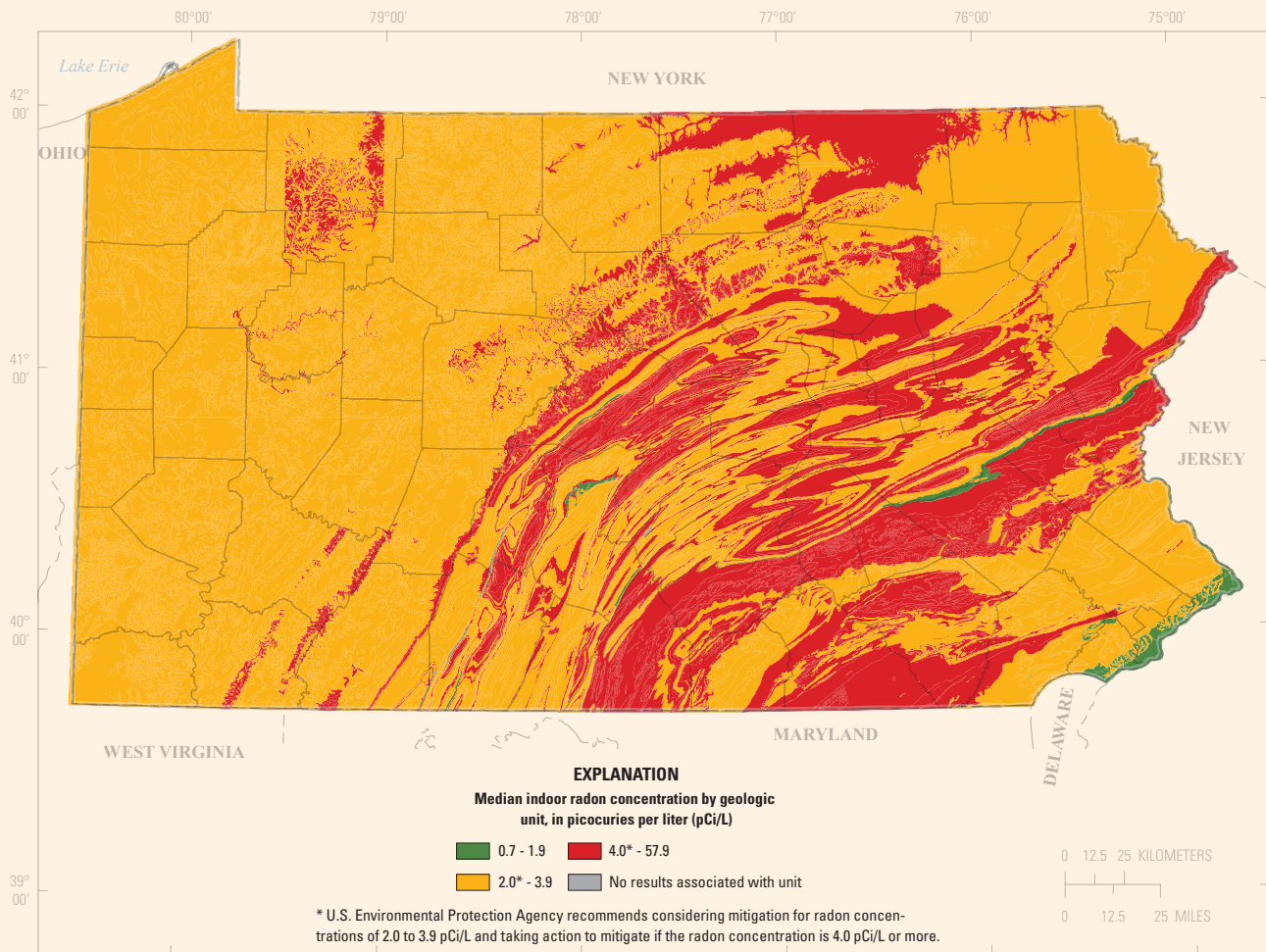


Prepared in cooperation with the
 Pennsylvania Department of Health and the
 Pennsylvania Department of Environmental Protection

Distribution of Indoor Radon Concentrations in Pennsylvania, 1990–2007



Base from U.S. Bureau of the Census digital data, 2000
 1:100,000 Albers Equal-Area Conic projection: Standard Parallels 40° N and 42° N,
 Central Meridian -78° W, Latitude of Origin 39°

Geologic unit digital data from Pennsylvania Geological Survey, 2001

Scientific Investigations Report 2013–5143

Distribution of Indoor Radon Concentrations in Pennsylvania, 1990–2007

By Eliza L. Gross

Scientific Investigations Report 2013–5143

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2013

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
Area		
square mile (mi ²)	2.59	square kilometer (km ²)
foot (ft)	0.305	meter (m)
Radioactivity		
picocurie per liter (pCi/L)	0.037	becquerel per liter (Bq/L)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Elevation, as used in this report, refers to distance above the vertical datum.

Distribution of Indoor Radon Concentrations in Pennsylvania, 1990–2007

By Eliza L. Gross

Abstract

Results from 548,507 indoor radon tests from a database compiled by the Pennsylvania Department of Environmental Protection, Bureau of Radiation Protection, Radon Division, are evaluated in this report in an effort to determine areas where concentrations of radon are highest. Indoor radon concentrations were aggregated according to geologic unit and hydrogeologic setting for spatial analysis. Indoor radon concentrations greater than or equal to the U.S. Environmental Protection Agency (USEPA) action level of 4 picocuries per liter (pCi/L) were observed for 39 percent of the test results; the highest concentration was 1,866.4 pCi/L.

When analyzed according to Pennsylvania's geologic units, 93 of the 188 (49.5 percent) geologic units with indoor radon concentrations had median concentrations greater than the USEPA action level of 4 pCi/L; most of these geologic units are located in the eastern part of the State and include metamorphic rocks, limestones, sandstones, shales, and glacial deposits. When analyzed according to Pennsylvania's hydrogeologic settings, 5 of the 20 (25 percent) settings had median indoor radon concentrations greater than the USEPA action level of 4 pCi/L; these settings are located mostly in the south-central part of the State.

Median indoor radon concentrations aggregated according to geologic units and hydrogeologic settings are useful for drawing general conclusions about the occurrence of indoor radon in specific geologic units and hydrogeologic settings, but the associated data and maps have limitations. The aggregated indoor radon data have testing and spatial accuracy limitations due to lack of available information regarding testing conditions and the imprecision of geocoded test locations. In addition, the associated data describing geologic units and hydrogeologic settings have spatial and interpretation accuracy limitations, which are a result of using statewide data to define conditions at test locations and geologic data that represent a broad interpretation of geologic units across the State. As a result, indoor air radon concentration distributions are not proposed for use in predicting individual concentrations at specific sites nor for use as a decision-making tool for property owners to decide whether to test for indoor radon concentrations at specific property locations.

Introduction

Exposure to radon, a colorless, odorless, and radioactive gas, has been identified as the second-leading cause of lung cancer (U.S. Environmental Protection Agency, 1992). Radon-222, the longest-lived radioisotope of radon, is produced by the radioactive decay of radium-226, which is derived from the decay of uranium-238, and is naturally present in soil and bedrock minerals. Radon gas moves from its source in rocks and soils through voids and fractures, and often enters buildings through foundation cracks and other openings. Radon gas can dissolve in groundwater and enter buildings through the use of water-supply wells (Hess and others, 1987; Folger and others, 1994).

Radon gets into the indoor air primarily from soil gas moving up from the soil under homes, though water can be a substantial source in those areas where groundwaters have extreme radon levels (Hess and others, 1987; Folger and others, 1994). Once radon gas enters buildings, it can become trapped, can accumulate, and then can be inhaled by anyone within the building. When inhaled, radon gas and its decay products may accumulate in the lungs and damage lung tissue (World Health Organization, 2009). Typically most radon is exhaled before causing much damage, but radon decay products can become attached to dust, smoke, or other fine particles from the air and remain trapped in the lungs. Accumulation of radioactive elements in constant, close contact with lung tissue can increase cancer risk. The dose-response relation is linear, which means that the risk of lung cancer increases proportionally with increasing radon exposure (National Academy of Science, 1999; World Health Organization, 2006, 2009). Because of this increase in risk, the U.S. Environmental Protection Agency (USEPA) recommends that homeowners consider mitigation of radon for concentrations of 2 to 4 picocuries per liter (pCi/L) and that homeowners take action to mitigate radon for concentrations of 4 pCi/L or more (U.S. Environmental Protection Agency, 2011). Outdoor radon levels are usually very low; the average concentration of radon in outdoor air is 0.4 pCi/L, which is one-tenth of the USEPA's action level of 4 pCi/L.

In Pennsylvania, the highest radon concentration (2,600 pCi/L) ever found in a private residence was measured

in December 1984 by the Pennsylvania Department of Environmental Protection (PADEP), Bureau of Radiation Protection (Gerusky, 1987; Smith and others, 1987) in the Reading Prong hydrogeologic setting. Since no radon action level was yet established in Pennsylvania in 1984, PADEP examined reports 77 and 78 from the National Council on Radiation Protection and Measurements, which discuss calculations of the potential risk associated with radon exposure and estimates of the risk to the general population from exposure to an assumed average environmental level of radon (National Council on Radiation Protection and Measurements, 1984a, 1984b). Because of the risk to human health, a house-to-house campaign was established to evaluate radon concentrations in the surrounding neighborhood. The Pennsylvania Department of Health (PADOH) received assistance from the Centers for Disease Control (CDC) to establish a radon concentration of 4 pCi/L as the accepted criterion for a concentration limit in domestic air.

Today (2012), the PADEP Bureau of Radiation Protection follows the USEPA recommendation that homes receive additional long-term monitoring if initial short-term testing shows radon concentrations of 4 pCi/L or greater and that homes receive mitigation if radon concentrations of 4 pCi/L or greater are confirmed (U.S. Environmental Protection Agency, 2012). For example, homeowners will usually start out with short-term testing (lasting 2 to 90 days). If the result of an initial short-term test is 4 pCi/L or higher, a second short-term test or a long-term test is recommended. Follow-up long-term tests are recommended to obtain a better understanding of year-round average indoor radon concentrations, whereas follow-up short-term tests are recommended if results are needed quickly. If the follow-up long-term test result is 4 pCi/L or more or if the average of the first and second short-term tests is 4 pCi/L or more, mitigation in the home is recommended. If measured indoor air concentrations are between 2 and 4 pCi/L, the USEPA recommends that homeowners still consider reducing radon levels in homes, because any radon exposure is believed to carry some risk (U.S. Environmental Protection Agency, 2012).

It is important to identify areas in the State that have indoor radon concentrations exceeding the USEPA action level to update, further refine, and identify potential indoor radon problem areas in Pennsylvania. To date, the PADEP Bureau of Radiation Protection, Radon Division has conducted 15 concentrated surveys in areas of known high radon occurrence. The U.S. Geological Survey (USGS), in cooperation with the PADEP and PADOH, initiated a study in 2012 to characterize the distribution of indoor radon concentrations in Pennsylvania and provide information on locations where additional concentrated surveys could be conducted. This distribution information will allow health officials to conduct additional studies, raise awareness, and direct resources towards areas of concern not previously identified.

Purpose and Scope

This report documents indoor radon concentrations in Pennsylvania during 1990–2007 and their spatial distribution according to geologic units and hydrogeologic settings. Indoor radon concentrations were aggregated according to geologic units and hydrogeologic settings in Pennsylvania to produce maps displaying areas of the State where median radon concentrations exceeded the USEPA action level of 4 pCi/L. Concentration data are characterized using a simple descriptive approach, in terms of the quartiles of measured values, and summary statistics (quartiles, skewness) for indoor radon concentrations are listed in tables.

Study Area

The State of Pennsylvania encompasses approximately 45,307 square miles and includes parts of seven major physiographic provinces: Atlantic Coastal Plain, Piedmont, New England, Blue Ridge, Ridge and Valley, Appalachian Plateaus, and Central Lowlands. In some areas, the Appalachian Plateaus and Central Lowlands are overlain by unconsolidated material (Soller and Packard, 1998), such as sand and gravel. Elevation of the land surface ranges from sea level in the Atlantic Coastal Plain province to 3,641 feet above the North American Vertical Datum of 1988 (NAVD 88) in the Appalachian Plateaus province (Gesch, 2007; Gesch and others, 2002).

Land Use and Population

Land use in Pennsylvania is about 63 percent forested (forest, shrub, grasslands, wetlands), 25 percent agricultural (pasture, cultivated crops), and 11 percent urban (developed, barren land) (fig. 1) (LaMotte, 2008). Forested land use is found primarily on ridge tops throughout the central part of the State and in the north-central tier. Agricultural land use is concentrated in valleys throughout the central and southeastern parts of Pennsylvania. Urban land use is mainly concentrated in the southeastern part of the State (fig. 1). Most cities with populations greater than 40,000 are located in eastern Pennsylvania (figs. 1 and 2). Cities with populations greater than 40,000 are Philadelphia with a population of 1,526,006; Pittsburgh, 305,704; Allentown, 118,032; Erie, 101,786; Reading, 88,082; Scranton, 76,089; Bethlehem, 74,982; Lancaster, 59,322; Harrisburg, 49,528; Altoona, 46,320; York, 43,718; and Wilkes-Barre, 41,498 (U.S. Bureau of the Census, 2010) (figs. 1 and 2). The locations of these cities correspond to those areas of the State with the highest population densities (greater than or equal to 25,001 people per square mile) (fig. 2). The north-central and south-central parts of Pennsylvania have large areas with the lowest population densities (less than or equal to 25 people per square mile) (fig. 2).

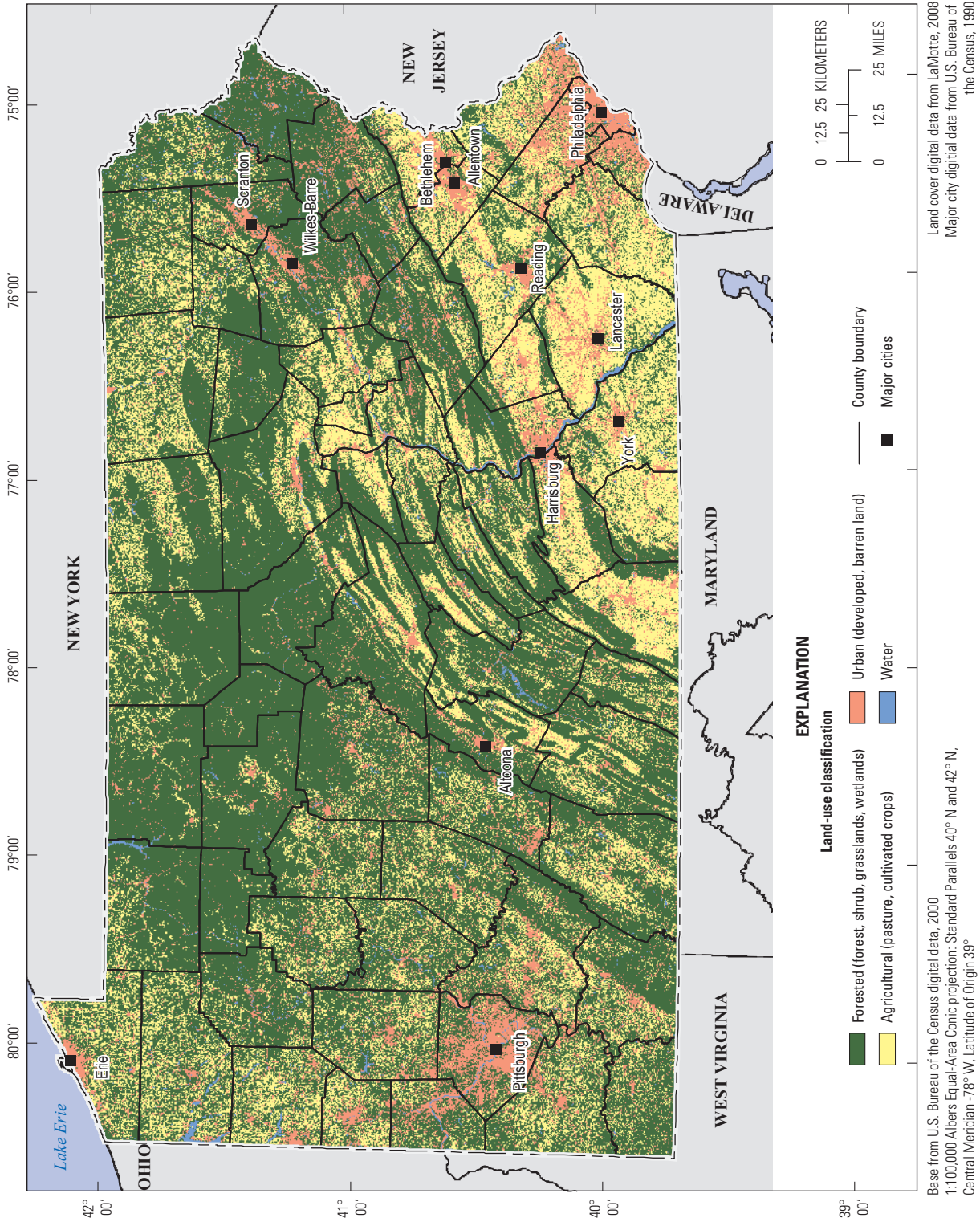


Figure 1. Land use in Pennsylvania, 2001.

4 Distribution of Indoor Radon Concentrations in Pennsylvania, 1990–2007

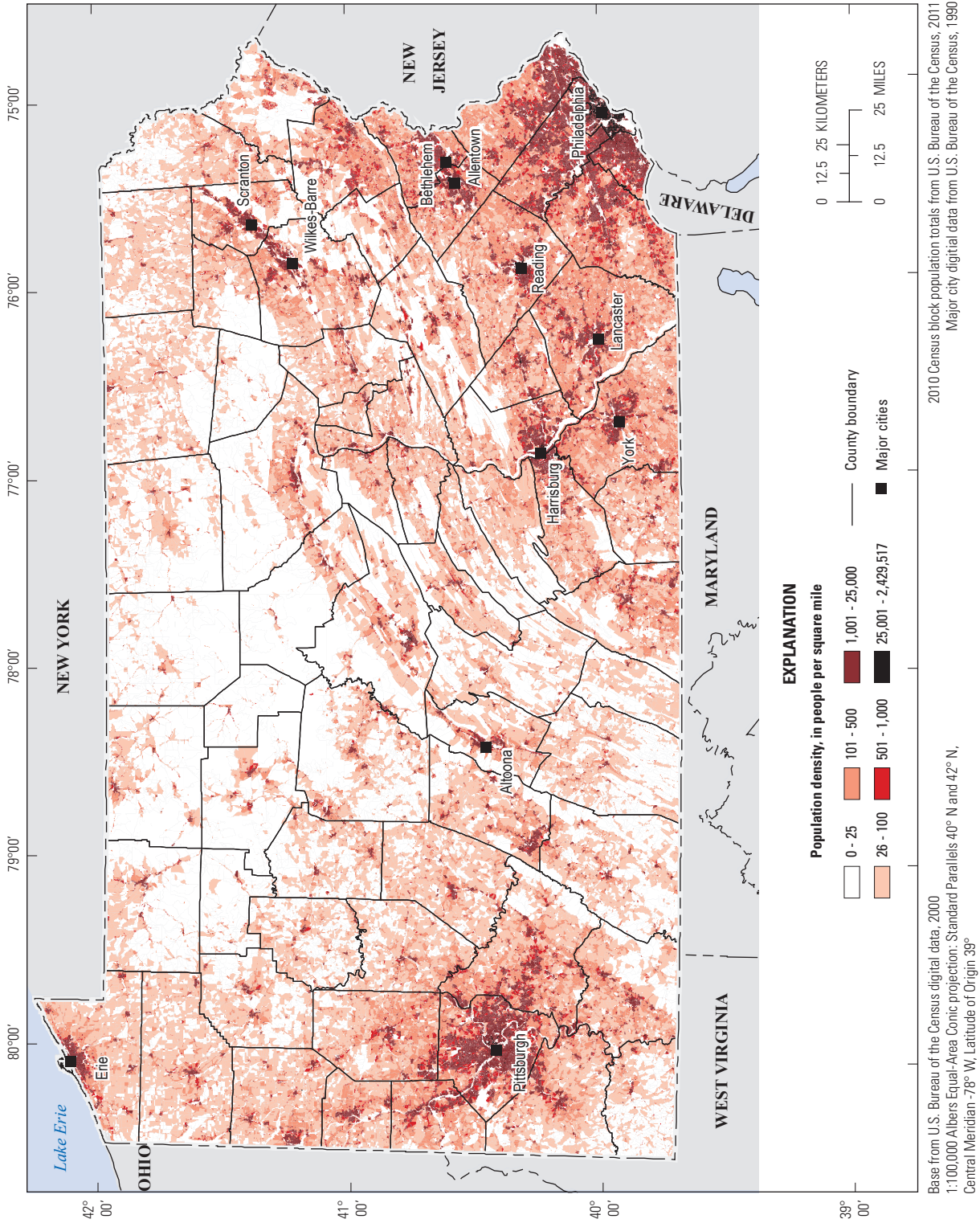


Figure 2. Population density in Pennsylvania, 2010.

Hydrogeologic Settings

The Pennsylvania Geological Survey recognizes 193 geologic units throughout the State (Pennsylvania Geological Survey, 2001). These geologic units were allocated to different hydrogeologic settings according to physiographic provinces and major aquifer types (carbonate, crystalline, siliciclastic, and surficial) by Lindsey and Bickford (1999) to define 20 hydrogeologic settings (fig. 3). Hydrogeologic settings are used in this report to assess and describe indoor radon occurrence on a broader scale than individual geologic units.

Hydrogeologic settings with carbonate aquifers—Appalachian Mountain, Devonian-Silurian, Great Valley, and Piedmont—consist mainly of limestone and dolomite. Those hydrogeologic settings with crystalline aquifers—Blue Ridge, Piedmont, and Reading Prong—are composed mostly of igneous and metamorphic rock. Hydrogeologic settings with siliciclastic aquifers are mainly composed of sandstone, siltstone, conglomerate, and shale; these settings are the Allegheny Mountain, Appalachian Mountain, Appalachian Plateaus Forested, Glaciated Low Plateau, Glaciated Pittsburgh Plateau, Great Valley, Pittsburgh Low Plateau, and Triassic Lowland. Hydrogeologic settings with surficial aquifers are composed of unconsolidated material, such as sand and gravel; these settings are the Allegheny-Monongahela Terraces, Atlantic Coastal Plain, Eastern Lake, Northeastern Glaciated Aquifers, and Northwestern Glaciated Aquifers.

Previous Studies

Indoor radon occurrence and its relation to geology and other environmental factors have been previously studied in Pennsylvania and surrounding areas. In 1980, Smith and Barnes (Pennsylvania Geological Survey, written commun., 1980) collected samples during a detailed study of the Reading Prong hydrogeologic setting (fig. 3) to analyze the geology and mineralogy of uranium and thorium in the area. This study enabled the Pennsylvania Geological Survey (PAGS) to pinpoint specific rock types, soils, and geologic units within the Reading Prong with high uranium content that could, in turn, create indoor radon problems in homes.

Sachs and others (1982) examined the spatial variability of radon concentrations in houses in eastern Pennsylvania and the variability of geological factors, such as bedrock type, uranium concentrations in groundwater, and radon emanation from soils, as indicators of potential radon sources in an attempt to predict where indoor radon concentrations are likely to be highest. They concluded that geological factors are likely to be the predominant causes of high indoor radon concentrations. They also concluded that, although there is poor predictability in using geological factors to predict high concentrations on a building-by-building basis because variability among unique house construction and ventilation factors cannot be constrained, knowledge of underlying geology

can be useful for predicting locations of high indoor radon concentrations within a region once areas of high concentrations are identified.

In a 1993 study, Gunderson (1993) concluded that bedrock geologic models for indoor radon, which include geologic parameters, soil radon data, and gamma-ray measurement data (fig. 4), could be used successfully to predict radon occurrence and concentrations in the eastern United States. Bedrock and soil properties (for example, porosity, permeability, moisture content, and clay content) are important radon indicators because bedrock and soils can contain uranium and (or) radium, from which radon is derived, and are capable of inhibiting or facilitating the movement of radon gas. Surficial gamma-ray measurement data (fig. 4) are also important potential radon indicators because they provide an estimate of uranium and radium concentrations in bedrock outcrop, soil, and surficial deposits. Gunderson (1991) estimated concentrations of uranium in soils and bedrock and identified faults and shear zones as sites of localized uranium concentrations. Faults and shear zones have been associated with some of the highest reported indoor radon concentrations.

In 1993, the USGS partnered with the USEPA to compile a series of geologic radon potential assessments for the United States, which resulted in a nationwide map of radon zones, with Zone 1 having the highest radon potential and Zone 3 having the lowest radon potential. (The data are available at <http://www.epa.gov/radon/pdfs/zonemapcolor.pdf>; U.S. Environmental Protection Agency, 1993). The country was divided according to the 10 USEPA regions, and the geologic radon potential was assessed within each region and extrapolated to counties so that each county could be assigned to a zone. As part of the study assessing geologic radon potential in region 3, which includes Delaware, Maryland, Pennsylvania, Virginia, and West Virginia, Gunderson and Smoot (1993) performed a detailed analysis of data on geology, radioactivity, and indoor radon in Pennsylvania. Gunderson and Smoot (1993) concluded that many of the soils, surficial deposits, and rocks in the State have the potential to generate indoor radon concentrations greater than 4 pCi/L. They classified rocks, soils, and surficial deposits across the State as having (1) low, (2) variable or moderate, or (3) high radon potential (fig. 5). The Atlantic Coastal Plain, southwestern part of the Triassic Lowland, and Blue Ridge hydrogeologic settings were identified as having low radon potential. The Allegheny Mountain, Glaciated Pittsburgh Plateau, northeastern part of the Triassic Lowland, eastern parts of the Appalachian Plateaus Forested, and parts of the Pittsburgh Low Plateau (fig. 3) were identified as having variable or moderate radon potential. The Reading Prong, Piedmont, northeastern part of the Triassic Lowland, Great Valley, and Appalachian Mountain hydrogeologic settings were identified as having high radon potential.

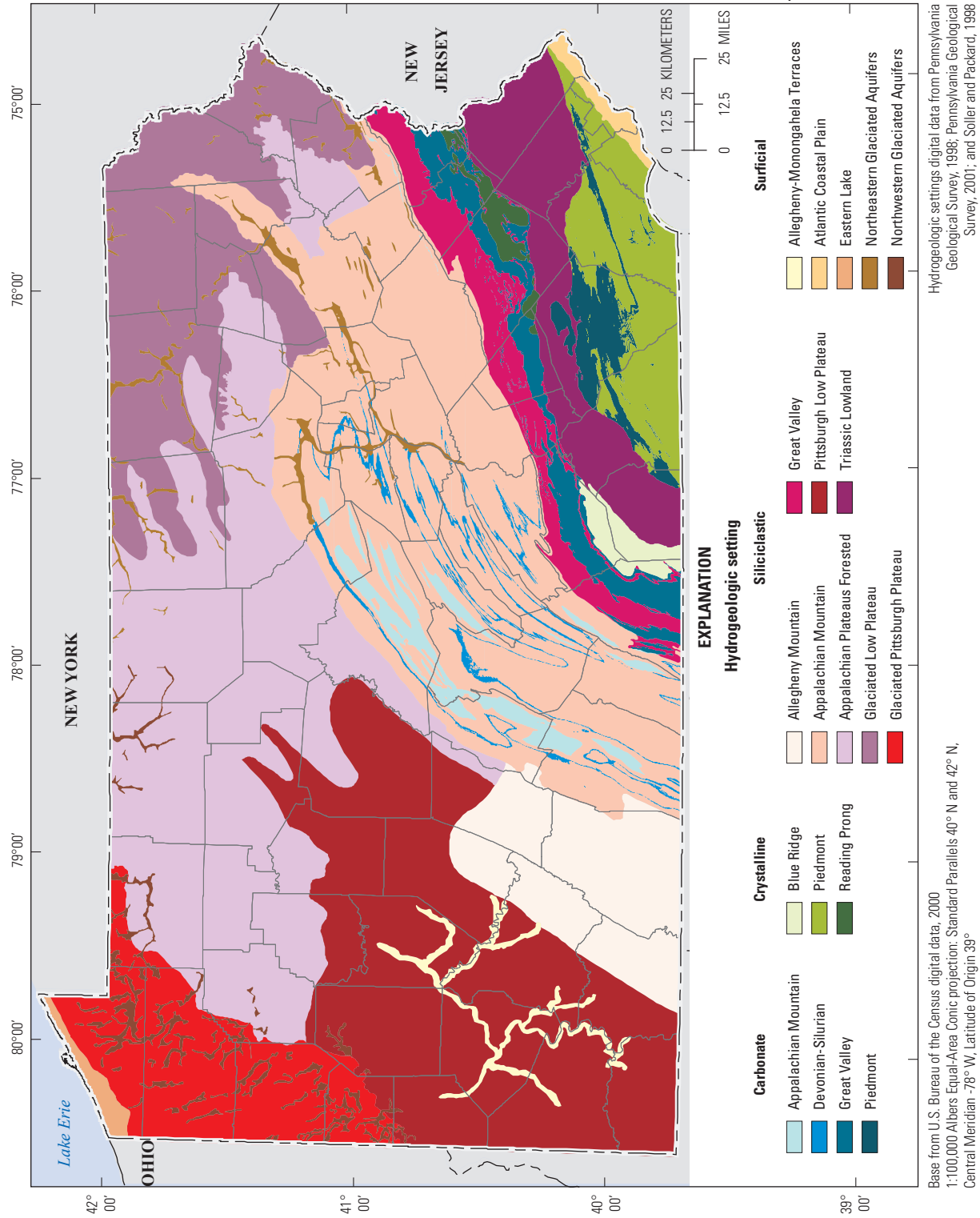


Figure 3. Hydrogeologic settings in Pennsylvania.

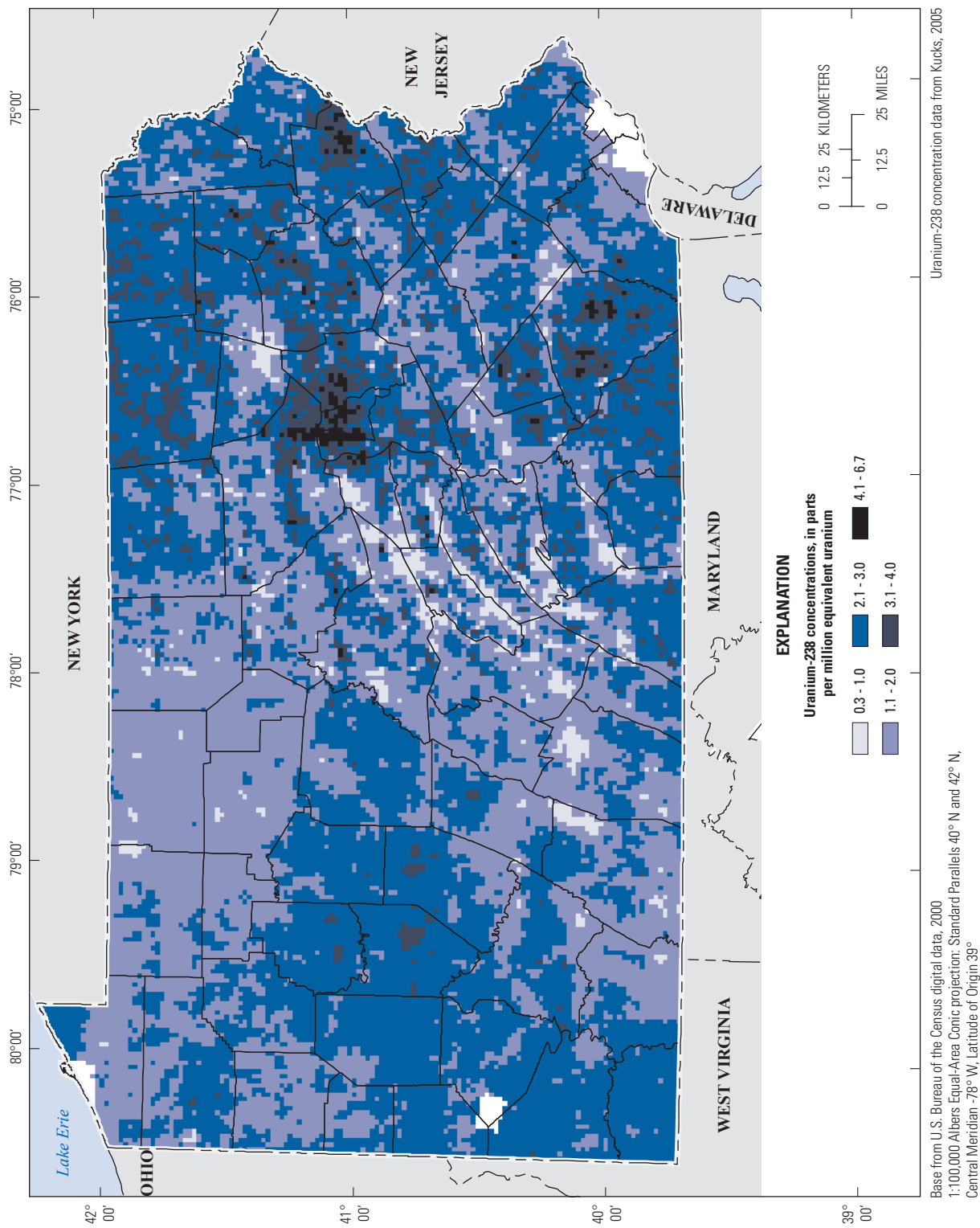


Figure 4. Aerial gamma-ray survey measuring the gamma-ray flux produced by the radioactive decay of the naturally occurring element uranium-238 in Pennsylvania. (Uranium-238 concentration data from Kucks, 2005)

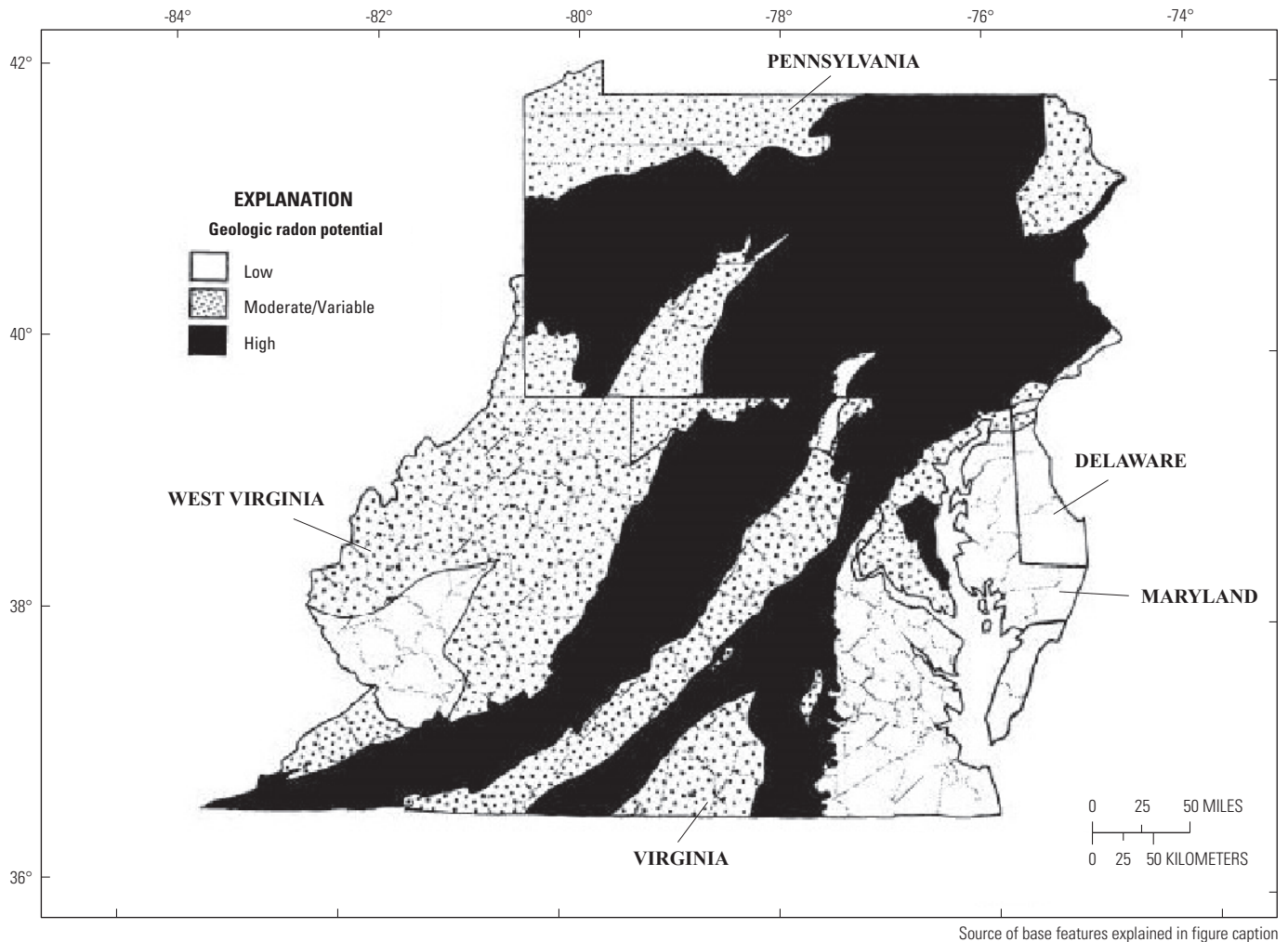


Figure 5. Geologic radon potential for U.S. Environmental Protection Agency, Region 3, adapted from Gunderson and Smoot, 1993.

Indoor Radon Concentration Data

Indoor radon concentration data were obtained from a database compiled by the PADEP, Bureau of Radiation Protection, Radon Division. The indoor radon concentration data are the results from indoor radon tests conducted in Pennsylvania from 1990 to 2007 and submitted to the PADEP by certified laboratories and testers. Most of the radon testing occurred during real estate transactions. The original data obtained from the PADEP contained 878,160 records with associated attribute information including county, municipality, zip code, spatial coordinates geocoded from address, geocoding precision score, house type (ranch, trailer, apartment), date (begin and end), test length (duration), test result, testing method (type of monitor used), and testing location (basement, first floor, second floor, and so forth). Source of water to the home was not recorded, which is a potential limitation because in homes that receive drinking water from a private well or public water supplier accessing groundwater containing dissolved radon, the

radon gas will escape from drinking water and accumulate in the air when it is used for showering and other household uses.

For the purposes of analyses presented in this report, the original dataset was edited to include only records with geocoding precision scores equal to 100 (scores can range from 0 to 100 and are a measure of confidence of geocoding precision, but even scores equal to 100 can still be inaccurate by as much as 700 feet), basement testing locations, short-term test results (results from tests lasting less than or equal to 90 days), and test results that were greater than or equal to zero to remove test results that did not have a value. Numerical values of test results were otherwise reported as obtained from the PADEP. Also, a geographic information system (GIS) was used to remove those records with spatial coordinates that did not fall within the Pennsylvania Geological Survey's bedrock geology dataset (Pennsylvania Geological Survey, 2001) because this dataset is used for most analyses. After all edits were completed, the final dataset contained 548,507 test results with indoor radon concentrations.

Distribution of Indoor Radon Concentrations

This section of the report documents the distribution of indoor radon concentrations in Pennsylvania, 1990–2007. The distribution of indoor radon concentrations was analyzed state-wide, and the data were aggregated and analyzed according to geologic units and hydrogeologic settings. Spatial distribution was defined using the quartiles of measured population distribution. Analysis using the lognormal distribution of the data, which can be used to focus analysis on the high concentrations in a measured population of data (for example, the upper quartile), was not conducted in this study.

The frequency distribution of 548,507 indoor radon concentrations in Pennsylvania is shown in figure 6. The median concentration was 3.0 picocuries per liter (pCi/L); the minimum and maximum concentrations were 0.0 pCi/L (set by data censoring) and 1,866.4 pCi/L, respectively. About 39 percent (215,138) of test results had indoor radon concentrations greater than or equal to the USEPA action level of 4 pCi/L.

The density of indoor radon test results is shown in figure 7 according to geologic unit to show the spatial distribution of test result locations. In most areas, the test results had a wide range of indoor radon concentrations. For the most part, test result locations are in urban and suburban areas across the State, which are mainly in and around the Philadelphia and Pittsburgh areas, because this is where most of the population within the State resides.

Indoor Radon Concentrations According to Geologic Unit

Indoor radon test results were analyzed according to 193 geologic units in Pennsylvania to determine general patterns of indoor radon concentrations among the units. Of the State's 193 geologic units, 5 units had no corresponding indoor radon concentration data. Concentrations of indoor radon in most of the geologic units were highly variable, so the units were classified on the basis of median indoor radon concentration, which is the concentration at which one-half of the samples have a lower concentration and one-half have a higher concentration. For data analysis, a median radon concentration of 4 pCi/L was chosen as a boundary value for grouping geologic units and hydrogeologic settings because the USEPA recommends fixing the home if the radon concentration is equal to or greater than 4 pCi/L. The degree of skewness is commonly high (table 1, back of report) and indicates that, for many geologic units, additional information might be gained from computing lognormal distributions and focusing additional analysis on the high-concentration data.

When analyzed according to Pennsylvania's geologic units, 93 of 188 (49.5 percent) geologic units with indoor radon concentrations had median concentrations greater than or equal to the USEPA action level of 4 pCi/L (table 1), likely

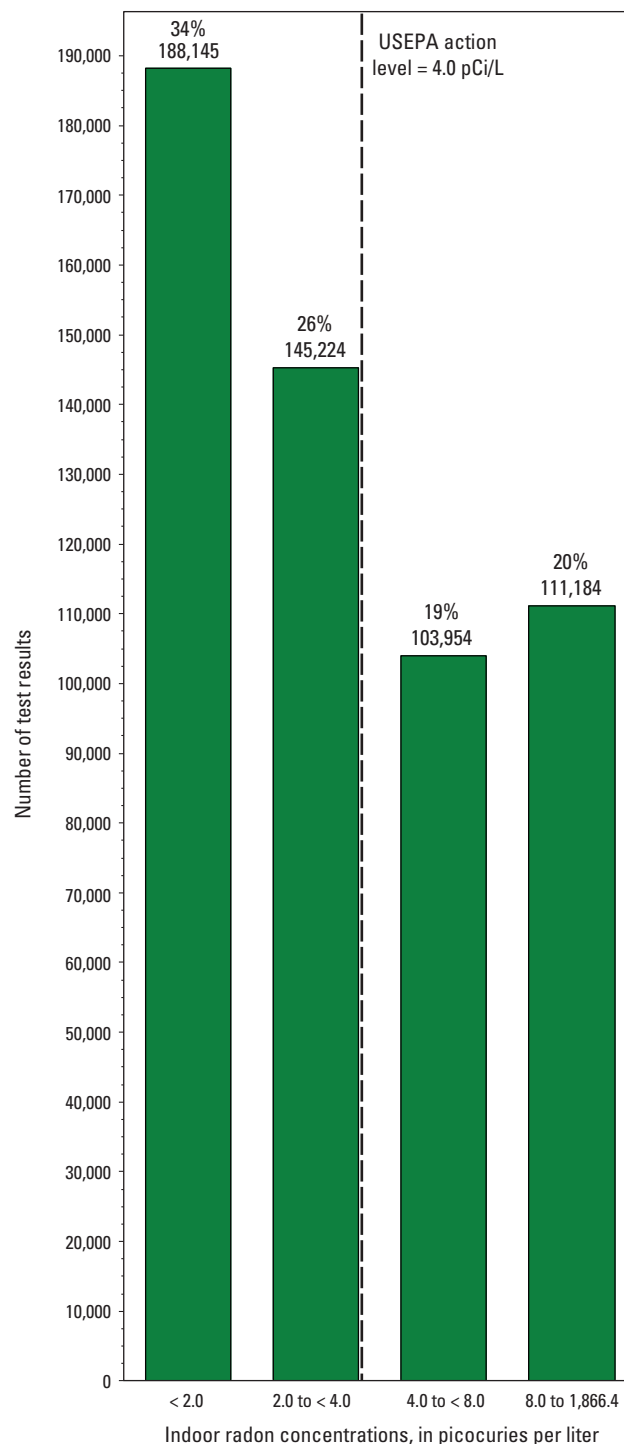


Figure 6. Frequency of indoor radon concentrations from tests from a database compiled by the Pennsylvania Department of Environmental Protection, Bureau of Radiation Protection, Radon Division. (USEPA, U.S. Environmental Protection Agency; pCi/L, picocuries per liter; %, percent of tests; <, less than)

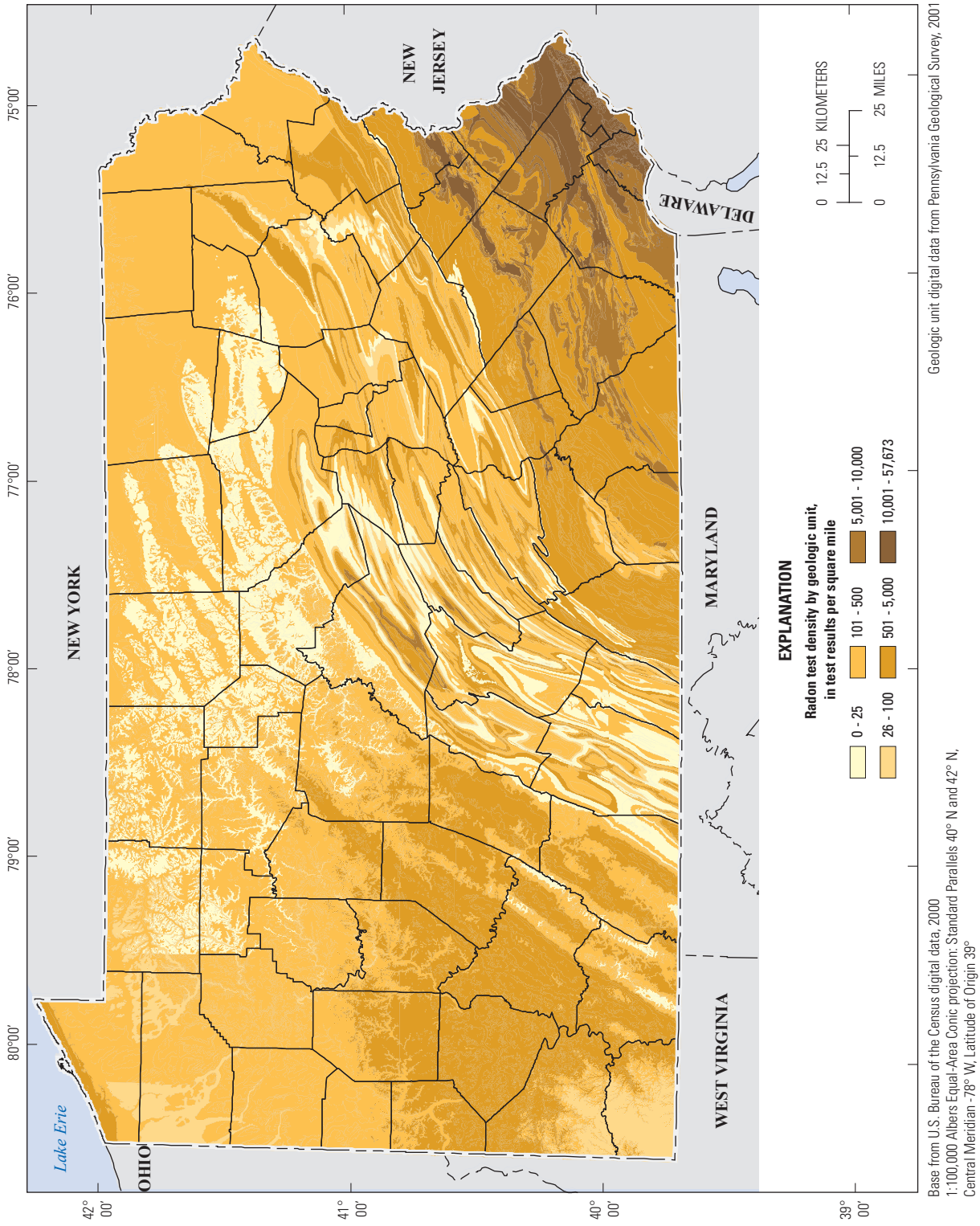


Figure 7. Radon test density in Pennsylvania according to geologic unit, 1990–2007.

representing the bulk of the 39 percent of test results greater than or equal to 4 pCi/L. Geologic units with median indoor radon concentrations greater than or equal to 4 pCi/L are shaded red in figure 8. Most of these units are located in the eastern part of the State. Many of these units are well represented by the dataset, but some are not. Thin units in complex crystalline and carbonate terranes are least likely to be represented adequately. For example, the Wakefield Marble (crystalline Piedmont hydrogeologic setting), which had the highest median indoor radon concentration of 57.9 pCi/L, had only two test results. The geologic unit with the most test results (47,897) was the Stockton Formation (siliciclastic Triassic Lowland hydrogeologic setting) with a median indoor radon concentration of 2.4 pCi/L. The geologic unit with the highest number of test results and median indoor radon concentration greater than or equal to 4 was the Octoraro Formation (crystalline Piedmont hydrogeologic setting) with 13,787 test results and a median concentration of 4.1 pCi/L. The highest indoor radon concentration from a single test result (1,866.4 pCi/L) was measured in an area of Lower Cambrian rocks (carbonate Great Valley hydrogeologic setting). A total of 920 test results were obtained for this unit; the median concentration was 6.1 pCi/L. The geologic unit with the lowest median indoor radon concentration (0.6 pCi/L) was the Shawangunk Formation (siliciclastic Appalachian Mountain hydrogeologic setting); nine test results were available for this unit.

Indoor Radon Concentrations According to Hydrogeologic Setting

Because indoor radon test results were not available for all 193 geologic units and the number of test results per unit varied widely for those units that had results (1 to 47,897), median indoor radon concentrations were further aggregated and analyzed according to 20 hydrogeologic settings (table 2). As was apparent for the geologic units, the degree of skewness is commonly high (table 2) for the hydrogeologic settings and indicates that additional information might be gained from computing lognormal distributions. The crystalline Blue Ridge hydrogeologic setting contained the lowest number of test results (535), whereas the Siliciclastic Triassic Lowland contained the highest number of test results (119,389).

Hydrogeologic settings with median indoor radon concentrations greater than the USEPA action level of 4 pCi/L are shaded red in figure 9; these include 5 of the 20 settings: carbonate Appalachian Mountain (6.3 pCi/L), siliciclastic Great Valley (6.0 pCi/L), carbonate Great Valley (5.0 pCi/L), crystalline Reading Prong (4.8 pCi/L), and carbonate Devonian-Silurian (4.1 pCi/L). These hydrogeologic settings are located mostly in the south-central part of the State. Three of the hydrogeologic settings with median indoor radon concentrations greater than the USEPA action level of 4 pCi/L are carbonate hydrogeologic settings. This is consistent with findings reported by previously conducted studies. Smith (1978) describes faulted shear zones within the Reading Prong

hydrogeologic setting that are known to contain crystalline rocks that are uranium-rich. Also, Gunderson and Smoot (1993) discuss how the dissolution of carbonate rocks creates soils that are enriched in impurities, including radionuclides such as uranium and radium. Greeman and Rose (1990) found that soils developed on carbonate rocks in central Pennsylvania exhibited radon emanation almost entirely attributed to highly emanative radium bound in soil organic matter. This pattern of radon-rich soil developing from uranium-rich strata, such as carbonate bedrock, has also been studied in West Virginia (Brower and others, 1991; Schultz and others, 1992). When comparing figures 8 and 9 to figure 4, it is apparent that the geologic units and hydrogeologic settings with the highest median indoor radon concentrations seem to correspond with those parts of the State with the highest uranium concentrations as measured by the aerial gamma-ray survey. Therefore, crystalline rocks and soils developed from carbonate rocks can have high uranium and radium contents and soil-gas radon concentrations, which can lead to high indoor radon concentrations (Gunderson and Smoot, 1993; Greeman and Rose, 1990). The black shales of the siliciclastic Great Valley are also cited in Gunderson and Smoot (1993) as having uranium content higher than other rock types and being effective emanators of radon (Gunderson and Smoot, 1993). Also, Gunderson (1991) discusses how shear zones within the Reading Prong rocks enhance the uranium content and radon potential of these rocks and create local occurrences of high uranium and indoor radon concentrations (Gunderson, 1991).

The surficial Atlantic Coastal Plain hydrogeologic setting had the lowest median indoor radon concentration (1.6 pCi/L) and was the only hydrogeologic setting with a median indoor radon concentration less than 2 pCi/L, which is the concentration above which the USEPA recommends that homeowners consider mitigation of radon. This low frequency of occurrence of high radon values is consistent with the findings of Gunderson and Smoot (1993), who state that the sediments, soils, and surficial deposits of the Atlantic Coastal Plain, in general, have low radon potential (Gunderson and Smoot, 1993).

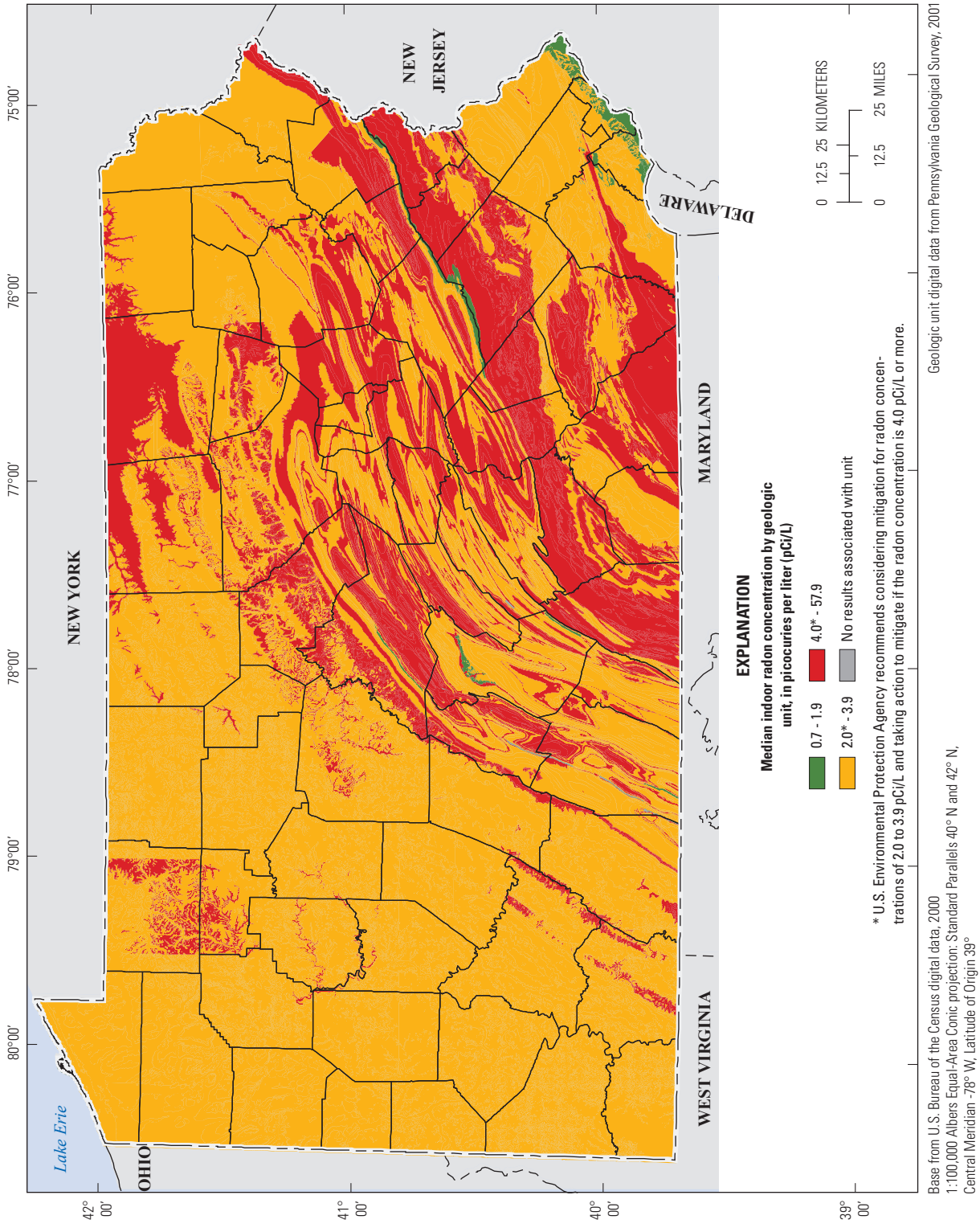


Figure 8. Geologic units shaded to indicate median indoor radon concentrations in Pennsylvania, 1990–2007.

Table 2. Summary of indoor radon concentrations according to hydrogeologic setting in Pennsylvania, 1990–2007.

[Shading indicates hydrogeologic setting with median indoor radon concentration equal to or greater than the U.S. Environmental Protection Agency (USEPA) action level of 4 pCi/L; pCi/L, picocuries per liter]

Major aquifer type	Hydrogeologic setting	Number of test results	Density of test results, per square mile	Percentage of test results equal to or greater than the USEPA action level of 4 pCi/L	Test result skewness, in pCi/L	Minimum indoor radon concentration, in pCi/L	25th percentile indoor radon concentration, in pCi/L	Median indoor radon concentration, in pCi/L	75th percentile indoor radon concentration, in pCi/L	Maximum indoor radon concentration, in pCi/L
Carbonate	Appalachian Mountain	9,070	1,540	61	15.2	0.07	2.5	6.3	14.9	801.0
	Devonian-Silurian	2,959	799	51	8.3	0.1	1.8	4.1	9.3	333.2
	Great Valley	48,288	5,226	57	31.4	0	2.0	5.0	10.8	1866.4
	Piedmont	30,376	5,688	50	13.3	0.002	1.9	3.9	8.6	630.6
Crystalline	Blue Ridge	535	208	49	5.1	0.1	1.7	3.9	9.3	161.3
	Piedmont	118,385	7,720	34	28.9	0	1.4	2.7	5.4	1604.0
	Reading Prong	3,556	1,744	56	12.4	0.1	1.9	4.8	12.4	891.4
	Allegheny Mountain	4,954	229	44	14.6	0.1	1.8	3.5	6.9	440.6
Siliciclastic	Appalachian Mountain	25,263	334	44	8.4	0	1.5	3.3	8.3	709.3
	Appalachian Plateaus Forested	3,671	46	43	8.9	0.1	1.6	3.3	7.2	531.4
	Glaciated Low Plateau	9,287	242	38	13.2	0.1	1.5	3.0	5.9	399.3
	Glaciated Pittsburgh Plateau	4,372	201	34	34.4	0.1	1.4	2.7	5.1	713.5
	Great Valley	26,761	2,327	61	6.7	0.008	2.0	6.0	16.2	918.2
	Pittsburgh Low Plateau	92,973	1,468	39	9.4	0.004	1.7	3.0	6.1	611.6
Surficial	Triassic Lowland	119,389	6,424	34	19.4	0	1.4	2.6	5.2	937.0
	Allegheny-Monongahela Terraces	8,470	2,480	27	8.6	0.1	1.4	2.5	4.2	156.5
	Atlantic Coastal Plain	27,054	13,635	13	93.1	0	0.9	1.6	2.8	847.6
	Eastern Lake	1,950	1,026	30	7.0	0.1	1.1	2.1	4.7	163.2
Surficial	Northeastern Glaciated Aquifers	9,606	2,270	35	13.2	0.05	1.4	2.7	5.5	383.6
	Northwestern Glaciated Aquifers	1,588	352	46	5.0	0.1	1.8	3.5	7.0	107.5

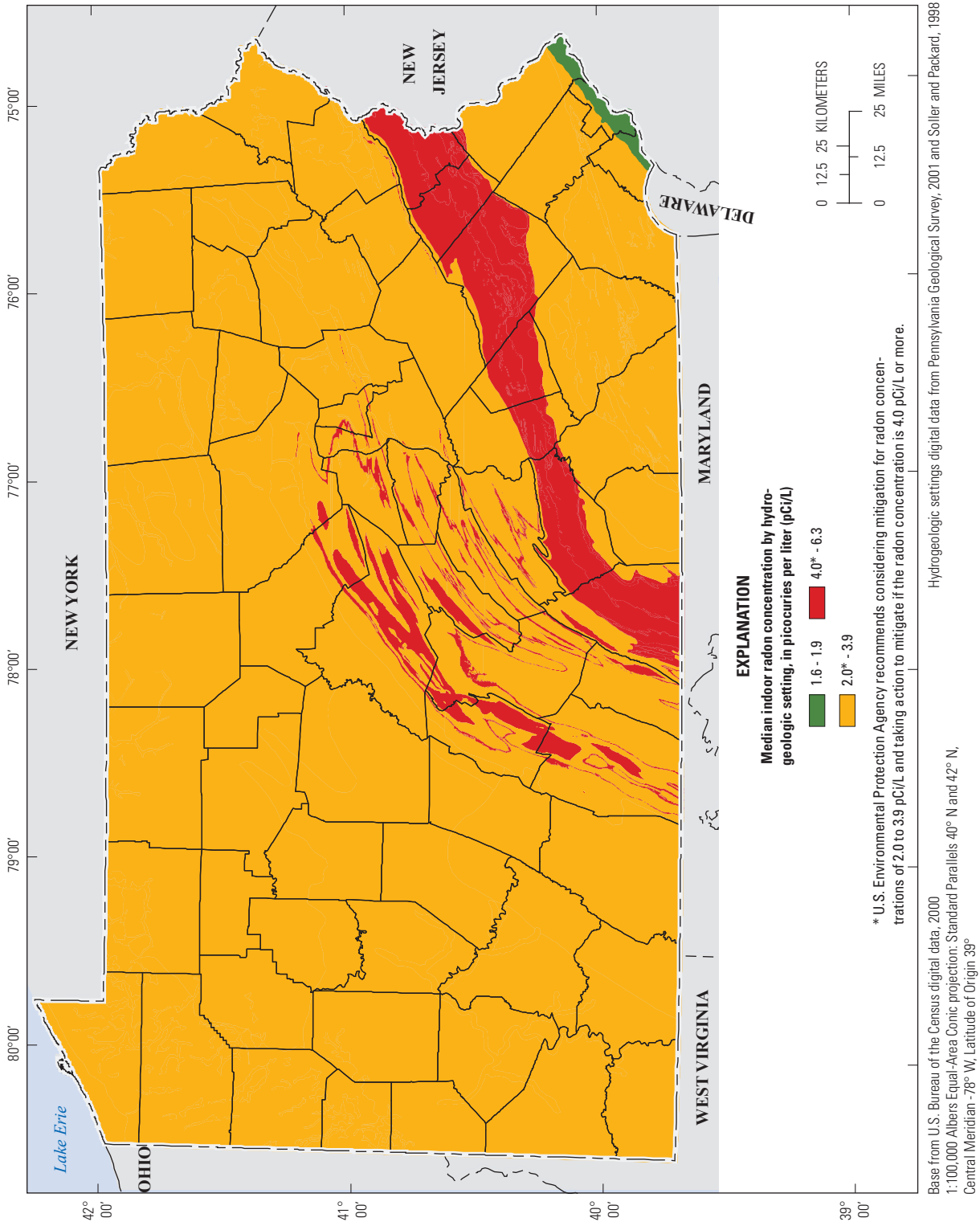


Figure 9. Hydrogeologic settings shaded to indicate median indoor radon concentrations in Pennsylvania, 1990–2007.

Uses and Limitations of Aggregated Radon Data

Aggregated radon data presented for Pennsylvania in the present study (figs. 8 and 9) indicate that most of Pennsylvania contains geologic units and hydrogeologic settings with median indoor radon concentrations greater than or equal to 2 pCi/L (the concentrations at which the USEPA recommends that property owners consider remediating homes or buildings) and less than 4 pCi/L (the concentration at which the USEPA recommends that property owners remediate homes or buildings). It is important to note that median concentrations of indoor radon are useful for drawing general conclusions about the occurrence of indoor radon in specific geologic units and hydrogeologic settings, but these concentration distributions are not proposed for use in predicting individual concentrations at specific sites nor for use as a decision-making tool for property owners to decide whether to test for indoor radon concentrations at specific property locations. Maps showing median indoor radon test results aggregated according to geologic unit and hydrogeologic setting in Pennsylvania (figs. 8 and 9) also indicate that the areas with high radon risk potential can be better and more narrowly defined than areas delineated at the national scale or on the basis of county, as has been done previously (<http://www.epa.gov/radon/pdfs/zonemapcolor.pdf>; U.S. Environmental Protection Agency, 1993).

Interpretations of the aggregated radon data may be affected in some cases by limitations of the data. For example, there is no information in the dataset about whether any test results were conducted after high radon concentrations in the tested building were identified and remediated. This could affect interpretations of the data in the Reading Prong hydrogeologic setting, where a large amount of data were collected prior to 1990. Data included in this study are from 1990 and later, so much of the test-result data from the Reading Prong hydrogeologic setting that are used in this report could represent post-remediation conditions or follow-up test results.

Another potential limitation of the data interpretation results from the uneven or inaccurate distribution of the data among geologic units. Some geologic units have inadequate sample distribution. For example, thin units in complex crystalline and carbonate terranes are the least likely to be represented adequately. In contrast, some geologic units have clusterings of test results and are over-represented. Geocoding scores, even with confidence scores of 100 out of 100, could be off as much as 700 feet, so some test results may be grouped into geologic units or hydrogeologic settings that they do not represent, and this would be especially true for small, thin geologic units. In addition, there is inherent error in the original geologic unit dataset created by the Pennsylvania Geological Survey (2001) because the dataset is accurate at a 1:250,000 scale and it represents a broad interpretation of geologic units across the State. More precise mapping designed to minimize interfering biases and maximize geological

factors is desirable for improved maps (Miles, 1998). Finally, some geologic units and (or) hydrogeologic settings might be better represented if they were separated into several units and (or) settings and listed in two categories of severity. For example, the Triassic Lowland hydrogeologic setting could be divided into the Gettysburg Basin and Newark Basin; with this approach, the potential risk associated with high radon concentrations in the Triassic Lowland hydrogeologic setting might be more accurately represented because one basin may have significantly higher radon test results than the other.

The maps derived from the indoor radon concentration data can be used as tools for resource decision-making and may also have value for ecological-level analysis of disease outcomes. These maps are intended to be available through databases of the Centers for Disease Control and the Pennsylvania Environmental Public Health Tracking programs that are available on the Internet. For further information regarding radon in Pennsylvania, visit the Pennsylvania Department of Environmental Protection Radon Website at www.depweb.state.pa.us (keyword: Radon) or call the PADEP Radon Hotline at 1-800-237-2366 or the PADEP Radon Division at 717-783-3594.

Summary and Conclusions

The distribution of indoor radon concentrations was evaluated for 548,507 test results collected from 1990 to 2007 throughout Pennsylvania. Indoor radon concentrations greater than or equal to the U.S. Environmental Protection Agency (USEPA) action level of 4 picocuries per liter (pCi/L) were observed for 39 percent of the test results. The highest test result was a concentration of 1,866.4 pCi/L.

Indoor radon concentrations were aggregated according to geologic units and hydrogeologic settings for spatial analysis. When analyzed according to Pennsylvania's geologic units, the median concentration for 93 of 188 (49.5 percent) geologic units with indoor radon concentrations was greater than the USEPA action level of 4 pCi/L; most of these geologic units are located in the eastern part of the State. When analyzed according to Pennsylvania's hydrogeologic settings, the median concentrations for 5 of the 20 (25 percent) settings were greater than the USEPA action level of 4 pCi/L; these settings are the carbonate Appalachian Mountain (6.3 pCi/L), siliciclastic Great Valley (6.0 pCi/L), carbonate Great Valley (5.0 pCi/L), crystalline Reading Prong (4.8 pCi/L), and carbonate Devonian-Silurian (4.1 pCi/L). The surficial Atlantic Coastal Plain hydrogeologic setting had the lowest median indoor radon concentration (1.6 pCi/L).

Median indoor radon concentrations aggregated according to geologic units and hydrogeologic settings are useful for drawing general conclusions about the occurrence of indoor radon in specific geologic units and hydrogeologic settings, but these concentration distributions are not proposed for use in predicting individual concentrations at specific sites

nor for use as a decision-making tool for property-owners to decide whether to test for indoor radon concentrations at specific property locations. The aggregated indoor radon data have testing and spatial accuracy limitations that potentially result from the lack of available information about testing conditions and the imprecision of geocoded test locations; whereas the associated geologic unit and hydrogeologic settings data have spatial and interpretation accuracy limitations that potentially result when statewide data are used to define conditions at test locations and heterogeneous geologic units are broadly defined.

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Table 1. Summary of indoor radon concentrations according to geologic unit in Pennsylvania, 1990–2007.

[Shading indicates geologic unit with median indoor radon concentration equal to or greater than the U.S. Environmental Protection Agency (USEPA) action level of 4 pCi/L; pCi/L, picocuries per liter; -, no data]

Map symbol ¹	Geologic formation name ¹	Primary lithology ¹	Number of test results	Density of test results, in test results per square mile	Percent-age of test results equal to or greater than the USEPA action level of 4 pCi/L	Test result skew-ness, in pCi/L	Minimum indoor radon con- centration, in pCi/L	25th percentile indoor radon con- centration, in pCi/L	Median in- door radon con- centra- tion, in pCi/L	75th percentile indoor radon con- centration, in pCi/L	Maximum indoor radon con- centration, in pCi/L
a	Anorthosite	Anorthosite	373	2,769	37	10.2	0.200	1.5	2.8	5.0	168.7
Ca	Antietam Formation	Quartzite	1,114	4,604	60	3.9	0.100	2.1	5.7	14.3	161.3
Cah	Antietam and Harpers Formations, undivided	Quartzite	3,636	3,113	64	4.2	0.049	2.5	6.4	17.7	309.0
Cal	Allentown Formation	Dolomite	13,901	11,194	48	12.6	0.000	1.5	3.7	8.1	505.4
Cbs	Buffalo Springs Formation	Limestone	1,550	4,129	55	4.2	0.001	1.9	4.9	12.4	188.9
Cch	Chickies Formation	Quartzite	7,520	7,707	37	8.2	0.002	1.5	2.9	6.1	381.0
Ce	Elbrook Formation	Calcareous shale	4,135	4,691	45	7.6	0.002	1.8	3.5	6.9	205.6
Cg	Gatesburg Formation	Dolomite	71	120	59	4.2	0.500	1.8	4.7	9.4	64.5
Cgl	Lower members of Gatesburg Formation, undivided	Sandstone	1,966	4,317	58	3.9	0.100	2.2	4.9	9.7	103.7
Cgm	Mines Member of Gatesburg Formation	Dolomite	559	3,738	60	7.0	0.400	2.6	5.4	10.8	206.0
Ch	Harpers Formation	Phyllite	386	2,963	49	4.0	0.100	1.6	3.8	11.9	151.4
Cha	Hardyston Formation	Quartzite	1,095	2,817	52	18.4	0.100	1.9	4.3	9.4	891.4
Chm	Montalto Member of Harpers Formation	Quartzite	135	201	49	4.2	0.200	1.7	3.8	7.7	68.0
Clk	Kinzers Formation	Shale	1,267	3,644	59	10.0	0.100	2.2	5.3	12.2	534.0

Table 1. Summary of indoor radon concentrations according to geologic unit in Pennsylvania, 1990–2007.—Continued

[Shading indicates geologic unit with median indoor radon concentration equal to or greater than the U.S. Environmental Protection Agency (USEPA) action level of 4 pCi/L; pCi/L, picocuries per liter; -, no data]

Map symbol ¹	Geologic formation name ¹	Primary lithology ¹	Number of test results	Density of test results, in test results per square mile	Percentage of test results equal to or greater than the USEPA action level of 4 pCi/L	Test result skewness, in pCi/L	Minimum indoor radon concentration, in pCi/L	25th percentile indoor radon concentration, in pCi/L	Median indoor radon concentration, in pCi/L	75th percentile indoor radon concentration, in pCi/L	Maximum indoor radon concentration, in pCi/L
Cl	Ledger Formation	Dolomite	5,011	5,622	46	7.5	0.002	1.8	3.6	7.5	268.3
Clv	Leithsville Formation	Dolomite	2,717	5,174	48	41.0	0.100	1.8	3.8	7.4	1,204.7
Cm	Millbach Formation	Limestone	1,254	7,538	56	5.3	0.100	2.1	4.8	10.5	159.1
Cms	Millbach and Schaefferstown Formations, undivided	Limestone	142	1,320	77	2.4	0.300	5.0	9.9	14.8	75.0
Cph	Pleasant Hill Formation	Argillaceous limestone	0	-	-	-	-	-	-	-	-
Cr	Richland Formation	Dolomite	1,899	6,297	62	9.4	0.100	2.5	5.6	11.4	402.6
Csb	Snitz Creek and Buffalo Springs Formations, undivided	Limestone	413	2,478	72	2.8	0.100	2.9	7.9	15.8	123.4
Csc	Snitz Creek Formation	Dolomite	269	2,016	66	2.6	0.200	2.8	7.1	14.6	92.6
Csg	Shadygrove Formation	Limestone	435	2,179	74	2.4	0.100	3.8	8.0	15.7	105.7
Ct	Tomstown Formation	Dolomite	673	1,298	57	3.9	0.100	2.4	4.7	9.4	97.6
Cul	Lower (Middle?) Cambrian rocks, undivided	Dolomite	920	25,215	63	25.1	0.140	2.6	6.1	14.4	1,866.4
Cv	Vintage Formation	Argillaceous dolomite	1,691	3,623	60	5.0	0.100	2.3	5.2	12.1	222.6
Cw	Warrior Formation	Limestone	17	194	53	2.7	0.500	2.4	4.3	8.1	30.4
Cwb	Waynesboro Formation	Shale	405	1,491	55	2.2	0.200	2.2	4.3	9.2	44.9

Table 1. Summary of indoor radon concentrations according to geologic unit in Pennsylvania, 1990–2007.—Continued

[Shading indicates geologic unit with median indoor radon concentration equal to or greater than the U.S. Environmental Protection Agency (USEPA) action level of 4 pCi/L; pCi/L, picocuries per liter; -, no data]

Map symbol ¹	Geologic formation name ¹	Primary lithology ¹	Number of test results	Density of test results, in test results per square mile	Percent-age of test results equal to or greater than the USEPA action level of 4 pCi/L	Test result skewness, in pCi/L	Minimum indoor radon concentration, in pCi/L	25th percentile indoor radon concentration, in pCi/L	Median indoor radon concentration, in pCi/L	75th percentile indoor radon concentration, in pCi/L	Maximum indoor radon concentration, in pCi/L
Cwl	Weverton and Loudoun Formations, undivided	Quartzite	22	45	77	0.5	1,300	4.8	6.8	7.4	14.5
Cz	Zullinger Formation	Limestone	1,066	1,570	72	8.1	0.100	3.2	8.0	15.1	350.0
Czc	Zooks Corner Formation	Dolomite	2,705	7,275	63	6.3	0.100	2.3	6.3	13.4	324.4
Dbe	Buttermilk Falls Limestone through Esopus Formation, undivided	Siliceous sandstone	585	2,413	50	7.3	0.100	1.8	3.9	9.2	197.0
Dbh	Brallier and Harrell Formations, undivided	Siltstone	1,550	652	40	5.0	0.100	1.4	2.9	7.5	228.9
Dbr	Berea Sandstone through Riceville Formation, undivided	Sandstone	320	368	24	6.2	0.100	1.2	2.3	3.8	65.9
Dbv	Berea Sandstone through Venango Formation, undivided	Sandstone	155	50	35	2.4	0.100	1.4	2.7	6.6	34.9
Deb	Buddys Run Member of Catskill Formation	Siltstone	55	91	55	2.8	0.300	1.5	6.2	17.5	241.0
Dcbr	Beaverdam Run Member of Catskill Formation	Siltstone	206	714	70	4.8	0.100	3.3	11.9	28.9	321.8
Debs	Berry Run and Sawmill Run Members of Catskill Formation, undivided	Sandstone	2	22	100	-	6,000	6.0	6.2	6.4	6.4
Decf	Clarks Ferry Member of Catskill Formation	Sandstone	8	41	100	1.4	5,900	26.4	50.2	62.0	144.9
Ded	Duncannon Member of Catskill Formation	Sandstone	1,275	345	32	7.5	0.100	1.3	2.5	5.0	187.2
Dch	Chadakoin Formation	Siltstone	1,080	254	41	5.2	0.100	1.4	3.0	6.3	123.9
Deiv	Irish Valley Member of Catskill Formation	Siltstone	747	276	64	4.9	0.100	2.6	6.9	25.1	627.5

Table 1. Summary of indoor radon concentrations according to geologic unit in Pennsylvania, 1990–2007.—Continued

[Shading indicates geologic unit with median indoor radon concentration equal to or greater than the U.S. Environmental Protection Agency (USEPA) action level of 4 pCi/L; pCi/L, picocuries per liter; -, no data]

Map symbol ¹	Geologic formation name ¹	Primary lithology ¹	Number of test results	Density of test results, in test results per square mile	Percentage of test results equal to or greater than the USEPA action level of 4 pCi/L	Test result skewness, in pCi/L	Minimum indoor radon concentration, in pCi/L	25th percentile indoor radon concentration, in pCi/L	Median indoor radon concentration, in pCi/L	75th percentile indoor radon concentration, in pCi/L	Maximum indoor radon concentration, in pCi/L
Dck	Catskill Formation	Sandstone	6,084	156	37	14.0	0.100	1.6	3.0	5.7	531.4
Dclr	Long Run Member of Catskill Formation	Sandstone	1,314	1,024	57	6.6	0.100	1.9	4.8	11.8	362.6
Dclw	Long Run and Waleksville Members of Catskill Formation, undivided	Sandstone	1,084	215	32	2.6	0.100	1.3	2.6	4.9	36.2
Dep	Packerton Member of Catskill Formation	Sandstone	120	742	40	5.8	0.300	1.2	2.4	6.6	128.9
Depg	Poplar Gap Member of Catskill Formation	Sandstone	608	651	33	4.2	0.100	1.3	2.7	5.0	55.3
Depp	Poplar Gap and Packerton Members of Catskill Formation, undivided	Sandstone	450	179	30	8.8	0.100	1.3	2.4	4.3	119.5
Dcr	Corry Sandstone through Riceville Formation, undivided	Sandstone	97	30	48	8.1	0.100	1.7	3.4	6.8	208.0
Desc	Sherman Creek Member of Catskill Formation	Mudstone	1,211	538	57	5.2	0.100	1.8	5.3	15.4	416.3
Dct	Towamensing Member of Catskill Formation	Sandstone	227	392	57	3.1	0.200	2.0	4.9	12.9	131.1
Dew	Waleksville Member of Catskill Formation	Sandstone	332	775	59	4.4	0.500	1.9	5.9	17.6	297.8
Dewt	Waleksville and Towamensing Members of Catskill Formation, undivided	Sandstone	55	804	64	2.1	0.100	2.5	8.0	25.4	106.5
Df	Foreknobs Formation	Sandstone	44	21	50	2.0	0.200	1.6	3.3	12.4	54.0
Dg	Girard Shale	Argillaceous shale	1,258	1,265	30	7.6	0.100	1.1	2.3	4.8	163.2
Dh	Hamilton Group	Shale	2,877	420	44	11.3	0.100	1.6	3.4	7.4	406.5

Table 1. Summary of indoor radon concentrations according to geologic unit in Pennsylvania, 1990–2007.—Continued

[Shading indicates geologic unit with median indoor radon concentration equal to or greater than the U.S. Environmental Protection Agency (USEPA) action level of 4 pCi/L; pCi/L, picocuries per liter; -, no data]

Map symbol ¹	Geologic formation name ¹	Primary lithology ¹	Number of test results	Density of test results, in test results per square mile	Percent-age of test results equal to or greater than the USEPA action level of 4 pCi/L	Test result skewness, in pCi/L	Minimum indoor radon concentration, in pCi/L	25th percentile indoor radon concentration, in pCi/L	Median indoor radon concentration, in pCi/L	75th percentile indoor radon concentration, in pCi/L	Maximum indoor radon concentration, in pCi/L
Dlh	Lock Haven Formation	Mudstone	1,523	133	52	5.7	0.100	1.9	4.3	11.4	305.2
Dm	Marcellus Formation	Black shale	1,378	3,190	52	4.2	0.100	2.0	4.2	8.5	108.9
Dmh	Mahantango Formation	Shale	1,185	1,129	51	7.9	0.050	1.7	4.2	9.2	399.3
Dne	Northeast Shale	Shale	617	1,149	29	4.4	0.100	1.1	2.0	4.5	78.7
Don	Onondaga Formation	Calcareous shale	15	817	40	1.1	0.700	1.0	3.5	8.2	14.4
Doo	Onondaga and Old Port Formations, undivided	Calcareous shale	881	419	49	12.3	0.200	1.7	3.8	9.0	709.3
Dor	Ridgeley Member of Old Port Formation	Sandstone	104	695	45	1.9	0.500	2.5	3.7	6.5	31.1
Dosn	Shriver, Mandata, Corriganville, and New Creek Members of Old Port Formation, undivided	Limestone	2	13	0	-	1.000	1.0	1.1	1.2	1.2
Drc	Ridgeley Formation through Coeymans Formation, undivided	Sandstone	119	946	64	8.2	0.500	2.3	5.2	9.9	204.6
Ds	Scherr Formation	Siltstone	34	20	47	2.7	0.500	2.3	3.8	6.8	54.7
DSkc	Keyser Formation through Clinton Group, undivided	Limestone	1	6	0	-	0.700	0.7	0.7	0.7	0.7
DSkm	Keyser Formation through Mifflintown Formation, undivided	Limestone	139	286	37	3.7	0.200	1.0	2.6	6.8	67.7
DSkt	Keyser and Tonoloway Formations, undivided	Limestone	2,817	975	52	8.4	0.100	1.8	4.2	9.4	333.2

Table 1. Summary of indoor radon concentrations according to geologic unit in Pennsylvania, 1990–2007.—Continued

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DSop	Onondaga Formation through Poxono Island Formation, undivided	Shale	78	1,081	47	4.1	0.200	2.4	3.6	6.8	81.4
Dtr	Trimmers Rock Formation	Siltstone	1,133	200	61	5.7	0.100	2.1	5.8	19.2	620.0
Dv	Venango Formation	Siltstone	910	200	42	10.3	0.100	1.2	3.0	7.0	262.0
fgh	Felsic and intermediate gneiss	Felsic gneiss	4,759	7,228	25	6.5	0.100	1.1	2.1	3.9	88.5
fgp	Felsic gneiss	Felsic gneiss	12,724	19,008	20	14.9	0.000	1.2	2.1	3.5	199.0
fin	Franklin Marble	Graphitic marble	233	28,008	72	2.9	0.200	3.7	9.4	20.5	177.4
gg	Graphitic felsic gneiss	Graphitic gneiss	2,213	5,483	39	6.5	0.100	1.4	3.1	6.3	232.6
gga	Banded mafic gneiss	Mafic gneiss	1,274	5,236	43	12.8	0.100	1.5	3.2	7.9	1,122.8
ggd	Felsic and intermediate gneiss	Felsic gneiss	5,792	10,656	35	20.1	0.060	1.4	2.7	5.4	790.7
gn	Felsic to mafic gneiss	Felsic gneiss	2,513	1,717	56	14.6	0.100	2.0	4.9	13.1	1,530.0
gqm	Graphitic felsic gneiss	Graphitic felsic gneiss	1,046	3,036	46	4.2	0.010	1.6	3.5	7.0	90.5
hg	Hornblende gneiss	Mafic gneiss	673	1,719	51	8.4	0.100	1.8	4.0	9.5	372.2
Jd	Diabase	Diabase	2,726	1,220	36	20.8	0.100	1.4	2.8	5.3	438.0
Js	Sedimentary strata at Jacksonwald and Aspers	Arkosic sandstone	77	8,229	56	5.5	0.500	2.3	4.6	8.4	86.2

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Kp	Patapsco(?) Formation	Ferruginous clay	465	30,981	30	3.4	0.100	1.6	2.7	4.9	36.5
mb	Metabasalt	Metabasalt	169	3	29	1.2	0.200	1.3	2.4	4.8	196.5
Mb	Burgoon Sandstone	Sandstone	24	623	58	6.8	0.700	1.7	14.2	31.1	94.0
Mbc	Burgoon Sandstone through Cuyahoga Group, undifferentiated	Sandstone	14	36	64	0.9	2.600	2.9	6.9	171.6	265.7
Mc	Cuyahoga Group	Siltstone	1,024	222	33	8.3	0.100	1.5	2.7	5.1	190.6
md	Metadiabase	Metadiabase	286	26,100	36	3.4	0.200	1.8	3.0	5.1	49.3
MDhm	Huntley Mountain Formation	Sandstone	32	2	31	3.0	0.200	1.7	2.9	4.8	125.1
MDpr	Pocono and Rockwell Formations, undivided	Sandstone	0	-	-	-	-	-	-	-	-
MDr	Rockwell Formation	Argillaceous sandstone	3	4	67	-1.7	2.000	2.0	16.0	17.0	17.0
MDsk	Spechtly Kopf Formation	Sandstone	45	39	51	2.6	0.200	1.8	4.1	9.7	43.4
MDso	Shenango Formation through Oswayo Formation, undivided	Sandstone	92	16	25	3.5	0.500	1.1	2.2	4.1	63.4
MDsr	Shenango Formation through Riceville Formation, undivided	Sandstone	11	15	82	1.5	2.000	4.3	6.3	28.0	59.0
mgh	Mafic gneiss	Mafic gneiss	1,062	11,313	24	14.5	0.013	1.3	2.3	3.9	192.7
mgp	Mafic gneiss	Mafic gneiss	1,470	16,790	14	19.9	0.000	1.1	1.9	2.9	128.5

Table 1. Summary of indoor radon concentrations according to geologic unit in Pennsylvania, 1990–2007.—Continued

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Mmc	Mauch Chunk Formation	Shale	2,314	230	54	4.5	0.100	2.0	4.5	10.4	230.0
Mp	Pocono Formation	Sandstone	60	19	42	6.2	0.300	1.7	3.2	5.0	51.9
mr	Metarhyolite	Metarhyolite	197	230	57	3.3	0.100	2.5	5.2	11.4	137.9
Ms	Shenango Formation	Sandstone	416	116	33	5.8	0.100	1.4	2.7	5.1	91.0
Msc	Shenango Formation through Cuyahoga Group, undivided	Sandstone	5	3	80	0.5	1.000	5.7	8.6	33.1	35.1
Oa	Axemann Formation	Limestone	1,504	6,588	63	14.3	0.100	2.8	7.6	15.6	535.6
Oan	Annville Formation	High-calcium limestone	105	1,975	70	3.9	0.300	3.2	8.8	24.3	221.7
Ob	Beekmantown Group	Limestone	1,729	6,102	48	6.5	0.100	1.4	3.7	8.4	217.7
Oba	Bellefonte and Axemann Formations, undivided	Dolomite	52	108	75	1.5	0.100	4.1	7.3	13.1	36.9
Obe	Bald Eagle Formation	Sandstone	11	6	45	2.0	1.300	1.4	3.2	36.9	163.0
Obf	Bellefonte Formation	Dolomite	2,433	2,549	62	3.3	0.070	2.7	6.7	16.6	159.0
Obl	Benner Formation through Loysburg Formation, undivided	Limestone	735	1,325	58	3.9	0.100	2.3	5.5	13.9	155.6
Obv	Valentine Member of Benner Formation	High-calcium limestone	21	642	67	0.9	1.600	3.5	6.7	12.1	23.6
Oc	Chambersburg Formation	Argillaceous limestone	317	1,186	63	2.3	0.100	2.8	5.7	12.6	77.1

Table 1. Summary of indoor radon concentrations according to geologic unit in Pennsylvania, 1990–2007.—Continued

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OCC	Conestoga Formation	Limestone	13,236	7,648	45	24.6	0.008	1.8	3.5	6.8	615.3
Ocl	Coburn Formation through Loysburg Formation, undivided	Limestone	61	114	49	2.4	0.100	1.8	3.7	6.7	39.6
Ocn	Coburn Formation through Nealmont Formation, undivided	Limestone	351	380	54	2.9	0.100	2.0	4.5	9.4	61.2
Oco	Cocalico Formation	Shale	2,470	4,710	71	4.2	0.100	3.1	11.2	30.3	471.1
Oe	Epler Formation	Limestone	8,494	6,017	61	7.3	0.028	2.2	6.1	13.1	435.5
Oh	Hamburg sequence rocks	Shale	12,741	4,098	64	8.6	0.100	2.4	6.7	16.7	918.2
Oha	Hershey Formation through Annville Formation, undivided	Argillaceous limestone	28	2,047	64	2.7	0.400	3.7	5.1	21.8	120.0
Ohg	Graywacke of Hamburg sequence	Graywacke	1,259	3,991	60	4.2	0.100	2.0	5.7	14.0	171.6
Ohjv	Jonestown Volcanic Suite	Andesite	5	163	60	0.1	0.700	0.7	7.2	7.5	12.1
Ohl	Limestone of Hamburg sequence	Limestone	706	3,229	57	4.8	0.200	2.2	5.1	11.5	187.9
Ohm	Hershey and Myerstown Formations, undivided	Argillaceous limestone	320	1,507	65	4.3	0.100	2.7	5.7	12.2	164.1
Ohsg	Shale and graywacke of Hamburg sequence	Shale	1,101	645	66	4.4	0.100	2.1	9.0	25.6	444.5
Oj	Juniata Formation	Sandstone	27	9	52	1.5	0.500	1.2	6.6	14.7	38.3
Ojb	Juniata and Bald Eagle Formations, undivided	Sandstone	2	4	50	-	3.300	3.3	9.2	15.0	15.0

Table 1. Summary of indoor radon concentrations according to geologic unit in Pennsylvania, 1990–2007.—Continued

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Ojk	Jacksonburg Formation	Shaly limestone	1,504	3,782	42	6.6	0.100	1.6	3.3	6.8	172.0
Om	Martinsburg Formation	Shale	7,944	1,371	57	4.7	0.008	1.6	5.4	15.8	464.1
Omg	Graywacke and shale of Martinsburg Formation	Graywacke	2,162	1,615	57	6.0	0.100	1.8	5.2	17.6	581.7
Oml	Limestone of Martinsburg Formation	Argillaceous limestone	1,688	20,667	59	4.4	0.100	2.0	5.3	10.5	129.2
On	Nittany Formation	Dolomite	2,161	6,928	59	3.5	0.100	2.2	6.2	15.0	206.6
Ons	Nittany and Stonehenge/Larke Formations, undivided	Dolomite	136	237	74	2.1	0.400	3.8	8.3	13.4	65.6
Oo	Ontelaunee Formation	Dolomite	1,858	5,990	63	8.3	0.100	2.3	6.2	14.5	411.0
Ops	Pinesburg Station Formation	Dolomite	711	3,855	71	2.4	0.100	3.0	7.3	14.3	80.1
Or	Reedsville Formation	Shale	132	54	51	3.2	0.290	2.5	4.1	9.2	144.3
Ori	Rickenbach Formation	Dolomite	1,462	5,846	53	11.0	0.100	1.9	4.5	9.6	354.7
Orr	Rockdale Run Formation	Limestone	2,456	2,755	70	3.2	0.100	2.9	8.2	17.6	190.0
Os	Stonehenge Formation	Limestone	2,224	3,646	70	9.8	0.100	3.0	8.2	17.1	630.6
Osl	Stonehenge/Larke Formation	Limestone	904	4,891	64	19.8	0.100	2.4	7.1	17.8	801.0
Osp	St. Paul Group	Limestone	2,796	3,457	71	8.4	0.073	3.4	7.5	14.2	403.7

Table 1. Summary of indoor radon concentrations according to geologic unit in Pennsylvania, 1990–2007.—Continued

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Pa	Allegheny Formation	Sandstone	5,109	175	40	9.2	0.100	1.6	3.0	6.3	348.3
Pap	Allegheny and Pottsville Formations, undivided	Sandstone	1	2	0	-	3.600	3.6	3.6	3.6	3.6
Pc	Conemaugh Group	Shale	2	10	100	-	4.970	5.0	7.3	9.7	9.7
Pcc	Casselman Formation	Shale	39,260	3,295	42	7.4	0.004	1.6	3.2	6.9	378.9
Peg	Glenshaw Formation	Shale	27,926	1,015	42	8.1	0.033	1.7	3.3	6.8	440.6
Pg	Greene Formation	Sandstone	303	69	47	5.5	0.100	1.9	3.4	8.0	119.0
Pl	Llewellyn Formation	Sandstone	10,574	3,230	25	14.3	0.100	1.1	2.1	4.0	309.7
Pm	Monongahela Group	Limestone	25,678	3,303	31	29.2	0.005	1.6	2.7	4.7	611.6
Pp	Pottsville Formation	Sandstone	4,200	127	37	22.7	0.100	1.5	2.9	5.4	713.5
PPw	Waynesburg Formation	Sandstone	8,037	2,537	31	6.8	0.040	1.5	2.7	4.7	125.1
Pw	Washington Formation	Sandstone	956	343	33	11.6	0.100	1.7	2.8	5.0	193.1
Qs	Sands of Presque Isle	Sand	0	-	-	-	-	-	-	-	-
Qt	Trenton Gravel	Gravelly sand	8,399	8,266	16	44.6	0.100	0.9	1.7	3.0	847.6
Sb	Bloomsburg Formation	Shale	184	259	49	6.6	0.300	2.0	3.9	9.9	181.2

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Sbm	Bloomsburg and Mifflintown Formations, undivided	Shale	1,070	366	43	5.5	0.000	1.4	3.4	7.7	195.0
Sc	Clinton Group	Shale	1,035	238	39	7.2	0.100	1.6	3.0	6.1	212.8
Sdp	Decker Formation through Poxono Island Formation, undivided	Calcareous sandstone	47	351	45	2.9	0.500	1.3	2.2	7.1	37.8
Ss	Shawangunk Formation	Sandstone	9	12	44	0.8	0.100	0.5	0.6	6.9	11.7
St	Tuscarora Formation	Quartzite	46	11	41	1.9	0.500	0.9	2.4	5.6	21.7
Swc	Wills Creek Formation	Calcareous shale	1,659	575	38	7.7	0.100	1.5	2.9	6.5	194.7
Swm	Wills Creek Formation through Mifflintown Formation, undivided	Calcareous shale	0	-	-	-	-	-	-	-	-
Tbm	Bryn Mawr Formation	Gravelly sand	4,035	50,307	17	4.7	0.080	1.1	2.0	3.3	37.0
Tpb	Pensauken and Bridgeton Formations, undifferentiated	Feldspathic quartz sand	14,638	22,737	16	13.4	0.000	1.0	1.8	3.1	137.2
Trb	Brunswick Formation	Mudstone	33,325	7,895	31	15.0	0.004	1.4	2.5	4.8	395.1
Trfl	Limestone fanglomerate	Limestone conglomerate	457	3,099	56	4.2	0.100	2.1	5.0	10.3	99.6
Trfq	Quartz fanglomerate	Quartz conglomerate	695	1,787	42	4.0	0.100	1.3	3.1	7.0	102.0
Trg	Gettysburg Formation	Silty mudstone	4,256	1,488	44	6.7	0.000	1.7	3.4	6.9	225.1
Trgc	Gettysburg conglomerate	Quartz conglomerate	553	2,047	57	5.2	0.100	2.3	4.6	9.4	159.1

Table 1. Summary of indoor radon concentrations according to geologic unit in Pennsylvania, 1990–2007.—Continued

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Trgh	Heidlersburg Member of Gettysburg Formation	Shale	331	795	49	6.9	0.200	1.7	3.9	7.8	171.8
Trh	Hammer Creek Formation	Sandstone	1,400	1,308	47	4.6	0.100	1.8	3.7	7.4	153.2
Trhc	Hammer Creek conglomerate	Quartz conglomerate	679	868	46	9.3	0.100	1.9	3.5	7.8	202.3
Trl	Lockatong Formation	Argillite	17,527	12,436	34	33.5	0.006	1.4	2.6	5.2	891.6
Trn	New Oxford Formation	Arkosic sandstone	2,878	1,656	53	28.3	0.100	2.1	4.3	8.1	937.0
Trnc	New Oxford conglomerate	Quartz conglomerate	84	1,039	45	4.3	0.200	1.8	3.6	8.5	138.8
Trs	Stockton Formation	Arkosic sandstone	47,897	23,592	30	10.2	0.000	1.3	2.4	4.6	351.5
Trsc	Stockton conglomerate	Quartz conglomerate	622	16,614	42	4.0	0.100	1.7	3.3	6.3	69.4
vs	Greenstone schist	Greenstone schist	39	719	69	2.3	0.400	1.8	7.2	12.5	51.5
Xa	Anorthosite	Anorthosite	562	14,667	10	13.9	0.100	0.8	1.5	2.7	77.4
Xc	Cockeysville Marble	Marble	290	3,290	35	11.8	0.400	1.6	2.7	4.8	322.8
Xgr	Granitic gneiss and granite	Granitic gneiss	5,830	57,673	29	8.7	0.100	1.3	2.6	4.5	123.1
Xgw	Glenarm Wissahickon formation	Oligoclase-mica schist	10,210	5,994	32	7.7	0.010	1.2	2.5	5.2	282.8
Xm	Marburg Schist	Phyllite	1,890	1,906	71	3.4	0.100	3.3	9.6	23.2	268.6

Table 1. Summary of indoor radon concentrations according to geologic unit in Pennsylvania, 1990–2007.—Continued

[Shading indicates geologic unit with median indoor radon concentration equal to or greater than the U.S. Environmental Protection Agency (USEPA) action level of 4 pCi/L; pCi/L, picocuries per liter; -, no data]

Map symbol ¹	Geologic formation name ¹	Primary lithology ¹	Number of test results	Density of test results, in test results per square mile	Percentage of test results equal to or greater than the USEPA action level of 4 pCi/L	Test result skewness, in pCi/L	Minimum indoor radon concentration, in pCi/L	25th percentile indoor radon concentration, in pCi/L	Median indoor radon concentration, in pCi/L	75th percentile indoor radon concentration, in pCi/L	Maximum indoor radon concentration, in pCi/L
Xmg	Metagabbro	Metagabbro	0	-	-	-	-	-	-	-	-
Xmgh	Mafic gneiss	Mafic gneiss	1,501	14,040	25	23.5	0.100	1.1	2.0	4.1	341.4
Xmgp	Mafic gneiss	Mafic gneiss	948	11,764	15	9.2	0.200	0.8	1.4	2.8	71.1
Xo	Octoraro Formation	Albite-chlorite schist	13,787	3,792	51	6.4	0.001	1.4	4.1	11.6	549.9
Xpb	Peach Bottom Slate and Cardiff Conglomerate, undivided	Slate	24	651	71	2.5	1.000	3.4	12.1	31.6	151.4
Xpc	Peters Creek Schist	Chlorite-sericite schist	1,572	1,014	63	5.7	0.100	2.4	6.4	15.0	324.1
Xpg	Pegmatite	Granitic pegmatite	123	10,062	25	7.6	0.400	1.1	1.8	4.0	269.4
Xsc	Sams Creek Metabasalt	Metabasalt	97	1,570	61	5.5	0.500	2.4	4.6	8.0	245.3
Xsq	Setters Quartzite	Feldspathic quartzite	517	5,069	30	7.4	0.100	1.3	2.6	4.7	137.7
Xu	Ultramafic rocks	Serpentinite	1,353	6,482	32	13.3	0.100	1.2	2.4	4.9	333.2
Xw	Wissahickon Formation	Oligoclase-mica schist	38,298	28,451	27	114.1	0.000	1.3	2.4	4.2	1,604.0
Xwk	Wakefield Marble	Marble	2	255	100	-	56.200	56.2	57.9	59.5	59.5

¹Geologic units from Pennsylvania Geological Survey, 2001; names may not conform to usage by the U.S. Geological Survey.

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