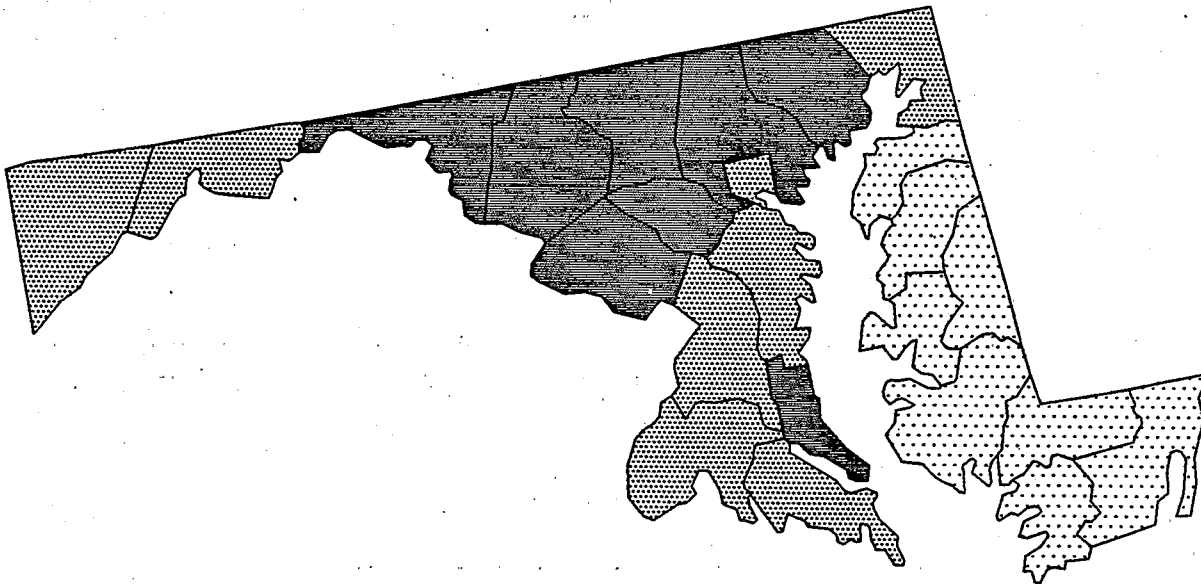




## EPA's Map of Radon Zones

### MARYLAND





**EPA'S MAP OF RADON ZONES  
MARYLAND**

**RADON DIVISION  
OFFICE OF RADIATION AND INDOOR AIR  
U.S. ENVIRONMENTAL PROTECTION AGENCY**

**SEPTEMBER, 1993**

## **ACKNOWLEDGEMENTS**

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## OVERVIEW

Sections 307 and 309 of the 1988 Indoor Radon Abatement Act (IRAA) direct EPA to identify areas of the United States that have the potential to produce elevated levels of radon. EPA, the U.S. Geological Survey (USGS), and the Association of American State Geologists (AASG) have worked closely over the past several years to produce a series of maps and documents which address these directives. The EPA Map of Radon Zones is a compilation of that work and fulfills the requirements of sections 307 and 309 of IRAA. The Map of Radon Zones identifies, on a county-by-county basis, areas of the U.S. that have the highest potential for elevated indoor radon levels (greater than 4 pCi/L).

The Map of Radon Zones is designed to assist national, State and local governments and organizations to target their radon program activities and resources. It is also intended to help building code officials determine areas that are the highest priority for adopting radon-resistant building practices. The Map of Radon Zones should not be used to determine if individual homes in any given area need to be tested for radon. **EPA recommends that all homes be tested for radon, regardless of geographic location or the zone designation of the county in which they are located.**

This document provides background information concerning the development of the Map of Radon Zones. It explains the purposes of the map, the approach for developing the map (including the respective roles of EPA and USGS), the data sources used, the conclusions and confidence levels developed for the prediction of radon potential, and the review process that was conducted to finalize this effort.

## BACKGROUND

Radon ( $\text{Rn}^{222}$ ) is a colorless, odorless, radioactive gas. It comes from the natural decay of uranium that is found in nearly all soils. It typically moves through the ground to the air above and into homes and other buildings through cracks and openings in the foundation. Any home, school or workplace may have a radon problem, regardless of whether it is new or old, well-sealed or drafty, or with or without a basement. Nearly one out of every 15 homes in the U.S. is estimated to have elevated annual average levels of indoor radon.

Radon first gained national attention in early 1984, when extremely high levels of indoor radon were found in areas of Pennsylvania, New Jersey, and New York, along the Reading Prong-physiographic province. EPA established a Radon Program in 1985 to assist States and homeowners in reducing their risk of lung cancer from indoor radon.

Since 1985, EPA and USGS have been working together to continually increase our understanding of radon sources and the migration dynamics that cause elevated indoor radon levels. Early efforts resulted in the 1987 map entitled "Areas with Potentially High Radon Levels." This map was based on limited geologic information only because few indoor radon measurements were available at the time. The development of EPA's Map of Radon Zones and its technical foundation, USGS' National Geologic Radon Province Map, has been based on additional information from six years of the State/EPA Residential Radon Surveys, independent State residential surveys, and continued expansion of geologic and geophysical information, particularly the data from the National Uranium Resource Evaluation project.

### Purpose of the Map of Radon Zones

EPA's Map of Radon Zones (Figure 1) assigns each of the 3141 counties in the United States to one of three zones:

- o Zone 1 counties have a predicted average indoor screening level > than 4 pCi/L
- o Zone 2 counties have a predicted average screening level  $\geq 2$  pCi/L and  $\leq 4$  pCi/L
- o Zone 3 counties have a predicted average screening level < 2 pCi/L

The Zone designations were determined by assessing five factors that are known to be important indicators of radon potential: indoor radon measurements, geology, aerial radioactivity, soil parameters, and foundation types.

The predictions of average screening levels in each of the Zones is an expression of radon potential in the lowest liveable area of a structure. This map is unable to estimate actual exposures to radon. EPA recommends methods for testing and fixing individual homes based on an estimate of actual exposure to radon. For more information on testing and fixing elevated radon levels in homes consult these EPA publications: *A Citizen's Guide to Radon*, *the Consumer's Guide to Radon Reduction* and *the Home Buyer's and Seller's Guide to Radon*.

EPA believes that States, local governments and other organizations can achieve optimal risk reductions by targeting resources and program activities to high radon potential areas. Emphasizing targeted approaches (technical assistance, information and outreach efforts, promotion of real estate mandates and policies and building codes, etc.) in such areas addresses the greatest potential risks first.

EPA also believes that the use of passive radon control systems in the construction of new homes in Zone 1 counties, and the activation of those systems if necessitated by follow-up testing, is a cost effective approach to achieving significant radon risk reduction.

The Map of Radon Zones and its supporting documentation establish no regulatory requirements. Use of this map by State or local radon programs and building code officials is voluntary. The information presented on the Map of Radon Zones and in the supporting documentation is not applicable to radon in water.

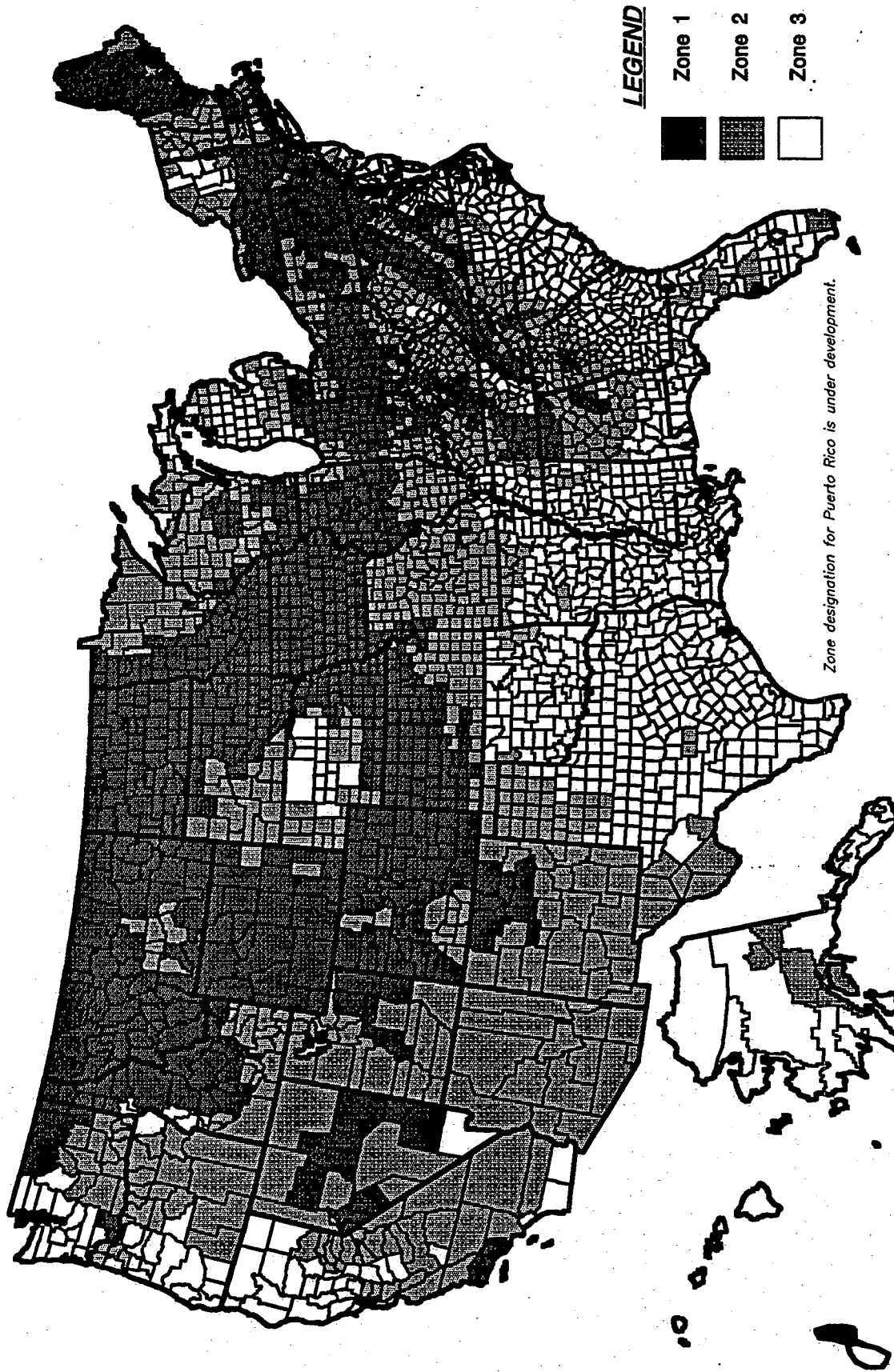
### Development of the Map of Radon Zones

The technical foundation for the Map of Radon Zones is the USGS Geologic Radon Province Map. In order to examine the radon potential for the United States, the USGS began by identifying approximately 360 separate geologic provinces for the U.S. The provinces are shown on the USGS Geologic Radon Province Map (Figure 2). Each of the geologic provinces was evaluated by examining the available data for that area: indoor radon measurements, geology, aerial radioactivity, soil parameters, and foundation types. As stated previously, these five factors are considered to be of basic importance in assessing radon



Figure 1

## EPA Map of Radon Zones



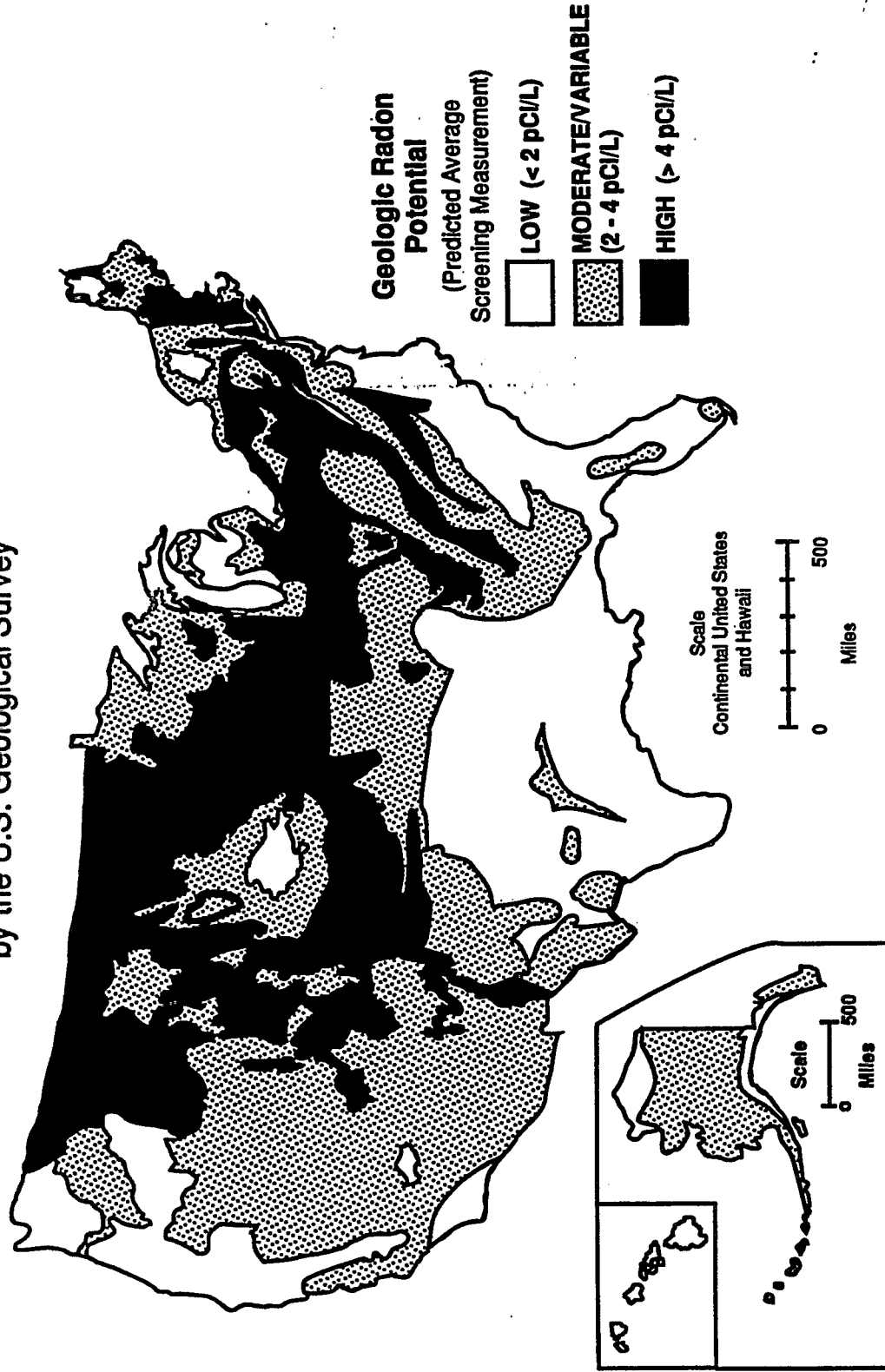
Guam -- Preliminary Zone designation.

The purpose of this map is to assist National, State and local organizations to target their resources and to implement radon-resistant building codes. This map is not intended to be used to determine if a home in a given zone should be tested for radon. Homes with elevated levels of radon have been found in all three zones. All homes should be tested, regardless of geographic location.

**IMPORTANT:** Consult the EPA Map of Radon Zones document (EPA-402-R-93-071) before using this map. This document contains information on radon potential variations within counties. EPA also recommends that this map be supplemented with any available local data in order to further understand and predict the radon potential of a specific area.

Figure 2

# GENERALIZED GEOLOGIC RADON POTENTIAL OF THE UNITED STATES by the U.S. Geological Survey



potential and some data are available for each of these factors in every geologic province. The province boundaries do not coincide with political borders (county and state) but define areas of general radon potential. The five factors were assigned numerical values based on an assessment of their respective contribution to radon potential, and a confidence level was assigned to each contributing variable. The approach used by USGS to estimate the radon potential for each province is described in Part II of this document.

EPA subsequently developed the Map of Radon Zones by extrapolating from the province level to the county level so that all counties in the U.S. were assigned to one of three radon zones. EPA assigned each county to a given zone based on its provincial radon potential. For example, if a county is located within a geologic province that has a predicted average screening level greater than 4 pCi/L, it was assigned to Zone 1. Likewise, counties located in provinces with predicted average screening levels  $\geq 2$  pCi/L and  $\leq 4$  pCi/L, and less than 2 pCi/L, were assigned to Zones 2 and 3, respectively.

If the boundaries of a county fall in more than one geologic province, the county was assigned to a zone based on the predicted radon potential of the province in which most of the area lies. For example, if three different provinces cross through a given county, the county was assigned to the zone representing the radon potential of the province containing most of the county's land area. (In this case, it is not technically correct to say that the predicted average screening level applies to the entire county since the county falls in multiple provinces with differing radon potentials.)

Figures 3 and 4 demonstrate an example of how EPA extrapolated the county zone designations for Nebraska from the USGS geologic province map for the State. As figure 3 shows, USGS has identified 5 geologic provinces for Nebraska. Most of the counties are extrapolated "straight" from their corresponding provinces, but there are counties "partitioned" by several provinces -- for example, Lincoln County. Although Lincoln county falls in multiple provinces, it was assigned to Zone 3 because most of its area falls in the province with the lowest radon potential.

It is important to note that EPA's extrapolation from the province level to the county level may mask significant "highs" and "lows" within specific counties. In other words, within-county variations in radon potential are not shown on the Map of Radon Zones. EPA recommends that users who may need to address specific within-county variations in radon potential (e.g., local government officials considering the implementation of radon-resistant construction codes) consult USGS' Geologic Radon Province Map and the State chapters provided with this map for more detailed information, as well as any locally available data.

### Map Validation

The Map of Radon Zones is intended to represent a preliminary assessment of radon potential for the entire United States. The factors that are used in this effort -- indoor radon data, geology, aerial radioactivity, soils, and foundation type -- are basic indicators for radon potential. It is important to note, however, that the map's county zone designations are not "statistically valid" predictions due to the nature of the data available for these 5 factors at the county level. In order to validate the map in light of this lack of statistical confidence, EPA conducted a number of analyses. These analyses have helped EPA to identify the best situations in which to apply the map, and its limitations.

Figure 3

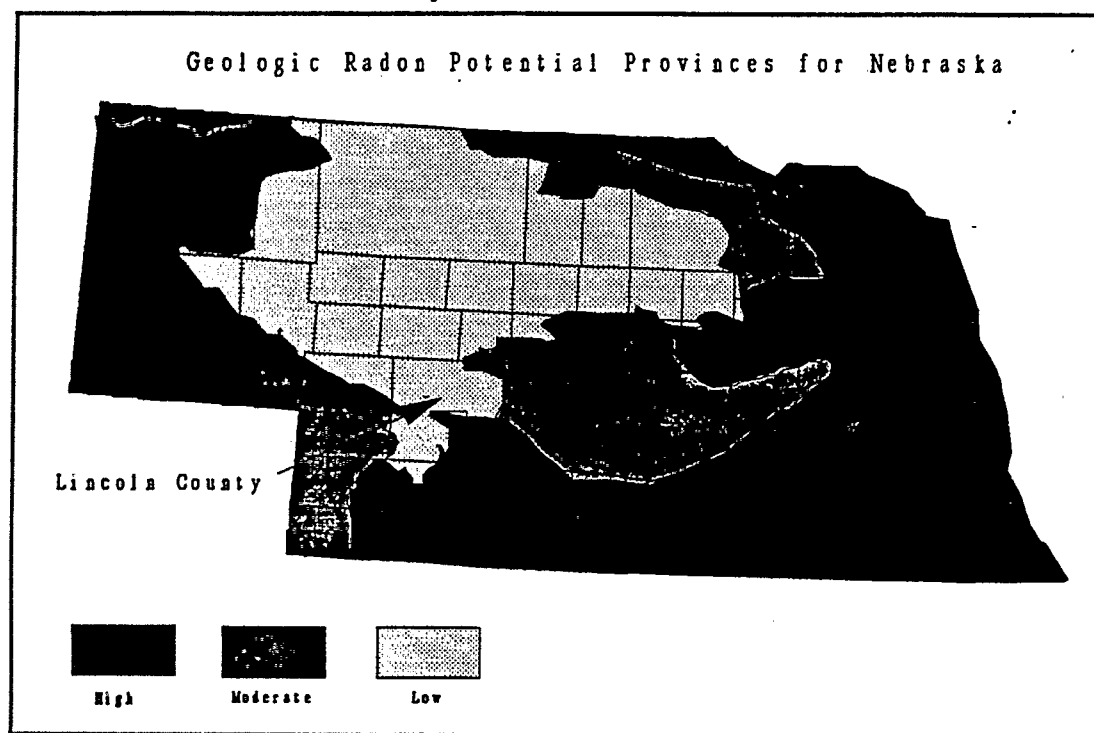
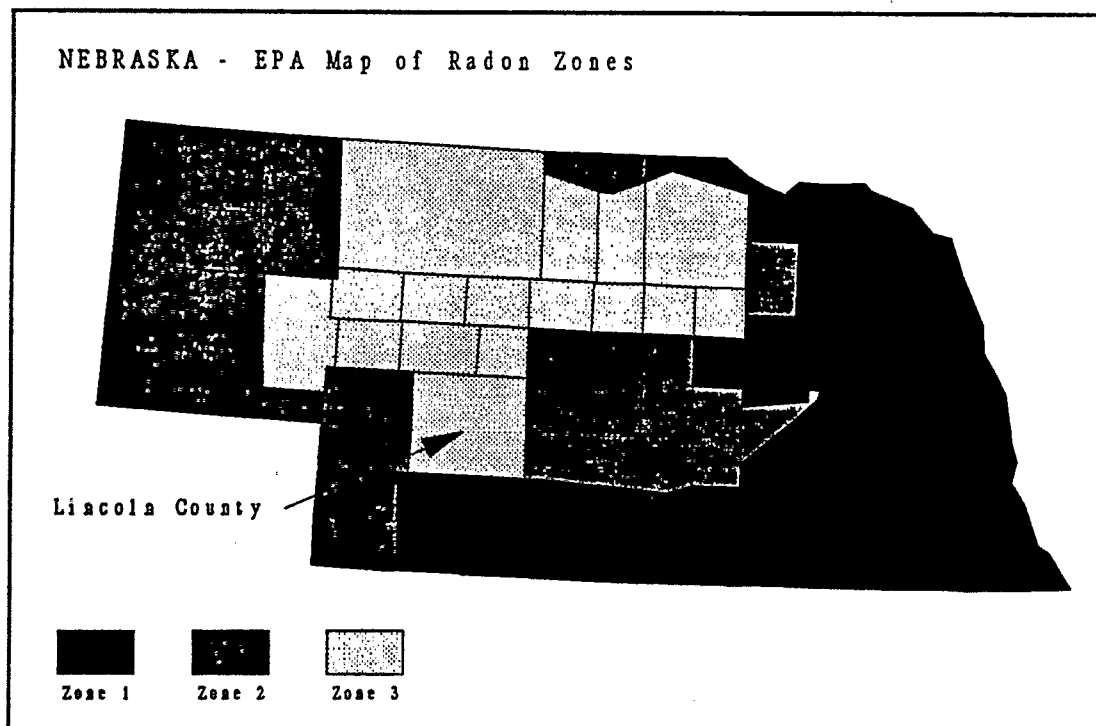


Figure 4



One such analysis involved comparing county zone designations to indoor radon measurements from the State/EPA Residential Radon Surveys (SRRS). Screening averages for counties with at least 100 measurements were compared to the counties' predicted radon potential as indicated by the Map of Radon Zones. EPA found that 72% of the county screening averages were correctly reflected by the appropriate zone designations on the Map. In all other cases, they only differed by 1 zone.

Another accuracy analysis used the annual average data from the National Residential Radon Survey (NRRS). The NRRS indicated that approximately 6 million homes in the United States have annual averages greater than or equal to 4 pCi/L. By cross checking the county location of the approximately 5,700 homes which participated in the survey, their radon measurements, and the zone designations for these counties, EPA found that approximately 3.8 million homes of the 5.4 million homes with radon levels greater than or equal to 4 pCi/L will be found in counties designated as Zone 1. A random sampling of an equal number of counties would have only found approximately 1.8 million homes greater than 4 pCi/L. In other words, this analysis indicated that the map approach is three times more efficient at identifying high radon areas than random selection of zone designations.

Together, these analyses show that the approach EPA used to develop the Map of Radon Zones is a reasonable one. In addition, the Agency's confidence is enhanced by results of the extensive State review process -- the map generally agrees with the States' knowledge of and experience in their own jurisdictions. However, the accuracy analyses highlight two important points: the fact that elevated levels will be found in Zones 2 and 3, and that there will be significant numbers of homes with lower indoor radon levels in all of the Zones. For these reasons, users of the Map of Radon Zones need to supplement the Map with locally available data whenever possible. Although all known "hot spots", i.e., localized areas of consistently elevated levels, are discussed in the State-specific chapters, accurately defining the boundaries of the "hot spots" on this scale of map is not possible at this time. Also, unknown "hot spots" do exist.

The Map of Radon Zones is intended to be a starting point for characterizing radon potential because our knowledge of radon sources and transport is always growing. Although this effort represents the best data available at this time, EPA will continue to study these parameters and others such as house construction, ventilation features and meteorology factors in order to better characterize the presence of radon in U.S. homes, especially in high risk areas. These efforts will eventually assist EPA in refining and revising the conclusions of the Map of Radon Zones. And although this map is most appropriately used as a targeting tool by the aforementioned audiences -- **the Agency encourages all residents to test their homes for radon, regardless of geographic location or the zone designation of the county in which they live.** Similarly, the Map of Radon Zones should not be used in lieu of testing during real estate transactions.

### Review Process

The Map of Radon Zones has undergone extensive review within EPA and outside the Agency. The Association of American State Geologists (AASG) played an integral role in this review process. The AASG individual State geologists have reviewed their State-specific information, the USGS Geologic Radon Province Map, and other materials for their geologic content and consistency.

In addition to each State geologist providing technical comments, the State radon offices were asked to comment on their respective States' radon potential evaluations. In particular, the States were asked to evaluate the data used to assign their counties to specific zones. EPA and USGS worked with the States to resolve any issues concerning county zone designations. In a few cases, States have requested changes in county zone designations. The requests were based on additional data from the State on geology, indoor radon measurements, population, etc. Upon reviewing the data submitted by the States, EPA did make some changes in zone designations. These changes, which do not strictly follow the methodology outlined in this document, are discussed in the respective State chapters.

EPA encourages the States and counties to conduct further research and data collection efforts to refine the Map of Radon Zones. EPA would like to be kept informed of any changes the States, counties, or others make to the maps. Updates and revisions will be handled in a similar fashion to the way the map was developed. States should notify EPA of any proposed changes by forwarding the changes through the Regional EPA offices that are listed in Part II. Depending on the amount of new information that is presented, EPA will consider updating this map periodically. The State radon programs should initiate proper notification of the appropriate State officials when the Map of Radon Zones is released and when revisions or updates are made by the State or EPA.

# THE USGS/EPA RADON POTENTIAL ASSESSMENTS: AN INTRODUCTION

by

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## BACKGROUND

The Indoor Radon Abatement Act of 1988 (15 U.S.C. 2661-2671) directed the U.S. Environmental Protection Agency (EPA) to identify areas of the United States that have the potential to produce harmful levels of indoor radon. These characterizations were to be based on both geological data and on indoor radon levels in homes and other structures. The EPA also was directed to develop model standards and techniques for new building construction that would provide adequate prevention or mitigation of radon entry. As part of an Interagency Agreement between the EPA and the U.S. Geological Survey (USGS), the USGS has prepared radon potential estimates for the United States. This report is one of ten booklets that document this effort. The purpose and intended use of these reports is to help identify areas where states can target their radon program resources, to provide guidance in selecting the most appropriate building code options for areas, and to provide general information on radon and geology for each state for federal, state, and municipal officials dealing with radon issues. *These reports are not intended to be used as a substitute for indoor radon testing, and they cannot and should not be used to estimate or predict the indoor radon concentrations of individual homes, building sites, or housing tracts. Elevated levels of indoor radon have been found in every State, and EPA recommends that all homes be tested for indoor radon.*

Booklets detailing the radon potential assessment for the U.S. have been developed for each State. USGS geologists are the authors of the geologic radon potential booklets. Each booklet consists of several components, the first being an overview to the mapping project (Part I), this introduction to the USGS assessment (Part II), including a general discussion of radon (occurrence, transport, etc.), and details concerning the types of data used. The third component is a summary chapter outlining the general geology and geologic radon potential of the EPA Region (Part III). The fourth component is an individual chapter for each state (Part IV). Each state chapter discusses the state's specific geographic setting, soils, geologic setting, geologic radon potential, indoor radon data, and a summary outlining the radon potential rankings of geologic areas in the state. A variety of maps are presented in each chapter—geologic, geographic, population, soils, aerial radioactivity, and indoor radon data by county. Finally, the booklets contain EPA's map of radon zones for each state and an accompanying description (Part V).

Because of constraints on the scales of maps presented in these reports and because the smallest units used to present the indoor radon data are counties, some generalizations have been made in order to estimate the radon potential of each area. Variations in geology, soil characteristics, climatic factors, homeowner lifestyles, and other factors that influence radon concentrations can be quite large within any particular geologic area, so these reports cannot be used to estimate or predict the indoor radon concentrations of individual homes or housing

tracts. Within any area of a given geologic radon potential ranking, there are likely to be areas where the radon potential is lower or higher than that assigned to the area as a whole, especially in larger areas such as the large counties in some western states.

In each state chapter, references to additional reports related to radon are listed for the state, and the reader is urged to consult these reports for more detailed information. In most cases the best sources of information on radon for specific areas are state and local departments of health, state departments responsible for nuclear safety or environmental protection, and U.S. EPA regional offices. More detailed information on state or local geology may be obtained from the state geological surveys. Addresses and telephone numbers of state radon contacts, geological surveys, and EPA regional offices are listed in Appendix C at the end of this chapter.

## RADON GENERATION AND TRANSPORT IN SOILS

Radon ( $^{222}\text{Rn}$ ) is produced from the radioactive decay of radium ( $^{226}\text{Ra}$ ), which is, in turn, a product of the decay of uranium ( $^{238}\text{U}$ ) (fig. 1). The half-life of  $^{222}\text{Rn}$  is 3.825 days. Other isotopes of radon occur naturally, but, with the exception of thoron ( $^{220}\text{Rn}$ ), which occurs in concentrations high enough to be of concern in a few localized areas, they are less important in terms of indoor radon risk because of their extremely short half-lives and less common occurrence. In general, the concentration and mobility of radon in soil are dependent on several factors, the most important of which are the soil's radium content and distribution, porosity, permeability to gas movement, and moisture content. These characteristics are, in turn, determined by the soil's parent-material composition, climate, and the soil's age or maturity. If parent-material composition, climate, vegetation, age of the soil, and topography are known, the physical and chemical properties of a soil in a given area can be predicted.

As soils form, they develop distinct layers, or horizons, that are cumulatively called the soil profile. The A horizon is a surface or near-surface horizon containing a relative abundance of organic matter but dominated by mineral matter. Some soils contain an E horizon, directly below the A horizon, that is generally characterized by loss of clays, iron, or aluminum, and has a characteristically lighter color than the A horizon. The B horizon underlies the A or E horizon. Important characteristics of B horizons include accumulation of clays, iron oxides, calcium carbonate or other soluble salts, and organic matter complexes. In drier environments, a horizon may exist within or below the B horizon that is dominated by calcium carbonate, often called caliche or calcrete. This carbonate-cemented horizon is designated the K horizon in modern soil classification schemes. The C horizon underlies the B (or K) and is a zone of weathered parent material that does not exhibit characteristics of A or B horizons; that is, it is generally not a zone of leaching or accumulation. In soils formed in place from the underlying bedrock, the C horizon is a zone of unconsolidated, weathered bedrock overlying the unweathered bedrock.

The shape and orientation of soil particles (soil structure) control permeability and affect water movement in the soil. Soils with blocky or granular structure have roughly equivalent permeabilities in the horizontal and vertical directions, and air and water can infiltrate the soil relatively easily. However, in soils with platy structure, horizontal permeability is much greater than vertical permeability, and air and moisture infiltration is generally slow. Soils with prismatic or columnar structure have dominantly vertical permeability. Platy and prismatic structures form in soils with high clay contents. In soils with shrink-swell clays, air



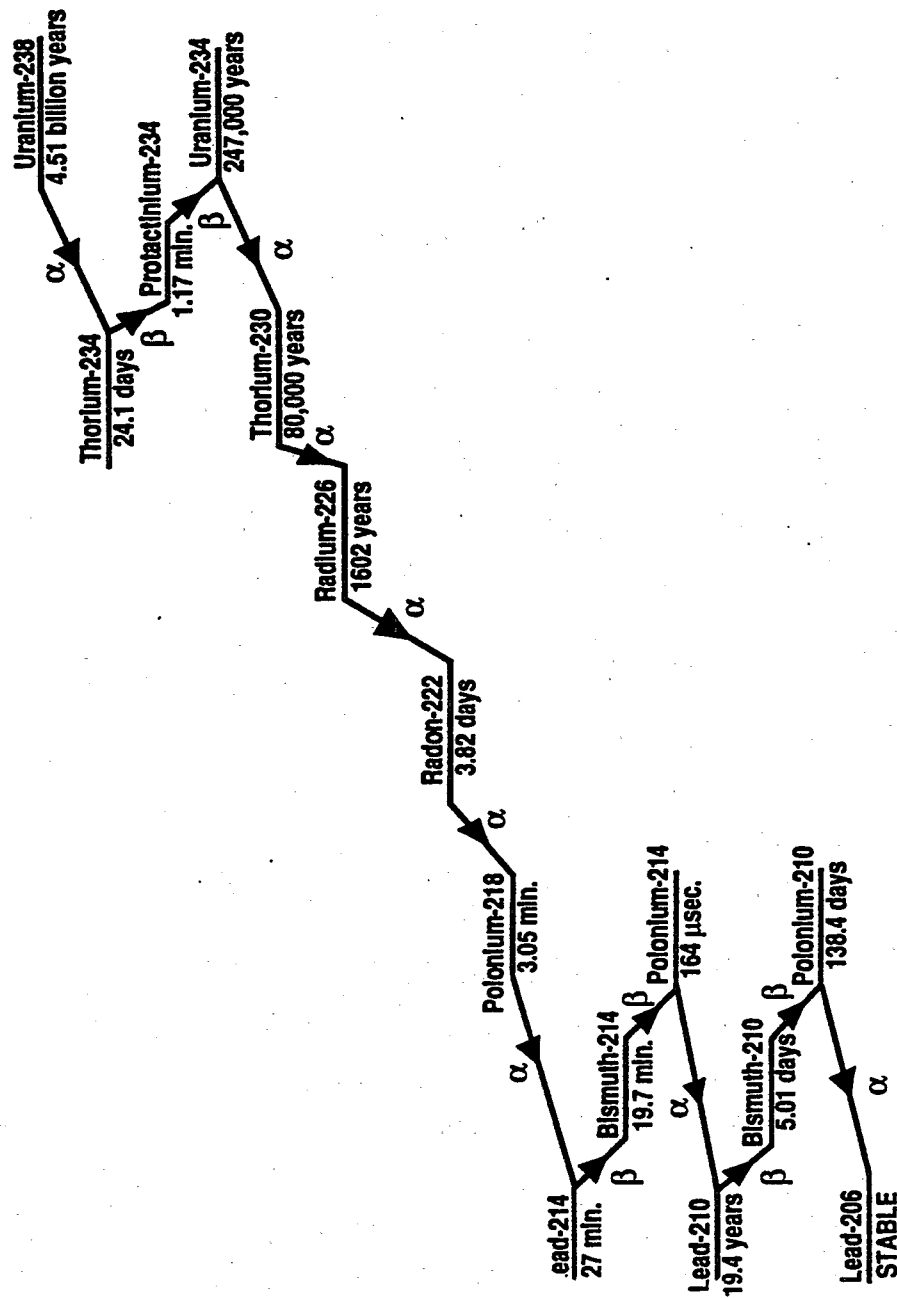


Figure 1. The uranium-238 decay series, showing the half-lives of elements and their modes of decay (after Wanty and Schoen, 1991).  $\alpha$  denotes alpha decay,  $\beta$  denotes beta decay.



and moisture infiltration rates and depth of wetting may be limited when the cracks in the surface soil layers swell shut. Clay-rich B horizons, particularly those with massive or platy structure, can form a capping layer that impedes the escape of soil gas to the surface (Schumann and others, 1992). However, the shrinkage of clays can act to open or widen cracks upon drying, thus increasing the soil's permeability to gas flow during drier periods.

Radon transport in soils occurs by two processes: (1) diffusion and (2) flow (Tanner, 1964). Diffusion is the process whereby radon atoms move from areas of higher concentration to areas of lower concentration in response to a concentration gradient. Flow is the process by which soil air moves through soil pores in response to differences in pressure within the soil or between the soil and the atmosphere, carrying the radon atoms along with it. Diffusion is the dominant radon transport process in soils of low permeability, whereas flow tends to dominate in highly permeable soils (Sextro and others, 1987). In low-permeability soils, much of the radon may decay before it is able to enter a building because its transport rate is reduced. Conversely, highly permeable soils, even those that are relatively low in radium, such as those derived from some types of glacial deposits, have been associated with high indoor radon levels in Europe and in the northern United States (Akerblom and others, 1984; Kunz and others, 1989; Sextro and others, 1987). In areas of karst topography formed in carbonate rock (limestone or dolomite) environments, solution cavities and fissures can increase soil permeability at depth by providing additional pathways for gas flow.

Not all radium contained in soil grains and grain coatings will result in mobile radon when the radium decays. Depending on where the radium is distributed in the soil, many of the radon atoms may remain imbedded in the soil grain containing the parent radium atom, or become imbedded in adjacent soil grains. The portion of radium that releases radon into the pores and fractures of rocks and soils is called the emanating fraction. When a radium atom decays to radon, the energy generated is strong enough to send the radon atom a distance of about 40 nanometers ( $1 \text{ nm} = 10^{-9}$  meters), or about  $2 \times 10^{-6}$  inches—this is known as alpha recoil (Tanner, 1980). Moisture in the soil lessens the chance of a recoiling radon atom becoming imbedded in an adjacent grain. Because water is more dense than air, a radon atom will travel a shorter distance in a water-filled pore than in an air-filled pore, thus increasing the likelihood that the radon atom will remain in the pore space. Intermediate moisture levels enhance radon emanation but do not significantly affect permeability. However, high moisture levels can significantly decrease the gas permeability of the soil and impede radon movement through the soil.

Concentrations of radon in soils are generally many times higher than those inside of buildings, ranging from tens of pCi/L to more than 100,000 pCi/L, but typically in the range of hundreds to low thousands of pCi/L. Soil-gas radon concentrations can vary in response to variations in climate and weather on hourly, daily, or seasonal time scales. Schumann and others (1992) and Rose and others (1988) recorded order-of-magnitude variations in soil-gas radon concentrations between seasons in Colorado and Pennsylvania. The most important factors appear to be (1) soil moisture conditions, which are controlled in large part by precipitation; (2) barometric pressure; and (3) temperature. Washington and Rose (1990) suggest that temperature-controlled partitioning of radon between water and gas in soil pores also has a significant influence on the amount of mobile radon in soil gas.

Homes in hilly limestone regions of the southern Appalachians were found to have higher indoor radon concentrations during the summer than in the winter. A suggested cause for this phenomenon involves temperature/pressure-driven flow of radon-laden air from subsurface



solution cavities in the carbonate rock into houses. As warm air enters solution cavities that are higher on the hillslope than the homes, it cools and settles, pushing radon-laden air from lower in the cave or cavity system into structures on the hillslope (Gammage and others, 1993). In contrast, homes built over caves having openings situated below the level of the home had higher indoor radon levels in the winter, caused by cooler outside air entering the cave, driving radon-laden air into cracks and solution cavities in the rock and soil, and ultimately, into homes (Gammage and others, 1993).

## RADON ENTRY INTO BUILDINGS

A driving force (reduced atmospheric pressure in the house relative to the soil, producing a pressure gradient) and entry points must exist for radon to enter a building from the soil. The negative pressure caused by furnace combustion, ventilation devices, and the stack effect (the rising and escape of warm air from the upper floors of the building, causing a temperature and pressure gradient within the structure) during cold winter months are common driving forces. Cracks and other penetrations through building foundations, sump holes, and slab-to-foundation wall joints are common entry points.

Radon levels in the basement are generally higher than those on the main floor or upper floors of most structures. Homes with basements generally provide more entry points for radon, commonly have a more pronounced stack effect, and typically have lower air pressure relative to the surrounding soil than nonbasement homes. The term "nonbasement" applies to slab-on-grade or crawl space construction.

## METHODS AND SOURCES OF DATA

The assessments of radon potential in the booklets that follow this introduction were made using five main types of data: (1) geologic (lithologic); (2) aerial radiometric; (3) soil characteristics, including soil moisture, permeability, and drainage characteristics; (4) indoor radon data; and (5) building architecture (specifically, whether homes in each area are built slab-on-grade or have a basement or crawl space). These five factors were evaluated and integrated to produce estimates of radon potential. Field measurements of soil-gas radon or soil radioactivity were not used except where such data were available in existing, published reports of local field studies. Where applicable, such field studies are described in the individual state chapters.

## GEOLOGIC DATA

The types and distribution of lithologic units and other geologic features in an assessment area are of primary importance in determining radon potential. Rock types that are most likely to cause indoor radon problems include carbonaceous black shales, glauconite-bearing sandstones, certain kinds of fluvial sandstones and fluvial sediments, phosphorites, chalk, karst-producing carbonate rocks, certain kinds of glacial deposits, bauxite, uranium-rich granitic rocks, metamorphic rocks of granitic composition, silica-rich volcanic rocks, many sheared or faulted rocks, some coals, and certain kinds of contact metamorphosed rocks. Rock types least likely to cause radon problems include marine quartz sands, non-carbonaceous shales and siltstones, certain kinds of clays, silica-poor metamorphic and

igneous rocks, and basalts. Exceptions exist within these general lithologic groups because of the occurrence of localized uranium deposits, commonly of the hydrothermal type in crystalline rocks or the "roll-front" type in sedimentary rocks. Uranium and radium are commonly sited in heavy minerals, iron-oxide coatings on rock and soil grains, and organic materials in soils and sediments. Less common are uranium associated with phosphate and carbonate complexes in rocks and soils, and uranium minerals.

Although many cases of elevated indoor radon levels can be traced to high radium and (or) uranium concentrations in parent rocks, some structural features, most notably faults and shear zones, have been identified as sites of localized uranium concentrations (Deffeyes and MacGregor, 1980) and have been associated with some of the highest reported indoor radon levels (Gundersen, 1991). The two highest known indoor radon occurrences are associated with sheared fault zones in Boyertown, Pennsylvania (Gundersen and others, 1988a; Smith and others, 1987), and in Clinton, New Jersey (Henry and others, 1991; Muessig and Bell, 1988).

#### NURE AERIAL RADIOMETRIC DATA

Aerial radiometric data are used to quantify the radioactivity of rocks and soils. Equivalent uranium (eU) data provide an estimate of the surficial concentrations of radon parent materials (uranium, radium) in rocks and soils. Equivalent uranium is calculated from the counts received by a gamma-ray detector from the 1.76 MeV (mega-electron volts) emission energy corresponding to bismuth-214 ( $^{214}\text{Bi}$ ), with the assumption that uranium and its decay products are in secular equilibrium. Equivalent uranium is expressed in units of parts per million (ppm). Gamma radioactivity also may be expressed in terms of a radium activity; 3 ppm eU corresponds to approximately 1 picocurie per gram (pCi/g) of radium-226. Although radon is highly mobile in soil and its concentration is affected by meteorological conditions (Kovach, 1945; Klusman and Jaacks, 1987; Schery and others, 1984; Schumann and others, 1992), statistical correlations between average soil-gas radon concentrations and average eU values for a wide variety of soils have been documented (Gundersen and others, 1988a, 1988b; Schumann and Owen, 1988). Aerial radiometric data can provide an estimate of radon source strength over a region, but the amount of radon that is able to enter a home from the soil is dependent on several local factors, including soil structure, grain size distribution, moisture content, and permeability, as well as type of house construction and its structural condition.

The aerial radiometric data used for these characterizations were collected as part of the Department of Energy National Uranium Resource Evaluation (NURE) program of the 1970s and early 1980s. The purpose of the NURE program was to identify and describe areas in the United States having potential uranium resources (U.S. Department of Energy, 1976). The NURE aerial radiometric data were collected by aircraft in which a gamma-ray spectrometer was mounted, flying approximately 122 m (400 ft) above the ground surface. The equivalent uranium maps presented in the state chapters were generated from reprocessed NURE data in which smoothing, filtering, recalibrating, and matching of adjacent quadrangle data sets were performed to compensate for background, altitude, calibration, and other types of errors and inconsistencies in the original data set (Duval and others, 1989). The data were then gridded and contoured to produce maps of eU with a pixel size corresponding to approximately 2.5 x 2.5 km (1.6 x 1.6 mi).

# FLIGHT LINE SPACING OF NURE AERIAL SURVEYS

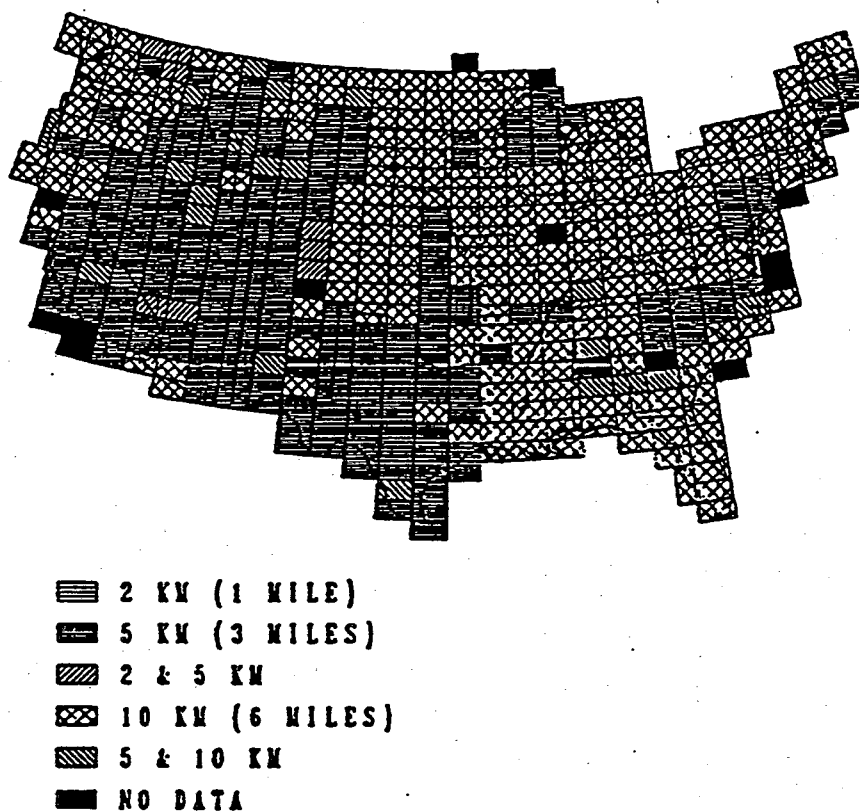


Figure 2. Nominal flightline spacings for NURE aerial gamma-ray surveys covering the contiguous United States (from Duval and others, 1990). Rectangles represent 1°x2° quadrangles.





Figure 2 is an index map of NURE 1° x 2° quadrangles showing the flight-line spacing for each quadrangle. In general, the more closely spaced the flightlines are, the more area was covered by the aerial gamma survey, and thus, more detail is available in the data set. For an altitude of 400 ft above the ground surface and with primary flightline spacing typically between 3 and 6 miles, less than 10 percent of the ground surface of the United States was actually measured by the airborne gamma-ray detectors (Duval and others, 1989), although some areas had better coverage than others due to the differences in flight-line spacing between areas (fig. 2). This suggests that some localized uranium anomalies may not have been detected by the aerial surveys, but the good correlations of eU patterns with geologic outcrop patterns indicate that, at relatively small scales (approximately 1:1,000,000 or smaller) the National eU map (Duval and others, 1989) gives reasonably good estimates of average surface uranium concentrations and thus can assist in the prediction of radon potential of rocks and soils, especially when augmented with additional geologic and soil data.

The shallow (20-30 cm) depth of investigation of gamma-ray spectrometers, either ground-based or airborne (Duval and others, 1971; Durrance, 1986), suggests that gamma-ray data may sometimes underestimate the radon-source strength in soils in which some of the radionuclides in the near-surface soil layers have been transported downward through the soil profile. In such cases the concentration of radioactive minerals in the A horizon would be lower than in the B horizon, where such minerals are typically concentrated. The concentration of radionuclides in the C horizon and below may be relatively unaffected by surface solution processes. Under these conditions the surface gamma-ray signal may indicate a lower radon source concentration than actually exists in the deeper soil layers, which are most likely to affect radon levels in structures with basements. The redistribution of radionuclides in soil profiles is dependent on a combination of climatic, geologic, and geochemical factors. There is reason to believe that correlations of eU with actual soil radium and uranium concentrations at a depth relevant to radon entry into structures may be regionally variable (Duval, 1989; Schumann and Gundersen, 1991). Given sufficient understanding of the factors cited above, these regional differences may be predictable.

#### SOIL SURVEY DATA

Soil surveys prepared by the U.S. Soil Conservation Service (SCS) provide data on soil characteristics, including soil-cover thickness, grain-size distribution, permeability, shrink-swell potential, vegetative cover, generalized groundwater characteristics, and land use. The reports are available in county formats and State summaries. The county reports typically contain both generalized and detailed maps of soils in the area.

Because of time and map-scale constraints, it was impractical to examine county soil reports for each county in the United States, so more generalized summaries at appropriate scales were used where available. For State or regional-scale radon characterizations, soil maps were compared to geologic maps of the area, and the soil descriptions, shrink-swell potential, drainage characteristics, depth to seasonal high water table, permeability, and other relevant characteristics of each soil group noted. Technical soil terms used in soil surveys are generally complex; however, a good summary of soil engineering terms and the national distribution of technical soil types is the "Soils" sheet of the National Atlas (U.S. Department of Agriculture, 1987).



Soil permeability is commonly expressed in SCS soil surveys in terms of the speed, in inches per hour (in/hr), at which water soaks into the soil, as measured in a soil percolation test. Although in/hr are not truly units of permeability, these units are in widespread use and are referred to as "permeability" in SCS soil surveys. The permeabilities listed in the SCS surveys are for water, but they generally correlate well with gas permeability. Because data on gas permeability of soils is extremely limited, data on permeability to water is used as a substitute except in cases in which excessive soil moisture is known to exist. Water in soil pores inhibits gas transport, so the amount of radon available to a home is effectively reduced by a high water table. Areas likely to have high water tables include river valleys, coastal areas, and some areas overlain by deposits of glacial origin (for example, loess).

Soil permeabilities greater than 6.0 in/hr may be considered high, and permeabilities less than 0.6 in/hr may be considered low in terms of soil-gas transport. Soils with low permeability may generally be considered to have a lower radon potential than more permeable soils with similar radium concentrations. Many well-developed soils contain a clay-rich B horizon that may impede vertical soil gas transport. Radon generated below this horizon cannot readily escape to the surface, so it would instead tend to move laterally, especially under the influence of a negative pressure exerted by a building.

Shrink-swell potential is an indicator of the abundance of smectitic (swelling) clays in a soil. Soils with a high shrink-swell potential may cause building foundations to crack, creating pathways for radon entry into the structure. During dry periods, desiccation cracks in shrink-swell soils provide additional pathways for soil-gas transport and effectively increase the gas permeability of the soil. Soil permeability data and soil profile data thus provide important information for regional radon assessments.

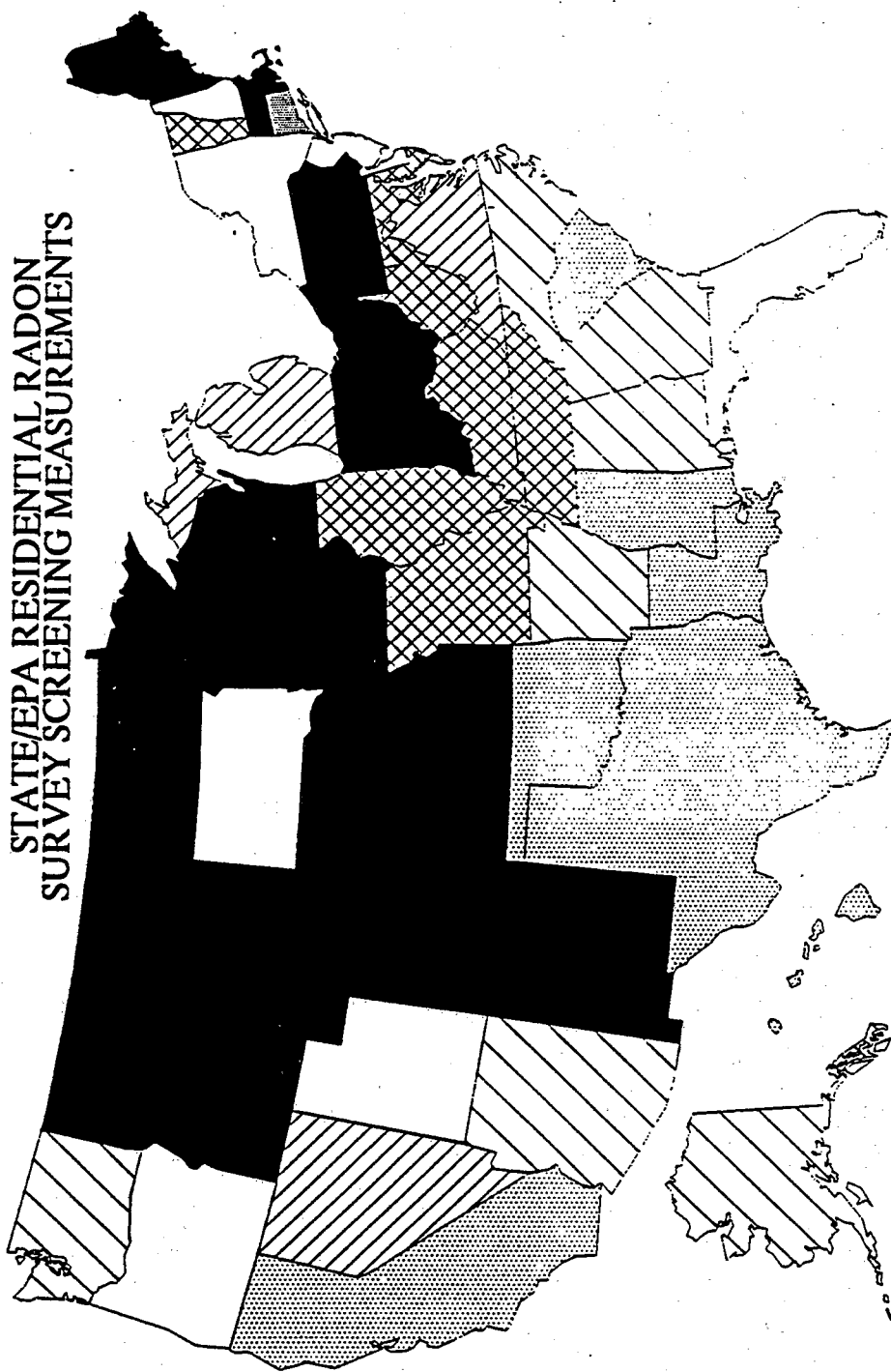
## INDOOR RADON DATA

Two major sources of indoor radon data were used. The first and largest source of data is from the State/EPA Residential Radon Survey (Ronca-Battista and others, 1988; Dziuban and others, 1990). Forty-two states completed EPA-sponsored indoor radon surveys between 1986 and 1992 (fig. 3). The State/EPA Residential Radon Surveys were designed to be comprehensive and statistically significant at the state level, and were subjected to high levels of quality assurance and control. The surveys collected screening indoor radon measurements, defined as 2-7 day measurements using charcoal canister radon detectors placed in the lowest livable area of the home. The target population for the surveys included owner-occupied single family, detached housing units (White and others, 1989), although attached structures such as duplexes, townhouses, or condominiums were included in some of the surveys if they met the other criteria and had contact with the ground surface. Participants were selected randomly from telephone-directory listings. In total, approximately 60,000 homes were tested in the State/EPA surveys.

The second source of indoor radon data comes from residential surveys that have been conducted in a specific state or region of the country (e.g. independent state surveys or utility company surveys). Several states, including Delaware, Florida, Illinois, New Hampshire, New Jersey, New York, Oregon, and Utah, have conducted their own surveys of indoor radon. The quality and design of a state or other independent survey are discussed and referenced where the data are used.

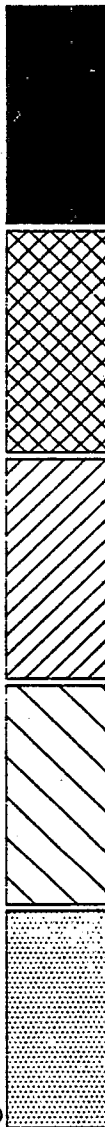


# STATE/EPA RESIDENTIAL RADON SURVEY SCREENING MEASUREMENTS



Estimated Percent of Houses with Screening Levels Greater than 4 pCi/L

0 5 10 15 20 and >



These results are based on 2-7 day screening measurements in the lowest livable level and should not be used to estimate annual averages or health risks.

The States of DE, HI, NJ, NY, and UT have conducted their own surveys. OR & SD declined to participate in the SRRS.

Figure 3. Percent of homes tested in the State/EPA Residential Radon Survey with screening indoor radon levels exceeding 4 pCi/L.



Data for only those counties with five or more measurements are shown in the indoor radon maps in the state chapters, although data for all counties with a nonzero number of measurements are listed in the indoor radon data tables in each state chapter. In total, indoor radon data from more than 100,000 homes nationwide were used in the compilation of these assessments. Radon data from State or regional indoor radon surveys, public health organizations, or other sources are discussed in addition to the primary data sources where they are available. Nearly all of the data used in these evaluations represent short-term (2-7 day) screening measurements from the lowest livable space of the homes. Specific details concerning the nature and use of indoor radon data sets other than the State/EPA Residential Radon Survey are discussed in the individual State chapters.


## RADON INDEX AND CONFIDENCE INDEX

Many of the geologic methods used to evaluate an area for radon potential require subjective opinions based on the professional judgment and experience of the individual geologist. The evaluations are nevertheless based on established scientific principles that are universally applicable to any geographic area or geologic setting. This section describes the methods and conceptual framework used by the U.S. Geological Survey to evaluate areas for radon potential based on the five factors discussed in the previous sections. The scheme is divided into two basic parts, a Radon Index (RI), used to rank the general radon potential of the area, and the Confidence Index (CI), used to express the level of confidence in the prediction based on the quantity and quality of the data used to make the determination. This scheme works best if the areas to be evaluated are delineated by geologically-based boundaries (geologic provinces) rather than political ones (state/county boundaries) in which the geology may vary across the area.

**Radon Index.** Table 1 presents the Radon Index (RI) matrix. The five factors—indoor radon data, geology, aerial radioactivity, soil parameters, and house foundation type—were quantitatively ranked (using a point value of 1, 2, or 3) for their respective contribution to radon potential in a given area. At least some data for the 5 factors are consistently available for every geologic province. Because each of these main factors encompass a wide variety of complex and variable components, the geologists performing the evaluation relied heavily on their professional judgment and experience in assigning point values to each category and in determining the overall radon potential ranking. Background information on these factors is discussed in more detail in the preceding sections of this introduction.

Indoor radon was evaluated using unweighted arithmetic means of the indoor radon data for each geologic area to be assessed. Other expressions of indoor radon levels in an area also could have been used, such as weighted averages or annual averages, but these types of data were not consistently available for the entire United States at the time of this writing, or the schemes were not considered sufficient to provide a means of consistent comparison across all areas. For this report, charcoal-canister screening measurement data from the State/EPA Residential Radon Surveys and other carefully selected sources were used, as described in the preceding section. To maintain consistency, other indoor radon data sets (vendor, state, or other data) were not considered in scoring the indoor radon factor of the Radon Index if they were not randomly sampled or could not be statistically combined with the primary indoor radon data sets. However, these additional radon data sets can provide a means to further refine correlations between geologic factors and radon potential, so they are

**TABLE 1. RADON INDEX MATRIX.** "ppm eU" indicates parts per million of equivalent uranium, as indicated by NURE aerial radiometric data. See text discussion for details.

FACTOR	INCREASING RADON POTENTIAL 		
	POINT VALUE		
	1	2	3
INDOOR RADON (average)	< 2 pCi/L	2 - 4 pCi/L	> 4 pCi/L
AERIAL RADIOACTIVITY	< 1.5 ppm eU	1.5 - 2.5 ppm eU	> 2.5 ppm eU
GEOLOGY*	negative	variable	positive
SOIL PERMEABILITY	low	moderate	high
ARCHITECTURE TYPE	mostly slab	mixed	mostly basement

\*GEOLOGIC FIELD EVIDENCE (GFE) POINTS: GFE points are assigned in addition to points for the "Geology" factor for specific, relevant geologic field studies. See text for details.


Geologic evidence supporting:	HIGH radon	+2 points
	MODERATE	+1 point
	LOW	-2 points
No relevant geologic field studies		0 points

**SCORING:**

Radon potential category	Point range	Probable average screening indoor radon for area
LOW	3-8 points	< 2 pCi/L
MODERATE/VARIABLE	9-11 points	2 - 4 pCi/L
HIGH	12-17 points	> 4 pCi/L

POSSIBLE RANGE OF POINTS = 3 to 17

**TABLE 2. CONFIDENCE INDEX MATRIX**

FACTOR	INCREASING CONFIDENCE 		
	POINT VALUE		
	1	2	3
INDOOR RADON DATA	sparse/no data	fair coverage/quality	good coverage/quality
AERIAL RADIOACTIVITY	questionable/no data	glacial cover	no glacial cover
GEOLOGIC DATA	questionable	variable	proven geol. model
SOIL PERMEABILITY	questionable/no data	variable	reliable, abundant

**SCORING:**

LOW CONFIDENCE	4 - 6 points
MODERATE CONFIDENCE	7 - 9 points
HIGH CONFIDENCE	10 - 12 points

POSSIBLE RANGE OF POINTS = 4 to 12



included as supplementary information and are discussed in the individual State chapters. If the average screening indoor radon level for an area was less than 2 pCi/L, the indoor radon factor was assigned 1 point, if it was between 2 and 4 pCi/L, it was scored 2 points, and if the average screening indoor radon level for an area was greater than 4 pCi/L, the indoor radon factor was assigned 3 RI points.

Aerial radioactivity data used in this report are from the equivalent uranium map of the conterminous United States compiled from NURE aerial gamma-ray surveys (Duval and others, 1989). These data indicate the gamma radioactivity from approximately the upper 30 cm of rock and soil, expressed in units of ppm equivalent uranium. An approximate average value of eU was determined visually for each area and point values assigned based on whether the overall eU for the area falls below 1.5 ppm (1 point), between 1.5 and 2.5 ppm (2 points), or greater than 2.5 ppm (3 points). . . . .

The geology factor is complex and actually incorporates many geologic characteristics. In the matrix, "positive" and "negative" refer to the presence or absence and distribution of rock types known to have high uranium contents and to generate elevated radon in soils or indoors. Examples of "positive" rock types include granites, black shales, phosphatic rocks, and other rock types described in the preceding "geologic data" section. Examples of "negative" rock types include marine quartz sands and some clays. The term "variable" indicates that the geology within the region is variable or that the rock types in the area are known or suspected to generate elevated radon in some areas but not in others due to compositional differences, climatic effects, localized distribution of uranium, or other factors. Geologic information indicates not only how much uranium is present in the rocks and soils but also gives clues for predicting general radon emanation and mobility characteristics through additional factors such as structure (notably the presence of faults or shears) and geochemical characteristics (for example, a phosphate-rich sandstone will likely contain more uranium than a sandstone containing little or no phosphate because the phosphate forms chemical complexes with uranium). "Negative", "variable", and "positive" geology were assigned 1, 2, and 3 points, respectively.

In cases where additional reinforcing or contradictory geologic evidence is available, Geologic Field Evidence (GFE) points were added to or subtracted from an area's score (Table 1). Relevant geologic field studies are important to enhancing our understanding of how geologic processes affect radon distribution. In some cases, geologic models and supporting field data reinforced an already strong (high or low) score; in others, they provided important contradictory data. GFE points were applied for geologically-sound evidence that supports the prediction (but which may contradict one or more factors) on the basis of known geologic field studies in the area or in areas with geologic and climatic settings similar enough that they could be applied with full confidence. For example, areas of the Dakotas, Minnesota, and Iowa that are covered with Wisconsin-age glacial deposits exhibit a low aerial radiometric signature and score only one RI point in that category. However, data from geologic field studies in North Dakota and Minnesota (Schumann and others, 1991) suggest that eU is a poor predictor of geologic radon potential in this area because radionuclides have

been leached from the upper soil layers but are present and possibly even concentrated in deeper soil horizons, generating significant soil-gas radon. This positive supporting field evidence adds two GFE points to the score, which helps to counteract the invalid conclusion suggested by the radiometric data. No GFE points are awarded if there are no documented field studies for the area.

"Soil permeability" refers to several soil characteristics that influence radon concentration and mobility, including soil type, grain size, structure, soil moisture, drainage, slope, and permeability. In the matrix, "low" refers to permeabilities less than about 0.6 in/hr; "high" corresponds to greater than about 6.0 in/hr, in U.S. Soil Conservation Service (SCS) standard soil percolation tests. The SCS data are for water permeability, which generally correlates well with the gas permeability of the soil except when the soil moisture content is very high. Areas with consistently high water tables were thus considered to have low gas permeability. "Low", "moderate", and "high" permeability were assigned 1, 2, and 3 points, respectively.

Architecture type refers to whether homes in the area have mostly basements (3 points), mostly slab-on-grade construction (1 point), or a mixture of the two. Split-level and crawl space homes fall into the "mixed" category (2 points). Architecture information is necessary to properly interpret the indoor radon data and produce geologic radon potential categories that are consistent with screening indoor radon data.

The overall RI for an area is calculated by adding the individual RI scores for the 5 factors, plus or minus GFE points, if any. The total RI for an area falls in one of three categories—low, moderate or variable, or high. The point ranges for the three categories were determined by examining the possible combinations of points for the 5 factors and setting rules such that a majority (3 of 5 factors) would determine the final score for the low and high categories, with allowances for possible deviation from an ideal score by the other two factors. The moderate/variable category lies between these two ranges. A total deviation of 3 points from the "ideal" score was considered reasonable to allow for natural variability of factors—if two of the five factors are allowed to vary from the "ideal" for a category, they can differ by a minimum of 2 (1 point different each) and a maximum of 4 points (2 points different each). With "ideal" scores of 5, 10, and 15 points describing low, moderate, and high geologic radon potential, respectively, an ideal low score of 5 points plus 3 points for possible variability allows a maximum of 8 points in the low category. Similarly, an ideal high score of 15 points minus 3 points gives a minimum of 12 points for the high category. Note, however, that if both other factors differ by two points from the "ideal", indicating considerable variability in the system, the total point score would lie in the adjacent (i.e., moderate/variable) category.

**Confidence Index.** Except for architecture type, the same factors were used to establish a Confidence Index (CI) for the radon potential prediction for each area (Table 2). Architecture type was not included in the confidence index because house construction data are readily and reliably available through surveys taken by agencies and industry groups including the National Association of Home Builders, U.S. Department of Housing and Urban Development, and the Federal Housing Administration; thus it was not considered necessary

to question the quality or validity of these data. The other factors were scored on the basis of the quality and quantity of the data used to complete the RI matrix.

Indoor radon data were evaluated based on the distribution and number of data points and on whether the data were collected by random sampling (State/EPA Residential Radon Survey or other state survey data) or volunteered vendor data (likely to be nonrandom and biased toward population centers and/or high indoor radon levels). The categories listed in the CI matrix for indoor radon data ("sparse or no data", "fair coverage or quality", and "good coverage/quality") indicate the sampling density and statistical robustness of an indoor radon data set. Data from the State/EPA Residential Radon Survey and statistically valid state surveys were typically assigned 3 Confidence Index points unless the data were poorly distributed or absent in the area evaluated.

Aerial radioactivity data are available for all but a few areas of the continental United States and for part of Alaska. An evaluation of the quality of the radioactivity data was based on whether there appeared to be a good correlation between the radioactivity and the actual amount of uranium or radium available to generate mobile radon in the rocks and soils of the area evaluated. In general, the greatest problems with correlations among eU, geology, and soil-gas or indoor radon levels were associated with glacial deposits (see the discussion in a previous section) and typically were assigned a 2-point Confidence Index score. Correlations among eU, geology, and radon were generally sound in unglaciated areas and were usually assigned 3 CI points. Again, however, radioactivity data in some unglaciated areas may have been assigned fewer than 3 points, and in glaciated areas may be assigned only one point, if the data were considered questionable or if coverage was poor.

To assign Confidence Index scores for the geologic data factor, rock types and geologic settings for which a physical-chemical, process-based understanding of radon generation and mobility exists were regarded as having "proven geologic models" (3 points); a high confidence could be held for predictions in such areas. Rocks for which the processes are less well known or for which data are contradictory were regarded as "variable" (2 points), and those about which little is known or for which no apparent correlations have been found were deemed "questionable" (1 point).

The soil permeability factor was also scored based on quality and amount of data. The three categories for soil permeability in the Confidence Index are similar in concept, and scored similarly, to those for the geologic data factor. Soil permeability can be roughly estimated from grain size and drainage class if data from standard, accepted soil percolation tests are unavailable; however, the reliability of the data would be lower than if percolation test figures or other measured permeability data are available, because an estimate of this type does not encompass all the factors that affect soil permeability and thus may be inaccurate in some instances. Most published soil permeability data are for water; although this is generally closely related to the air permeability of the soil, there are some instances when it may provide an incorrect estimate. Examples of areas in which water permeability data may not accurately reflect air permeability include areas with consistently high levels of soil moisture, or clay-rich soils, which would have a low water permeability but may have a

significantly higher air permeability when dry due to shrinkage cracks in the soil. These additional factors were applied to the soil permeability factor when assigning the RI score, but may have less certainty in some cases and thus would be assigned a lower CI score.

The Radon Index and Confidence Index give a general indication of the relative contributions of the interrelated geologic factors influencing radon generation and transport in rocks and soils, and thus, of the potential for elevated indoor radon levels to occur in a particular area. However, because these reports are somewhat generalized to cover relatively large areas of States, it is highly recommended that more detailed studies be performed in local areas of interest, using the methods and general information in these booklets as a guide.

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# APPENDIX A GEOLOGIC TIME SCALE

Subdivisions (and their symbols)						Age estimates of boundaries in mega-annum (Ma) <sup>1</sup>		
Eon or Eonothem	Era or Erathem	Period, System, Subperiod, Subsystem		Epoch or Series				
Phanerozoic <sup>2</sup>	Cenozoic <sup>2</sup> (Cz)	Quaternary <sup>2</sup> (Q)		Holocene		0.010		
				Pleistocene		1.6 (1.6–1.9)		
		Tertiary (T)	Neogene <sup>2</sup> Subperiod or Subsystem (N)	Pliocene		5 (4.9–5.3)		
				Miocene		24 (23–26)		
			Paleogene <sup>2</sup> Subperiod or Subsystem (Pt)	Oligocene		38 (34–38)		
				Eocene		55 (54–56)		
				Paleocene		66 (63–66)		
			Mesozoic <sup>2</sup> (Mz)	Cretaceous (K)		Late	Upper	96 (95–97)
				Early	Lower	138 (135–141)		
	Jurassic (J)			Late	Upper			
				Middle	Middle			
				Early	Lower	205 (200–215)		
	Triassic (T)			Late	Upper			
				Middle	Middle			
				Early	Lower	-240		
	Paleozoic <sup>2</sup> (Pz)	Permian (P)		Late	Upper			
				Early	Lower	290 (290–305)		
		Carboniferous Systems (C)	Pennsylvanian (P)	Late	Upper			
				Middle	Middle			
				Early	Lower	-330		
			Mississippian (M)	Late	Upper			
				Early	Lower	360 (360–365)		
		Devonian (D)		Late	Upper			
				Middle	Middle			
				Early	Lower	410 (405–415)		
		Silurian (S)		Late	Upper			
				Middle	Middle			
				Early	Lower	435 (435–440)		
		Ordovician (O)		Late	Upper			
				Middle	Middle			
				Early	Lower	500 (495–510)		
		Cambrian (C)		Late	Upper			
	Middle			Middle				
	Early			Lower	-570 <sup>3</sup>			
	Proterozoic (P)	Late Proterozoic (Z)	None defined				900	
Middle Proterozoic (Y)		None defined				1600		
Early Proterozoic (X)		None defined				2500		
Archean (A)	Late Archean (W)	None defined				3000		
	Middle Archean (V)	None defined				3400		
	Early Archean (U)	None defined				3800 <sup>7</sup>		
pre-Archean (pA) <sup>4</sup>								

<sup>1</sup> Ranges reflect uncertainties of isotopic and biostratigraphic age assignments. Age boundaries not closely bracketed by existing data shown by ~. Decay constants and isotopic ratios employed are cited in Steiger and Jäger (1977). Designation m.y. used for an interval of time.

<sup>2</sup> Modifiers (lower, middle, upper or early, middle, late) when used with these items are informal divisions of the larger unit; the first letter of the modifier is lowercase.

<sup>3</sup> Rocks older than 570 Ma also called Precambrian (p-C), a time term without specific rank.

<sup>4</sup> Informal time term without specific rank.



## APPENDIX B GLOSSARY OF TERMS

### Units of measure

**pCi/L** (picocuries per liter)- a unit of measure of radioactivity used to describe radon concentrations in a volume of air. One picocurie ( $10^{-12}$  curies) is equal to about 2.2 disintegrations of radon atoms per minute. A liter is about 1.06 quarts. The average concentration of radon in U.S. homes measured to date is between 1 and 2 pCi/L.

**Bq/m<sup>3</sup>** (Becquerels per cubic meter)- a metric unit of radioactivity used to describe radon concentrations in a volume of air. One becquerel is equal to one radioactive disintegration per second. One pCi/L is equal to 37 Bq/m<sup>3</sup>.

**ppm** (parts per million)- a unit of measure of concentration by weight of an element in a substance, in this case, soil or rock. One ppm of uranium contained in a ton of rock corresponds to about 0.03 ounces of uranium. The average concentration of uranium in soils in the United States is between 1 and 2 ppm.

**in/hr** (inches per hour)- a unit of measure used by soil scientists and engineers to describe the permeability of a soil to water flowing through it. It is measured by digging a hole 1 foot (12 inches) square and one foot deep, filling it with water, and measuring the time it takes for the water to drain from the hole. The drop in height of the water level in the hole, measured in inches, is then divided by the time (in hours) to determine the permeability. Soils range in permeability from less than 0.06 in/hr to greater than 20 in/hr, but most soils in the United States have permeabilities between these two extremes.

### Geologic terms and terms related to the study of radon

**aerial radiometric, aeroradiometric survey** A survey of radioactivity, usually gamma rays, taken by an aircraft carrying a gamma-ray spectrometer pointed at the ground surface.

**alluvial fan** A low, widespread mass of loose rock and soil material, shaped like an open fan and deposited by a stream at the point where it flows from a narrow mountain valley out onto a plain or broader valley. May also form at the junction with larger streams or when the gradient of the stream abruptly decreases.

**alluvium, alluvial** General terms referring to unconsolidated detrital material deposited by a stream or other body of running water.

**alpha-track detector** A passive radon measurement device consisting of a plastic film that is sensitive to alpha particles. The film is etched with acid in a laboratory after it is exposed. The etching reveals scratches, or "tracks", left by the alpha particles resulting from radon decay, which can then be counted to calculate the radon concentration. Useful for long-term (1-12 months) radon tests.

**amphibolite** A mafic metamorphic rock consisting mainly of pyroxenes and(or) amphibole and plagioclase.

**argillite, argillaceous** Terms referring to a rock derived from clay or shale, or any sedimentary rock containing an appreciable amount of clay-size material, i.e., argillaceous sandstone.

**arid** Term describing a climate characterized by dryness, or an evaporation rate that exceeds the amount of precipitation.

**basalt** A general term for a dark-colored mafic igneous rocks that may be of extrusive origin, such as volcanic basalt flows, or intrusive origin, such as basalt dikes.

**batholith** A mass of plutonic igneous rock that has more than 40 square miles of surface exposure and no known bottom.

**carbonate** A sedimentary rock consisting of the carbonate ( $\text{CO}_3$ ) compounds of calcium, magnesium, or iron, e.g. limestone and dolomite.

**carbonaceous** Said of a rock or sediment that is rich in carbon, is coaly, or contains organic matter.

**charcoal canister** A passive radon measurement device consisting of a small container of granulated activated charcoal that is designed to adsorb radon. Useful for short duration (2-7 days) measurements only. May be referred to as a "screening" test.

**chert** A hard, extremely dense sedimentary rock consisting dominantly of interlocking crystals of quartz. Crystals are not visible to the naked eye, giving the rock a milky, dull luster. It may be white or gray but is commonly colored red, black, yellow, blue, pink, brown, or green.

**clastic** pertaining to a rock or sediment composed of fragments that are derived from preexisting rocks or minerals. The most common clastic sedimentary rocks are sandstone and shale.

**clay** A rock containing clay mineral fragments or material of any composition having a diameter less than 1/256 mm.

**clay mineral** One of a complex and loosely defined group of finely crystalline minerals made up of water, silicate and aluminum (and a wide variety of other elements). They are formed chiefly by alteration or weathering of primary silicate minerals. Certain clay minerals are noted for their small size and ability to absorb substantial amounts of water, causing them to swell. The change in size that occurs as these clays change between dry and wet is referred to as their "shrink-swell" potential.

**concretion** A hard, compact mass of mineral matter, normally subspherical but commonly irregular in shape; formed by precipitation from a water solution about a nucleus or center, such as a leaf, shell, bone, or fossil, within a sedimentary or fractured rock.

**conglomerate** A coarse-grained, clastic sedimentary rock composed of rock and mineral fragments larger than 2 mm, set in a finer-grained matrix of clastic material.

**cuesta** A hill or ridge with a gentle slope on one side and a steep slope on the other. The formation of a cuesta is controlled by the different weathering properties and the structural dip of the rocks forming the hill or ridge.

**daughter product** A nuclide formed by the disintegration of a radioactive precursor or "parent" atom.

**delta, deltaic** Referring to a low, flat, alluvial tract of land having a triangular or fan shape, located at or near the mouth of a river. It results from the accumulation of sediment deposited by a river at the point at which the river loses its ability to transport the sediment, commonly where a river meets a larger body of water such as a lake or ocean.

**dike** A tabular igneous intrusion of rock, younger than the surrounding rock, that commonly cuts across the bedding or foliation of the rock it intrudes.

**diorite** A plutonic igneous rock that is medium in color and contains visible dark minerals that make up less than 50% of the rock. It also contains abundant sodium plagioclase and minor quartz.

**dolomite** A carbonate sedimentary rock of which more than 50% consists of the mineral dolomite ( $\text{CaMg}(\text{CO}_3)_2$ ), and is commonly white, gray, brown, yellow, or pinkish in color.

**drainage** The manner in which the waters of an area pass, flow off of, or flow into the soil. Also refers to the water features of an area, such as lakes and rivers, that drain it.

**eolian** Pertaining to sediments deposited by the wind.

**esker** A long, narrow, steep-sided ridge composed of irregular beds of sand and gravel deposited by streams beneath a glacier and left behind when the ice melted.

**evapotranspiration** Loss of water from a land area by evaporation from the soil and transpiration from plants.

**extrusive** Said of igneous rocks that have been erupted onto the surface of the Earth.

**fault** A fracture or zone of fractures in rock or sediment along which there has been movement.

**fluvial, fluvial deposit** Pertaining to sediment that has been deposited by a river or stream.

**foliation** A linear feature in a rock defined by both mineralogic and structural characteristics. It may be formed during deformation or metamorphism.

**formation** A mappable body of rock having similar characteristics.

**glacial deposit** Any sediment transported and deposited by a glacier or processes associated with glaciers, such as glaciofluvial sediments deposited by streams flowing from melting glaciers.

**gneiss** A rock formed by metamorphism in which bands and lenses of minerals of similar composition alternate with bands and lenses of different composition, giving the rock a striped or "foliated" appearance.

**granite** Broadly applied, any coarsely crystalline, quartz- and feldspar-bearing igneous plutonic rock. Technically, granites have between 10 and 50% quartz, and alkali feldspar comprises at least 65% of the total feldspar.

**gravel** An unconsolidated, natural accumulation of rock fragments consisting predominantly of particles greater than 2 mm in size.

**heavy minerals** Mineral grains in sediment or sedimentary rock having higher than average specific gravity. May form layers and lenses because of wind or water sorting by weight and size.

and may be referred to as a "placer deposit." Some heavy minerals are magnetite, garnet, zircon, monazite, and xenotime.

**igneous** Said of a rock or mineral that solidified from molten or partly molten rock material. It is one of the three main classes into which rocks are divided, the others being sedimentary and metamorphic.

**intermontane** A term that refers to an area between two mountains or mountain ranges.

**intrusion, intrusive** The processes of emplacement or injection of molten rock into pre-existing rock. Also refers to the rock formed by intrusive processes, such as an "intrusive igneous rock".

**kame** A low mound, knob, hummock, or short irregular ridge formed by a glacial stream at the margin of a melting glacier; composed of bedded sand and gravel.

**karst terrain** A type of topography that is formed on limestone, gypsum and other rocks by dissolution of the rock by water, forming sinkholes and caves.

**lignite** A brownish-black coal that is intermediate in coalification between peat and subbituminous coal.

**limestone** A carbonate sedimentary rock consisting of more than 50% calcium carbonate, primarily in the form of the mineral calcite ( $\text{CaCO}_3$ ).

**lithology** The description of rocks in hand specimen and in outcrop on the basis of color, composition, and grain size.

**loam** A permeable soil composed of a mixture of relatively equal parts clay, silt, and sand, and usually containing some organic matter.

**loess** A fine-grained eolian deposit composed of silt-sized particles generally thought to have been deposited from windblown dust of Pleistocene age.

**mafic** Term describing an igneous rock containing more than 50% dark-colored minerals.

**marine** Term describing sediments deposited in the ocean, or precipitated from ocean waters.

**metamorphic** Any rock derived from pre-existing rocks by mineralogical, chemical, or structural changes in response to changes in temperature, pressure, stress, and the chemical environment. Phyllite, schist, amphibolite, and gneiss are metamorphic rocks.

**moraine** A mound, ridge, or other distinct accumulation of unsorted, unbedded glacial material, predominantly till, deposited by the action of glacial ice.

**outcrop** That part of a geologic formation or structure that appears at the surface of the Earth, as in "rock outcrop".

**percolation test** A term used in engineering for a test to determine the water permeability of a soil. A hole is dug and filled with water and the rate of water level decline is measured.

**permeability** The capacity of a rock, sediment, or soil to transmit liquid or gas.

**phosphate, phosphatic, phosphorite** Any rock or sediment containing a significant amount of phosphate minerals, i.e., minerals containing  $\text{PO}_4$ .

**physiographic province** A region in which all parts are similar in geologic structure and climate, which has had a uniform geomorphic history, and whose topography or landforms differ significantly from adjacent regions.

**placer deposit** See heavy minerals

**residual** Formed by weathering of a material in place.

**residuum** Deposit of residual material.

**rhyolite** An extrusive igneous rock of volcanic origin, compositionally equivalent to granite.

**sandstone** A clastic sedimentary rock composed of sand-sized rock and mineral material that is more or less firmly cemented. Sand particles range from 1/16 to 2 mm in size.

**schist** A strongly foliated crystalline rock, formed by metamorphism, that can be readily split into thin flakes or slabs. Contains mica; minerals are typically aligned.

**screening level** Result of an indoor radon test taken with a charcoal canister or similar device, for a short period of time, usually less than seven days. May indicate the potential for an indoor radon problem but does not indicate annual exposure to radon.

**sediment** Deposits of rock and mineral particles or fragments originating from material that is transported by air, water or ice, or that accumulate by natural chemical precipitation or secretion of organisms.

**semiarid** Refers to a climate that has slightly more precipitation than an arid climate.

**shale** A fine-grained sedimentary rock formed from solidification (lithification) of clay or mud.

**shear zone** Refers to a roughly linear zone of rock that has been faulted by ductile or non-ductile processes in which the rock is sheared and both sides are displaced relative to one another.

**shrink-swell clay** See clay mineral.

**siltstone** A fine-grained clastic sedimentary rock composed of silt-sized rock and mineral material and more or less firmly cemented. Silt particles range from 1/16 to 1/256 mm in size.

**sinkhole** A roughly circular depression in a karst area measuring meters to tens of meters in diameter. It is funnel shaped and is formed by collapse of the surface material into an underlying void created by the dissolution of carbonate rock.

**slope** An inclined part of the earth's surface.

**solution cavity** A hole, channel or cave-like cavity formed by dissolution of rock.

**stratigraphy** The study of rock strata; also refers to the succession of rocks of a particular area.

**surficial materials** Unconsolidated glacial, wind-, or waterborne deposits occurring on the earth's surface.

**tablelands** General term for a broad, elevated region with a nearly level surface of considerable extent.

**terrace gravel** Gravel-sized material that caps ridges and terraces, left behind by a stream as it cuts down to a lower level.

**terrain** A tract or region of the Earth's surface considered as a physical feature or an ecological environment.

**till** Unsorted, generally unconsolidated and unbedded rock and mineral material deposited directly adjacent to and underneath a glacier, without reworking by meltwater. Size of grains varies greatly from clay to boulders.

**uraniferous** Containing uranium, usually more than 2 ppm.

**vendor data** Used in this report to refer to indoor radon data collected and measured by commercial vendors of radon measurement devices and/or services.

**volcanic** Pertaining to the activities, structures, and extrusive rock types of a volcano.

**water table** The surface forming the boundary between the zone of saturation and the zone of aeration; the top surface of a body of unconfined groundwater in rock or soil.

**weathering** The destructive process by which earth and rock materials, on exposure to atmospheric elements, are changed in color, texture, composition, firmness, or form with little or no transport of the material.



## APPENDIX C EPA REGIONAL OFFICES

EPA Regional Offices	State	EPA Region
EPA Region 1 JFK Federal Building Boston, MA 02203 (617) 565-4502	Alabama.....	4
	Alaska.....	10
	Arizona.....	9
	Arkansas.....	6
	California.....	9
	Colorado.....	8
	Connecticut.....	1
	Delaware.....	3
	District of Columbia.....	3
	Florida.....	4
	Georgia.....	4
	Hawaii.....	9
	Idaho.....	10
	Illinois.....	5
	Indiana.....	5
	Iowa.....	7
	Kansas.....	7
	Kentucky.....	4
	Louisiana.....	6
	Maine.....	1
	Maryland.....	3
	Massachusetts.....	1
	Michigan.....	5
	Minnesota.....	5
	Mississippi.....	4
	Missouri.....	7
	Montana.....	8
	Nebraska.....	7
	Nevada.....	9
	New Hampshire.....	1
	New Jersey.....	2
	New Mexico.....	6
	New York.....	2
	North Carolina.....	4
	North Dakota.....	8
	Ohio.....	5
	Oklahoma.....	6
	Oregon.....	10
	Pennsylvania.....	3
	Rhode Island.....	1
	South Carolina.....	4
	South Dakota.....	8
	Tennessee.....	4
	Texas.....	6
	Utah.....	8
	Vermont.....	1
	Virginia.....	3
	Washington.....	10
	West Virginia.....	3
	Wisconsin.....	5
	Wyoming.....	8
EPA Region 2 (2AIR:RAD) 26 Federal Plaza New York, NY 10278 (212) 264-4110		
Region 3 (3AH14) 841 Chestnut Street Philadelphia, PA 19107 (215) 597-8326		
EPA Region 4 345 Courtland Street, N.E. Atlanta, GA 30365 (404) 347-3907		
EPA Region 5 (5AR26) 77 West Jackson Blvd. Chicago, IL 60604-3507 (312) 886-6175		
EPA Region 6 (6T-AS) 1445 Ross Avenue Dallas, TX 75202-2733 (214) 655-7224		
EPA Region 7 726 Minnesota Avenue Kansas City, KS 66101 (913) 551-7604		
EPA Region 8 (8HWM-RP) 999 18th Street One Denver Place, Suite 1300 Denver, CO 80202-2413 (303) 293-1713		
EPA Region 9 (A-3) 75 Hawthorne Street San Francisco, CA 94105 (415) 744-1048		
EPA Region 10 1200 Sixth Avenue Seattle, WA 98101 (202) 442-7660		

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May, 1993

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## EPA REGION 3 GEOLOGIC RADON POTENTIAL SUMMARY

by  
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EPA Region 3 includes the states of Delaware, Maryland, Pennsylvania, Virginia, and West Virginia. For each state, geologic radon potential areas were delineated and ranked on the basis of geologic, soil, housing construction, and other factors. Areas in which the *average screening indoor radon level of all homes within the area* is estimated to be greater than 4 pCi/L were ranked high. Areas in which the average screening indoor radon level of all homes within the area is estimated to be between 2 and 4 pCi/L were ranked moderate/variable, and areas in which the average screening indoor radon level of all homes within the area is estimated to be less than 2 pCi/L were ranked low. Information on the data used and on the radon potential ranking scheme is given in the introduction to this volume. More detailed information on the geology and radon potential of each state in Region 3 is given in the individual state chapters. The individual chapters describing the geology and radon potential of the states in EPA Region 3, though much more detailed than this summary, still are generalized assessments and there is no substitute for having a home tested. Within any radon potential area homes with indoor radon levels both above and below the predicted average will likely be found.

Figure 1 shows a generalized map of the major physiographic/geologic provinces in EPA Region 3. The summary of radon potential in Region 3 that follows refers to these provinces. Figure 2 shows average screening indoor radon levels by county. The data for Maryland, Pennsylvania, Virginia, and West Virginia are from the State/EPA Residential Radon Survey. Data for Delaware were compiled by the Delaware Department of Health and Social Services. Figure 3 shows the geologic radon potential areas in Region 3, combined and summarized from the individual state chapters in this booklet.

### DELAWARE

#### *Piedmont*

The Piedmont in Delaware has been ranked moderate in geologic radon potential. Average measured indoor radon levels in the Piedmont vary from low (<2 pCi/L) to moderate (2-4 pCi/L). Individual readings within the Piedmont can be locally very high (> 20 pCi/L). This is not unexpected when a regional-scale look at the Atlantic coastal states shows that the Piedmont is consistently an area of moderate to high radon potential. Much of the western Piedmont in Delaware is underlain by the Wissahickon Formation, which consists predominantly of schist. This formation has moderate to locally high geologic radon potential. Equivalent schists in the Piedmont of Maryland can have uranium concentrations of 3-5 ppm, especially where faulted. The Wilmington Complex and James Run Formation, in the central and eastern portions of the Delaware Piedmont, are variable in radon potential. In these units, the felsic gneiss and schist may contribute to elevated radon levels, whereas mafic rocks such as amphibolite and gabbro, and relatively quartz-poor granitic rocks such as charnockite and diorite are probably lower in radon potential. The average indoor radon is distinctly lower in parts of the Wilmington Complex than in surrounding areas, particularly in areas underlain by the Bringham Gabbro and the Arden pluton. The permeability of soils in the Piedmont is variable and dependent on the composition of the rocks from which the soils are derived. Most soils are moderately permeable, with local areas of slow to



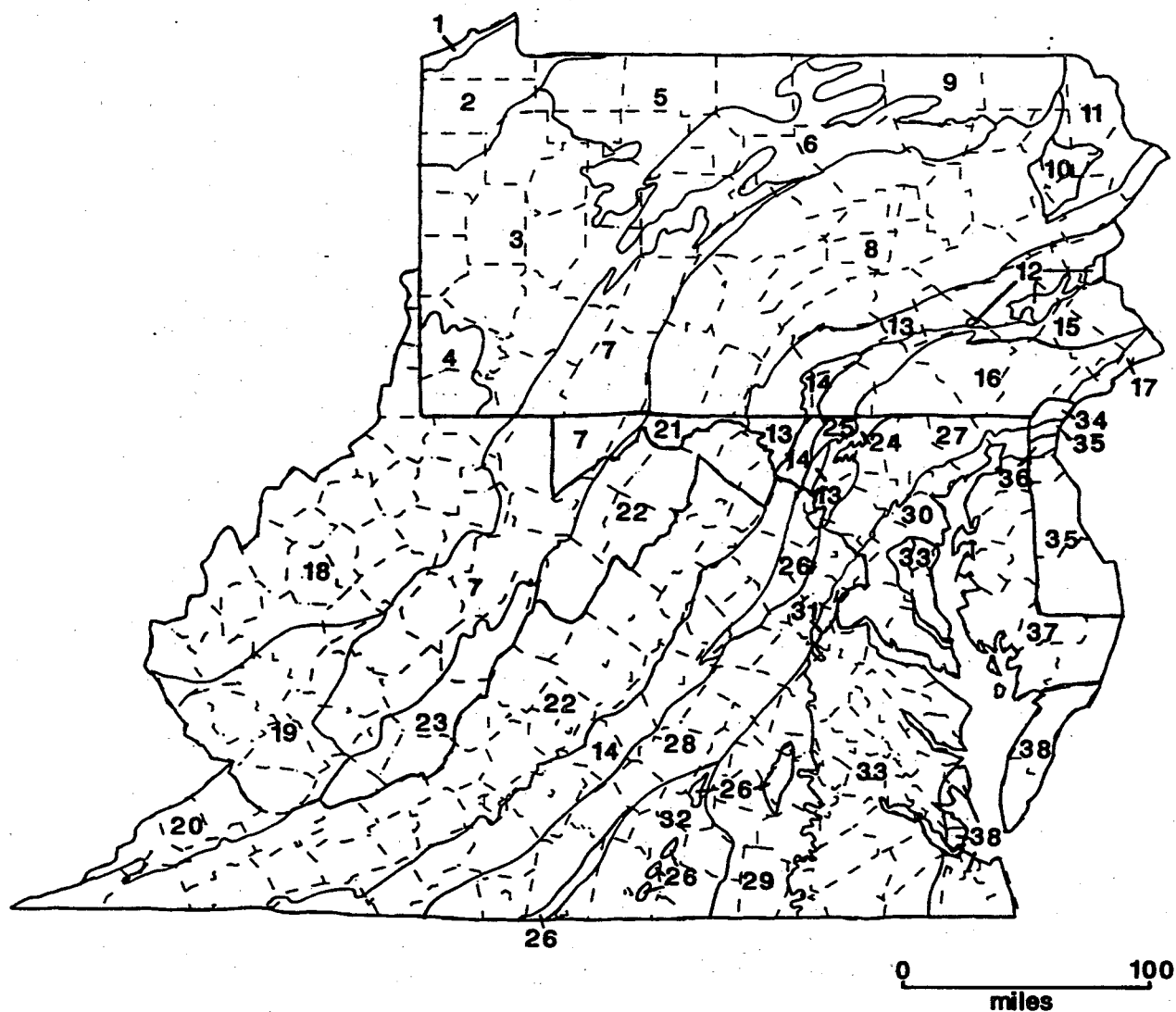
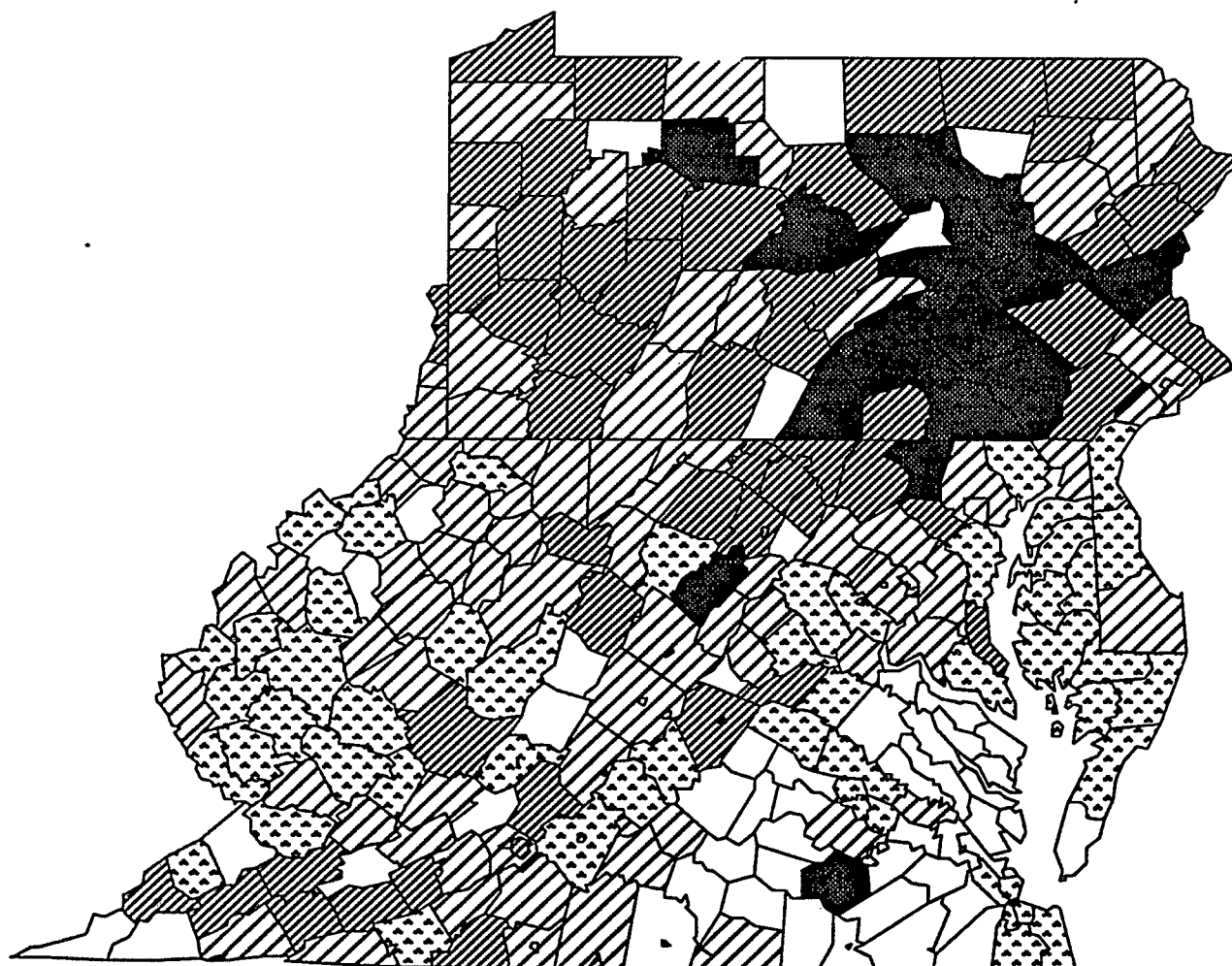


Figure 1. Geologic radon potential areas of EPA Region 3. 1-Central Lowland; 2-Glaciaded Pittsburgh Plateau; 3-Pennsylvanian rocks of the Pittsburgh Low Plateau; 4-Permian rocks of the Pittsburgh Low Plateau; 5-High Plateau Section; 6-Mountainous High Plateau; 7-Allegheny Plateau and Mountains; 8-Appalachian Mountains; 9-Glaciaded Low Plateau, Western Portion; 10-Glaciaded Pocono Plateau; 11-Glaciaded Low Plateau, Eastern Portion; 12-Reading Prong; 13-Great Valley/Frederick Valley carbonates and clastics; 14-Blue Ridge Province; 15-Gettysburg-Newark Lowland Section (Newark basin) 16, 34-Piedmont; 17-Atlantic Coastal Plain; 18-Central Allegheny Plateau; 19-Cumberland Plateau and Mountains; 20-Appalachian Plateau; 21-Silurian and Devonian rocks in Valley and Ridge; 22, 23-Valley and Ridge (Appalachian Mountains); 24-Western Piedmont Phyllite; 25-Culpeper, Gettysburg, and other Mesozoic basins; 26-Mesozoic basins; 27-Eastern Piedmont, schist and gneiss; 28-Inner Piedmont; 29-Goochland Terrane; 30, 31-Coastal Plain (Cretaceous, Quaternary, minor Tertiary sediments); 32-Carolina terrane; 33-Coastal Plain (Tertiary sediments); 35, 37, 38-Coastal Plain (quartz-rich Quaternary sediments); 36-Glauconitic Coastal Plain sediments.



100 Miles

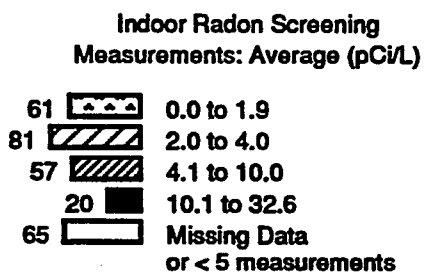


Figure 2. Screening indoor radon averages for counties with 5 or more measurements in EPA Region 3. Data for Maryland, Pennsylvania, Virginia, and West Virginia are from the State/EPA Residential Radon Survey. Data for Delaware were compiled by the Delaware Department of Health and Social Services. Histograms in map legend show the number of counties in each category.

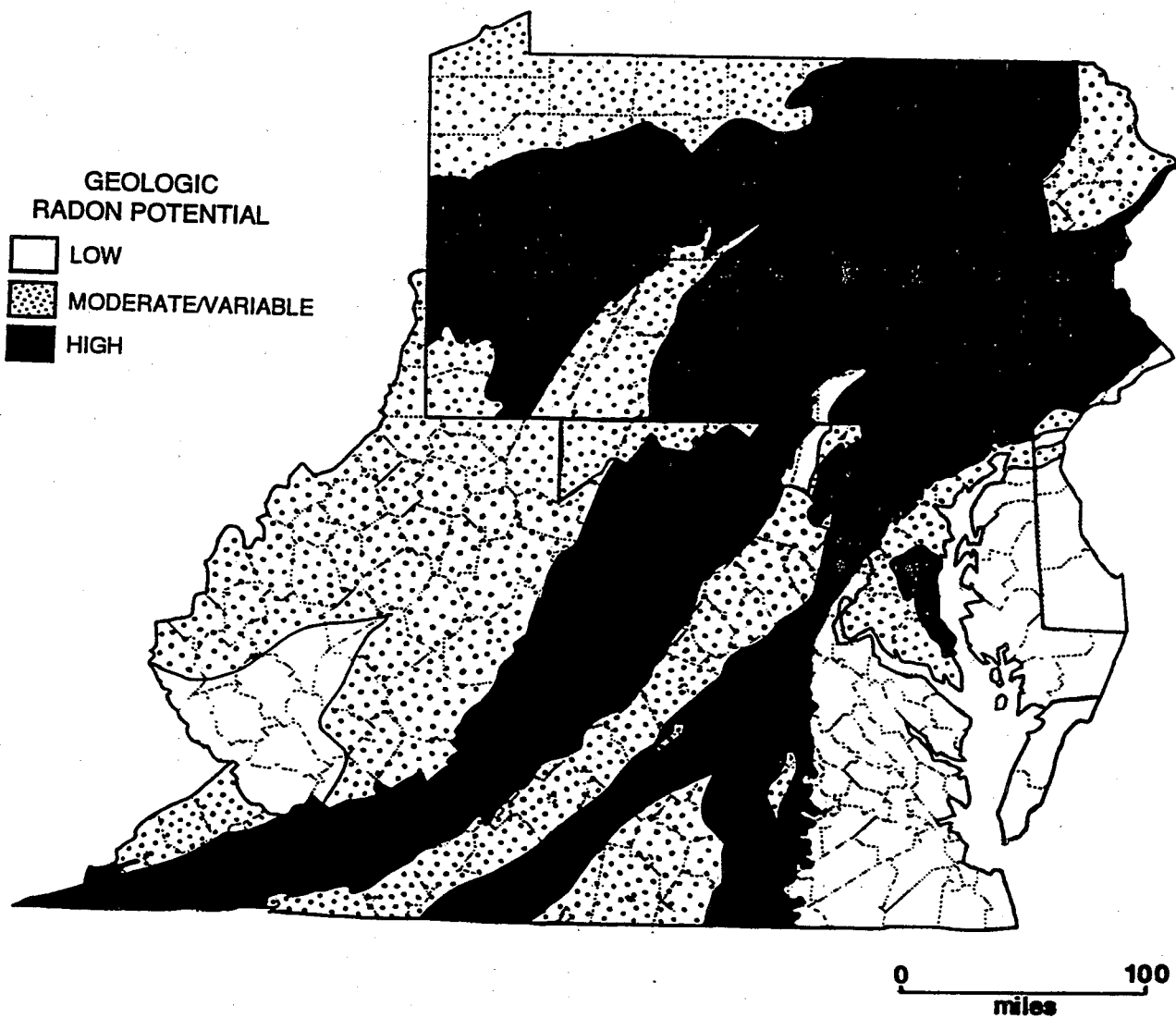


Figure 3. Geologic radon potential of EPA Region 3. For more detail, refer to individual state radon potential chapters.

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rapid permeability. Limited aerial radioactivity data for the Delaware Piedmont indicates that equivalent uranium is generally moderate (1.5-2.5 ppm).

#### *Coastal Plain*

Studies of radon and uranium in Coastal Plain sediments in New Jersey and Maryland suggest that glauconitic marine sediments equivalent to those in the northern portion of the Delaware Coastal Plain can cause elevated levels of indoor radon. Central New Castle County is underlain by glauconitic marine sediments of Cretaceous and Tertiary age that have moderate to locally high radon potential. Aerial radiometric data indicate that moderate concentrations of uranium occur in rocks and soils associated with the Piedmont and parts of the Coastal Plain of northern Delaware. Chemical analyses of Cretaceous and Tertiary glauconitic marine sediments and fluvial sediments of the Columbia Formation performed by the Delaware geological survey indicate variable but generally moderate concentrations of uranium, averaging 1.89 ppm or greater. The permeability of soils in these areas is variable but generally moderate to high, allowing radon gas to move readily through the soil. Data for New Castle County from the State indoor radon survey shows that areas underlain by the Cretaceous fluvial sediments (not glauconitic) have lower average indoor radon levels than the glauconitic parts of the upper Cretaceous and lower Tertiary sequence to the south. Kent County and all of Sussex County are underlain by quartz-dominated sands, silts, gravels, and clays with low radon potential. These sediments are low in radioactivity and generally have a low percentage of homes with indoor radon levels greater than 4 pCi/L.

### MARYLAND

#### *Coastal Plain*

The Western Shore of Maryland has been ranked moderate to locally high in radon potential and the Eastern Shore has been ranked low in radon potential. The Coastal Plain Province is underlain by relatively unconsolidated fluvial and marine sediments that are variably phosphatic and glauconitic on the Western Shore, and dominated by quartz in the Eastern Shore. Radioactivity in the Coastal Plain is moderate over parts of the Western Shore sediments, particularly in the Upper Cretaceous and Tertiary sediments of Prince George's, Anne Arundel, and northern Calvert counties. Moderate radioactivity also appears to be associated with the Cretaceous and Tertiary sediments of the Eastern Shore where these sediments are exposed in major drainages in Kent, Queen Anne's, and Talbot counties. Soil-gas radon studies in Prince George's County indicate that soils formed from the locally phosphatic, carbonaceous, or glauconitic sediments of the Calvert, Aquia, and Nanjemoy Formations can produce significantly high radon (average soil radon > 1500 pCi/L). The Cretaceous Potomac Group had more moderate levels of soil radon, averaging 800-900 pCi/L, and the Tertiary-Cretaceous Brightseat Formation and Monmouth Group had average soil radon of 1300 pCi/L. Soil permeability on the Western Shore varies from low to moderate with some high permeability in sandier soils. Well-developed clayey B horizons with low permeability are common. Indoor radon levels measured in the State/EPA Residential Radon Survey are variable among the counties of the Western Shore but are generally low to moderate. Moderate to high average indoor radon is found in most of the Western Shore counties.

For this assessment we have ranked part of the Western Shore as high in radon potential, including Calvert County, southern Anne Arundel County, and eastern Prince George's County. This area has the highest radioactivity, high indoor radon, and significant exposure of Tertiary rock

units. The part of the Western Shore ranked moderate consists of Quaternary sediments with low radon potential, Cretaceous sediments with moderate radon potential, and lesser amounts of Tertiary sediments with high radon potential. The Quaternary sediments of the Eastern Shore have low radioactivity associated with them and are generally quartzose and thus low in uranium. Heavy-mineral concentrations within these sediments may be very local sources of uranium. Indoor radon appears to be generally low on the Eastern Shore with only a few measurements over 4 pCi/L reported.

### *Piedmont*

Gneisses and schists in the eastern Piedmont, phyllites in the western Piedmont, and Paleozoic metasedimentary rocks of the Frederick Valley are ranked high in radon potential. Sedimentary and igneous rocks of the Mesozoic basins have been ranked moderate in radon potential. Radioactivity in the Piedmont is generally moderate to high. Indoor radon is moderate to high in the eastern Piedmont and nearly uniformly high in the western Piedmont. Permeability is low to moderate in soils developed on the mica schists and gneisses of the eastern Piedmont, Paleozoic sedimentary rocks of the Frederick Valley, and igneous and sedimentary rocks of the Mesozoic Basins. Permeability is moderate to high in the soils developed on the phyllites of the western Piedmont. The Maryland Geological Survey has compared the geology of Maryland with the Maryland indoor radon data. They report that most of the Piedmont rocks, with the exception of ultramafic rocks, can contribute to indoor radon readings exceeding 4 pCi/L. Their data indicate that the phyllites of the western Piedmont have much higher radon potential than the schists in the east. Ninety-five percent of the homes built on phyllites of the Gillis Formation had indoor radon measurements greater than 4 pCi/L, and 47 percent of the measurements were greater than 20 pCi/L. In comparison, 80 percent of the homes built on the schists and gneiss of the Loch Raven and Oella Formations had indoor radon readings greater than 4 pCi/L, but only 9 percent were greater than 20 pCi/L.

Studies of the phyllites in Frederick County show high average soil-gas radon (>1000 pCi/L) when compared to other rock types in the county. Limestone and shale soils of the Frederick Valley and some of the Triassic sedimentary rocks may be significant sources of radon (500-2000 pCi/L in soil gas). Because of the highly variable nature of the Triassic sediments and the amount of area that the rocks cover with respect to the county boundaries, it is difficult to say with confidence whether the high indoor radon in Montgomery, Frederick, and Carroll counties is partly attributable to the Triassic sediments. In Montgomery County, high uranium concentrations in fluvial crossbeds of the upper Manassas Sandstone containing gray carbonaceous clay intraclasts and drapes have been documented. Similar lithologic associations are common in the upper New Oxford Formation. Black shales and gray sandstones of the Heidlersburg Member are similar to uranium-bearing strata in the Culpeper basin in Virginia and may be a source of radon. Black shales in the overlying Gettysburg Formation may also be locally uranium rich. The lower New Oxford Formation, the lower Manassas Sandstone, the lower Gettysburg Formation, and the Balls Bluff Siltstone in Maryland are not likely to have concentrations of uranium except where altered by diabase intrusives and/or faulted. The diabase bodies are low in radon potential.

### *Appalachian Mountains*

The Appalachian Province is divided into the Blue Ridge, Great Valley, Valley and Ridge, and Allegheny Plateau. Each of these areas is underlain by a distinct suite of rocks with a particular geologic radon potential. The Blue Ridge is ranked low in radon potential but may be

locally moderate to high. The Catoctin volcanic rocks that underlie a significant portion of the Blue Ridge have low radioactivity, yield low soil radon and have low soil permeability. The quartzite and conglomerates overlying the Catoctin also have low radioactivity and low soil-gas radon. Further, the Pennsylvania Topographic and Geologic Survey calculated the median uranium content of 80 samples of Catoctin metabasalt and metadiabase to be less than 0.5 ppm. The Harpers Formation phyllite bordering the Catoctin volcanic rocks yields high soil-gas radon ( $>1000$  pCi/L), has greater surface radioactivity than the surrounding rocks and is a potential source of radon. The Precambrian gneiss that crops out in the Middletown Valley of the southern Blue Ridge appears to have moderate radioactivity associated with it and yielded some high radon in soil gas. It is difficult, given the constraints of the indoor radon data, to associate the high average indoor radon in the part of Frederick County underlain by parts of this province with the actual rocks. The Blue Ridge is provisionally ranked low in geologic radon potential, but this cannot be verified with the presently existing indoor radon data.

Carbonates and black shales in the Great Valley in Maryland have been ranked high in radon potential. Radioactivity is moderate to high over the Great Valley in Washington County. Washington County has more than 100 indoor radon measurements, has an average indoor radon concentration of 8.1 pCi/L in the State/EPA Survey, with over half of the readings greater than 4 pCi/L. To the north in Pennsylvania, carbonate rocks of the Great Valley and Appalachian Mountain section have been the focus of several studies and the carbonate rocks in these areas produce soils with high uranium and radium contents that generate high radon concentrations. In general, indoor radon in these areas is higher than 4 pCi/L. Studies in the carbonates of the Great Valley in West Virginia suggest that the deepest, most mature soils have the highest radium and radon concentrations and generate moderate to high indoor radon. High radon in soils and high indoor radon in homes over the black shales of the Martinsburg Formation of the Great Valley were also measured in West Virginia.

The Silurian and Devonian rocks of the Valley and Ridge have been ranked moderate to locally high in geologic radon potential. Indoor radon measurements are generally moderate to high in Allegany County. Soil permeability is variable but is generally moderate. Radioactivity in this part of the Valley and Ridge is moderate to locally high. The Tonoloway, Keyser, and Wills Creek Formations, and Clinton and Hamilton Groups have high equivalent uranium associated with them and the shales, limestone soils, and hematitic sands are possible sources of the high readings over these units.

The Devonian through Permian rocks of the Allegheny Plateau are ranked moderate in geologic radon potential. Indoor radon measurements are generally moderate to high. Radioactivity in the Allegheny Plateau is low to moderate with locally high equivalent uranium associated with the Pocono Group and Mauch Chunk Formation. Soil permeability is variable but generally moderate.

## PENNSYLVANIA

### *New England Province*

The New England Province is ranked high in geologic radon potential. A number of studies on the correlation of indoor radon with geology in Pennsylvania have been done. The Reading Prong area in the New England Province is the most notable example because of the national publicity surrounding a particularly severe case of indoor radon. These studies found that shear zones within the Reading Prong rocks enhanced the radon potential of the rocks and created

local occurrences of very high uranium and indoor radon. Several of the rock types in the Reading Prong were found to be highly uraniferous in general and they are the source for high radon levels throughout much of the province.

### *Piedmont*

The Piedmont is underlain by metamorphic, igneous, and sedimentary rocks of Precambrian to Mesozoic age that have generally moderate to high radon potential. Rock types in the metamorphic crystalline portion of the Piedmont that have naturally elevated uranium concentrations include granitic gneiss, biotite schist, and gray phyllite. Rocks that are known sources of radon and have high indoor radon associated with them include phyllites and schists, such as the Wissahickon Formation and Peters Creek Schist, shear zones in these rocks, and the faults surrounding mafic bodies within these rocks.

Studies in the Newark Basin of New Jersey indicate that the black shales of the Lockatong and Passaic Formations and fluvial sandstones of the Stockton Formation are a significant source of radon in indoor air and in water. Where these rock units occur in Pennsylvania, they may be the source of high indoor radon as well. Black shales of the Heidlersburg Member and fluvial sandstones of the New Oxford Formation may also be sources of locally moderate to high indoor radon in the Gettysburg Basin. Diabase sheets and dikes within the basins have low eU. The Mesozoic basins as a whole, however, are variable in their geologic radon potential. The Narrow Neck area is distinctly low in radioactivity and Montgomery County, which is underlain almost entirely by Mesozoic basin rocks, has an indoor radon average less than 4 pCi/L. Other counties underlain partly by the Mesozoic basin rocks, however, have average indoor radon greater than 4 pCi/L. The Newark basin is high in radon potential whereas the Gettysburg basin is low to locally moderate. For the purposes of this report the basins have been subdivided along the Lancaster-Berks county boundary. The Newark basin comprises the Mesozoic rocks east of this county line.

### *Blue Ridge*

The Blue Ridge Province is underlain by metasedimentary and metavolcanic rocks and is generally an area of low radon potential. A distinct low area of radioactivity is associated with the province on the map, although phyllite of the Harpers Formation may be uraniferous. Soils generally have variable permeability. The metavolcanic rocks in this province have very low uranium concentrations. It is difficult, given the constraints of the indoor radon data, to associate the high average indoor radon in counties underlain by parts of this province with specific rock units. When the indoor radon data are examined at the zip code level, it appears that most of the high indoor radon is attributable to the Valley and Ridge soils and rocks. The conclusion is that the Blue Ridge is provisionally ranked low in geologic radon potential although this cannot be verified with the presently available indoor radon data.

### *Ridge and Valley and Appalachian Plateaus*

Carbonate rocks of the Great Valley and Appalachian Mountain section have been the focus of several studies and the carbonates in these areas produce soils with high uranium and radium contents and soil radon concentrations. In general, indoor radon in these areas is higher than 4 pCi/L and the geologic radon potential of the area is high, especially in the Great Valley where indoor radon is distinctly higher on the average than in surrounding areas. Soils developed on

limestone and dolomite rock at the surface in the Great Valley, Appalachian Mountains, and Piedmont are probably sources of high indoor radon.

The clastic rocks of the Ridge and Valley and Appalachian Plateaus province, particularly the Ordovician through Pennsylvanian-age black to gray shales and fluvial sandstones, have been extensively cited in the literature for their uranium content as well as their general uranium potential. It appears from the uranium and radioactivity data and comparison with the indoor radon data that the black shales of the Ordovician Martinsburg Formation, the lower Devonian black shales, Pennsylvanian black shales of the Allegheny Group, Conemaugh Group, and Monogahela Group, and the fluvial sandstones of the Devonian Catskill and Mississippian Mauch Chunk Formation may be the source of most moderate to high indoor radon levels in the Appalachian Plateau and parts of the Appalachian Mountains section.

Only a few areas in these provinces appear to have geologically low to moderate radon potential. The Greene Formation in Greene County appears to correlate with distinctly low radioactivity. The indoor radon for Greene County averages less than 4 pCi/L for the few measurements available in the State/EPA survey.

Somerset and Cambria Counties in the Allegheny Mountain section have indoor radon averages less than 4 pCi/L, and it appears that low radioactivity and slow permeability of soils may be factors in the moderate geologic radon potential of this area. These two counties and most of the Allegheny Mountain section are underlain by Pennsylvanian-age sedimentary rocks. The radioactivity map shows low to moderate radioactivity for the Pennsylvanian-age rocks in the Allegheny Mountain section and much higher radioactivity in the Pittsburgh Low Plateau section. Most of the reported uranium occurrences in these rocks appear to be restricted to the north and west of the Allegheny Mountain section. Approximately half of the soils developed on these sediments have slow permeability and seasonally high water tables.

#### *Coastal Plain*

Philadelphia and Delaware Counties, in the southeastern corner of Pennsylvania, have average indoor radon less than 4 pCi/L and have low radioactivity. Part of Delaware County and most of Philadelphia County are underlain by Coastal Plain sediments with low uranium concentrations. Soils developed on these sediments are variable, but a significant portion are clayey with slow permeability.

#### *Glaciated Areas of Pennsylvania*

Radiometric lows and relatively lower indoor radon levels appear to be associated with the glaciated areas of the State, particularly the eastern portion of the Glaciated Low Plateau and Pocono Plateau in Wayne, Pike, Monroe, and Lackawanna Counties. Glacial deposits are problematic to assess for radon. In some areas of the glaciated portion of the United States, glacial deposits enhance radon potential, especially where the deposits have high permeability and are derived from uraniferous source rocks. In other portions of the glaciated United States, glacial deposits blanket more uraniferous rock or have low permeability and corresponding low radon potential. The northeastern corner of Pennsylvania is covered by the Olean Till, made up of 80-90 percent sandstone and siltstone clasts with minor shale, conglomerate, limestone, and crystalline clasts. A large proportion of the soils developed on this till have seasonally high water tables and poor drainage, but some parts of the till soils are stony and have good drainage and high permeability. Low to moderate indoor radon levels and radioactivity in this area may be due to the seasonally saturated ground and to the tills being made up predominantly of sandstones and

siltstones with low uranium contents. A similar situation exists in the northwestern part of the State, which is covered by a wide variety of tills, predominantly the Kent Till, which contains mostly sandstone, siltstone, and shale clasts. Many of the soils in this area also have low permeabilities and seasonally high water tables. Where the tills are thinner, the western portion of the Glaciated Low Plateau has higher indoor radon and high radioactivity.

## VIRGINIA

### *Coastal Plain*

The Coastal Plain of Virginia is ranked low in geologic radon potential. Indoor radon is generally low; however, moderate to high indoor radon can occur locally and may be associated with phosphatic, glauconitic, or heavy mineral-bearing sediments. Equivalent uranium over the Tertiary units of the Coastal Plain is generally moderate. Soils developed on the Cretaceous and Tertiary units are slowly to moderately permeable. Studies of uranium and radon in soils indicate that the Yorktown Formation could be a source for elevated levels of indoor radon. The Quaternary sediments generally have low eU associated with them. Heavy mineral deposits of monazite found locally within the Quaternary sediments of the Coastal Plain may have the potential to generate locally moderate to high indoor radon.

### *Piedmont*

The Goochland terrane and Inner Piedmont have been ranked high in radon potential. Rocks of the Goochland terrane and Inner Piedmont have numerous well-documented uranium and radon occurrences associated with granites; pegmatites; granitic gneiss; monazite-bearing metasedimentary schist and gneiss; graphitic and carbonaceous slate, phyllite, and schist; and shear zones. Indoor radon is generally moderate but significant very high radon levels occur in several areas. Equivalent uranium over the Goochland terrane and Inner Piedmont is predominantly high to moderate with areas of high eU more numerous in the southern part. Permeability of soils developed over the granitic igneous and metamorphic rocks of the Piedmont is generally moderate. Within the Goochland terrane and Inner Piedmont, local areas of low to moderate radon potential will probably be found over mafic rocks (such as gabbro and amphibolite), quartzite, and some quartzitic schists. Mafic rocks have generally low uranium concentrations and slow to moderate permeability in the soils they form.

The Carolina terrane is variable in radon potential but is generally moderate. Metavolcanic rocks have low eU but the granites and granitic gneisses have moderate to locally high eU. Soils developed over the volcanic rocks are slowly to moderately permeable. Granite and gneiss soils have moderate permeability.

The Mesozoic basins have moderate to locally high radon potential. It is not possible to make any general associations between county indoor radon averages and the Mesozoic basins as a whole because of the limited extent of many the basins. However, sandstones and siltstones of the Culpeper basin, which have been lightly metamorphosed and altered by diabase intrusion, are mineralized with uranium and cause documented moderate to high indoor radon levels in northern Virginia. Lacustrine black shales and some of the coarse-grained gray sandstones also have significant uranium mineralization, often associated with green clay clasts and copper. Equivalent uranium over the Mesozoic basins varies among the basins. The Danville basin has very high eU associated with it whereas the other basins have generally moderate eU. This radioactivity may be related to extensive uranium mineralization along the Chatham fault on the west side of the Danville

basin. Localized high eU also occurs over the western border fault of the Culpeper basin. Soils are generally slowly to moderately permeable over the sedimentary and intrusive rocks of the basins.

### *Valley and Ridge*

The Valley and Ridge has been ranked high in geologic radon potential but some areas have locally low to moderate radon potential. The Valley and Ridge is underlain by Cambrian dolomite, limestone, shale, and sandstone; Silurian-Ordovician limestone, dolomite, shale, and sandstone; and Mississippian-Devonian sandstone, shale, limestone, gypsum, and coal. Soils derived from carbonate rocks and black shales, and black shale bedrock may be sources of the moderate to high levels of indoor radon in this province. Equivalent uranium over the Valley and Ridge is generally low to moderate with isolated areas of high radioactivity. Soils are moderately to highly permeable. Studies of radon in soil gas and indoor radon over the carbonates and shales of the Great Valley in West Virginia and Pennsylvania indicate that the rocks and soils of this province constitute a significant source of indoor radon. Sandstones and red siltstones and shales are probably low to moderate in radon potential. Some local uranium accumulations are contained in these rocks.

### *Appalachian Plateaus*

The Appalachian Plateaus Province has been ranked moderate in geologic radon potential. The plateaus are underlain by Pennsylvanian-age sandstone, shale, and coal. Black shales, especially those associated with coal seams, are generally elevated in uranium and may be the source for moderate to high radon levels. The coals themselves may also be locally elevated in uranium. The sandstones are generally low to moderate in radon potential but have higher soil permeability than the black shales. Equivalent uranium of the province is low to moderate and indoor radon is variable from low to high, but indoor radon data are limited in number.

## WEST VIRGINIA

### *Allegheny Plateau*

The Central Allegheny Plateau Province has moderate geologic radon potential overall, due to persistently moderate eU values and the occurrence of steep, well-drained soils. However, Brooke and Hancock counties, in the northernmost part of this province, have average indoor radon levels exceeding 4 pCi/L. This appears to be related to underlying Conemaugh and Monongahela Group sedimentary rocks which have elevated eU values in this area and in adjacent areas of western Pennsylvania.

The Cumberland Plateau and Mountains Province has low radon potential. The eU values for the province are low except in areas of heavy coal mining, where exposed shale-rich mine waste tends to increase values. Indoor radon levels average less than 2 pCi/L in most counties.

The Eastern Allegheny Plateau and Mountains Province has moderate radon potential overall. Locally high indoor radon levels are likely in homes on dark gray shales of Devonian age and colluvium derived from them in Randolph County. The southern part of this province has somewhat lower eU values and indoor radon averages.

### ***Ridge and Valley Province***

The southern part of the Appalachian Ridge and Valley Province in West Virginia has moderate radon potential overall. The eU signature for this province is elevated ( $> 2.5$  ppm eU). Locally high radon potential occurs in areas of deep residual soils developed on limestones of the Mississippian Greenbrier Group, especially in central Greenbrier County, where eU values are high. Elevated levels of radon may be expected in soils developed on dark shales in this province or in colluvium derived from them.

The northern part of the Appalachian Ridge and Valley Province in West Virginia has high geologic radon potential. The soils in this area have an elevated eU signature. Soils developed on the Martinsburg Formation and on limestones and dolomites throughout the Province contain elevated levels of radon and a very high percentage of homes have indoor radon levels exceeding 4 pCi/L in this province. Karst topography and associated locally high permeability in soils increases the radon potential. Structures sited on uraniferous black shales may have very high indoor radon levels. Steep, well-drained soils developed on phyllites and quartzites of the Harpers Formation in Jefferson County also produce high average indoor radon levels.



# PRELIMINARY GEOLOGIC RADON POTENTIAL ASSESSMENT OF MARYLAND

by  
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## INTRODUCTION

A random sampling of indoor radon in 1126 homes in Maryland was conducted for the State/EPA Residential Radon Survey during the winter of 1991. Indoor radon was measured by charcoal canister and the average for the State was 3.1 pCi/L. Twenty percent of these indoor radon measurements exceeded the EPA guideline of 4 pCi/L. The Maryland State Department of the Environment has also collected more than 37,000 indoor radon measurements from Maryland residents and commercial vendors since 1986. Examination of these data in the context of geology, soil parameters, and radioactivity suggest that many of the soils and rocks of the Piedmont and Great Valley have the potential to produce high levels of indoor radon ( $> 4$  pCi/L). Soils and rocks of the Allegheny Plateau, Valley and Ridge, and the western shore of the Coastal Plain have moderate to locally high radon potential. Soils and rocks of the Blue Ridge and Eastern Shore of the Coastal Plain have relatively low geologic radon potential.

This is a generalized assessment of geologic radon potential of rocks, soils, and surficial deposits of Maryland. The scale of this assessment is such that it is inappropriate for use in identifying the radon potential of small areas such as neighborhoods, individual building sites, or housing tracts. Any localized assessment of radon potential must be supplemented with additional data and information from the locality. Within any area of a given radon potential ranking, there are likely to be areas with higher or lower radon levels than characterized for the area as a whole. Indoor radon levels, both high and low, can be quite localized, and there is no substitute for testing individual homes. Elevated levels of indoor radon have been found in every State, and EPA recommends that all homes be tested. For more information, the reader is urged to consult the local or State (1-800-872-3666) radon program or EPA regional office. More detailed information on state or local geology may be obtained from the state geological survey. Addresses and phone numbers for these agencies are listed in chapter 1 of this booklet.

## PHYSIOGRAPHIC AND GEOGRAPHIC SETTING

The physiography of Maryland (fig. 1) is in part a reflection of the underlying bedrock geology (fig. 2a, 2b). Maryland has three major physiographic regions: the Appalachian Province, the Piedmont Province, and the Coastal Plain Province. Each of these provinces is subdivided into several smaller regions (fig. 1). The Coastal Plain Province covers approximately one half of Maryland and is subdivided into the dissected rolling plain of the Western Shore and the nearly flat Eastern Shore. Elevations range from sea level to 400 feet at the Fall Line. The Fall Line is actually a zone where the sediments of the Coastal Plain are thinnest and overlap onto the crystalline rocks of the Piedmont Province. Across this zone, there is a striking change in the water velocity of rivers and streams; falls and rapids characterize the streams of the Piedmont. West of the Fall Line lies the rolling hills of the Piedmont, which is divided into lowlands and uplands. The Piedmont uplands is underlain by crystalline igneous and metamorphic rocks, and the Piedmont lowlands are underlain by sedimentary and igneous rocks of the Frederick Valley and Mesozoic basins. The Appalachian Province lies to the west of the Piedmont. It is subdivided into four distinct subdivisions, and it is underlain by folded and faulted sedimentary and igneous rocks.



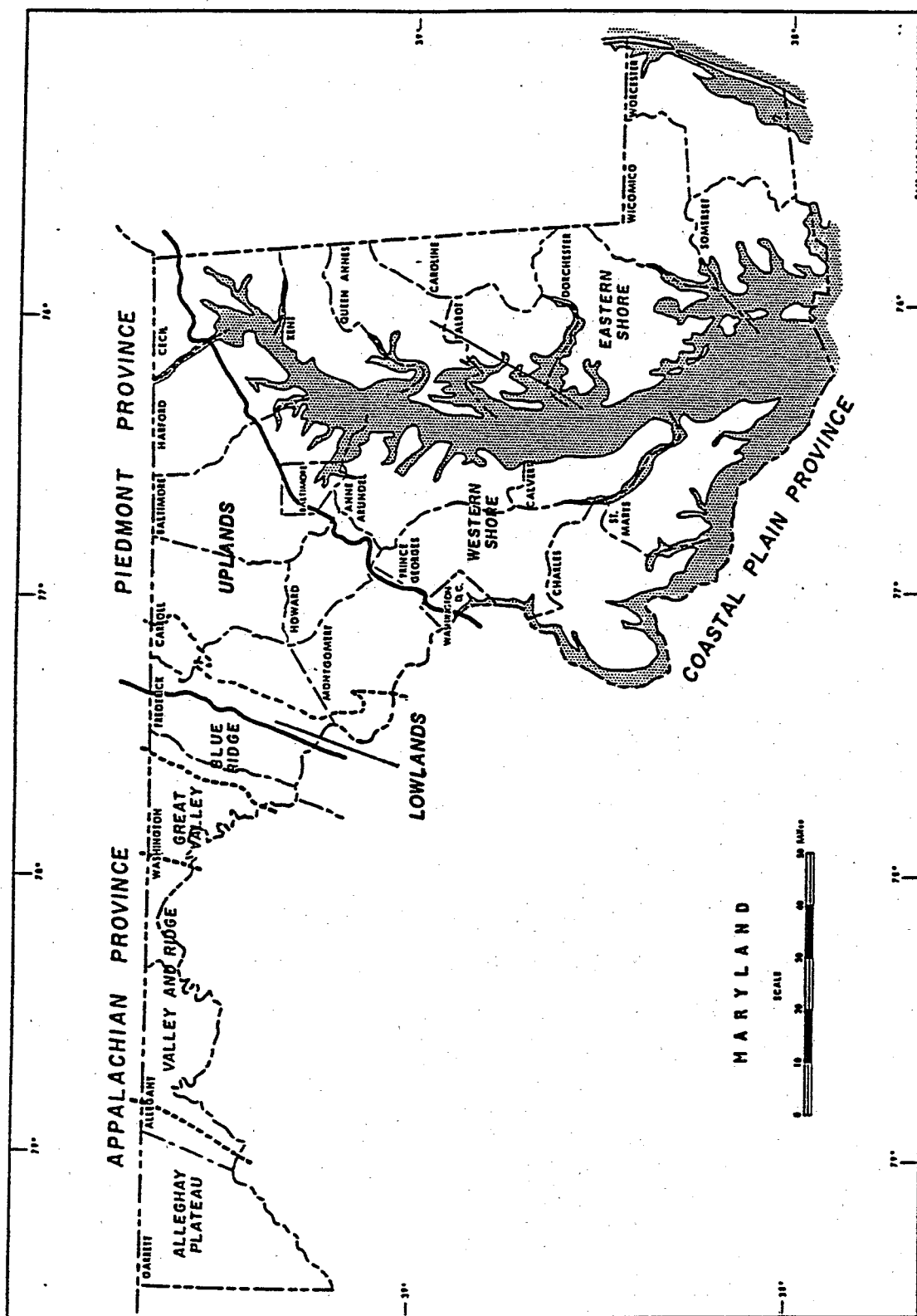


Figure 1. Physiographic/geologic provinces and subdivisions of Maryland (after Vokes, 1957, and Thornbury, 1965).

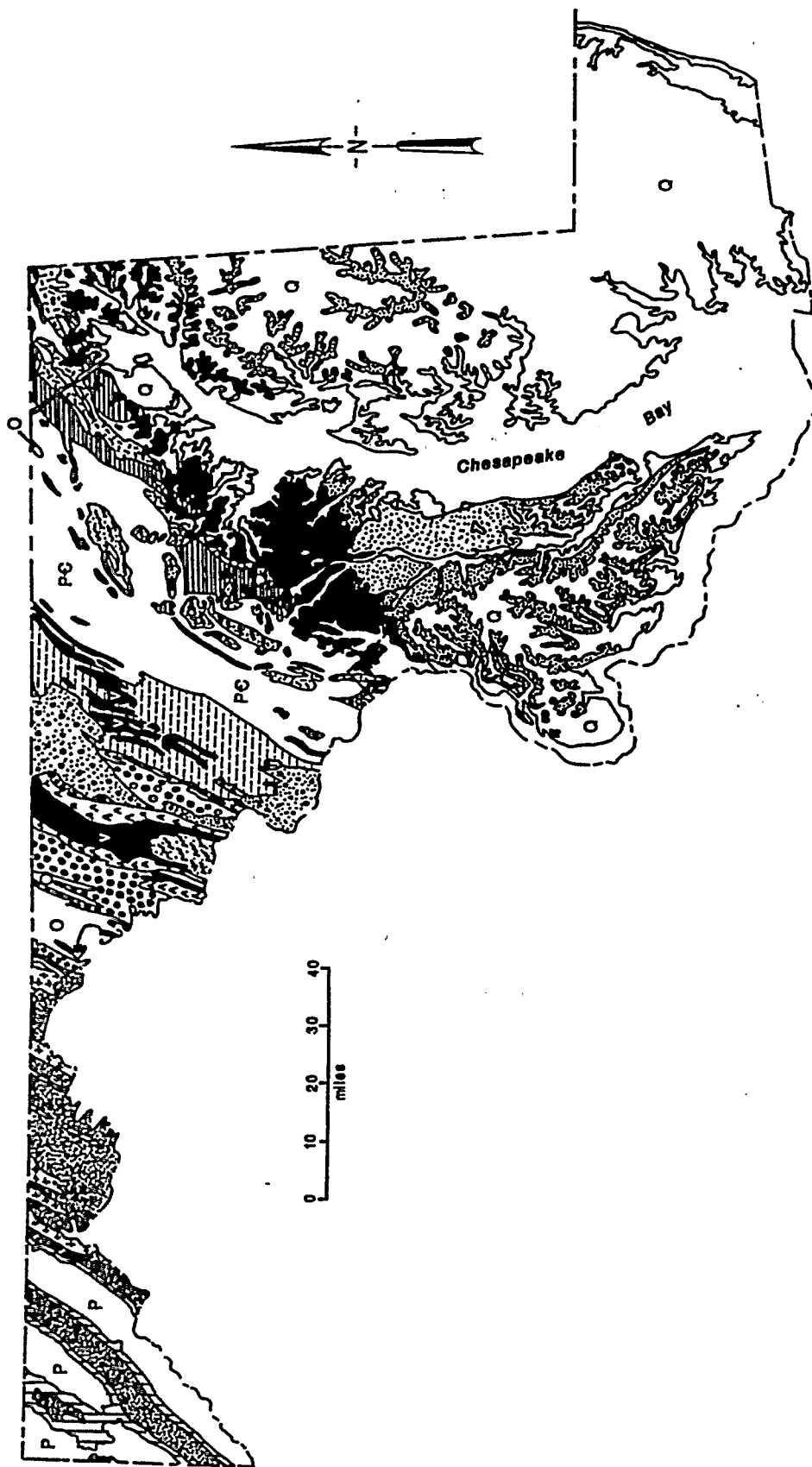



















Figure 2a. Generalized geologic map of Maryland (after Maryland Geological Survey, 1967).

## GENERALIZED GEOLOGIC MAP OF MARYLAND EXPLANATION

-  **QUATERNARY**—sand, silt, gravel, clay, and peat
-  **TERTIARY**—sand, clay, silt, greensand, and diatomaceous earth
-  **CRETACEOUS**—sand, gravel, silt, and clay
-  **TRIASSIC**—red shale, red sandstone, and conglomerate, intruded by diabase dikes and sills (indicated by T)
-  **PERMIAN & PENNSYLVANIAN**—cyclic sequences of shale, siltstone, sandstone, clay, limestone, and coal
-  **MISSISSIPPIAN**—red beds, shale, siltstone, sandstone, and limestone
-  **DEVONIAN**—shale, siltstone, sandstone, limestone, and chert
-  **SILURIAN**—shale, mudstone, sandstone, and limestone
-  **ORDOVICIAN**—limestone, dolomite, shale, siltstone, and red beds. Slate and conglomerate in northern Hartford County
-  **CAMBRIAN**—limestone, dolomite, shale, and sandstone
-  **PALEOZOIC GRANITIC ROCKS**—quartz diorite to granite intrusive rocks and diamicite
-  **PALEOZOIC BASIC IGNEOUS ROCKS**—intrusive rocks; gabbro, serpentine
-  **CAMBRIAN TO PRECAMBRIAN (?)**—(South Mountain area) quartzite, sandstone, shale, and phyllite
-  **PRECAMBRIAN (?)**—(South Mountain area and western Piedmont) metabasalt, metarhyolite, marble, and phyllite
-  **PRECAMBRIAN (?)**—(Western Piedmont) tuffaceous and non-tuffaceous phyllite, slate, and quartzite
-  **PRECAMBRIAN-PALEOZOIC (?)**—(Eastern Piedmont) schist, metagraywacke, quartzite, diamicite, marble, and metavolcanic rocks
-  **PRECAMBRIAN BASEMENT COMPLEX**—gneiss, migmatite, and augen gneiss



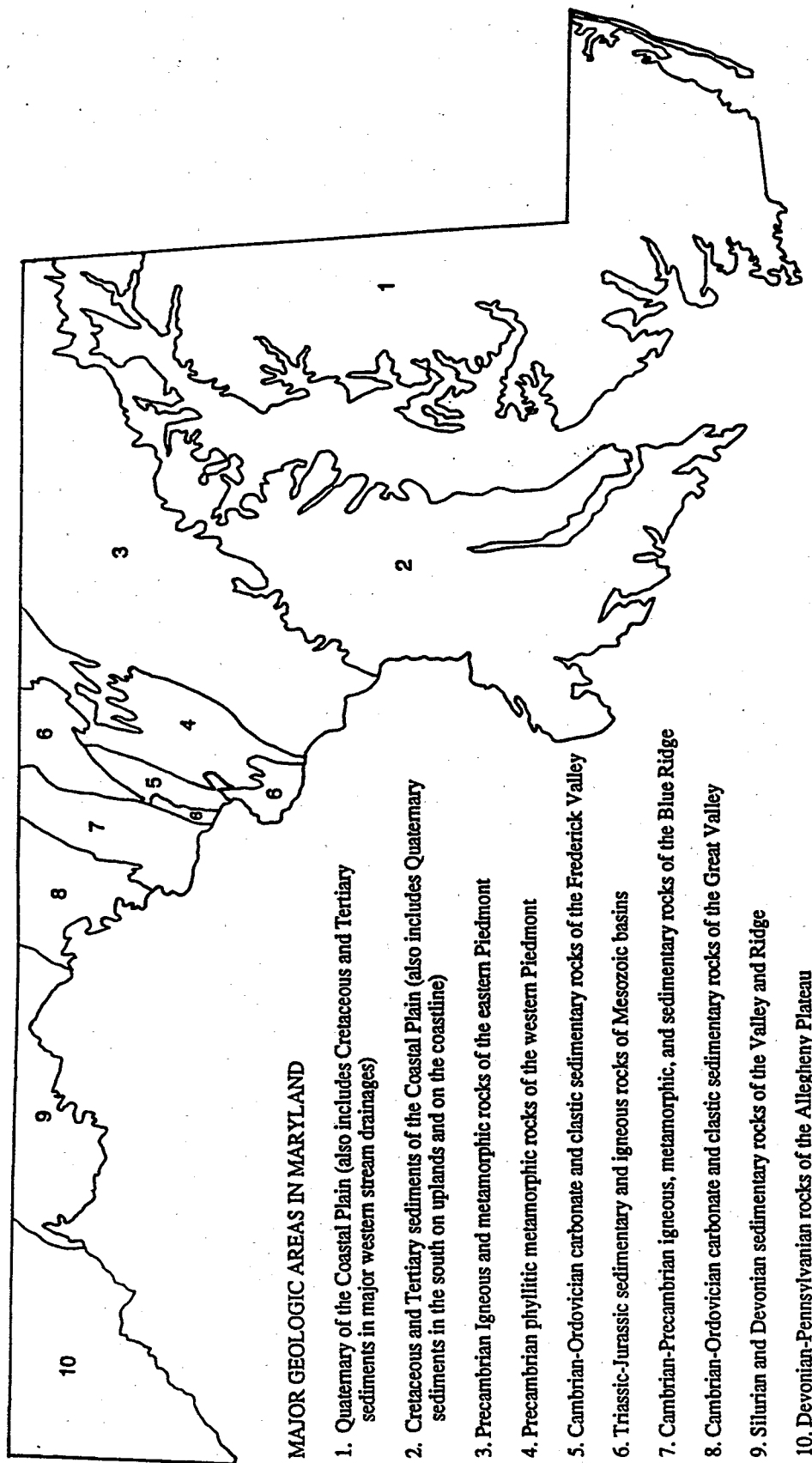


Figure 2b. Major geologic areas in Maryland.





The Blue Ridge has rugged topography, with ridges made of resistant quartzite and valley floors underlain by metavolcanic rocks. West of the Blue Ridge lies the Great Valley, which is underlain by limestones and shales and has a rolling to nearly level topography. The Valley and Ridge bounds the western side of the Great Valley and has steep ridges of resistant sandstone and deep valleys underlain by limestone and shale. The westernmost part of Maryland is in the Allegheny Plateau, a broad upland crossed by mountain ranges. The highest elevation in Maryland, 3360 feet above sea level, is in this province. Sedimentary rocks, which include several coal deposits, underlie the Allegheny Plateau.

Maryland's climate is continental in the western regions to humid subtropical in the east. Average annual precipitation is similar throughout the State, averaging about 44 inches (fig. 3). In 1990 Maryland's population was 4,781,468, with 80 percent of the population living in urban centers (fig. 4). Population density is approximately 442 per square mile.

## GEOLOGIC SETTING

The geology of Maryland is complex, ranging from unconsolidated sands and clays to granites, marbles, limestones, and volcanic rocks. Names of rock formations and the way rocks are grouped have changed with time. This description of the geology tries to convey the major rock types of an area, especially as they pertain to the radon problem. Descriptions in this report are derived from the following references: Hopson (1964), Cleaves and others (1968), Reinhardt (1974), Edwards (1986, 1988), Hansen and Edwards (1986), Higgins and Conant (1990), and Smoot (1991). A general geologic map is given in figure 2a and general geologic areas and terminology are defined in figure 2b. This terminology will be used throughout this report. It is suggested that the reader refer to the more detailed state geologic map (Cleaves and others, 1968) as well as the numerous detailed geologic maps available from the Maryland Geological Survey (1992).

### The Coastal Plain

The Coastal Plain Province is underlain by relatively unconsolidated fluvial and marine sediments forming a wedge of strata that thickens to the east. The Coastal Plain is divided into an inner belt of Cretaceous- and early Tertiary-age sediments and an outer belt of younger Tertiary- and Quaternary-age units. The Lower Cretaceous units are composed of fluvial sediments including quartz sand, gravel, and clay, whereas the Upper Cretaceous through Quaternary sediments are largely marine in origin and include calcareous clays and silts, glauconitic clays, silts, and sands, micaceous clays, silts, and fine sands, and finally, the young coastal deposits of beach, lagoon, and marsh environments that dominate the shoreline.

The oldest and most extensive Cretaceous-age rocks are the Potomac Group, composed of interbedded quartz gravels, quartzitic argillaceous sands, and variegated silts and clays. The younger Cretaceous sediments crop out in narrow belts from north and west of Annapolis to Washington, D.C., and along drainages in the northern part of the Eastern Shore. Overlying the Potomac Group is the Magothy Formation, consisting of white, cross-bedded, lignitic sands, gray silty clays, and ferruginous quartz gravels. The Matawan Formation overlies the Magothy Formation and is characterized by fine-grained, glauconitic, micaceous sand and silt. The Severn Formation forms the top of the Cretaceous section and consists of fine- to coarse-grained, glauconitic, micaceous sand with a basal gravel.



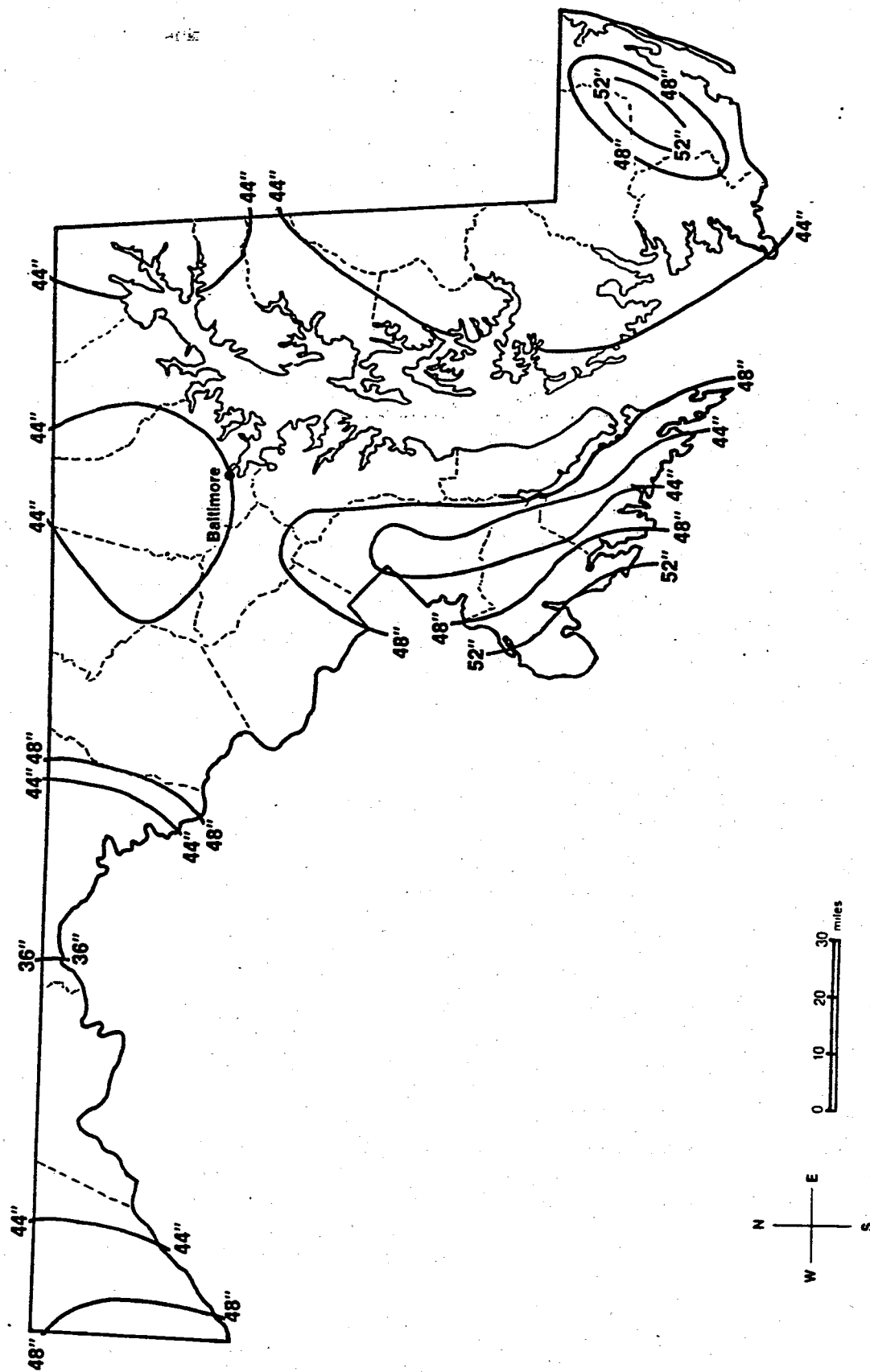


Figure 3. Average annual precipitation in Maryland (from Facts on File, 1984).

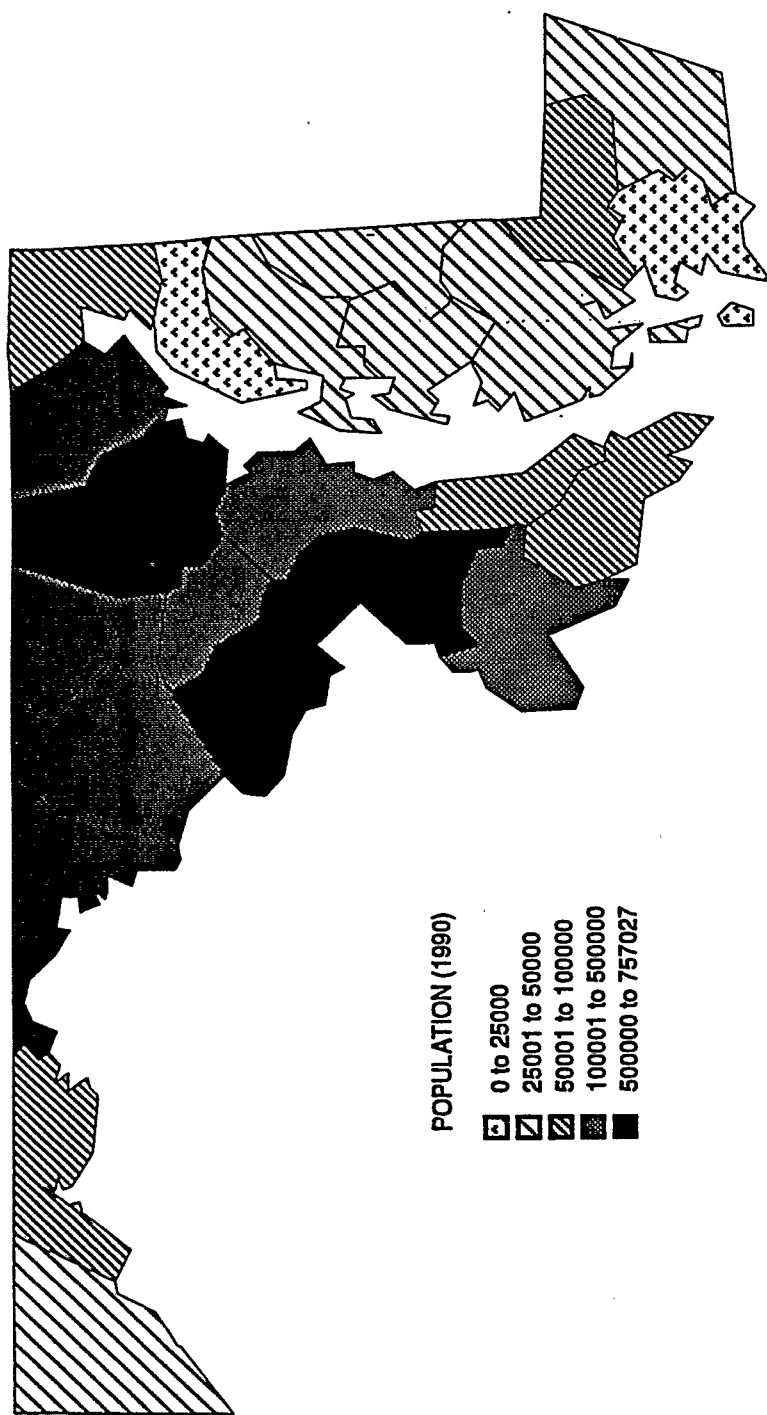


Figure 4. Population of counties in Maryland (1990 U.S. Census data).

Tertiary-age rocks of the Coastal Plain crop out for the most part on the Western Shore and along major drainages in the central and northern parts of the Eastern Shore. The base of the Tertiary section is the Pamunkey Group, consisting of the Brightseat, Aquia, Marlboro, and Nanjemoy Formations. These sediments form a wide band from Washington, D.C. to Annapolis. The Brightseat consists of fine- to coarse-grained, micaceous and locally glauconitic sand with locally indurated calcareous beds and phosphatic pebbles and fossils. The glauconitic, fossiliferous sands of the Aquia Formation overlie the Brightseat Formation. These sands contain as much as 70 percent glauconite. The Marlboro Clay consists of pink to gray clay with lenses of fine white sand. The Nanjemoy Formation is characterized by fine- to medium-grained, argillaceous, glauconitic sands with minor clay. Overlying the Pamunkey Group is the Chesapeake Group, consisting of the Calvert, Choptank, and St. Marys Formations. The Calvert Formation crops out extensively in the central portion of the Western Shore. The base of the Calvert is a diatomaceous clay with fine argillaceous sand overlain by interbedded fine grained argillaceous sand, shelly sand, carbonaceous clay, and sandy clay. Sand is locally cemented to form sandstone. The Calvert is succeeded by the quartzose, fine-grained sand, silt, shelly sand, and sandstone of the Choptank Formation. The St. Marys Formation is a sandy clay and fine-grained sand that crops out predominantly in the southern part of the Western Shore.

The youngest Tertiary rocks in Maryland occur in the subsurface or are of questionable age. The end of Tertiary time and beginning of Quaternary time was a period of deposition and erosion, including the deposition of very coarse-grained sand and gravel that formed upland deposits of the Western Shore (McCarten, 1990). Quartzose, cross-bedded sand and gravel, and minor silt and clay of Tertiary age form upland deposits on the Eastern Shore. Quaternary deposits occurring in lowlands and along shorelines include quartzose gravel, sand, silt and clay, peat, marsh muds, and shell-bearing clays and sands.

### The Piedmont

For the purposes of this assessment, the Piedmont of Maryland is subdivided into an eastern and western part (fig. 2b), each underlain by a distinctive sequence of rocks. The Precambrian-Cambrian (?) crystalline rocks of the western Piedmont consist of phyllite and schist with thin interbeds of quartzite, and a major belt of metabasalt with minor marble and volcanic phyllite. To the west of these rocks lie the Paleozoic carbonates, shales, and fine sandstones of Frederick Valley and the sandstones, siltstones, shales, conglomerates, and diabase dikes of the Mesozoic Basins. Rocks of the eastern Piedmont are exposed in a large structure called the Baltimore-Washington anticlinorium. In the core of the anticlinorium is the Precambrian Baltimore Gneiss, surrounded by younger, Paleozoic metasedimentary schist and marble of the Glenarm Supergroup. The anticlinorium is flanked by mafic and ultramafic rocks of the Baltimore Mafic Complex, metavolcanic rocks of the James Run Formation, and various bodies of diamictite, granitic plutons, and metagraywacke. A more detailed description of the Piedmont from east to west is given in the following paragraphs.

Metamorphosed volcanic rocks, including greenstone, greenschist, amphibolite, and felsite of the James Run Formation, crop out in several large irregular areas along the Fall Line, especially north of the Susquehanna River. Numerous isolated bodies of granitic gneiss and granite plutons also crop out along the eastern edge of the Piedmont. The Aberdeen metagabbro, consisting of metagabbro and amphibolite, underlies a large area of eastern Harford County, in the area of Havre de Grace. To the west of these mafic rocks is a wide band of generally granitic rocks, including granitic gneiss, granofels, schist, felsite, and metagraywacke of the Port Deposit Gneiss, James

Run Formation, the Conowingo Diamictite, and several unnamed rock units that extend from the northeast corner of the State south to Baltimore. The Port Deposit Gneiss is a deformed complex of extrusive and shallow intrusive rocks, predominantly biotite-diorite in composition, that is locally sheared. The James Run Formation is a complicated sequence of metavolcanic rocks ranging in composition from mafic to felsic as described above. The Conowingo Diamictite is a metasedimentary rock with abundant grains and pebbles of quartz, as well as clasts, blocks, and slabs of other rock types including quartzite, gneiss, schist, graywacke, and amphibolite. The Baltimore Mafic Complex lies west of the Conowingo Diamictite and east of the Baltimore Gneiss domes and the Glenarm Supergroup, cropping out from northern Cecil County to southwest of Baltimore and the Patuxent River. The Baltimore Mafic Complex is composed of gabbro, serpentinite, amphibolite, and talc schist. The Precambrian Baltimore Gneiss is exposed in several large domes through Baltimore and Howard Counties and comprises biotite-quartz-feldspar gneiss, biotite hornblende gneiss, and amphibolite. Paleozoic rocks of the lower Glenarm Supergroup unconformably overlie the Baltimore Gneiss and consist of the Setters Formation, a quartzite interbedded with mica schist, and the Cockeysville Marble, which overlies the Setters Formation and consists of metadolomite, calc-silicate schist and marble, and calcite marble. The Cockeysville Marble is overlain by the areally extensive pelitic schist of the Loch Raven Schist and the Oella Formation that comprise the upper Glenarm Supergroup (formerly termed the lower pelitic schist of the Wissahickon Formation). To the west of the gneiss domes and the Glenarm Supergroup is the diamictite of the Sykesville Formation, and extensive areas of metagraywacke and schist (formerly mapped as Wissahickon) with isolated bodies of mafic rocks and granitic plutons.

The crystalline rocks of the western Piedmont are distinctly different from the rocks of the eastern Piedmont. The western Piedmont crystalline rocks are dominated by schist and phyllite of the Gillis, Marburg, Urbana, and Ijamsville Formations, and metavolcanic rocks of the Sams Creek Formation. The Gillis crops out in a wide band from southwestern Montgomery County north to Mt. Airy and to the west and north through eastern Frederick County into southern Carroll County. It is composed of interbedded green chloritic phyllite, gray graphitic phyllite, metasiltstone, and metagraywacke with white vein quartz. The Marburg Schist crops out to the north of the Gillis and is a fine-grained muscovite-chlorite schist interbedded with quartzite. Around Linwood is a small mass of crystalline, schistose limestone and calcareous slate called the Silver Run Limestone Member of the Marburg Schist. The Urbana Formation crops out west of the Gillis and extends north to New London. It is composed of gray to green chloritic phyllite interbedded with siltstone, quartzite, and marble. The Sams Creek Formation crops out in sinuous bands within the phyllites and schists from Hyattstown northeast to the state line. The Sams Creek Formation consists of massive to schistose metabasalt with minor phyllite and quartzite. The Wakefield Marble Member of the Sams Creek Formation forms thin bands in association with the metabasalt.

The crystalline rocks of the Piedmont are bounded on the west by the Gettysburg and Culpeper basins and by carbonate and clastic rocks of the Frederick Valley. The Frederick Valley is underlain by locally deformed and metamorphosed Cambrian-Ordovician clastic and carbonate rocks. The base of the Cambrian sequence is the Araby Formation, consisting of locally phyllitic siltstone, silty shale, and argillaceous sandstone. It forms a narrow ridge on the east side of the valley. At the top of the Araby is the highly deformed Cash Smith Formation, a gray to black phyllitic shale and calcareous shale with limestone nodules. The Frederick Formation overlies the Cash Smith Formation and is the most areally extensive unit of the Frederick Valley. It consists of three members: the thin bedded, locally sandy, limestone, dolomite, and minor shale of the Rocky

Springs Station Member; the laminated limestone of the Adamstown Member; and the fossiliferous, laminated, locally silty and sandy, limestone and dolomite of the Lime Kiln Member. The Ordovician Grove Formation overlies the Frederick Formation and consists of fossiliferous limestone and dolomite with minor sandstone.

Late Triassic-early Jurassic continental sedimentary and igneous rocks of the Newark Supergroup occur in parts of two half-graben basins (Mesozoic basins) that form a north-south belt across the central part of the State. The southern corner of the Gettysburg basin extends south from Pennsylvania. The strata dip westward to the border fault and are folded into broad synclines separated by faults. The basal Triassic New Oxford Formation forms a belt that thins to the south along the southeastern margin of the basin. The New Oxford Formation consists of fluvial arkosic sandstone, siltstone, and conglomerate. It is more conglomeratic along its basal contact with older rocks on the southeastern margin of the basin. The New Oxford in Maryland is overlain by Triassic Gettysburg Formation, which comprises the rest of the basin fill. The lower part of the Gettysburg Formation consists of fluvial red siltstones with thin arkosic sandstones. The upper part of the Gettysburg Formation consists of lacustrine red and black shales and siltstones. The lower part of this portion of the Gettysburg Formation contains more frequent occurrences of black shale and is called the Heidlerburg Member.

South of the Gettysburg basin, the northernmost part of the Culpeper basin extends into Virginia. The Culpeper strata also dip westward toward the border fault and are part of a broad syncline that extends into Virginia, but they are cut by numerous north-northeast trending faults. The basal Manassas Sandstone is a fluvial arkosic sandstone, siltstone, and conglomerate. The Manassas Sandstone is overlain by the Balls Bluff Siltstone, which in Maryland consists of fluvial siltstones and thin arkosic sandstones similar to the lower Gettysburg Formation. Along the western faulted margin of both basins, all of the formations intertongue with conglomerates containing clasts of the older rocks immediately outside of the basin. In the Culpeper basin, the conglomerates derived from Paleozoic limestones adjacent to the border are called the Leesburg Conglomerate Member of the Balls Bluff Siltstone. The sedimentary rocks in both basins are intruded by Jurassic diabase dikes and sheets.

### The Appalachian Province

The Appalachian Province is bounded on the east by Precambrian to Cambrian metamorphic rocks of the Blue Ridge. The Great Valley, Valley and Ridge, and Allegheny Plateau comprise a sequence of marine and fluvial sedimentary rocks folded into distinct ridges and valleys. The rocks range from Cambrian to Permian in age, with limestone and shale forming the valleys and more resistant sandstones forming the prominent ridges.

The South Mountain Anticlinorium dominates the Blue Ridge and forms prominent mountains just west of the Mesozoic basins. It is cored by Precambrian granodiorite and biotite granite gneiss that crop out in the Middletown Valley, which lies between South Mountain and Catoctin Mountain in the southern part of the area. Overlying the Precambrian basement is a thin discontinuous unit named the Swift Run Formation, a coarse-grained quartzite interbedded with phyllite, tuffaceous slate, and minor marble. This in turn is overlain by the Precambrian-Cambrian Catoctin Metabasalt, which underlies most of the area. It is composed of metabasalt layers with minor metarhyolite, meta-andesite, and tuffaceous phyllite. Epidote alteration is common. In the north, the metabasalt is overlain by metarhyolite and associated pyroclastic sediments. A thick sequence of Cambrian-Ordovician clastic and carbonate sediments overlies the volcanic sequence and includes thin conglomerate of the Loudoun Formation, which is overlain by a thick layer of the

ridge-forming quartzite of the Weverton Formation and followed by phyllite of the Harpers Formation. This sequence is repeated on both the east and west sides of the anticlinorium. On the west side of South Mountain, the sequence continues with the Antietam Formation overlying the Harpers. This unit is succeeded by the Tomstown Dolomite as the section passes into the Great Valley.

West of South Mountain, the Tomstown Dolomite is succeeded by the thin-bedded siltstone, shale, sandstone, and dolomite of the Waynesboro Formation. A sequence of Cambrian through Ordovician limestones and shales follows and underlies most of eastern Washington County and the Great Valley. This sequence includes the argillaceous limestone, shale, and dolomite of the Elbrook Limestone, the argillaceous limestone, minor conglomerate, shale, and sandstone of the Conococheague Limestone, the dolomite, limestone, and conglomerate of the Stonehenge Limestone, the thick cherty dolomite and limestone of the Rockdale Run Formation, and the cherty dolomite of the Pinesburg Station Dolomite. These last three units are gathered into the Beekmantown Group. The Beekmantown Group is followed by Ordovician limestones of the St. Paul Group, including the Row Park Limestone and the New Market Limestone. The St. Paul Group is overlain by the Chambersburg Limestone at the top of the Ordovician carbonate sequence. West of Hagerstown, a fault separates the carbonate sequence from a wide band of Ordovician shales, siltstones, and graywackes known as the Martinsburg Formation. West of this wide band of Martinsburg, the carbonate units and Martinsburg Formation are tightly folded into thin bands and faulted. Just west of Clear Spring, the North Mountain Fault separates the Great Valley from younger sedimentary rocks of Silurian and Devonian age. Folded Silurian and Devonian sedimentary rocks underlie most of Allegany County and western Washington County and comprise the Valley and Ridge in Maryland. Silurian rocks are exposed in several major folds in central Washington County and eastern and western Allegany County. At the base of the Silurian section is the Tuscarora Sandstone, which consists of thin to thick-bedded orthoquartzite that crops out most extensively in western Allegany County. The Tuscarora is overlain by the Clinton Group, including the interbedded gray shales and sandstones of the Rose Hill Formation, the quartzite and calcareous quartzite of the Keefer Sandstone, and the calcareous, gray Rochester Shale. The Clinton Group is overlain by the McKenzie Formation, consisting of gray shales and argillaceous limestone which grade into interbedded red shales and sandstones to the west. The interbedded red siltstone, shale, and sandstone of the Bloomsburg Formation and limestone, dolomite, and shale of the Wills Creek Formation occur extensively in the synclines. They are overlain by the thick limestone, dolomitic limestone, calcareous shale, and sandstone of the Tonoloway Limestone.

At the top of the Silurian section and base of the Devonian section are the Keyser Limestone, comprising calcarenite, limestone, and shale, and the Helderberg Formation, consisting of limestone with minor shale and sandstone. These rocks underlie only small areas in this province. The Devonian Oriskany Group overlies, and, in places, intertongues with the Helderberg Formation and crops out in wide bands in western Washington and Allegany Counties. The Oriskany Group comprises the black shales and bedded cherts of the Shriver Chert and calcareous quartzite and limestone of the Oriskany Sandstone. The Devonian Needmore Shale overlies the Oriskany and crops out extensively in southern Allegheny County and central and western Washington County. It consists of black shale and argillaceous limestone which is succeeded by the black carbonaceous and pyritic Marcellus Shale, and the dark gray shale, siltstone, and fine sandstone of the Mahantango Formation. Overlying the Mahantango is the thin, gray, laminated Harrell Shale, the thick gray shale and siltstone of the Brallier Formation, the



sandy shale, graywacke, and conglomeratic sandstones of the Scherr and Foreknobs Formations. Broad bands of Devonian Hampshire Formation crop out in Allegany and Garrett Counties. It consists of interbedded red and green mudstone, siltstone, sandstone, and shale. In western Allegany County, it is followed by thin bands of Mississippian sedimentary rocks and marks the beginning of the Allegheny Plateau. The Allegheny Plateau is underlain by folded Devonian to Permian sedimentary rocks. At the base of the Mississippian is the Rockwell Formation, consisting of cross-bedded sandstone and conglomerate interbedded with gray and red shale, mudstone, and siltstone. It also includes arkosic sandstone, conglomerate, shale, and thin coal beds. Sandstone, conglomerate, shale, and coal comprise the overlying Purslane Sandstone. The Greenbrier Formation consists of narrow belts of red calcareous shale and sandstone interbedded with argillaceous limestone. It is overlain by the red and green shale, mudstone, and crossbedded sandstone of the Mauch Chunk Formation, which also forms relatively narrow belts. Overlying the Mauch Chunk are the Pennsylvanian Pottsville and Allegheny Formations, consisting of a cyclic sequence of interbedded sandstone, siltstone, mudstone, shale and coal beds with a conglomeratic quartz sandstone at the base. These two formations crop out extensively in wide belts throughout the Allegheny Plateau. Overlying the Allegheny Formation is the Conemaugh Formation, which is composed of gray and brown mudstone, shale, siltstone, and sandstone with several coal beds. Broad bands of Conemaugh Formation underlie approximately a third of the Allegheny Plateau. The Monongahela Formation overlies the Conemaugh and comprises interbedded mudstone, argillaceous limestone, shale, sandstone, and coal beds. The Permian Dunkard Group overlies the Monongahela and consists of red and green shale, siltstone and sandstone with thin lenticular beds of argillaceous limestone and coal.

## SOILS

Soils in Maryland include Ultisols, Alfisols, Inceptisols, and Histosols (U.S. Soil Conservation Service, 1987). Ultisols are mineral soils with a horizon containing an appreciable amount of translocated clay (but they do not contain fragipans) and they often have a moist or wet substratum. Ultisols occur mainly in the Coastal Plain and Piedmont. Alfisols are mineral soils with clayey subsurface horizons or fragipans, and may contain plinthite (iron-rich horizons) or calcic horizons in the subsurface. Alfisols cover large parts of the Piedmont and the Blue Ridge. Inceptisols are described as soils with weakly developed horizons in which materials have been altered or removed and they may contain horizons of accumulated silica, iron, or bases, but they generally do not have clayey subsurface horizons. These soils cover most of the Appalachian Province. Histosols are organic soils such as peats or mucks which occur locally along coastlines or in river valleys (Soil Survey Staff, 1975). Figure 5 is a generalized soil map of Maryland. The reader is urged to consult State soil maps and reports and U.S. Soil Conservation Service county soil surveys for more detailed information.

### Coastal Plain Soils

The Coastal Plain is covered by poorly drained to somewhat well-drained soils on the more dissected and rolling western shore, and mostly poorly drained soils on the nearly flat Eastern Shore (Miller, 1967). Deep, poorly to well-drained, fine and very fine sand with minor amounts of glauconite occur on rolling uplands in the southern part of the western shore (fig. 5). These soils are weakly to moderately well developed and have slightly to moderately clayey subsoils. Shallow to moderately deep, poorly drained to moderately well drained, sandy and silty soils with



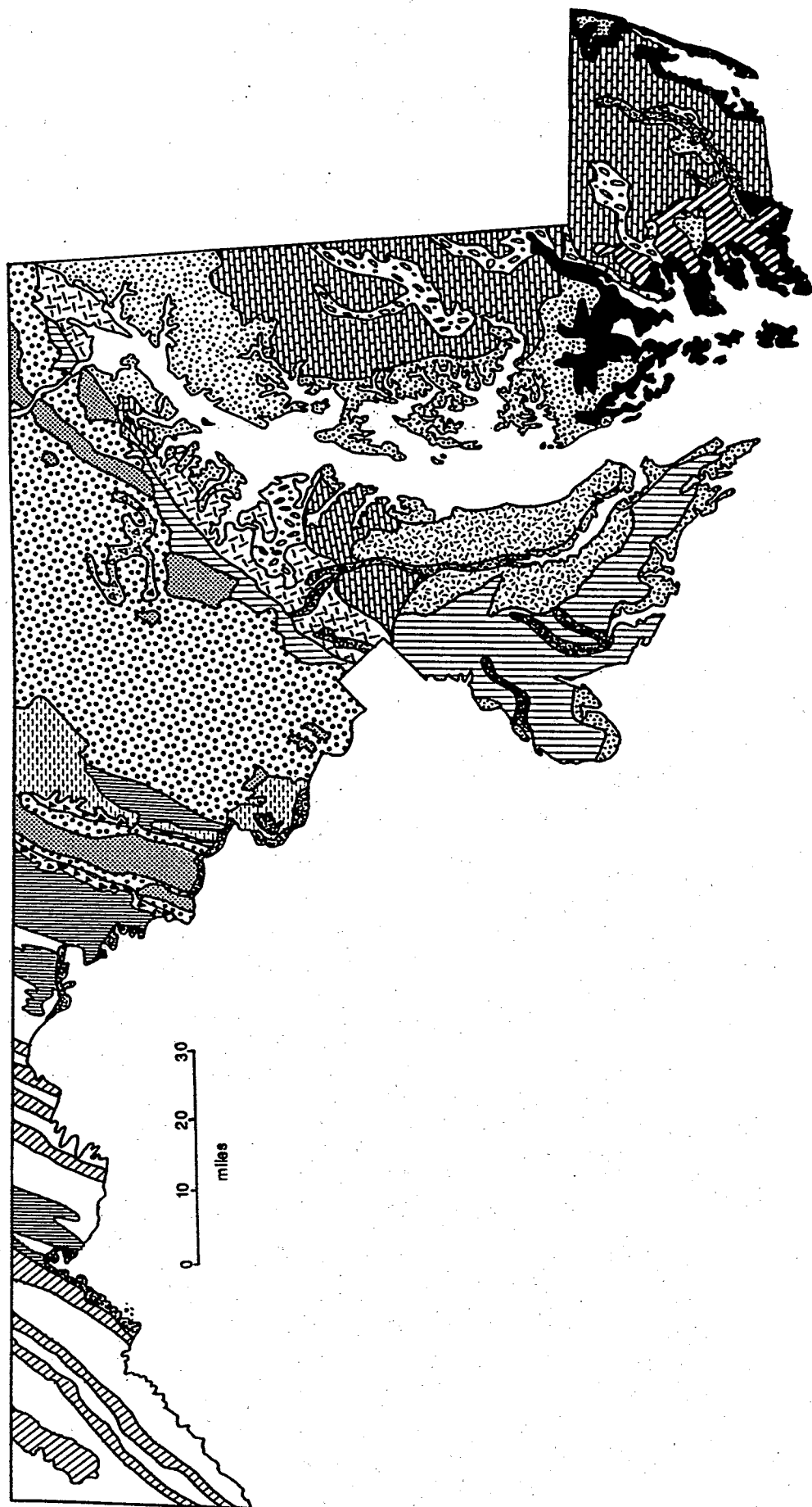






Figure 5. Generalized soil map of Maryland (after Miller, 1967).







# EXPLANATION FOR THE GENERALIZED SOILS MAP OF MARYLAND









## SOILS FORMED FROM SEDIMENTARY ROCKS

-  Shallow to moderately deep, moderately well drained to excessively drained, sandy loam, silt loam, and silty clay loam formed in residuum from gray acid shale, sandstone, and alluvium; *mostly moderate permeability, clayey soils developed on shales have lower permeability*
-  Shallow to moderately deep, well drained to excessively drained, stony, silty and sandy soils formed in residuum from red and gray acid shale, siltstone, and sandstone; *moderate to locally high permeability.*
-  Shallow to deep, poorly to moderately drained, clayey, silty, and sandy soils developed on red shale, siltstone, and sandstone; *low to moderate permeability*
-  In valleys, deep, well drained, silt loams, some with with clayey substrata, formed in residuum from limestones, calcareous shale, and interbedded limestone and shale; *low to moderate permeability. Along valley slopes, includes soils developed on colluvium from sandstone and shale; mostly moderate permeability*


## SOILS FORMED FROM IGNEOUS AND METAMORPHIC ROCKS

-  Deep, somewhat poorly drained to well drained, silty soils with clayey substrata or fragipans, formed on residuum from metabasalt (greenstone), schist, gneiss, diabase, and locally, quartzite; *low permeability*
-  In the western part, shallow, well to excessively drained, skeletal, silt loams formed on residuum from hard schist and phyllite; *moderate to high permeability.*  
In the eastern part, shallow to moderately deep, poorly to well drained, clayey sandy soils with clayey substrata developed from soft mica schist; *low to locally moderate permeability*
-  Deep, well drained, gravelly to stony soils formed on colluvium of crystalline rocks; *high permeability*
-  Deep, well drained silty to gravelly soils formed on colluvium of schist and limestone; *moderate to high permeability*

## SOILS FORMED FROM UNCONSOLIDATED COASTAL PLAIN SEDIMENTS

-  Very deep, poorly drained to excessively drained, sandy, silty, and clayey soils formed on sandy and silty deposits (contains moderate amounts of glauconite on Western Shore); *moderate to high permeability*
-  Very deep, sandy, excessively drained to locally poorly drained soils formed on nearly level to steep uplands of the Coastal Plain; *locally moderate to mostly high permeability*
-  Deep, well drained, fine and very fine sand with minor amounts of glauconite; *moderate permeability*
-  Shallow to moderately deep, poorly drained to moderately well drained, sandy and silty soils with fragipans and clayey subsoils, overlying older gravelly and sandy sediments; *low to moderate permeability*
-  Deep, generally poorly drained, silt loams and clay loams with clayey B horizons and commonly high water tables; *low permeability*
-  Deep, very poorly drained, silty soils in low-lying areas; *moderate permeability, typically wet*
-  Deep, well drained, clayey soils on higher uplands of the Coastal Plain; *low permeability*
-  Organic-rich soils of tidal marshes; commonly flooded

## SOILS FORMED FROM ALLUVIAL MATERIALS

-  Deep, clayey, silty, sandy, and gravelly soils developed on alluvial sediments; upland alluvial soils and soils of old, high terraces of the Potomac River are generally moderately well to well drained; alluvial soils of the Coastal Plain are more poorly drained; *permeability is variable depending on parent lithology*



fragipans and clayey subsoils that overlie older gravelly and sandy sediments cover the southern and western Coastal Plain. These soils are slowly permeable and are subject to seasonally high water tables due to clay fragipans that form at 15-25 inches depth. Deep, well-drained, clayey, red soils cover higher uplands of the Coastal Plain. The subsoil clay separates into distinct blocks, giving these soils low to locally moderate permeability. Some of the soils in this map unit contain considerable amounts of sand, although the matrix of the soil is dominantly clay.

Very deep, poorly drained to excessively drained, sandy and silty soils cover much of the Eastern Shore of the Coastal Plain (fig. 5). These yellow and brown soils are common to much of the Coastal Plain region of the Mid-Atlantic States (Miller, 1967). Where these soils are formed on rolling topography, they are moderately to well-drained; however, they tend to have high water tables in flatter areas. Soils of this map unit on the Western Shore are silty and clayey soils containing moderate amounts of glauconite. Deep, generally poorly drained silt loams and clay loams with slowly permeable B horizons and commonly high water tables are extensive on the Eastern Shore (fig. 5). Some of these soils have distinctive mottling, indicating that they remain wet for considerable periods of time during the year. Soils in the southern part of the Coastal Plain are deep, very poorly drained, silty soils in low-lying areas, and organic-rich soils of tidal marshes. The silty soils overlie moderately to highly permeable sands and silts, but because they are low-lying, these and the adjacent tidal marshes are typically wet throughout the year.

#### Piedmont Soils

Soils of the Piedmont are formed primarily on igneous and metamorphic rocks, except for the sedimentary rocks that underlie the Frederick Valley. Shallow to moderately deep, well-drained to excessively drained, silty and sandy soils form in residuum of red Triassic shale, siltstone, and sandstone. The red soils have a distinct, red clayey B horizon and they are generally more poorly drained than the gray soils in this area (Miller, 1967). Shallow to moderately deep, well-drained, silt loams formed on residuum from mica schist, phyllite, quartzose schist, and quartzite cover most of the Piedmont province (fig. 5). Soils formed on relatively soft mica schist saprolites in the eastern half of the province are well developed and contain 20-25 percent clay in the subsoil (Miller, 1967). Soils in the western Piedmont are formed on more resistant schist and phyllite and are generally shallow, skeletal, poorly developed, silty or loamy throughout the profile, and generally well- to excessively drained. Deep, well-drained, gravelly to stony soils formed on colluvium of quartzite, quartzitic schist, and phyllite occur on the eastern and western slopes of Catoctin Mountain. These soils are gravelly to stony, poorly developed, excessively drained, and highly permeable. Colluvial soils formed mainly from schist are found in the eastern Piedmont just north of Baltimore. These deep, well-drained, silty to gravelly soils occur at the base of slopes, and they locally contain fragments of limestone parent material.

#### Appalachian Province Soils

Soils of the Appalachian province are shallow to moderately deep, moderately well drained to excessively drained, sandy loam, silt loam, and silty clay loam formed in residuum from gray acid shale, sandstone, and siltstone. These soils have generally low to moderate permeability and are common in the Allegheny Plateau and Valley and Ridge provinces. Deep, well-drained, silt loams, some with clayey substrata, formed in residuum from limestones, calcareous shale, and interbedded limestone and shale cover most of the Great Valley, Frederick Valley, and areas underlain by cherty limestones in the western Valley and Ridge (fig. 5). These soils have a slowly permeable, plastic clay subsoil and are acidic because most of the carbonates have been leached





from the soil profile (Miller, 1967). In the Valley and Ridge, these soils are typically well drained because they occur on steep slopes and limestone-capped ridgetops. Deep, somewhat poorly drained to well drained, silty soils with slowly permeable, clayey substrata, formed on residuum from metabasalt, schist, gneiss, diabase, and quartzite, are found in the Blue Ridge province.

## RADIOACTIVITY

An aeroradiometric map of Maryland (fig. 6) was compiled from spectral gamma-ray data acquired during the Department of Energy's National Uranium Resource Evaluation (NURE) program (Duval and others, 1989). For the purposes of this report, low equivalent uranium (eU) on the map is defined as less than 1.5 parts per million (ppm), moderate equivalent uranium is defined as 1.5-2.5 ppm, and high equivalent uranium is defined as greater than 2.5 ppm. Low eU appears to be associated with the Blue Ridge metavolcanic and metasedimentary rocks, Jurassic diabase in the western Piedmont, and the Quaternary sediments of the Eastern Shore. Low to moderate eU covers much of the Allegheny Plateau, the Tertiary and Cretaceous sediments of the Coastal Plain, and parts of the Valley and Ridge. High eU areas in the State appear to be associated with Cambrian and Ordovician sediments of the Great Valley; Precambrian, Cambrian, and Triassic igneous, metamorphic, and sedimentary rocks of the western Piedmont; and metamorphic and igneous rocks of the eastern Piedmont.

The NURE reports for the Harrisburg Quadrangle (LKB Resources, 1978), the Baltimore Quadrangle (Texas Instruments Incorporated, 1978a), the Cumberland Quadrangle (Texas Instruments Incorporated, 1980), and the Washington Quadrangle (Texas Instruments Incorporated, 1978b) indicate that high to moderate eU is associated with particular geologic units along the flightlines of the aerial radiometric survey. Rock units with high eU include: Precambrian schists and Baltimore Gneiss of the Piedmont; the Precambrian-Cambrian Harpers Formation; the Cambrian Elbrook Limestone, Waynesboro Formation, Kinzers Formation, Tomstown, and Weverton Formations; the Ordovician Chambersburg Limestone, Martinsburg Formation, and Rockdale Run Formation; the Silurian Tonoloway, Keyser, and Wills Creek Formations and the Clinton Group; the Devonian Hampshire Formation and Hamilton Group; the Pennsylvanian Monongahela Formation; and the Tertiary Calvert Formation.

## INDOOR RADON

Indoor radon data from 1126 homes sampled in the State/EPA Residential Radon Survey conducted in Maryland during the winter of 1991 are shown in map format in figure 7 and statistically in Table 1. A map with county names is also included for reference (fig. 8). Indoor radon was measured by charcoal canister. The maximum value recorded in the survey was 139.6 pCi/L in Carroll County. The average for the State was 3.1 pCi/L and 19.9 percent of the homes tested had indoor radon levels exceeding 4 pCi/L. Notable counties include Calvert, Carroll, Frederick, Howard, and Washington Counties, in which the average indoor radon for the county was  $\geq 4$  pCi/L. The State of Maryland compiled data from volunteers, the University of Pittsburgh Radon Project (Cohen, 1990), and commercial vendors to produce a non-random data set of more than 37,000 data points (State of Maryland, 1989). These data are presented in Table 2 for comparison with the StateEPA/ data. Non-random (volunteer) indoor radon data tend to be biased toward higher values compared to randomly sampled surveys because it is more likely that many of the data points are from homeowners that tested their homes after receiving word of a nearby high value. Four percent of the homes in this dataset had indoor radon levels exceeding 20 pCi/L and



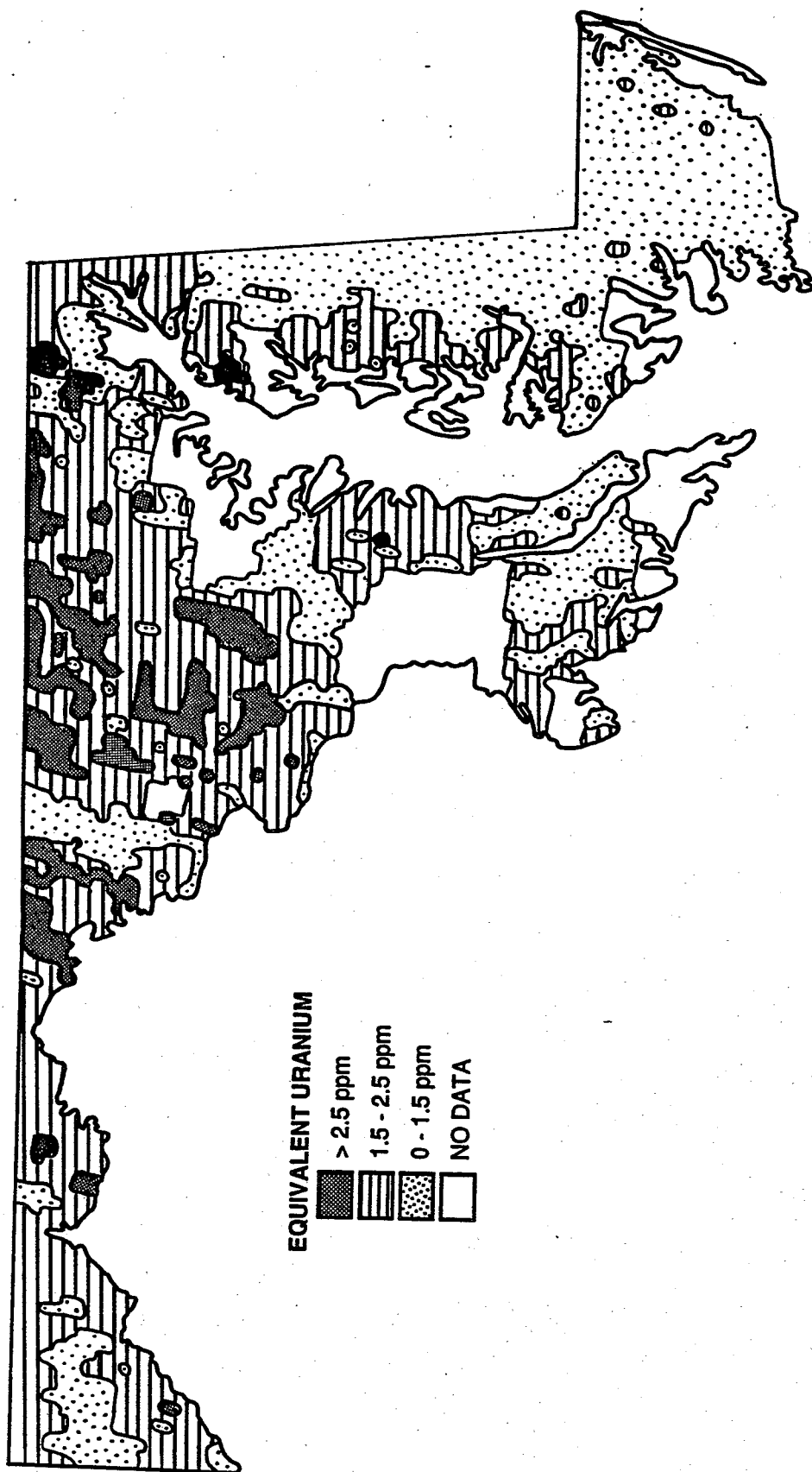


Figure 6. Aerial radiometric map of Maryland (after Duval and others, 1989).



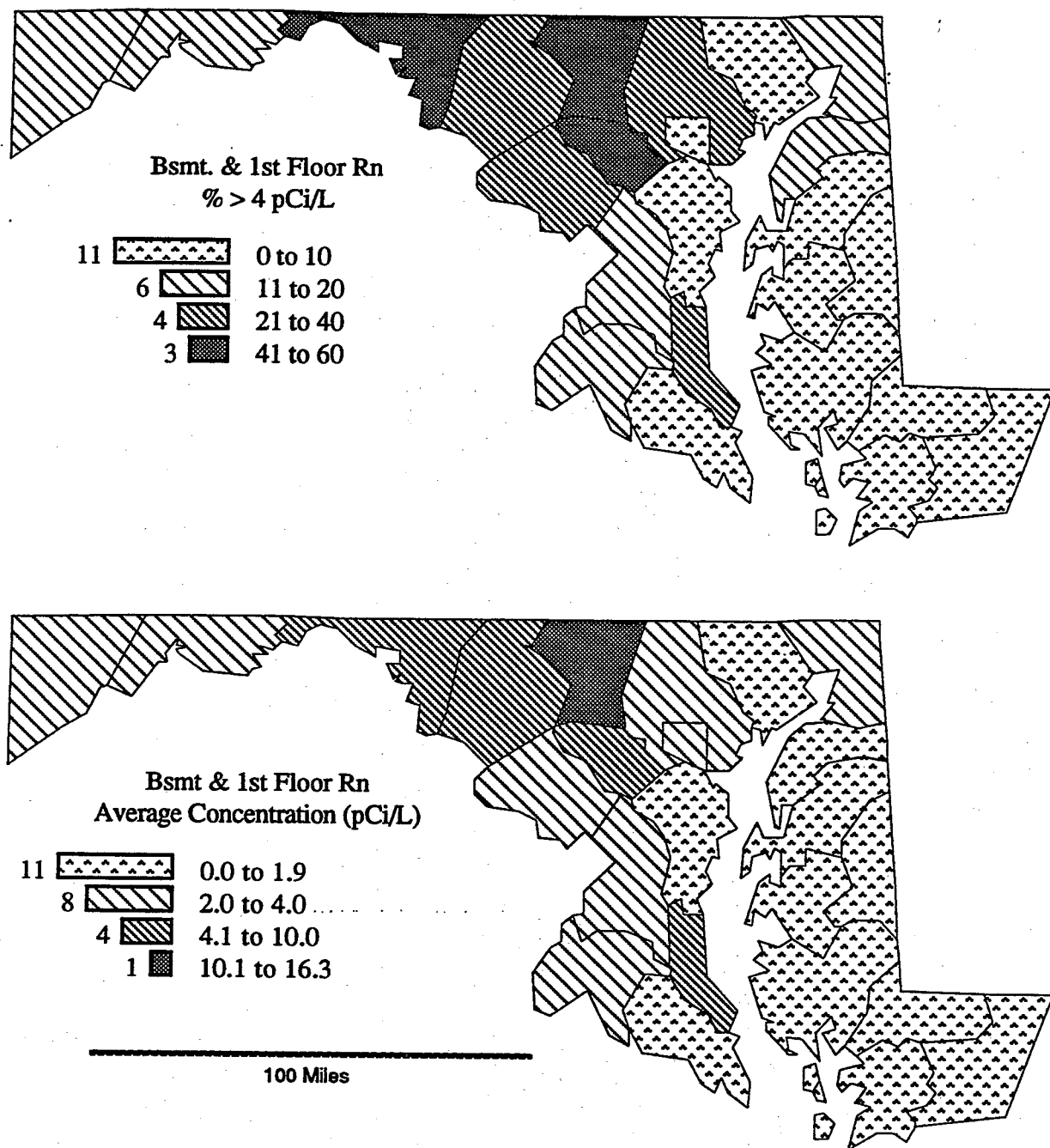


Figure 7. Screening indoor radon data from the EPA/State Residential Radon Survey of Maryland, 1990-91, for counties with 5 or more measurements. Data are from 2-7 day charcoal canister tests. Histograms in map legends show the number of counties in each category. The number of samples in each county (See Table 1) may not be sufficient to statistically characterize the radon levels of the counties, but they do suggest general trends. Unequal category intervals were chosen to provide reference to decision and action levels.



**TABLE 1. Screening indoor radon data from the EPA/State Residential Radon Survey of Maryland conducted during 1990-91. Data represent 2-7 day charcoal canister measurements from the lowest level of each home tested.**

COUNTY	NO. OF MEAS.	MEAN	GEOM. MEAN	MEDIAN	STD. DEV.	MAXIMUM	%>4 pCi/L	%>20 pCi/L
ALLEGANY	74	2.7	1.3	1.3	5.8	46.0	12	1
ANNE ARUNDEL	86	1.6	0.8	1.0	2.2	13.2	6	0
BALTIMORE	40	2.3	1.0	1.0	2.8	10.8	23	0
BALTIMORE CITY	79	2.1	0.5	0.4	7.4	63.2	8	1
CALVERT	16	4.9	1.4	1.1	9.4	37.9	31	6
CAROLINE	23	0.4	0.2	0.2	0.6	2.8	0	0
CARROLL	16	16.3	5.5	6.3	33.7	139.6	50	13
CECIL	61	2.1	1.1	1.3	2.4	11.2	15	0
CHARLES	19	2.6	0.6	0.4	7.3	32.1	16	5
DORCHESTER	18	0.2	0.1	0.1	0.4	1.5	0	0
FREDERICK	96	5.3	2.7	2.7	6.8	35.8	40	4
GARRETT	31	3.6	1.2	1.4	7.5	40.4	19	3
HARFORD	27	1.7	1.0	0.9	2.0	8.4	7	0
HOWARD	30	5.4	3.3	3.4	4.8	18.0	43	0
KENT	16	1.1	0.3	0.2	2.0	6.5	13	0
MONTGOMERY	101	3.1	1.7	1.8	3.9	26.1	24	1
PRINCE GEORGE'S	126	2.0	1.0	1.1	2.7	18.7	13	0
QUEEN ANNE'S	19	0.4	0.2	0.2	0.9	4.0	0	0
SOMERSET	17	0.2	0.1	0.1	0.7	2.8	0	0
ST. MARY'S	15	1.1	0.6	0.9	1.1	4.0	0	0
TALBOT	25	0.4	0.2	0.1	0.6	2.5	0	0
WASHINGTON	115	8.1	4.9	5.3	8.4	63.7	59	6
WICOMICO	50	0.2	0.2	0.1	0.4	1.3	0	0
WORCESTER	26	0.1	0.1	0.0	0.3	1.1	0	0

Table 2. Maryland Radon Data Summary. The minimum, maximum, and average radon levels in pCi/l are presented for each county with at least 100 data points. An asterisk (\*) highlights those jurisdictions with less than 100 data points, indicating insufficient data to characterize the radon situation in those jurisdictions. Compare the county average with the State average of 5.32 pCi/l.

(from State of Maryland, 1989)

<u>Code</u>	<u>County</u>	<u># Tests</u>	<u>Minimum pCi/l</u>	<u>Maximum pCi/l</u>	<u>Avg pCi/l</u>
01	Allegany	152	.05	48.00	5.23
03	Anne Arundel	1599	.05	313.00	4.10
05	Baltimore	594	.05	270.30	7.62
07*	Balto. City	70	.05	13.00	
09	Calvert	317	.05	52.00	5.40
11*	Caroline	6	.30	5.80	
13	Carroll	1140	.05	482.90	15.06
15*	Cecil	52	.05	49.00	
17	Charles	577	.05	76.00	2.72
19*	Dorchester	7	.05	5.00	
21	Frederick	1978	.05	491.00	11.20
23*	Garrett	45	.60	36.10	
25	Harford	230	.05	87.30	7.24
27	Howard	2512	.05	895.30	8.61
29*	Kent	2	.05	2.50	
31	Montgomery	20356	.05	376.90	4.67
33	Prince Georges	6516	.05	209.00	2.41
35*	Queen Anne's	28	.10	11.00	
37	Saint Marys	260	.05	22.00	2.03
39*	Somerset	1	6.70	6.70	
41*	Talbot	38	.20	6.70	
43	Washington	612	.05	679.80	12.64
45*	Wicomico	5	.40	2.10	
47*	Worcester	2	.40	.90	



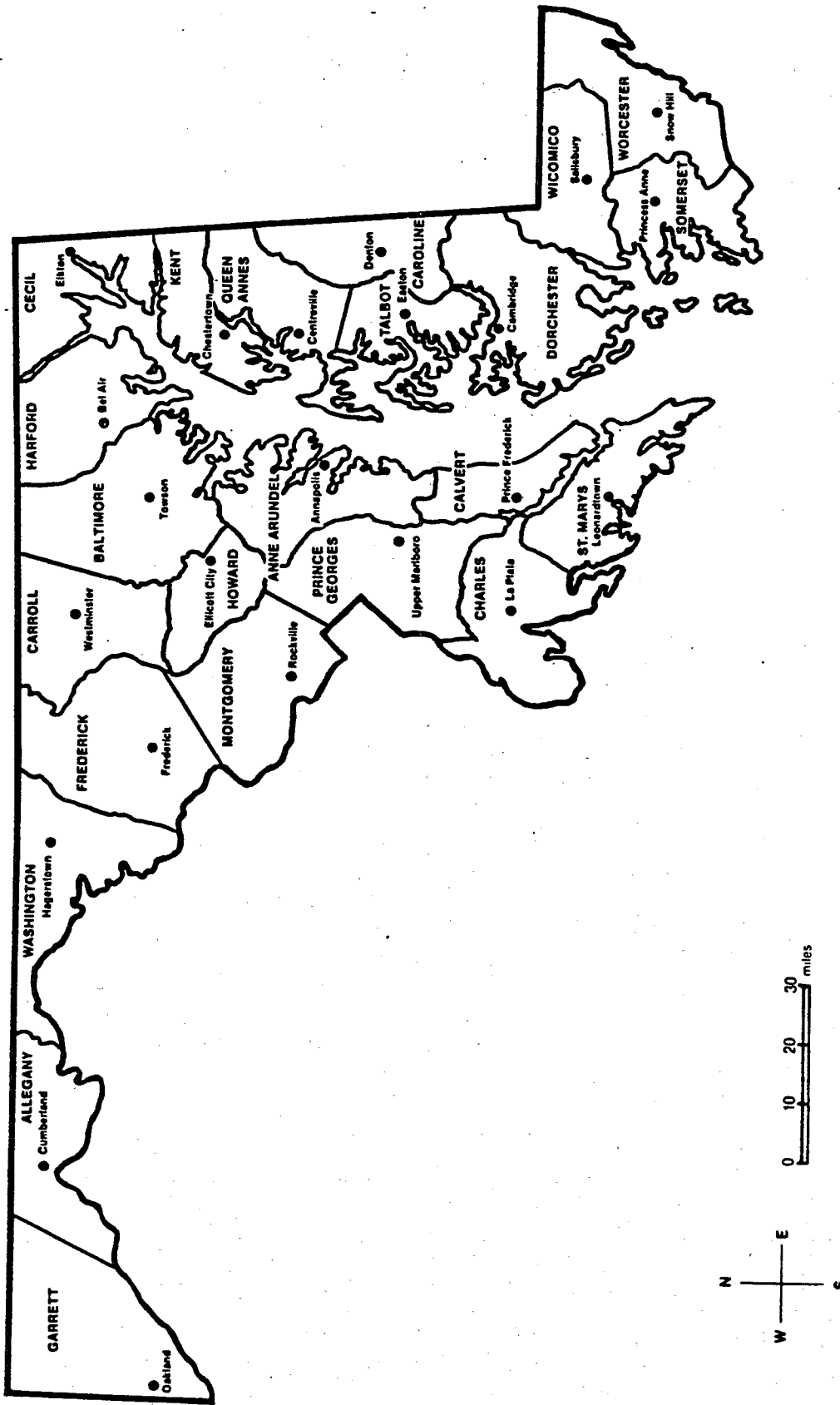


Figure 8. Maryland counties (from Facts on File, 1984).



29 percent of the homes tested had indoor radon levels between 4 and 20 pCi/L. Carroll, Frederick, and Washington Counties had indoor radon averages greater than 10 pCi/L. Charles, Prince George's, and Saint Mary's Counties, all located in the Coastal Plain, had indoor radon averages less than 4 pCi/L.

## GEOLOGIC RADON POTENTIAL

### Coastal Plain Province

The Western Shore has been ranked moderate to locally high in geologic radon potential and the Eastern Shore has been ranked low in radon potential. The Coastal Plain Province is underlain by relatively unconsolidated fluvial and marine sediments that are variably phosphatic and glauconitic on the Western Shore and dominated by quartz in the Eastern Shore. Radioactivity in the Coastal Plain is moderate over parts of the Western Shore sediments, particularly in the Upper Cretaceous and Tertiary sediments of Prince George's, Anne Arundel, and northern Calvert Counties. Moderate radioactivity also appears to be associated with the Cretaceous and Tertiary sediments of the Eastern Shore where these sediments are exposed in major drainages in Kent, Queen Anne's, and Talbot Counties. Soil radon studies in Prince George's County (Otton, 1992; Reimer, 1988; Reimer and others, 1991) indicate that soils formed from the locally phosphatic, carbonaceous, or glauconitic sediments of the Calvert, Aquia, and Nanjemoy Formations can produce significantly high radon (average soil radon > 1500 pCi/L). Otton (1992) indicates that the Cretaceous Potomac Group had generally moderate levels of soil radon, averaging 800-900 pCi/L, and the Tertiary-Cretaceous Brightseat Formation and Monmouth Group had average soil radon of 1300 pCi/L. Permeability in the Western Shore is variably low to moderate with some high permeability in sandier soils. Well-developed clayey B horizons with low permeability are common. Indoor radon from the State/EPA Residential Radon Survey is variable among the counties of the Western Shore and indoor radon levels are generally low to moderate, with Calvert County having a high average (4.9 pCi/L, but only 16 measurements in the county). The Maryland radon data summary (Table 2) indicates moderate to high average indoor radon for most of the Western Shore counties. For this assessment we have ranked part of the Western Shore as high in radon potential, including Calvert County, southern Anne Arundel County, and eastern Prince George's County. This area has the highest radioactivity, high indoor radon, and significant exposure of Tertiary rock units. The part of the Western Shore ranked moderate consists of Quaternary sediments with low radon potential, Cretaceous sediments with moderate radon potential, and lesser amounts of Tertiary sediments with high radon potential. The Quaternary sediments of the Eastern Shore have low radioactivity associated with them and are generally quartzose and thus low in uranium. Heavy-mineral concentrations within these sediments may be very local sources of uranium. Indoor radon appears to be generally low on the Eastern Shore with only a few measurements over 4 pCi/L reported.

### Piedmont Province

Gneisses and schists in the eastern Piedmont, phyllites in the western Piedmont, and Paleozoic metasedimentary rocks of the Frederick Valley have been ranked high in geologic radon potential. Sedimentary and igneous rocks of the Mesozoic basins have been ranked moderate in radon potential. Radioactivity in the Piedmont is generally moderate to high. Indoor radon is moderate to high in the eastern Piedmont and nearly uniformly high in the western Piedmont. Permeability is low to moderate in soils developed in the mica schists and gneisses of the eastern

Piedmont, Paleozoic sedimentary rocks of the Frederick Valley, and igneous and sedimentary rocks of the Mesozoic Basins. Permeability is moderate to high in the soils developed on the phyllites of the western Piedmont. The Maryland Geological Survey has conducted a comparison of the geology of Maryland with the Maryland radon data summary in Table 2. They report (State of Maryland, 1989) that most of the Piedmont rocks, with the exception of ultramafics, can generate indoor radon readings exceeding 4 pCi/L. Their data indicate that the phyllites of the western Piedmont have much higher radon potential than the schists in the east. Ninety-five percent of the homes built on phyllites of the Gillis Formation had indoor radon measurements greater than 4 pCi/L, and 47 percent of the measurements were greater than 20 pCi/L. In comparison, 80 percent of the homes built on the schists and gneiss of the Loch Raven and Oella Formations had indoor radon readings greater than 4 pCi/L, but only 9 percent were greater than 20 pCi/L. Studies by Gundersen and others (1988), Mose and others (1988a, b), and Mose and Mushrush (1988a, b, c) support this conclusion.

Szarzi and others (1990) have also shown that the phyllites in Frederick County yield the highest average soil-gas radon when compared to the other rock types, and that soils derived from limestone and shale, and some of the Triassic sedimentary rocks, in the Frederick Valley may be significant sources of radon (500-2000 pCi/L in soils). In Maryland, Gundersen and others (1988) noted high uranium concentrations in fluvial crossbeds of the upper Manassas Sandstone containing gray carbonaceous clay intraclasts and drapes. Similar lithologic associations are common in the upper New Oxford Formation. Black shales and gray sandstones of the Heidlersburg Member are similar to uranium-bearing strata in the Culpeper basin in Virginia. Black shales in the overlying Gettysburg Formation may also be locally uranium rich. The lower New Oxford Formation, the lower Manassas Sandstone, the lower Gettysburg Formation, and the Balls Bluff Siltstone in Maryland are not likely to have significant concentrations of uranium except where altered by diabase intrusives and/or faulted. The diabase bodies are low in radon potential. Because of the highly variable nature of the Triassic sediments and the amount of area the rocks cover with respect to the county boundaries, it is difficult to say with confidence whether the high indoor radon in Montgomery, Frederick, and Carroll Counties is partly attributable to the Triassic sediments.

### Appalachian Province

The Appalachian Province is divided into the Blue Ridge, Great Valley, Valley and Ridge, and Allegheny Plateau. Each of these areas is underlain by a distinct suite of rocks with a particular radon potential. The Blue Ridge is ranked low in radon potential but may be locally moderate to high. The Catoclin volcanic rocks that underlie a significant portion of the Blue Ridge have low radioactivity, yield low soil radon (Szarzi and others, 1990) and have low soil permeability. The quartzite and conglomerates overlying the Catoclin also have low radioactivity and low soil radon (Szarzi and others, 1990). Further, the Pennsylvania Topographic and Geologic Survey (J. Barnes and R. Smith, unpub. data) calculated the median uranium content of 80 samples of Catoclin metabasalt and metadiabase (measured by delayed neutron activation) and found it to be less than 0.5 ppm. The Harpers Formation phyllite yields high soil radon (1000 pCi/L), has higher surface radioactivity than the surrounding rocks (Szarzi and others, 1990), and is a potential source of radon. The Precambrian gneiss that crops out in the Middletown Valley of the southern Blue Ridge appears to have moderate radioactivity associated with it and yielded some high soil-gas radon in Szarzi and others' (1990) study. It is difficult, given the constraints of the indoor radon data, to associate the high average indoor radon in the part of Frederick County

underlain by parts of this province with the actual rocks. The Blue Ridge is provisionally ranked low in geologic radon potential, but this cannot be verified with the present indoor radon data.

Carbonates and black shales in the Great Valley in Maryland have been ranked high in radon potential. Radioactivity is moderate to high over the Great Valley in Washington County. Washington County has more than a hundred indoor radon measurements, has an average indoor radon of 8.1 pCi/L in the State/EPA Survey, and more than half of the readings are greater than 4 pCi/L. To the north in Pennsylvania, carbonate rocks of the Great Valley and Appalachian Mountain section have been the focus of several studies (van Assendelft and Sachs, 1982; Gross and Sachs, 1982; Greeman and Rose, 1990; Luetzelschwab and others, 1989), and the carbonates in these areas produce soils with high uranium and radium contents that generate high radon concentrations. In general, indoor radon levels in these areas are more than 4 pCi/L. Soils developed from carbonate rocks are often elevated in uranium and radium. Carbonate soils are derived from the dissolution of the  $\text{CaCO}_3$  that makes up the majority of the carbonate rock. When the  $\text{CaCO}_3$  has been dissolved away, the soils are enriched in the remaining impurities, predominantly base metals, including radionuclides. Studies in the carbonates of the Great Valley in West Virginia suggest that the deepest, most mature soils have the highest radium and radon concentrations (Schultz and others, 1992). Rinds containing high concentrations of uranium and uranium-bearing minerals can be formed on the surfaces of rocks affected by  $\text{CaCO}_3$  dissolution and karstification. Karst and cave morphology is also thought to promote the flow and accumulation of radon. Schultz and others (1992) also measured high radon in soils and high indoor radon in homes over the black shales of the Martinsburg Formation.

The Silurian and Devonian rocks of the Valley and Ridge have been ranked moderate to locally high in geologic radon potential. Indoor radon measurements from the State/EPA Residential Radon Survey in Allegany County have an average of 2.7 pCi/L and 12 percent of the 74 measurements were greater than 4 pCi/L. In the Maryland radon data summary (Table 2) the average for Allegany County was 5.23 pCi/L and 30 percent of the 152 measurements were greater than 4 pCi/L. Bedford County, Pennsylvania, which is adjacent to Allegany County and is underlain by the same rock types, has a high indoor radon average in the State/EPA survey. Soil permeability is variable but is generally moderate. Radioactivity in the Valley and Ridge is moderate to locally high. The Tonoloway, Keyser, and Wills Creek Formations and Clinton and Hamilton Groups have high equivalent uranium associated with them in the NURE aeroradiometric data. The shales, limestone soils, and hematitic sands are possible sources of these high readings.

The Devonian through Permian rocks of the Allegheny Plateau have been ranked moderate in geologic radon potential. Indoor radon measurements from the State/EPA survey for Garrett County have an average of 3.5 pCi/L for the 31 measurements taken in the county. Radioactivity in the Allegheny Plateau is low to moderate. Soil permeability is variable but is generally moderate. The NURE report for the Harrisburg Quadrangle (LKB Resources, 1978) reports high equivalent uranium associated with the Pocono Group and Mauch Chunk Formation.

Van Assendelft and Sachs (1982) list an extensive table of indoor radon and associated geologic units in Pennsylvania that may be applicable to equivalent units in Maryland. It appears from the uranium and radioactivity data and comparison with the indoor radon data that the Cambrian-Ordovician limestone soils, the black shales of the Ordovician Martinsburg Formation, the early Devonian black shales, Pennsylvanian black shales of the Allegheny Group, Conemaugh Group, and Monongahela Group, and the fluvial sandstones of the Devonian Hampshire and Mississippian Mauch Chunk Formations may be sources of moderate to high indoor radon levels in the Appalachian Province.

## SUMMARY

For the purpose of this assessment, Maryland has been divided into ten geologic radon potential areas and each area assigned a Radon Index (RI) and a Confidence Index (CI) score using the information outlined in the sections above (Table 3). The RI is a relative measure of radon potential based on geology, soils, radioactivity, architecture, and indoor radon. The CI is a measure of the confidence of the RI assessment based on the quality and quantity of the data used to assess geologic radon potential (please see the introduction chapter to this regional booklet for a detailed explanation of the RI and CI). The geologic radon potential areas are shown in figure 9.

Geology, soil permeability, indoor radon, and radioactivity data for Maryland suggest that many of the soils and rocks of the Piedmont and Great Valley have the potential to produce moderate (2-4 pCi/L) to high (> 4 pCi/L) levels of indoor radon. Soils and rocks of the Allegheny Plateau, Valley and Ridge, and the Western Shore of the Coastal Plain are generally moderate in radon potential but can be locally high in geologic radon potential. Soils and rocks of the Blue Ridge and Eastern Shore of the Coastal Plain are relatively low in radon potential.

This is a generalized assessment of the State's geologic radon potential and there is no substitute for having a home tested. The conclusions about radon potential presented in this report cannot be applied to individual homes or building sites. Indoor radon levels, both high and low, can be quite localized, and within any radon potential area there will likely be areas with higher or lower radon potential than assigned to the area as a whole. Any local decisions about radon should not be made without consulting all available local data. For additional information on radon and how to test, contact your State radon program or EPA regional office. More detailed information on state or local geology may be obtained from the state geological survey. Addresses and phone numbers for these agencies are listed in chapter 1 of this booklet.

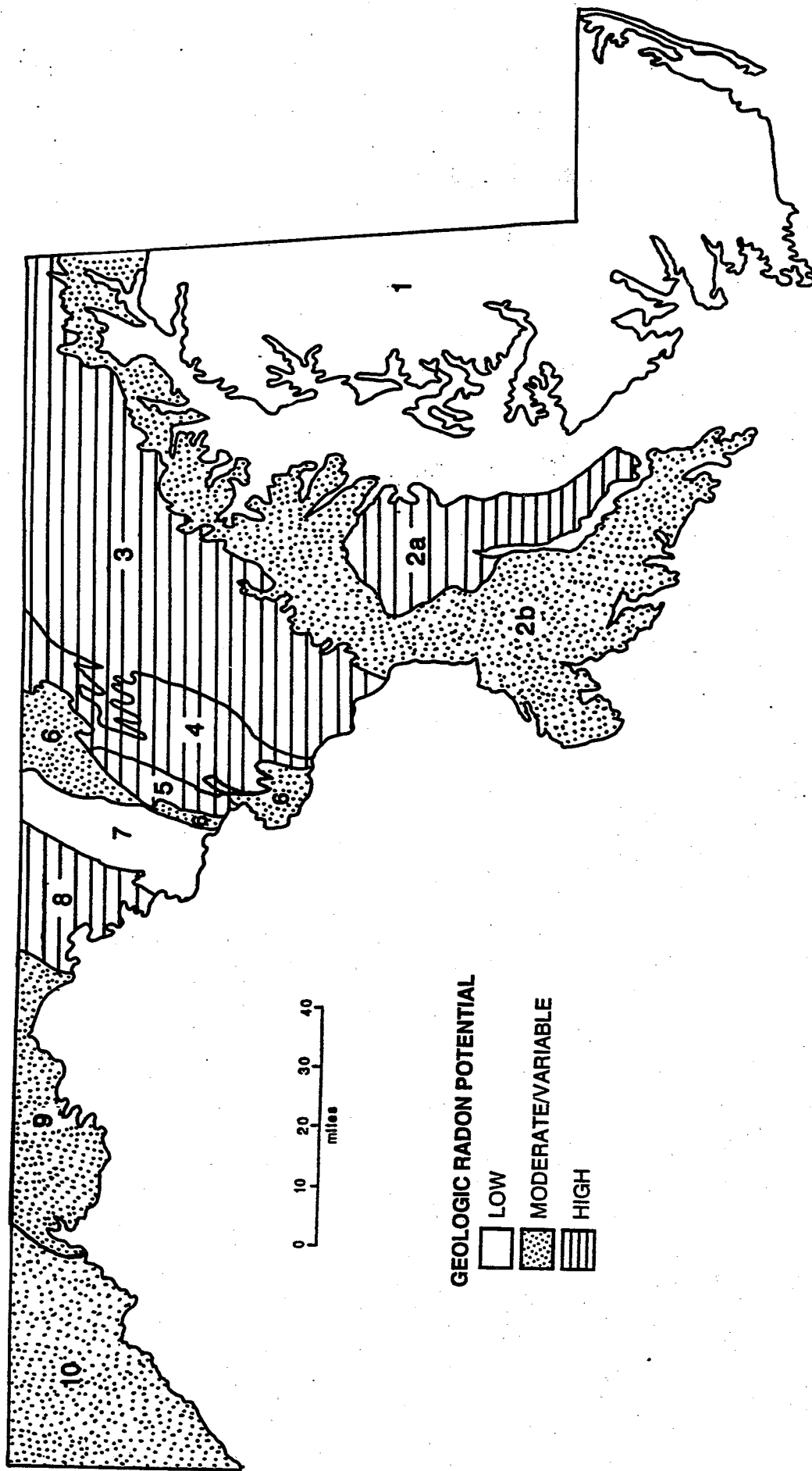


Figure 9. Geologic radon potential areas of Maryland. Refer to Table 3 for RI and CI scores of areas.





TABLE 3. RI and CI scores for geologic radon potential areas of Maryland. See figure 9 for locations of areas.

(2b) Western Shore, Cretaceous Quaternary, minor Tertiary			(1) Eastern Shore Quaternary		(3) Eastern Piedmont schist and gneiss		(2a) Western Shore Tertiary	
FACTOR	RI	CI	RI	CI	RI	CI	RI	CI
INDOOR RADON	2	2	1	2	3	3	3	3
RADIOACTIVITY	2	2	1	2	2	3	2	3
GEOLOGY	2	3	1	3	2	3	3	3
SOIL PERM.	2	3	2	3	2	3	2	3
ARCHITECTURE	2	-	2	-	3	-	2	-
GFE POINTS	0	-	0	-	0	-	0	-
TOTAL	10	10	7	10	12	12	12	12
RANKING	Mod	High	Low	High	High	High	High	High

(4) Western Piedmont Phyllite			(7) Blue Ridge igneous and sedimentary		(8) Great Valley carbonates and clastics		(5) Frederick Valley	
FACTOR	RI	CI	RI	CI	RI	CI	RI	CI
INDOOR RADON	3	3	1?	1?	3	3		
RADIOACTIVITY	2	3	1	3	2	3		
GEOLOGY	2	3	1	2	3	3		
SOIL PERM.	3	3	2	3	2	3		
ARCHITECTURE	3	-	3	-	3	-		
GFE POINTS	2	-	0	-	0	-		
TOTAL	15	12	8	9	13	12		
RANKING	High	High	Low	Mod	High	High		

(9) Valley and Ridge Silurian and Devonian			(10) Allegheny Plateau		(6) Mesozoic Basins Culpeper/Gettysburg basins	
FACTOR	RI	CI	RI	CI	RI	CI
INDOOR RADON	2	2	2	3	2?	1
RADIOACTIVITY	2	3	2	3	2	3
GEOLOGY	2	2	2	3	2	3
SOIL PERM.	2	3	2	3	2	3
ARCHITECTURE	3	-	3	-	3	-
GFE POINTS	0	-	0	-	0	-
TOTAL	11	10	11	12	11	10
RANKING	Mod	High	Mod	High	Mod	High

#### RADON INDEX SCORING:

Radon potential category	Point range	Probable screening indoor radon average for area
LOW	3-8 points	< 2 pCi/L
MODERATE/VARIABLE	9-11 points	2 - 4 pCi/L
HIGH	> 11 points	> 4 pCi/L

Possible range of points = 3 to 17

#### CONFIDENCE INDEX SCORING:

LOW CONFIDENCE	4 - 6 points
MODERATE CONFIDENCE	7 - 9 points
HIGH CONFIDENCE	10 - 12 points

Possible range of points = 4 to 12



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AND GENERAL REFERENCES RELEVANT TO RADON IN MARYLAND**

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## **EPA's Map of Radon Zones**

The USGS' Geologic Radon Province Map is the technical foundation for EPA's Map of Radon Zones. The Geologic Radon Province Map defines the radon potential for approximately 360 geologic provinces. EPA has adapted this information to fit a county boundary map in order to produce the Map of Radon Zones.

The Map of Radon Zones is based on the same range of predicted screening levels of indoor radon as USGS' Geologic Radon Province Map. EPA defines the three zones as follows: Zone One areas have an average predicted indoor radon screening potential greater than 4 pCi/L. Zone Two areas are predicted to have an average indoor radon screening potential between 2 pCi/L and 4 pCi/L. Zone Three areas are predicted to have an average indoor radon screening potential less than 2 pCi/L.

Since the geologic province boundaries cross state and county boundaries, a strict translation of counties from the Geologic Radon Province Map to the Map of Radon Zones was not possible. For counties that have variable radon potential (i.e., are located in two or more provinces of different rankings), the counties were assigned to a zone based on the predicted radon potential of the province in which most of its area lies. (See Part I for more details.)

### **MARYLAND MAP OF RADON ZONES**

The Maryland Map of Radon Zones and its supporting documentation (Part IV of this report) have received extensive review by Maryland geologists and radon program experts. The map for Maryland generally reflects current State knowledge about radon for its counties. Some States have been able to conduct radon investigations in areas smaller than geologic provinces and counties, so it is important to consult locally available data.

Although the information provided in Part IV of this report -- the State chapter entitled "Preliminary Geologic Radon Potential Assessment of Maryland" -- may appear to be quite specific, it cannot be applied to determine the radon levels of a neighborhood, housing tract, individual house, etc. **THE ONLY WAY TO DETERMINE IF A HOUSE HAS ELEVATED INDOOR RADON IS TO TEST.** Contact the Region 3 EPA office or the Maryland radon program for information on testing and fixing homes. Telephone numbers and addresses can be found in Part II of this report.

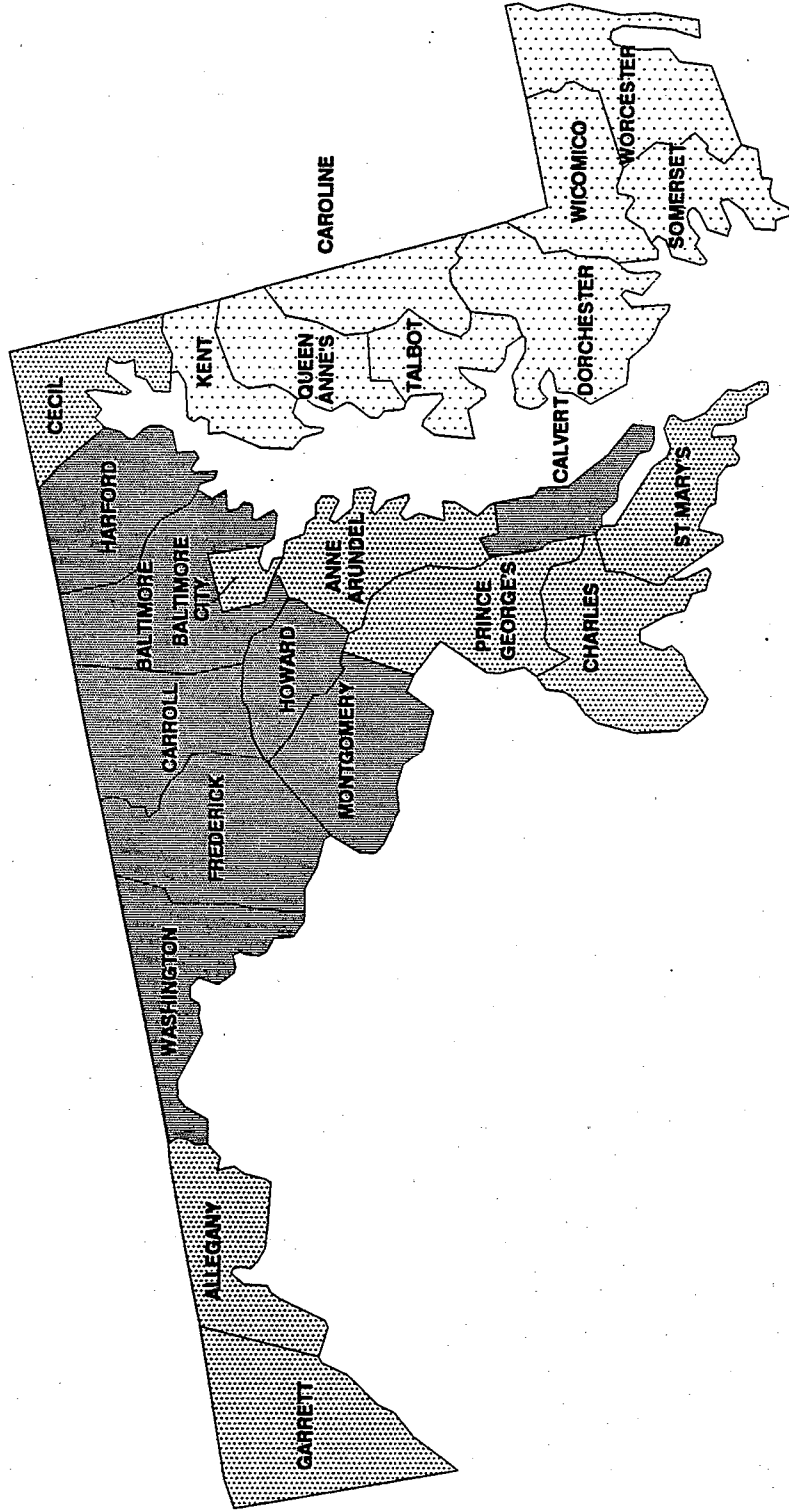




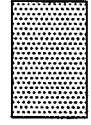
# MARYLAND - EPA Map of Radon Zones

The purpose of this map is to assist National, State and local organizations to target their resources and to implement radon-resistant building codes.

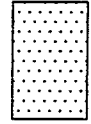
This map is not intended to determine if a home in a given zone should be tested for radon. Homes with elevated levels of radon have been found in all three zones. **All homes should be tested, regardless of zone designation.**



Zone 1



Zone 2



Zone 3

**IMPORTANT:** Consult the publication entitled "Preliminary Geologic Radon Potential Assessment of Maryland" before using this map. This document contains information on radon potential variations within counties. EPA also recommends that this map be supplemented with any available local data in order to further understand and predict the radon potential of a specific area.

