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Geological controls on radon potential in Northern Ireland

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ABSTRACT

Moderate and high radon potential in Northern Ireland is associated mainly with (i) the Neoproterozoic psammites, semipelites, meta-limestones, volcanics and mafic intrusives of Counties Londonderry and Tyrone; (ii) Silurian Hawick Group greywackes and, to a much more limited extent Gala Group greywackes, in the southern sector of Counties Armagh and Down; (iii) Ordovician and Silurian acid intrusives and volcanics in eastern Counties Londonderry and Tyrone; (iv) Middle-Late Devonian conglomerates in County Tyrone; (v) Lower Carboniferous (Dinantian) limestone in the western sector of Northern Ireland, especially in County Fermanagh; (vi) Palaeogene and Late Caledonian acid intrusive rocks of the Mourne Mountains Complex, Slieve Gullion Complex and Newry Granodiorite Complex in the SE sector in County Down and County Armagh.

Moderate to high radon potential is sometimes associated with glacio-fluvial sand and gravel deposits where these overlie a range of bedrocks, some of which have relatively low radon potential. In this latter case the enhanced radon potential is probably caused by the high permeability of superficial deposits. Radon potential tends to be lower when bedrocks characterised by moderate or high radon potential are overlain by relatively impermeable silt-clay alluvium, glaciolacustrine, and lacustrine deposits; peat; and glacial till and moraine. Redistribution of rock debris derived from uranium-rich bedrocks, such as the Mourne Mountains granites, through glacial, alluvial and other processes can also result in higher radon potential being associated with superficial deposits relative to underlying bedrocks.

1. Introduction

Radon (^{222}Rn) is produced by the radioactive decay of radium (^{226}Ra), which in turn is derived from the radioactive decay of uranium. Uranium is found at variable concentrations in all soils and rocks. The most important factors controlling the migration and accumulation of radon in buildings include: (i) characteristics of the bedrock and soils that affect fluid transport, including porosity and permeability; (ii) the construction of the building and its use which includes the level of ventilation and heating; and (iii) environmental factors such as temperature (increased heating in buildings during the colder months causes a stack effect which draws soil gases including radon into the property), plus wind speed and direction which can increase the stack effect. Radon in soil air can be drawn into buildings through gaps and cracks in solid floors, walls and service pipes below construction level; through the voids in suspended floors and crawl spaces, and via small cracks or pores in hollow-block walls or wall cavities.

Radon can accumulate in buildings and provides about 50% of the total radiation dose to the average person in the UK (Watson et al., 2005). Radon gas decays to form short-lived solid radioactive decay particles that can enter the body by inhalation and has been linked to an increase in the risk of developing lung cancer. Radon is responsible for an estimated 1100 lung cancer deaths a year in the UK (McColl et al., 2010) and is the second largest cause of lung cancer deaths after smoking (HPA, 2009). Radon concentrations in outdoor air in the UK are generally low, on average 4 Bq m^{-3} (becquerels per cubic metre) whilst radon in indoor air in UK dwellings ranges from less than 10 Bq m^{-3} to over 17,000 Bq m^{-3} (Rees et al., 2011) with a population-weighted average of 20 Bq m^{-3}. PHE (Public Health England) recommends that radon levels should be reduced in homes where the annual average is at or above 200 Bq m^{-3}. This is termed the Action Level. PHE defines radon Affected Areas as those with 1% chance or more of a house having a radon concentration at or above the Action Level. PHE advises that homes in radon Affected Areas should be tested for radon.

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Geology is usually one of the most important factors controlling the distribution and level of indoor radon and the radon hazard. A previous study (Appleton and Miles, 2010) demonstrated that mapped bedrock geology explains on average 25% of the variation of indoor radon in England and Wales, 17% in Scotland and 11% in Northern Ireland. Mapped superficial geology explains, on average, an additional 1–2% (Appleton and Miles, 2010). In England, the proportion of the total variation controlled by geology is lower (14%) where the influence of confounding geological controls, such as uranium mineralisation, cut across mapped geological boundaries (Appleton and Miles, 2010).

Published data for Northern Ireland indicate that the geological units associated with the highest levels of naturally occurring radon are: (i) Late Caledonian and Palaeogene acid intrusive rocks of the Mourne Mountains, (ii) Carboniferous limestones and some Carboniferous shales (iii) Silurian Hawick Group greywackes, and (iv) Neoproterozoic psammites, semipelites and meta-limestones in the western sector of Northern Ireland (Appleton et al., 2011). This paper describes in greater detail the geological control on radon potential in Northern Ireland based on a new geological radon potential map compiled using recently published 1:10,000 scale digital geological map data and 23,000 radon measurements in homes held by Public Health England (PHE). It replaces the current maps presented as radon potential in 1-km squares on the Irish grid (Green et al., 2009).

Access to accurate radon maps is essential to enable preventative (protective) measures to be installed in new buildings (Radon: guidance on protective measures for new buildings in Northern Ireland; BR-413); to help identify houses and workplaces that are at elevated risk of having radon above the Action Level which should be measured for radon and have high levels remediated; and to allow measurement campaigns and public awareness to be targeted on areas at greatest risk. The radon map data helps local authorities to communicate quickly and effectively with existing homeowners or developers planning to build new homes in radon Affected Areas.

However, it is important to remember that a wide range of indoor radon levels is likely to be found in any particular area. This is because there is a long chain of factors that influence the radon level found in a building, such as radium content and permeability of the ground below it, and construction details of the building (Miles and Appleton, 2000). Radon potential does not indicate whether a building constructed on a particular site will have a radon concentration that exceeds the Action Level. This can only be established through measuring radon in the building. Radon potential indicates the probability that homes in a locality will have radon above the Action Level. This informs decisions about whether to test specific premises for radon.

This paper is the last of a series that describes the radon potential of geological units in the UK (Appleton and Miles, 2005; Scheib et al., 2009, 2013). Reference is made to the Tellus airborne gamma spectrometry eU (equivalent uranium) and soil total U data (Appleton et al., 2008, 2011).

2. Materials and methods

2.1. Radon mapping

The factors that influence radon concentrations in buildings are largely independent and multiplicative so the distribution of radon concentrations is usually lognormal. Therefore lognormal modelling was used to produce accurate estimates of the proportion of homes above the Action Level in the UK (Miles, 1998; Miles et al., 2007). When indoor radon measurements are grouped by geology and 1-km squares of the national grid, the cumulative percentage of the variation between and within mapped geological units is shown to be 34–40% (Appleton and Miles, 2010). Combining the grid square and geological mapping methods gives more accurate maps than either method can provide separately (Appleton and Miles, 2002; Miles and Appleton, 2005). The integrated mapping method allows significant variations in radon potential within bedrock geological units to be identified.

The reliability and spatial precision of the mapping method is, in general, proportional to the indoor radon measurement density and the accuracy of the geological boundaries. Other uncertainties in the mapping process relate to house-specific factors, proximity to geological boundaries and measurement error (Hunter et al., 2009, 2011; Miles and Appleton, 2005).

The radon mapping method has been used to produce the current radon maps and indicative atlases for England and Wales (Appleton and Miles, 2005; Miles et al., 2007; Scheib et al., 2013) and Scotland (Scheib et al., 2009; Miles et al., 2011).

The radon potential map described here for Northern Ireland is based on 23,000 indoor radon measurements made by PHE and 1: 10,000 scale digital geology information provided by the Geological Survey of Northern Ireland (GSNI), or 1:250,000 scale digital geology in those areas where the 1: 10,000 data is not yet available (Fig. 1). The indoor radon measurements were made using two passive integrating detectors placed in each dwelling for 3 months (Green et al., 2009).

The land area is first divided up using a combination of bedrock and superficial geological characteristics derived from GSNI 1:10,000 DiGMap and 1:250,000 scale digital geological map data (Fig. 1; GSNI, 1991, 1997; http://www.bgs.ac.uk/gsni/geology/status/index.html). Each different combination of geological characteristics may appear at the land surface in many discontinuous locations across the country.

In order to facilitate the seamless 1-km interpolation of radon potential within major geological units, simplified bedrock and superficial geology classification systems were developed. These ensure continuity and also group some geological units with similar characteristics. Grouping similar geological units ensured that there were a sufficient number of indoor radon measurements for intra-geological unit grid square mapping to be carried out over a greater proportion of Northern Ireland. There are 360 named 1:10,000 scale bedrock geological units in Northern Ireland and 44 bedrock units in the area with only 1:250,000 scale bedrock geology. These were grouped using a simplified bedrock classification comprising 69 units. The geological map in Fig. 2 was produced after additional grouping of bedrock units on the basis of age. There are 12 individually named 1:250,000 scale superficial geological units and 27 1:10,0000 scale superficial geology units. A simplified superficial geology classification comprising 13 units was used in the radon mapping procedure (Table 1; Fig. 3). Once the superficial geology has been unioned (combined) with bedrock geology there are a total of 466 bedrock/superficial (BS) geology combinations. The geology of Northern Ireland is summarised in Mitchell (2004).

Accurate coordinates for house measurement results are required for the radon mapping method. Of the approximately 24,000 radon measurements for domestic dwellings available in Northern Ireland (Green et al., 2009), 23,000 have precise coordinates obtained from the Land and Property Services (LPS) Pointer® location data (http://maps.osni.gov.uk/CMSPages/moreinfo_address_data.aspx). These results were used for preparing the radon maps. Each of these measurements is allocated to the bedrock–superficial geological combination underlying it. Taking each geological combination in turn, the spatial variation of radon potential is mapped, treating the combination as if it were continuous over the land area. All of the maps of radon potential within different geological combinations are then combined to produce a map of variation in radon potential over the whole land surface.