of Man

Geology is a key component in radon health risk (Field,1999) as the underlying geology is the source of radon gas. Here we provide a brief overview of the geology of the Isle of Man before using this information to screen the most likely areas on the island where radon levels may be of greatest interest to public health.

The Isle of Man is largely composed of deformed Lower Palaeozoic (Ordovician and Silurian) metasedimentary rocks and granitic intrusions (Chadwick et al. 2021). At its fringes Upper Palaeozoic (Devonian, Carboniferous and Permian) to Mesozoic (mainly Triassic) sediments onlap the island and form thick sedimentary packages in the surrounding Irish Sea basin. The focus here is on the metasedimentary rocks and granitic intrusions, these rocks form the upland massifs, and on the potential for radon from organic rich sedimentary rocks at the island's fringes.

### The Lower Palaeozoic

The Manx Group metasedimentary rocks are formed mainly from turbiditic layers of sand, mud and siltstone, with the occasional volcanic rock. The Dalby Group also form part of the lower Palaeozoic succession (Ordovician and Silurian) and are similar in nature to the Manx Group (Figure 2). After deposition these rocks have been deformed and metamorphosed and form a steeply dipping NW younging succession (Chadwick et al. 2021). These rocks are cut by a number of strike parallel faults. Palaeozoic intrusive rocks crop out on the island. They form three small bodies in outcrop: the Dhoon granodiorite (in the NE of the Island), the Foxdale granite (centrally in the island), and the Oatlands Complex (in the SE). The Dhoon granodiorite is the earliest intrusion, derived from relationship with early deformation events with the Foxdale granite intruding later. The Foxdale granite has an isotopic age of 400 Ma (Chadwick et al. 2021, personal comm. S F Crowley and P S Kennan). Acid sheets are found along the central spine of the island, and there are other minor intrusions with a range of compositions in the Manx Group. At Poortown, basic intrusive rocks (dolerite and andesite) are found and may have been emplaced during volcanic activity associated with closure of the Iapetus Ocean (Piper et al. 1999).

As with all intrusive rocks the 3D shape and nature of the intrusive rocks of the Isle of Man in the subsurface is not easily interpreted from the geological map pattern. Geophysical analyses show aeromagnetic anomalies over SW Scotland and Central Island suggesting blocks of magnetic mid-crustal material (Kimbell and Stone, 1995; Morris and Max, 1995), that may be composed of Precambrian crystalline basement and/or magnetic igneous rocks generated by arc magmatism associated with the closure of the Iapetus Ocean (Kimbell and Stone, 1995). Cornwell (1972) suggests that granitic rocks may underlie much of the island. This could be an important factor when considering the radon health risk across the island.

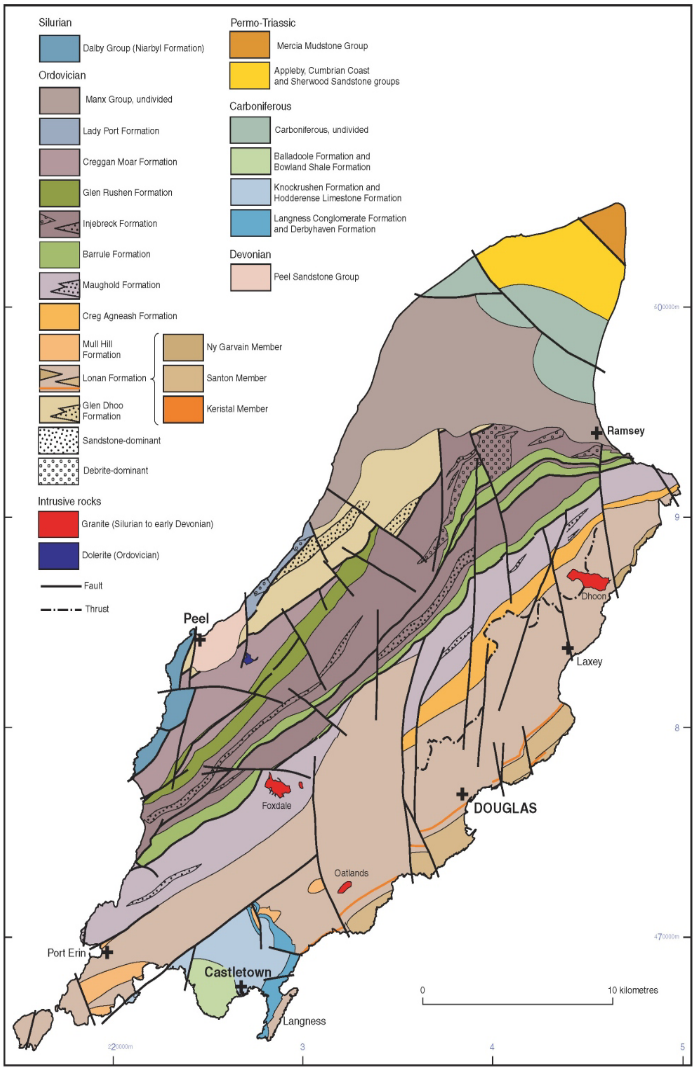

*Figure 2. Geological map of the Isle of Man showing the main geological units and their associated ages. The oldest rocks are from the Lower Palaeozoic (Ordovician and Silurian), followed by Devonian, Carboniferous and then the Permo-Triassic (after Chadwick et al. 2001).*

### The Devonian and Carboniferous

The sedimentary successions include red beds of Devonian age that crop out around Peel, and are termed the Peel Sandstone Group. They consist of red sandstones and conglomerates with minor, siltstone, claystone and calcrete palaeosols (Chadwick et al. 2001). Carboniferous rocks on the island crop out in the south of the Island, but are also present in the North albeit concealed by Permo–Triassic strata and Quaternary deposits. The Carboniferous rocks in the south of the Island, are known as the Langness Conglomerate Formation and lie at the base of the succession and comprise a red-bed sequence. In mid-Dinantian times, a marine transgression introduced a predominantly carbonate succession in this area, evolving into a carbonate platform, which was followed by more basinal deposits. Parts of the Carboniferous succession can be lithologically and bio-stratigraphically compared with the succession in northern England (Chadwick et al. 2001). In the north of the island Westphalian siliciclastic Carboniferous sediments are seen in boreholes (Chadwick et al. 2001).

### The Permo-Triassic

Rifting was significant in the Permian and Triassic (Permo-Trias) and the Isle of Man was part of a rift system extending from the English Channel to the West of Scotland. In the early Triassic deposition of the Sherwood Sandstone Group occurred followed by the Mercia Mudstone Group, in the rift basins. Sherwood Sandstone and Mercia Mudstone deposits cropping out in the NE of the island are overlain by a relatively thin layer of Penarth Group. It is thought that the Mercia mudstone may have once covered the whole island, but was later eroded. A bituminous marine mudstone was deposited in the Lias but has also been mainly eroded leaving minor remnants (Chadwick et al. 2001).

Further detailed information on the geology of the island can be found in the British Geological Survey memoir for the Isle of Man (Chadwick et al. 2001).
https://webapps.bgs.ac.uk/Memoirs/docs/B06265.html

## Existing radon data for the Isle of Man

In the late 1990s a radon survey was conducted on the Isle of Man as part of the wider European Longitudinal Study of Pregnancy and Childhood (ELSPC study) on the Isle of Man. In the radon survey, the results of which are discussed in Grainger et al. (2000), 8 subjects had radon meters in their houses for 12 months between mid-May 1998 to mid-May 1999, with an additional 285 homes having a radon meter for 3 months over winter months 1998/1999. The average radon level for homes on the Isle of Man was found to be 48 Bq $m^{-3}$, more than double the average of 20 Bq $m^{-3}$ for the UK.

The data are presented by Grainger et al. (2000) are further broken down on a postcode area basis, and are summarised in Table 1, and Figures 2, 3 and 4. While the data in the Grainger et al. (2000) study are presented in a relatively coarse spatial distribution, they indicate higher than average mean home radon levels in postcodes IM2 and IM4, both of which have at least one home with levels significantly exceeding the UKHPA action level of 200 Bq $m^{-3}$, as well as at least one home in IM9 where levels significantly exceed the UKHPA action level.

In the Grainger et al. (2000) paper they cite two other studies of radon levels on the Isle of Man, neither of which appear to be currently publicly available digitally. One of these was conducted by the National Radiogenic Protection Board in 1990 and looked at 39 schools on the Isle of Man. They found a mean radon level of 38.8 Bq $m^{-3}$, with a range of range <30–150 Bq $m^{-3}$. The second study cited is an Isle of Man Local Government report from 1991, where 74 homes were surveyed from 1984 to 1991. This study found mean concentrations of 42 Bq $m^{-3}$ for the island and 86 Bq $m^{-3}$ for the ex-mining area in IM4.

| Postcode area | Min. | Max. | Mean | Median | Number of homes |
|---|---|---|---|---|---|
| IM1 | 4 | 182 | 28 | 17 | 16 |
| IM2 | 4 | 420 | 62 | 33 | 74 |
| IM3 | 6 | 120 | 43 | 38 | 37 |
| IM4 | 8 | 517 | 70 | 33 | 45 |
| IM5 | 4 | 101 | 21 | 16 | 22 |
| IM6 | 37 | 62 | 47 | 41 | 3 |
| IM7 | 11 | 139 | 43 | 29 | 15 |
| IM8 | 4 | 101 | 22 | 19 | 23 |
| IM9 | 4 | 305 | 42 | 18 | 50 |

*Table 1. From Grainger et al. (2000) Average home radon levels by postcode (Bq $m^{-3}$) using the IoM seasonal correction factor.*

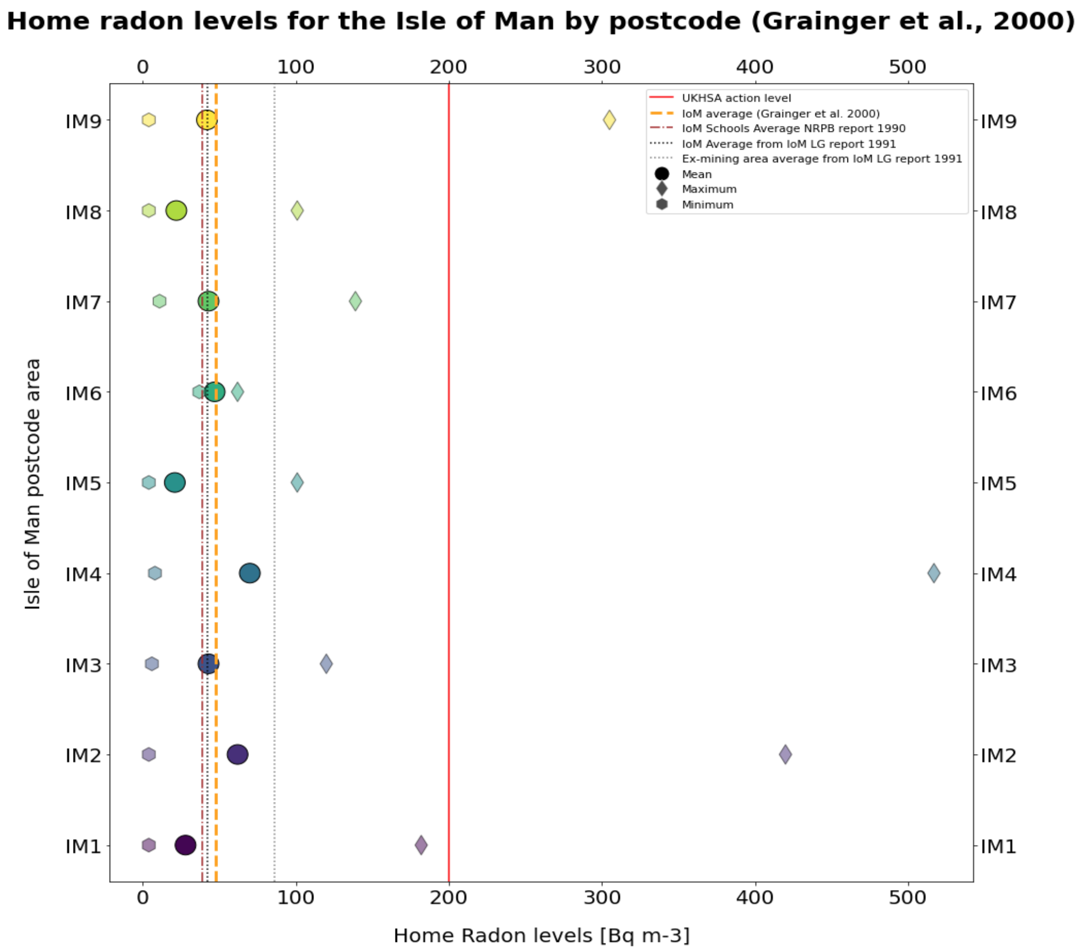

*Figure 2. Home radon levels for Isle of Man postcode regions from Grainger et al. (2000). Large circles indicate the mean radon level in that postcode, the diamonds show the maximum radon level reported in that postcode, while the hexagon shows the minimum radon level in that postcode. The orange dashed line marks the average home radon level found by Grainger et al (2000), the brown dot-dash line marks the average school radon level found in the NRPB 1990 report, the black dotted line marks the average radon level found in the Isle of Man Local Government 1991 report, and the grey dotted line marks the average radon level found in the ex-mining area in IM. These figures are taken from those reported in Grainger et al. (2000). The red line marks the UK Health Security Agency's action level for radon.*

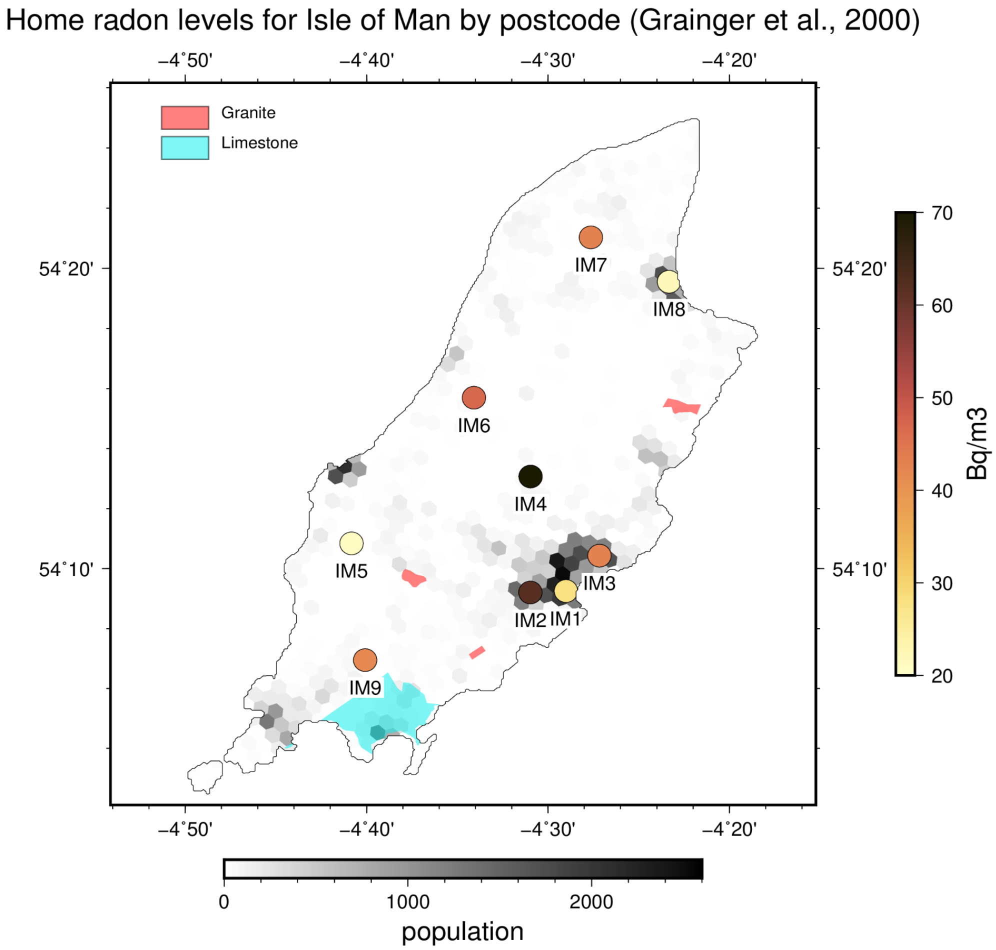

*Figure 3. Home radon levels reported by Grainger et al. (2000) shown as coloured circles located at an approximately central point in the postcode district (see Figure 4 for a map showing postcode districts). Light shades indicate lower levels than dark shades. The locations of mapped granite and limestone are shown in red and cyan respectively. Population levels within a 400m hexagon from the Kontur Population dataset are also shown, with darker shades indicating areas of higher population. Contains British Geological Survey materials © UKRI 2022*

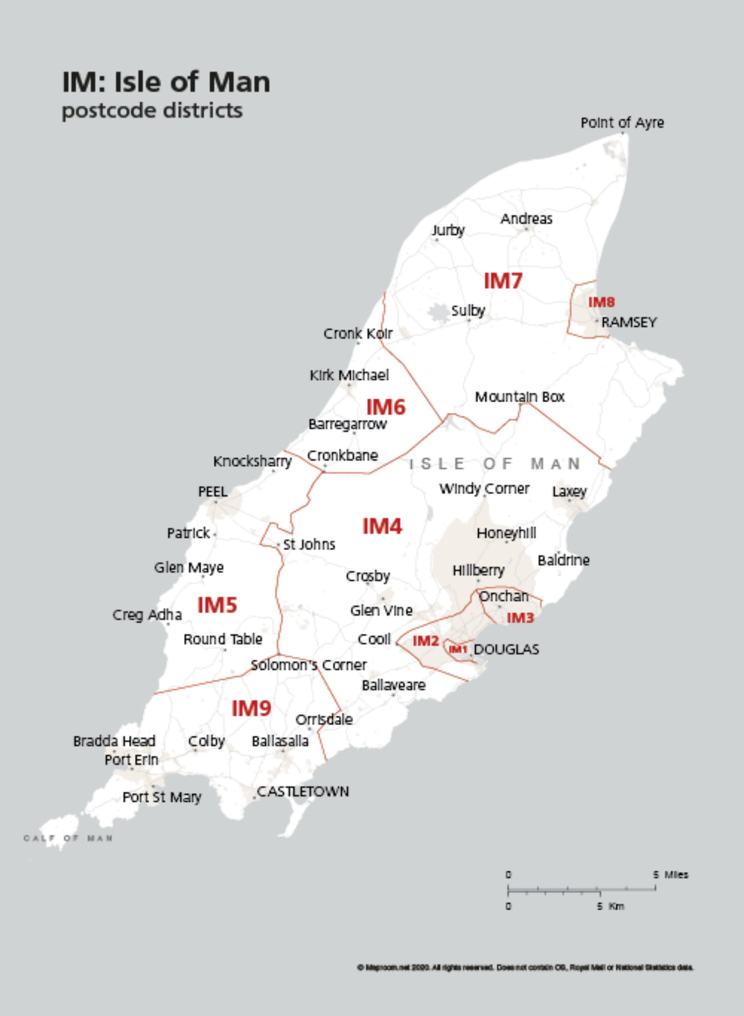

*Figure 4. Postcode districts on the Isle of Man from https://maproom.net/shop/map-of-im-postcode-districts/*

## Comparison with other localities

It is useful to compare existing data from the Isle of Man with data from other global locations as a benchmark. We first compare average indoor radon concentration data from a range of countries and then look in more detail at the variations that exist and how these relate to the underlying geology. Specifically, we consider data from the UK via the publicly available radon map (https://www.ukradon.org/information/ukmaps) which has similar geology to the Isle of Man, to the extent that some areas can be geologically linked, for example the limestone of northern England can be lithologically and bio-stratigraphically correlated to limestones that crop out on the Isle of Man (Chadwick et al. 2001).

## National data comparisons

Data collected at a national level by the World Health Organisation can be compared to the mean levels from Grainger et al. (2000) for the Isle of Man. This comparison shows (Figure 5) that the Isle of Man's average indoor radon concentration ranks 28th out of the 41 countries, with similar levels to Argentina, the USA and Germany. It is worth noting that all but two of these national means (Turkmenistan and Moldova) fall below the UK action level 200 Bqm$^{-3}$ (HPA, 2010)

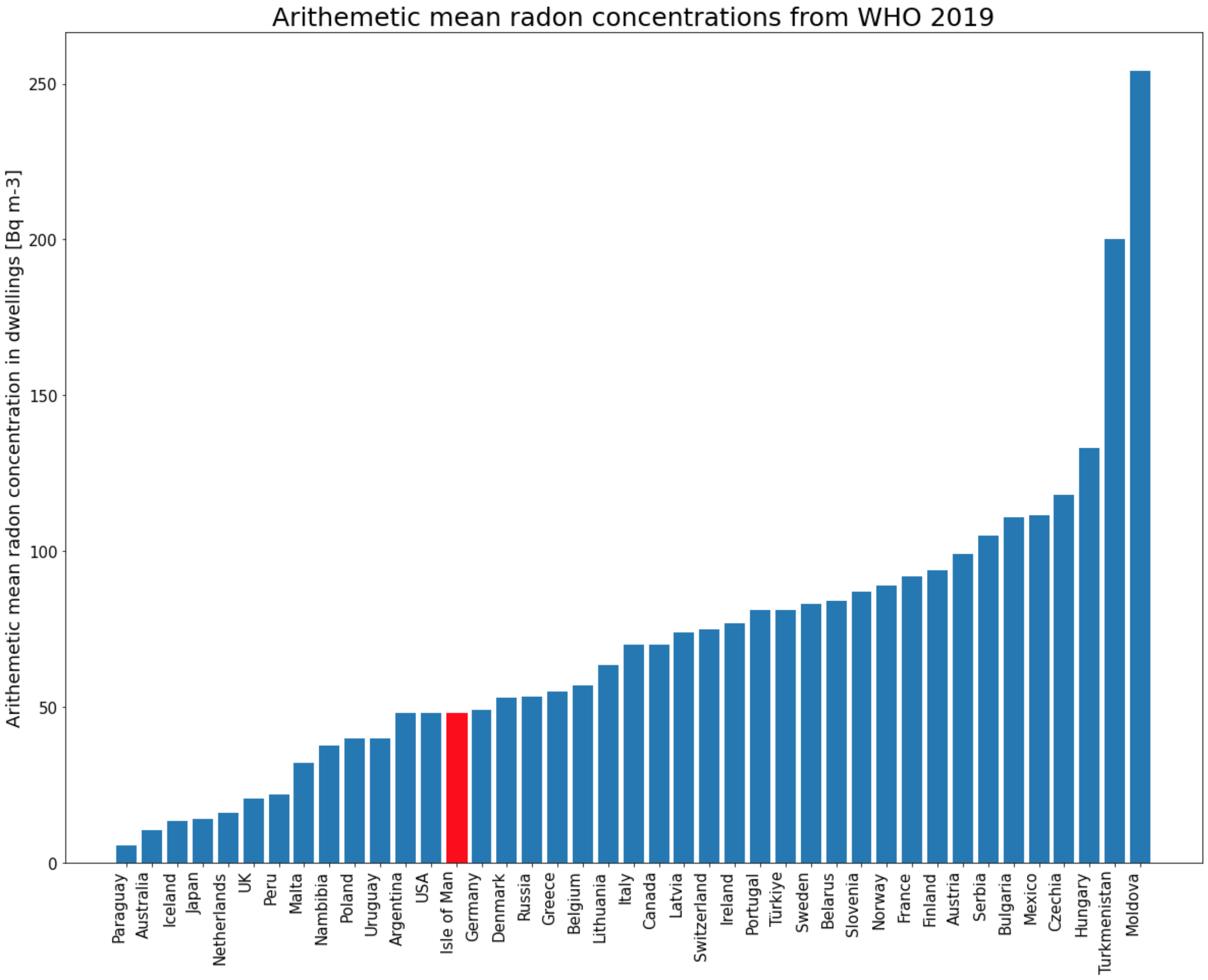

*Figure 5. The arithmetic mean of radon concentrations from the World Health Organisation (WHO) database (2019), with the addition of the mean value for the Isle of Man from Grainger et al. (2000) highlighted in red. Source: https://www.who.int/data/gho/data/indicators/indicator-details/GHO/gho-phe-radon-database-national-radon-concentration-levels*

We now consider the range and variability of concentration levels for the Isle of Man, using the UK (as a comparator). Grainger et al. (2000) note that the mean indoor radon concentration value for the Isle of Man is double that of the UK but lower than the 5 highest counties in the UK, with Schieb et al. (2013) reporting that although the average indoor radon concentration in the UK is 20 Bq $m^{-3}$, with a range of 5–10 000 Bq $m^{-3}$, or more. From the existing Isle of Man data (Figure 2) we see variability between and within postcodes. At the maximum end of this variability indoor radon concentration levels exceed both the UK and internationally recommended levels (Figure 2) with a maximum recorded value of 517 Bq $m^{-3}$ -more than twice that of the UK action level.

## UK Radon variability and geological correlations

The UK has completed a high-resolution survey of indoor radon concentration levels, this data is publicly available and can be visualised in map form via a website https://www.ukradon.org/information/ukmaps. The overall pattern, showing the areas of highest radon concentration for Scotland and England are shown in Figures 6 and 9 respectively.

When we consider the variability in UK radon levels, we can do so with reflection on the underlying geology, and then use this information to predict potential trends for radon concentration levels on the Isle of Man from geological similarities. Work by Scheib et al. (2009 and 2013) for both Scotland and England draws on geological data relating radon concentration variability to the underlying geology. In Scotland, Scheib et al. (2009) show that the highest radon levels are found in areas of Uranium rich highly evolved Silurian-Devonian biotite granites found to west of Aberdeen and in the granites of Helmsdale, that also have high uranium mineralisation. This relationship is highlighted in Figure 6 which outlines the relevant geological units, Dinantian and Yoredale limestones and Intrusive Felsic rocks (Granites and similar) with data from the UK radon map.

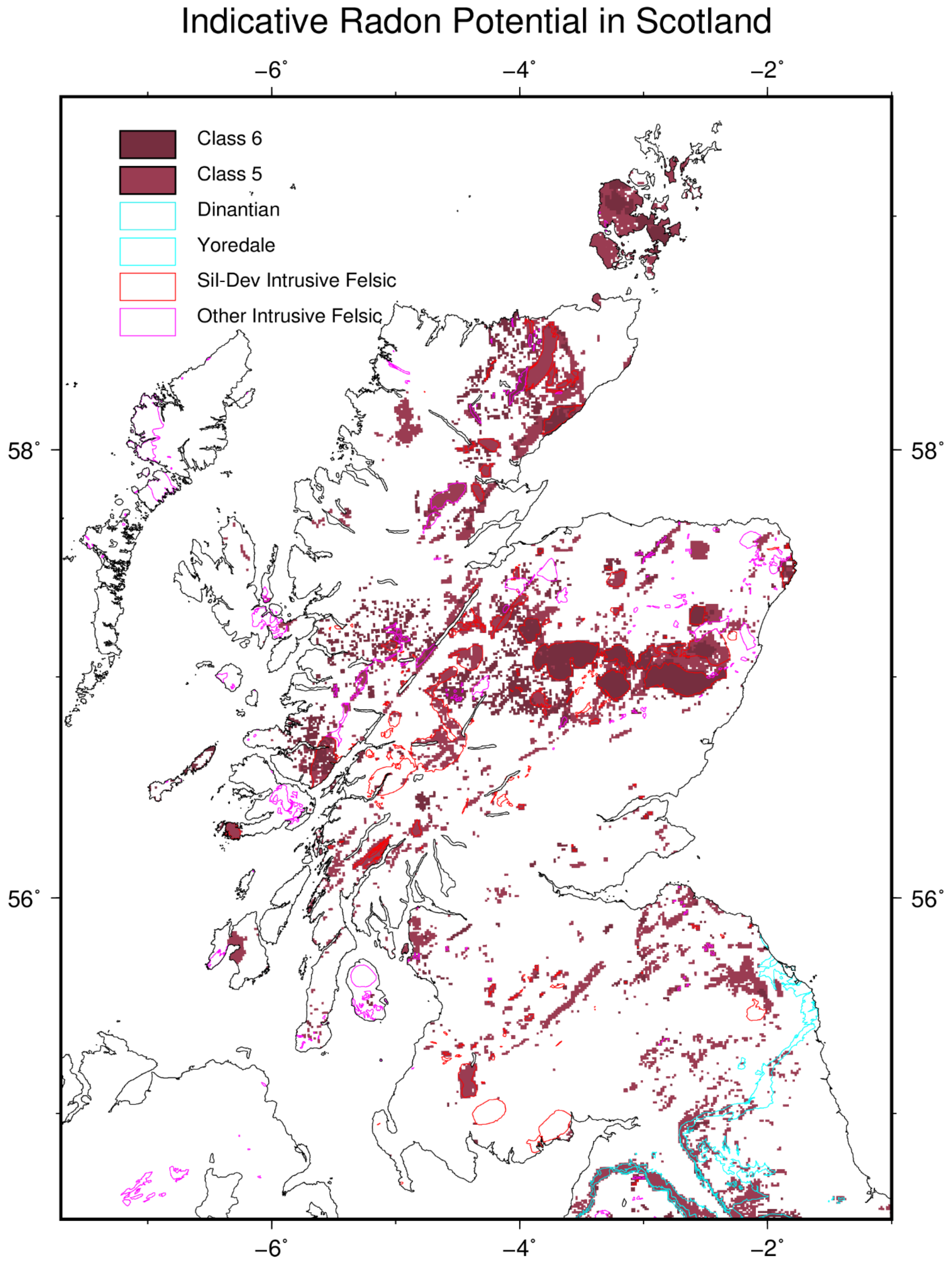

*Figure 6: Indicative Radon potential in Scotland from (https://www.ukradon.org/information/ukmaps) for the two highest concern classes, Class 6, 30-100% probability of exceedance of the 200 Bq m$^{-3}$ action level, and Class 5, 10-<30% probability of exceedance, shown in solid colour. Relevant geological units, Dinantian and Yoredale limestones and Intrusive Felsic rocks (Granites and similar) are shown as coloured outlines.* *Contains British Geological Survey materials © UKRI 2022*

The geochemistry of stream sediments Scheib et al. (2009) supports the conclusion that decay of Uranium is correlated with radon concentration level, with Uranium (U) correlating most strongly followed by Rubidium (Rb), Potassium (K), Yttrium (Y), Lanthanum (La) and Zirconium (Z) (Scheib et al. 2009). Similarly, work on granites in Scotland, with a view to their geothermal potential (resulting from radioactive decay), shows a correlation between Uranium concentration and heat production (Figure 7).

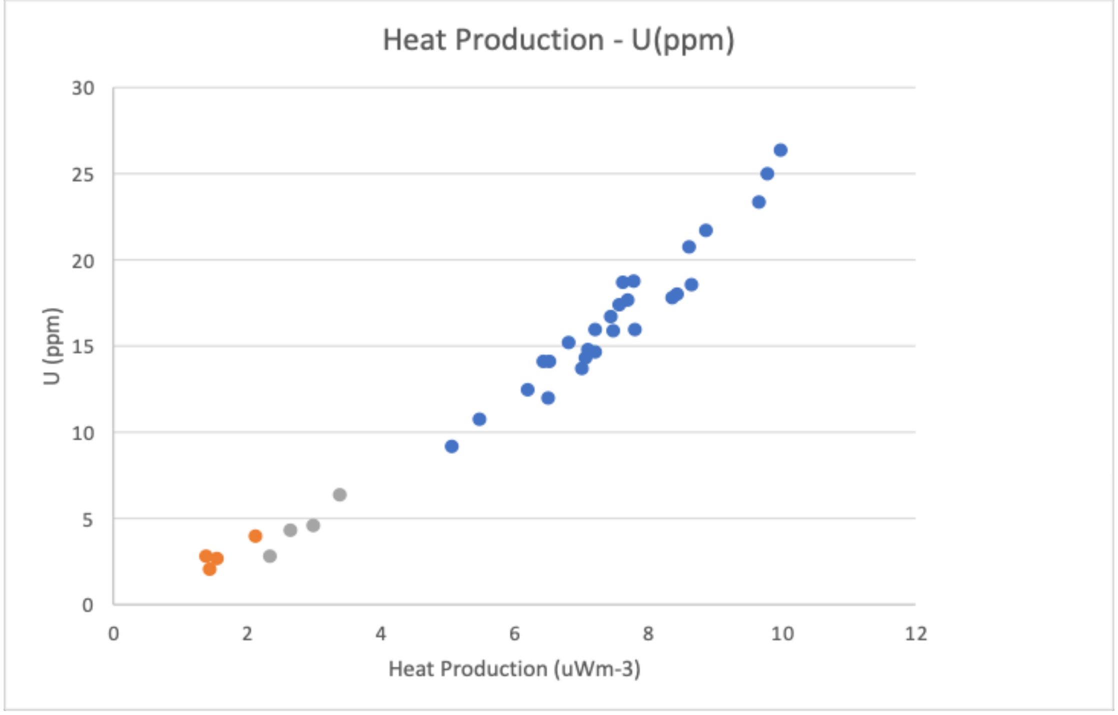

*Figure 7. Surface heat production calculated from Gamma Ray Spectrometry data, for three Aberdeenshire granites plotted against Uranium (U) concentration in ppm. Authors data (unpublished).*

It is worth noting the range in both U (ppm) and calculated heat production across the three granites. Variations in predicted heat production across Scottish granites more broadly, also suggest varying levels of radioactive decay (Figure 7) and hence for our interests in radon generation. This variability in radon generation, and its specificity with respect to granite geochemistry is important to note as it means prediction of radon concentration levels is more complex than simply identifying granites.

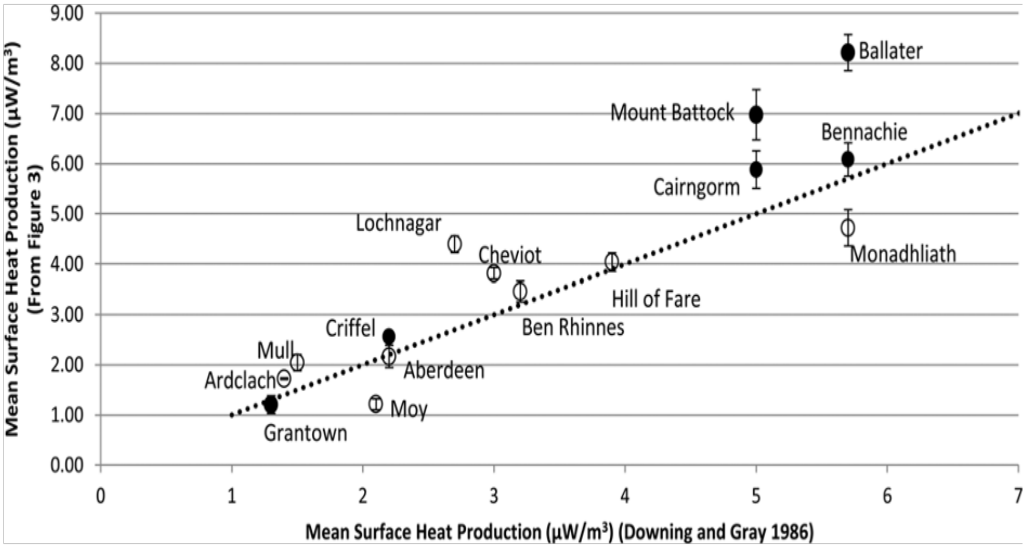

*Figure 8. Predicted mean surface heat production by McCay and Younger (2017) and Downing and Gray (1986) for Scottish granites. Figure from McCay and Younger (2017).*

Schieb et al. (2009) also recognised the following rock formations as being of ‘medium’ radon generating interest:

- Dalradian Metasediments (Appin and Argyll group meta limestones)
- Old Red Sandstone in areas with dark, organic, phosphatic rich sediments
- Riccarton group in the Ordo-Silurian Greywakes (source rock evolved granite)
- Carboniferous limestone in Midland Valley
- Late Jurassic mudstones, siltstones, sandstones near Helmsdale (high Uranium source from granite)
- Psammites, pelites and semipelites in Shetland
- Devonian mafic lavas and tufts near Cheviot granite (Uranium mineralisation)
- Places with glaciofluvial deposits derived from high Uranium sources.

Notable in this list are the associations to high Uranium granites, and or organic rich sediments. These trends are followed in England. Scheib et al. (2013) show that the granites in SW England have high Uranium concentrations, and note that they are also deeply weathered. Schieb et al. (2013) suggests that the lack of glaciation in SW England, unlike in Scotland, results in the weathering of and hence decay of Uranium. They also propose that the weathering creates effective transport pathways for radon gas to the surface. Together these factors result in high radon levels in SW England (Figure 9).

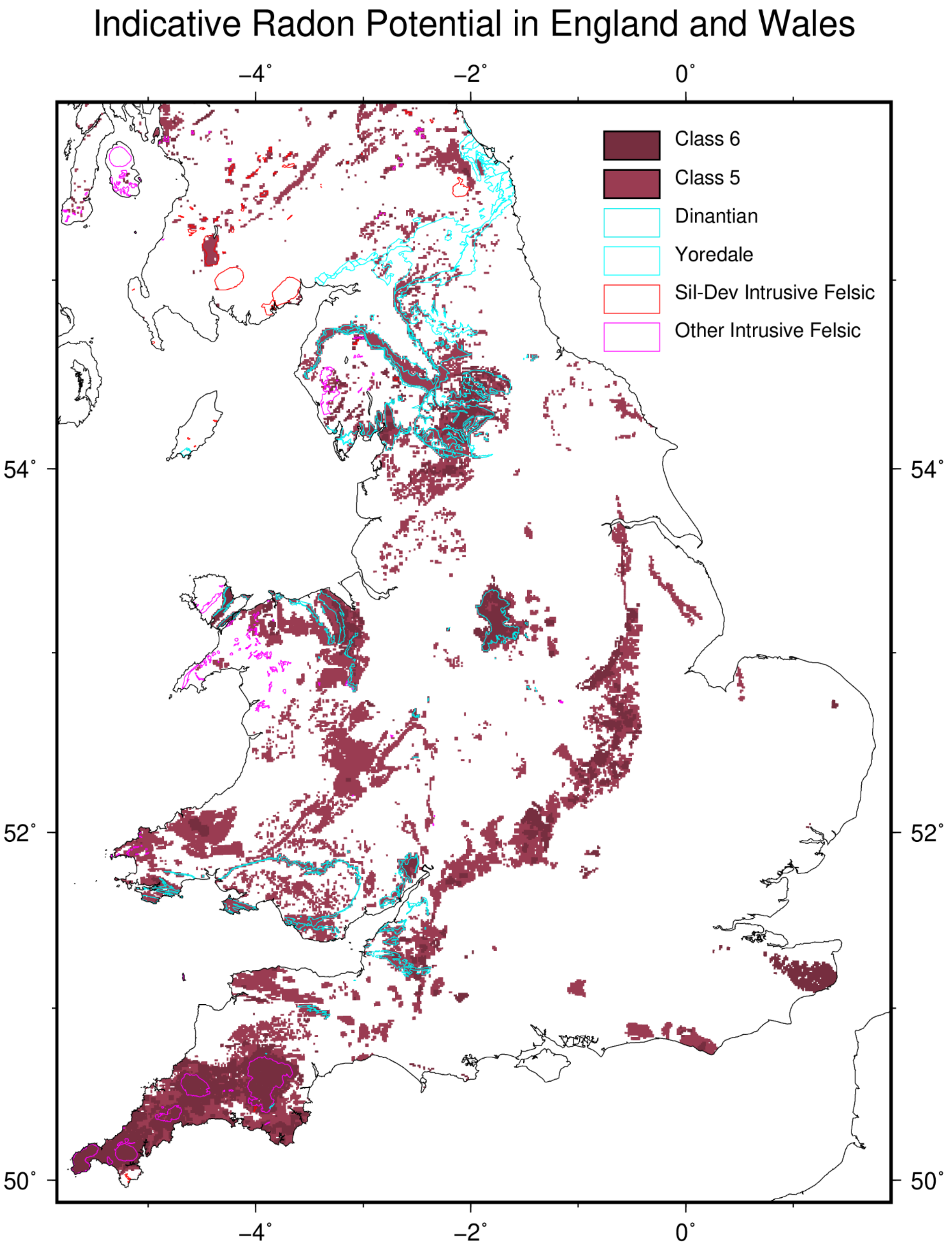

*Figure 9: Indicative Radon potential in England and Wales from (https://www.ukradon.org/information/ukmaps) for the two highest concern classes, Class 6, 30-100% probability of exceedance of the 200 Bq m$^{-3}$ action level, and Class 5, 10-<30% probability of exceedance, shown in solid colour. Relevant geological units, Dinantian and Yoredale limestones and Intrusive Felsic rocks (Granites and similar) are shown as coloured outlines. Contains British Geological Survey materials © UKRI 2022*

Scheib et al. (2013) also highlight the limestones of Northern England as having high radon levels, specifically the Lower Carboniferous Dinantian. This correlation is also seen in Figure 9. In this group of limestone formations Schieb et al. (2013) report the highest recorded indoor radon measurement in the UK, on limestone bedrock, of 6252 Bq $m^{-3}$. They report that over 13,000 indoor radon measurements have been made on this limestone group, with 13.7% of dwellings expected to exceed the UK Action Level (Scheib et al. 2013). These high limestone levels are of particular interest as the Carboniferous limestones of the Isle of Man have been correlated to those in Northern England.

Palaeographic constructions are used alongside biostratigraphic and lithological markers to link sediments that were deposited in ancient sedimentary basins that have since become fragmented. There are several works that show the Carboniferous limestones of the Isle of Man, which mainly crop out in the area around Castletown, linking across the Irish Sea to deposits in Northern England (George, 1958; Dickson et al. 1987; Quirk and Kimbell, 1997; Dean et al. 2011). These studies use lithological and bio-stratigraphical markers, combined with information on tectonic lineaments. The Lower Carboniferous map of George (1958) Figure 10 shows a simplified map and extent of the Lower Carboniferous basins across the UK.

*Figure 10. Map showing the extent of the Lower Carboniferous basins across the UK and Ireland. Highs are shown as outlined and named hatched areas, with the basins in white. The approximate location of the Isle of Man is shown as an orange star. Note the Manx-ridge forming a central high, dividing basins to the North and the South, from George (1958).*

Limestones in the north of the Isle of Man sampled by boreholes have been correlated with limestone groups in West Cumberland (Smith, 1927), but do not bear resemblance to limestones in the south of the island around Castletown. This supports the idea that the Manx massif formed part of an upstanding block that separated the different Lower Carboniferous, Dinantian provinces. Comparison of the Castletown Dinantian sequence with limestones on the Furness coast to the south, show some resemblance; and the Langness Conglomerate is interpreted by Gawthorpe (1986) as evidence of a wide spread basin over much of Northern England. More recent work by Wakefield et al. (2016), correlates sediments logged in offshore boreholes in the Irish Sea to help define the extent of Carboniferous strata. We present one of their correlations Figure 11 to show the extent of correlation across the Irish Sea, note that in these plots the Dinantian is sub-divided into the Tournasian and Visean.

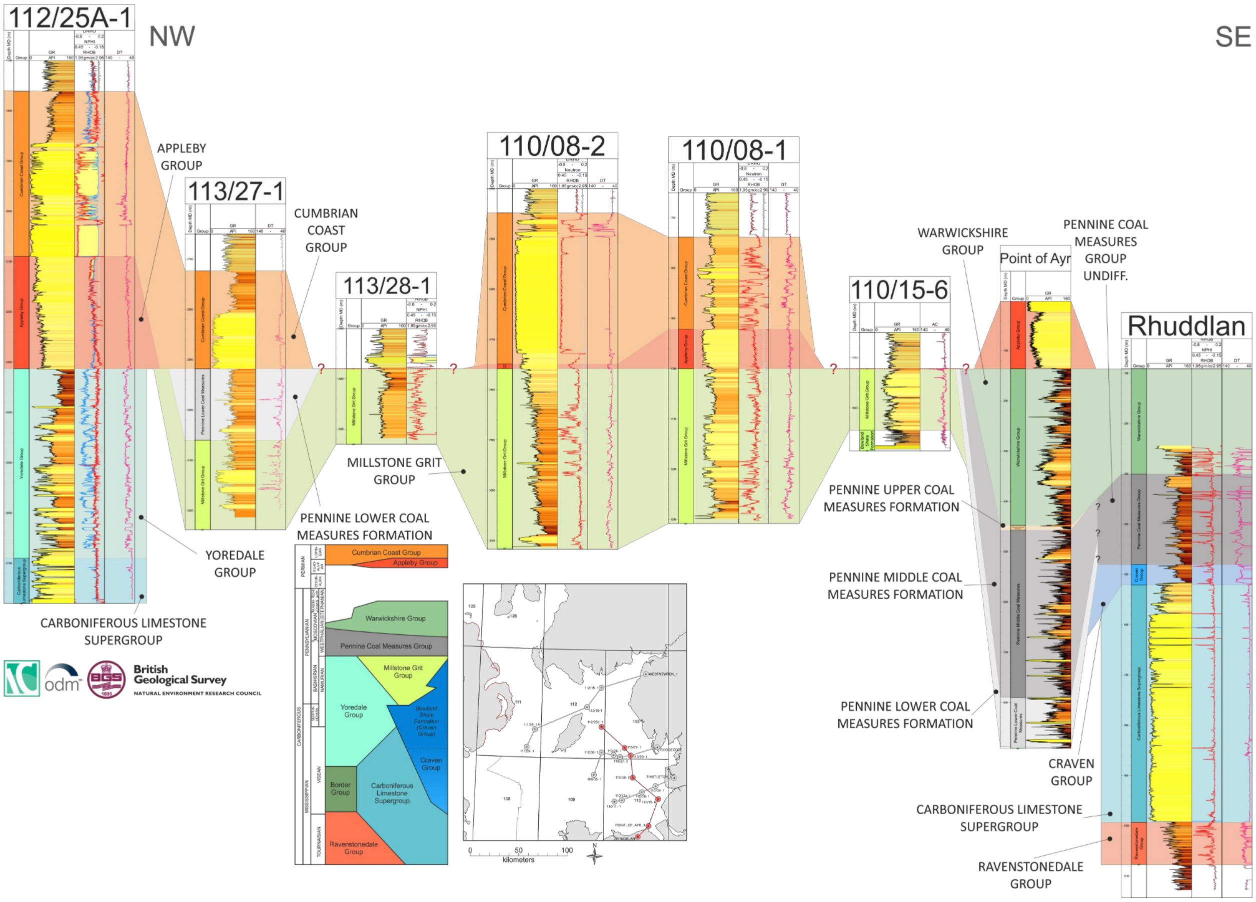

*Figure 11. Correlation of Carboniferous strata across the Southern Irish Sea from Wakefield at al. (2016).*

## Geological and radon data summary

There are two main geologies of interest for radon generation on the Isle of Man, these are the granite intrusions and the Carboniferous sediments, notably the Lower Carboniferous limestones.

With respect to the granites, although small in outcrop extent, multiple authors have suggested, based on geophysical data, that granites may be extensive in the sub-surface (see Chadwick et al. 2001). Further, fractures, faulting and the inclined deformation fabric of the overlying Manx Group metasediments, may provide pathways for granites generating radon at depth routes to the surface. Evidence from the Siluro-Devonian granites of Scotland, suggest that high radon levels are coincident with granites with high Uranium enrichment (Schieb, 2013) and data presented here). These Scottish granites, many of which are Uranium rich, show significant heat generation potential through decay of radioactive elements. Although it should be noted that the Uranium concentrations and heat potential vary significantly within and between Scottish granites. There is little to no data on the uranium content of the outcropping granite, although these granites intruded synchronously with the Siluro-Devonian granites of Scotland, many of which are Uranium rich. It should be noted that the Uranium concentrations and heat potential vary significantly within and between Scottish granites.

The correlation of Lower Carboniferous strata in the Castletown area to strata across the Southern Irish Sea and into Northern England, where high radon concentration levels are found (Schieb, 2013 and data presented here) highlights the potential for the Isle of Man limestones to produce high concentrations of radon.

## Built infrastructure

Many authors highlight the importance of built infrastructure on indoor radon concentration levels (e.g. Chao et al. 1997, Scivyer, 2007. Burghele et al. 2021). Whilst radon gas released from rocks and soils quickly disperse in the atmosphere, where levels are low (4 Bq $m^{-3}$ in the UK; HPA, 2010), radon gas in buildings is often higher as radon gas is trapped by the built infrastructure. The construction method, material and degree of ventilation will all impact indoor radon concentration levels. Seasonal fluctuations are also seen in indoor radon concentration levels, influenced by atmospheric pressure, wind, and temperature (Miles et al., 2012). Although not studied here, future more expansive studies on indoor radon levels on the Isle of Man should consider the built environment as part of building understanding of the controls on radon concentration.

## Summary and Recommendations

Existing data from the Isle of Man shows **average radon concentrations below action levels defined for the UK and internationally**. However, these **averages mask variability in radon concentration levels that exceed recommendations**.

In an attempt to delineate the underlying causes of elevated radon levels on the Isle of Man we attempted to correlate information on the island's geology to variability in radon level. Although we can draw general inferences, the **limited spatial information derived from broad postcode boundaries, does not allow the level of detail required to make clear assertions on the geological controls on radon concentrations for the Isle of Man.**

To support geological inferences made for the Isle of Man we have used **data from the UK radon map and the British Geological Survey (BGS) database to create imagery that relates high radon concentrations to underlying geology**. We have then used **published literature on geological correlations and similarities to infer that similar radon concentrations may be expected on the Isle of Man.**

We acknowledge that **built infrastructure will also play a role in indoor radon concentration** levels.

We list a series of recommendations and ways forward to allow further analysis of indoor radon concentration levels on the Isle of Man. These take the form of both further desk-based work through to in-home radon data collection.

- Grainger et al. (2000) refer to their own and other radon concentration data in existence for the Isle of Man. Here we have used data available in the published work of Grainger et al. (2000), but the full dataset collected is not publically available. Notes on the studies (http://www.bristol.ac.uk/population-health-sciences/projects/isleofmanstudy/data-access/data-availability/) suggest that the data could be cleaned (anonymised) for release if funding was found to do so. The extent of information collected alongside the radon data is unknown, but we assume that full postcode and potentially other information such as building construction data would likely have been collected and would provide a richness to the work presented in this report.

- Grainger et al. (2000) also refer to two other datasets, which do not appear to be publically available. The first a 1991 Isle of Man local government report that collected data from 74 home's between 1984 to 1991 and found a mean concentration of 42 Bq m−3 for the island and 86 Bq m−3 for the ex-mining area in IM4. The second, a survey from 1990 by the National Radiogenic Protection Board of 39 schools on the Isle of Man reporting a mean of 38.8 Bq m−3 (range <30–150 Bq m−3). Access to data from these additional surveys would add to the current report.

- Uranium (U) concentration in granites appears to be correlated to radon concentration levels. We could not find publicly available data on uranium, or other radioactive mineral concentrations for the Isle of Man granites. A gamma ray spectrometer could be used, simply and cheaply, to take readings from granite and limestone outcrops to determine the concentration in ppm of U to compare with UK granites, limestones and the UK radon map.

- Geophysical work could help determine the extent and depth of granite in the subsurface below the island, but the cost of such analyses may be better spent on in-home/building radon gas monitoring. Similarly, geochemical data analysis of stream sediments would add to information on Uranium concentrations, but is probably less useful than actual gamma ray spectrometry data.
- The information derived from the recommendations above could form the basis of a targeted radon data collection campaign that would focus on areas susceptible to higher radon level concentrations. This in turn could inform building regulations to help prevent high radon levels in new buildings (Scivyer. 2007) or to remediate existing buildings.

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