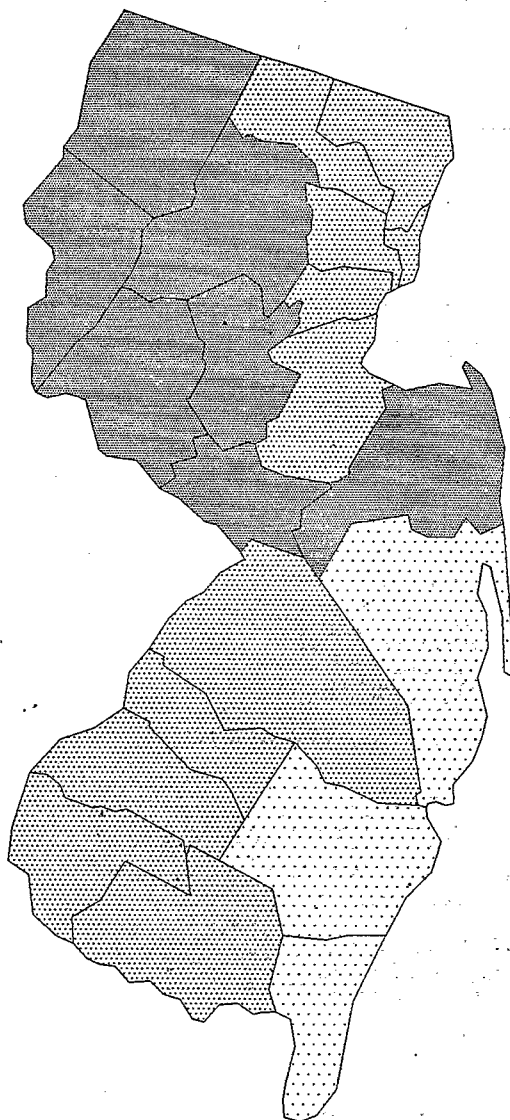
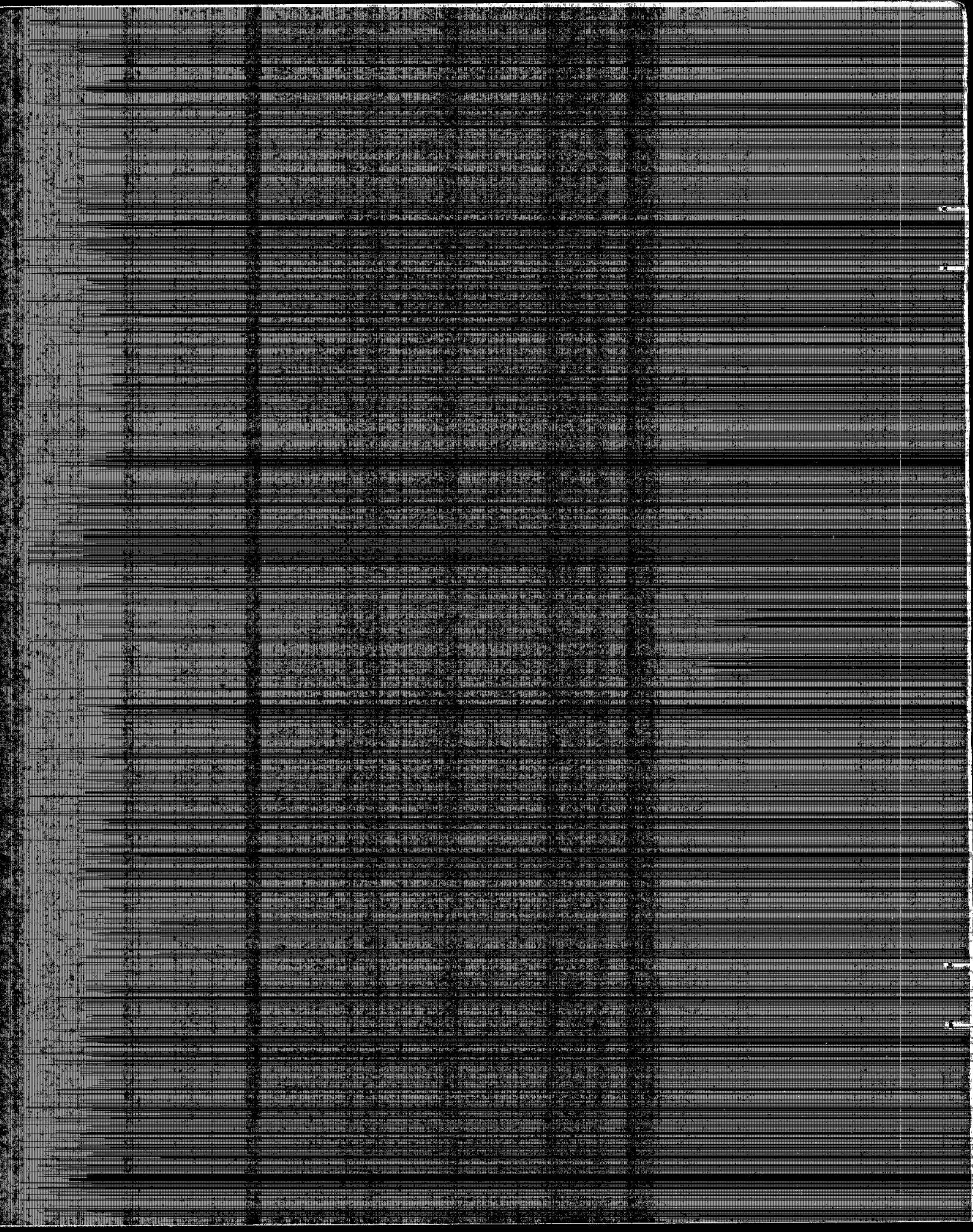




## EPA's Map of Radon Zones

### NEW JERSEY

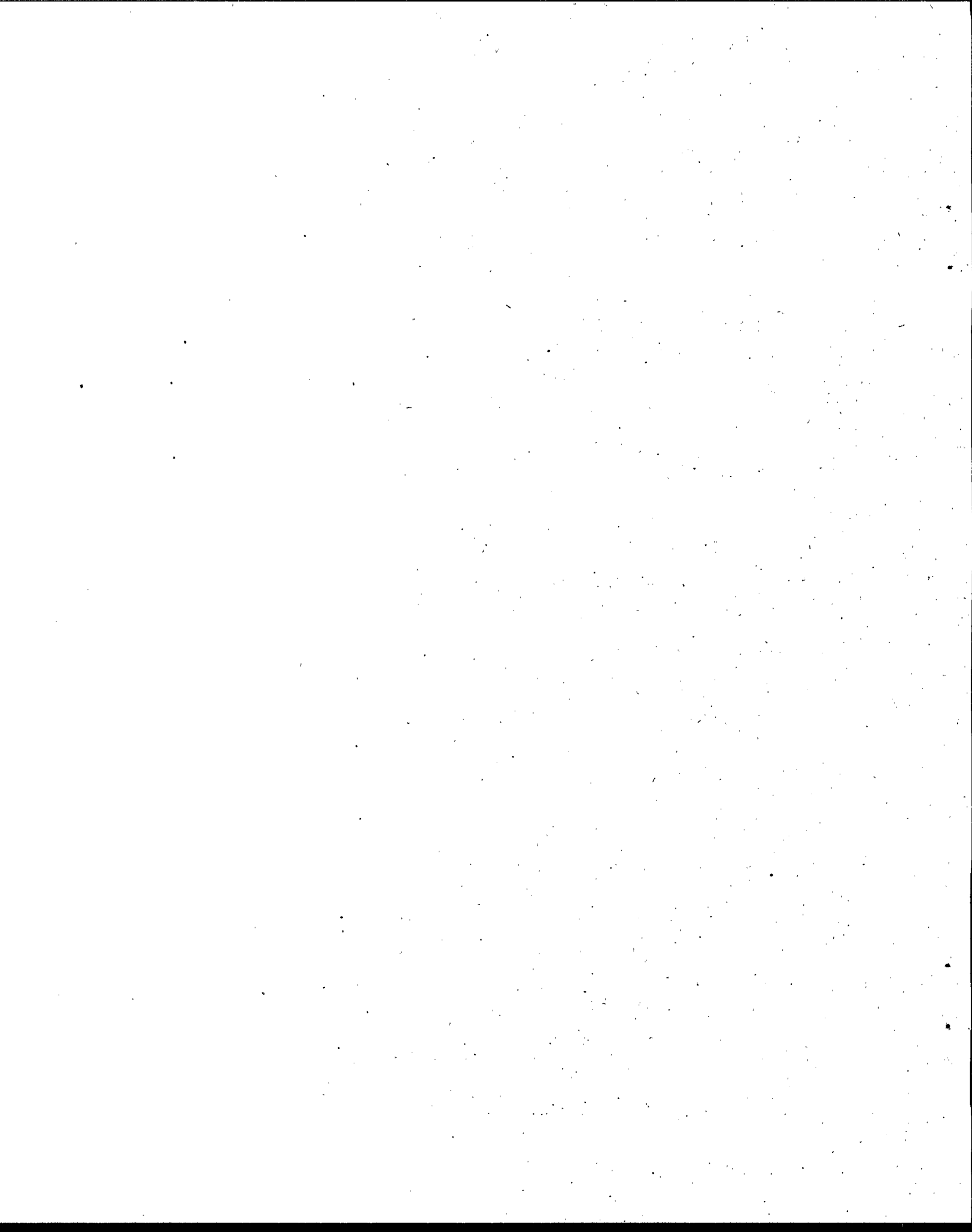




**EPA'S MAP OF RADON ZONES  
NEW JERSEY**

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

**SEPTEMBER, 1993**





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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.

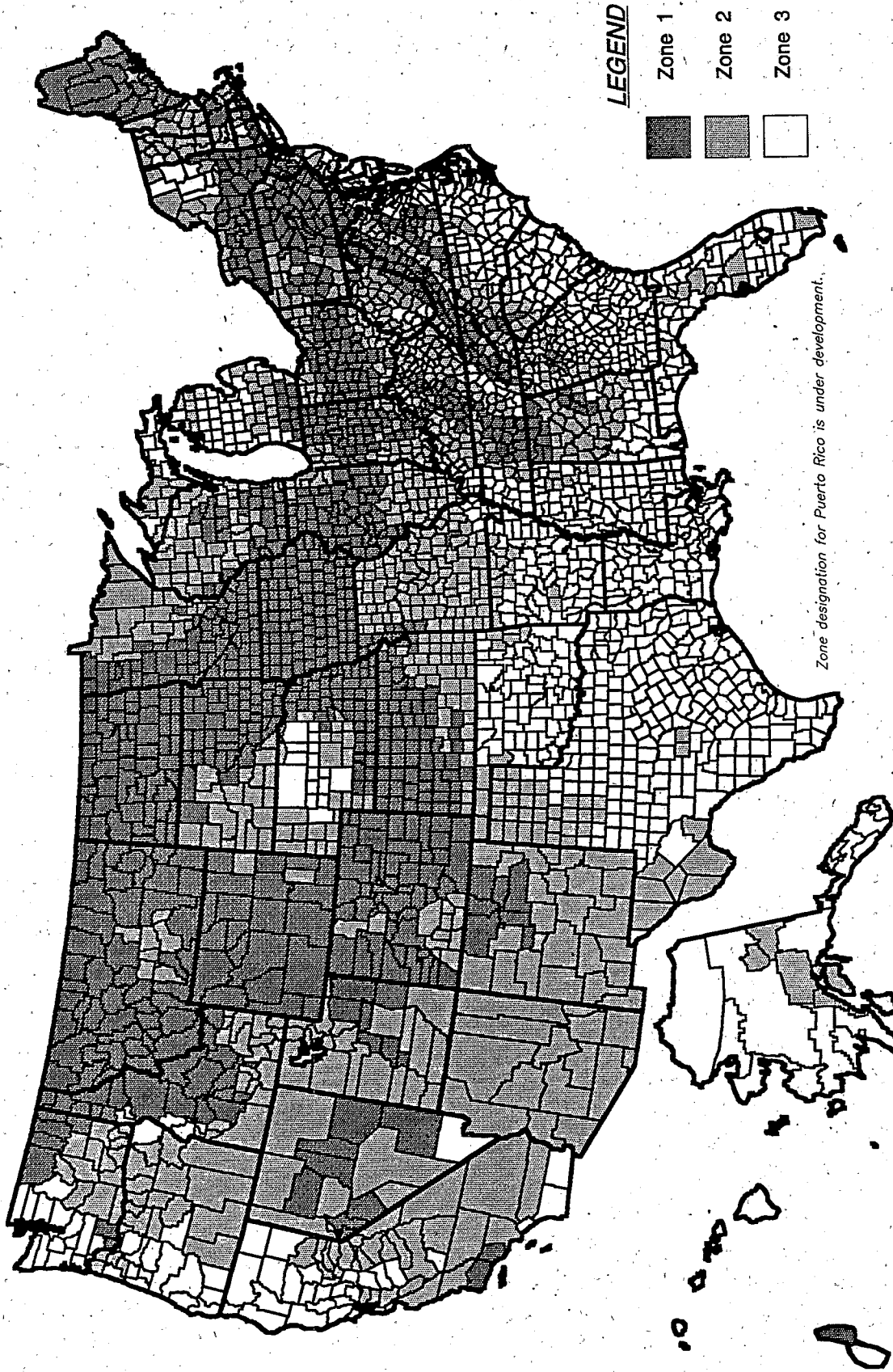
The Map of Radon Zones and its supporting documentation establish no regulatory requirements. Use of this map by State or local radon programs and building code officials is voluntary. The information presented on the Map of Radon Zones and in the supporting documentation is not applicable to radon in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

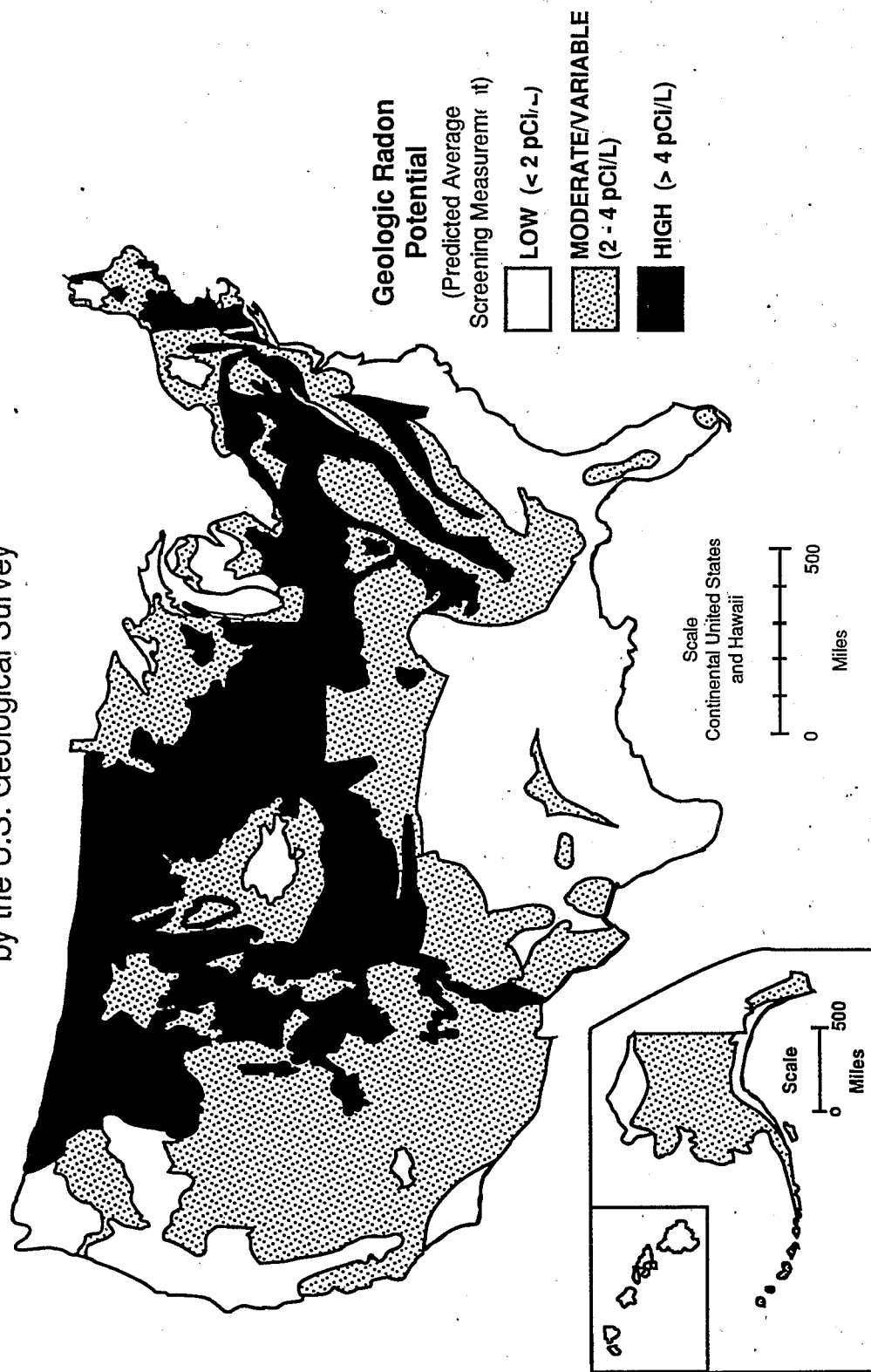
The purpose of this map is to assist National, State and local organizations to target their resources and to implement radon-resistant building codes. This map is not intended to be used to determine if a home in a given zone should be tested for radon. Homes with elevated levels of radon have been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

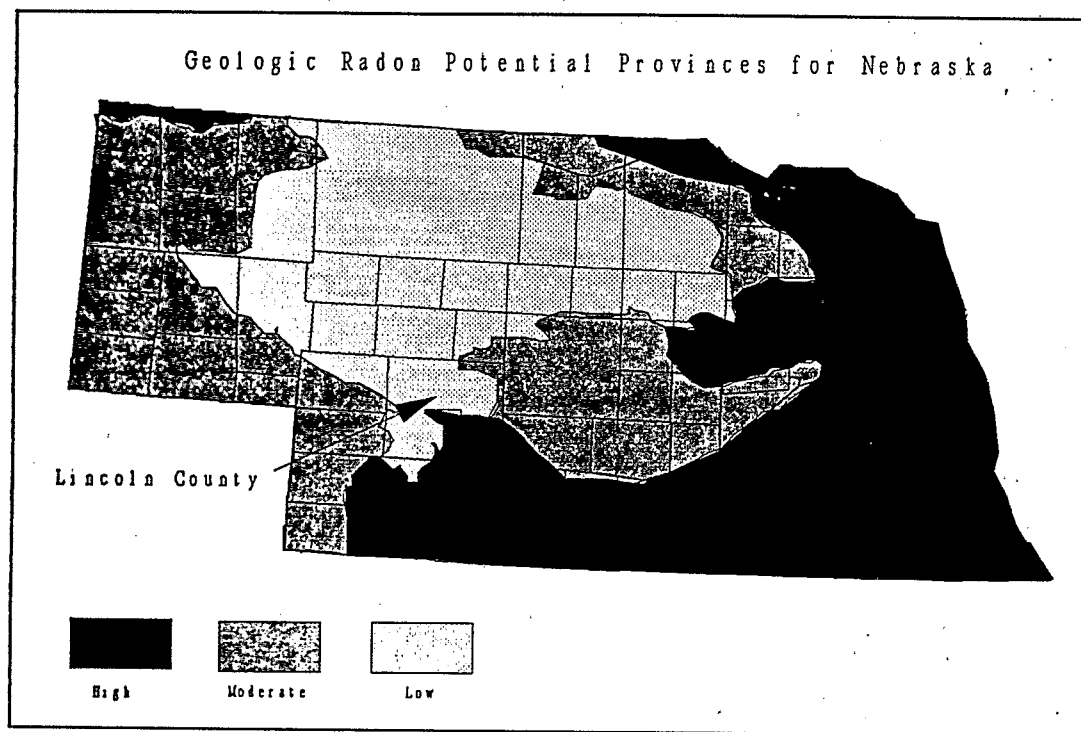
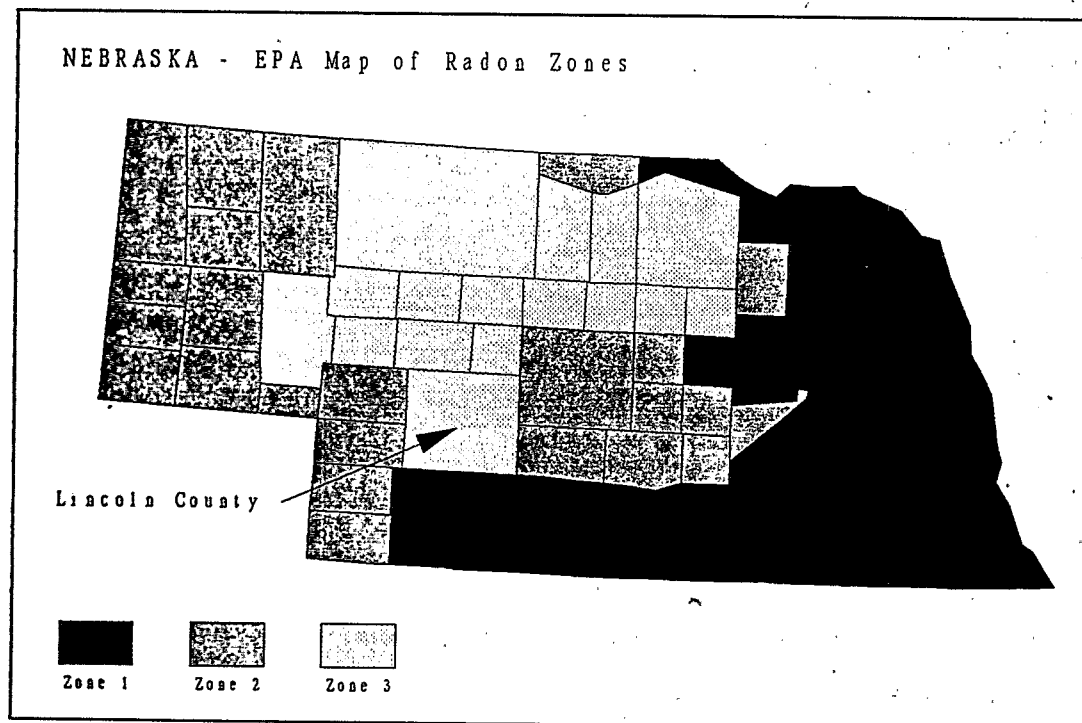


Figure 4



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



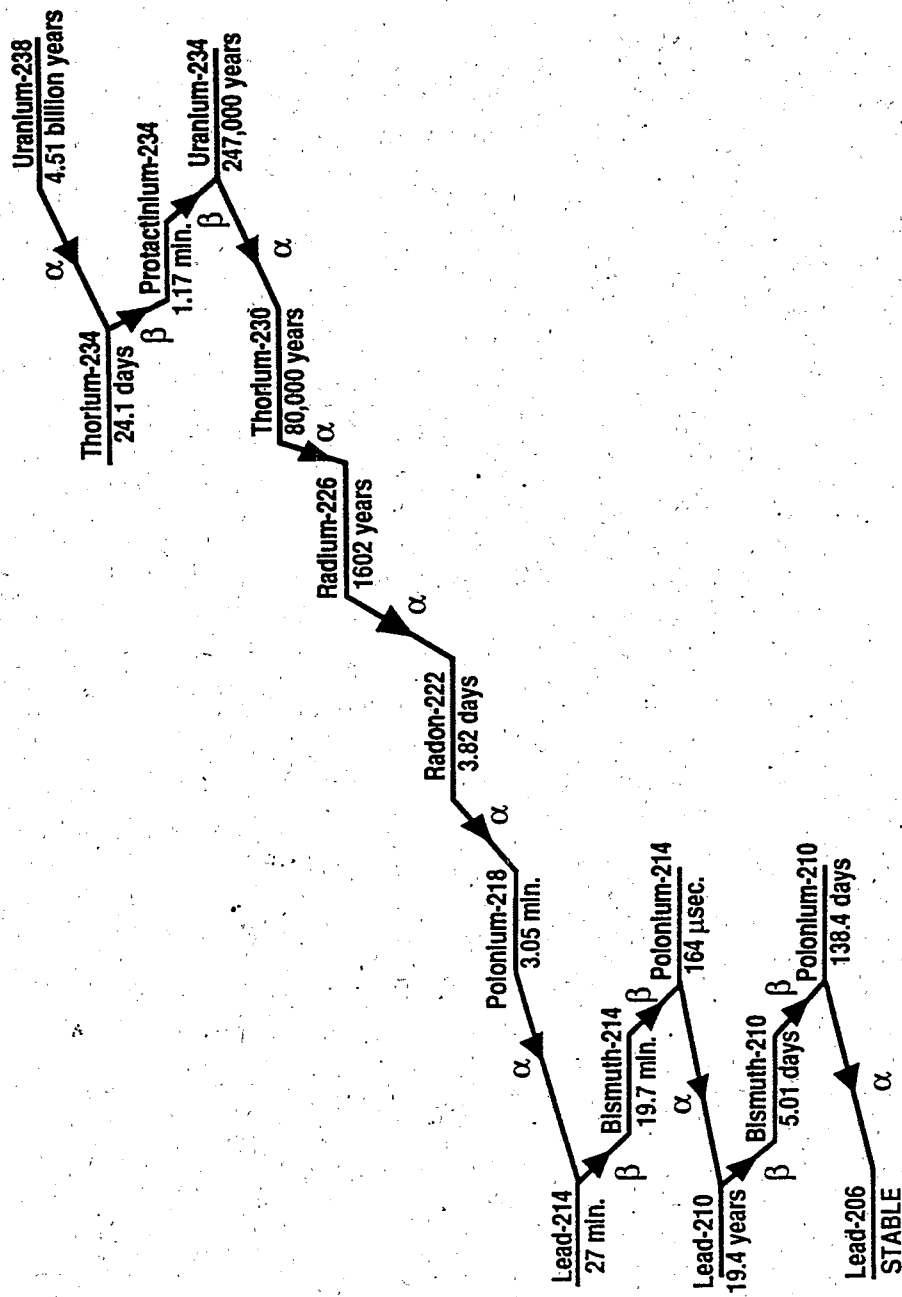


Figure 1. The uranium-238 decay series, showing the half-lives of elements and their modes of decay (after Wanty and Schoen, 1991).  $\alpha$  denotes alpha decay,  $\beta$  denotes beta decay.

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.

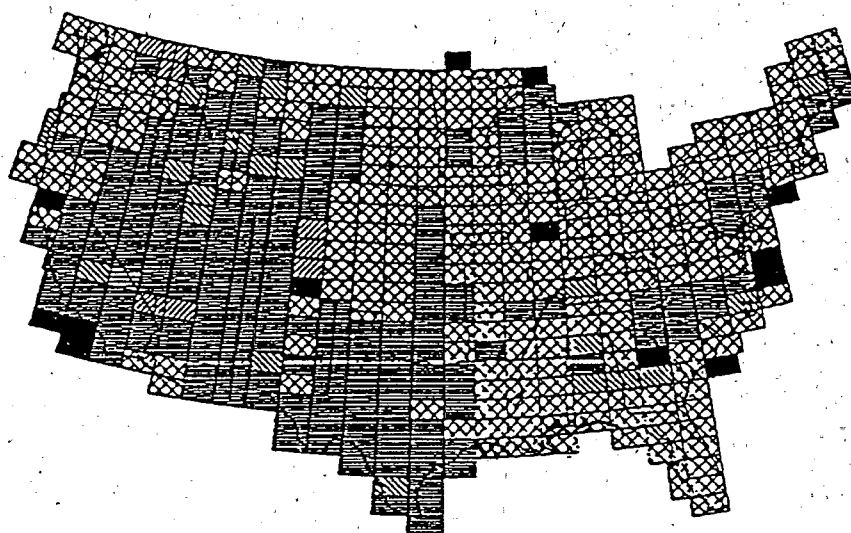
Although many cases of elevated indoor radon levels can be traced to high radium and (or) uranium concentrations in parent rocks, some structural features, most notably faults and shear zones, have been identified as sites of localized uranium concentrations (Deffeyes and MacGregor, 1980) and have been 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



- 2 KM (1 MILE)
- 5 KM (3 MILES)
- 2 & 5 KM
- 10 KM (6 MILES)
- 5 & 10 KM
- NO DATA

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

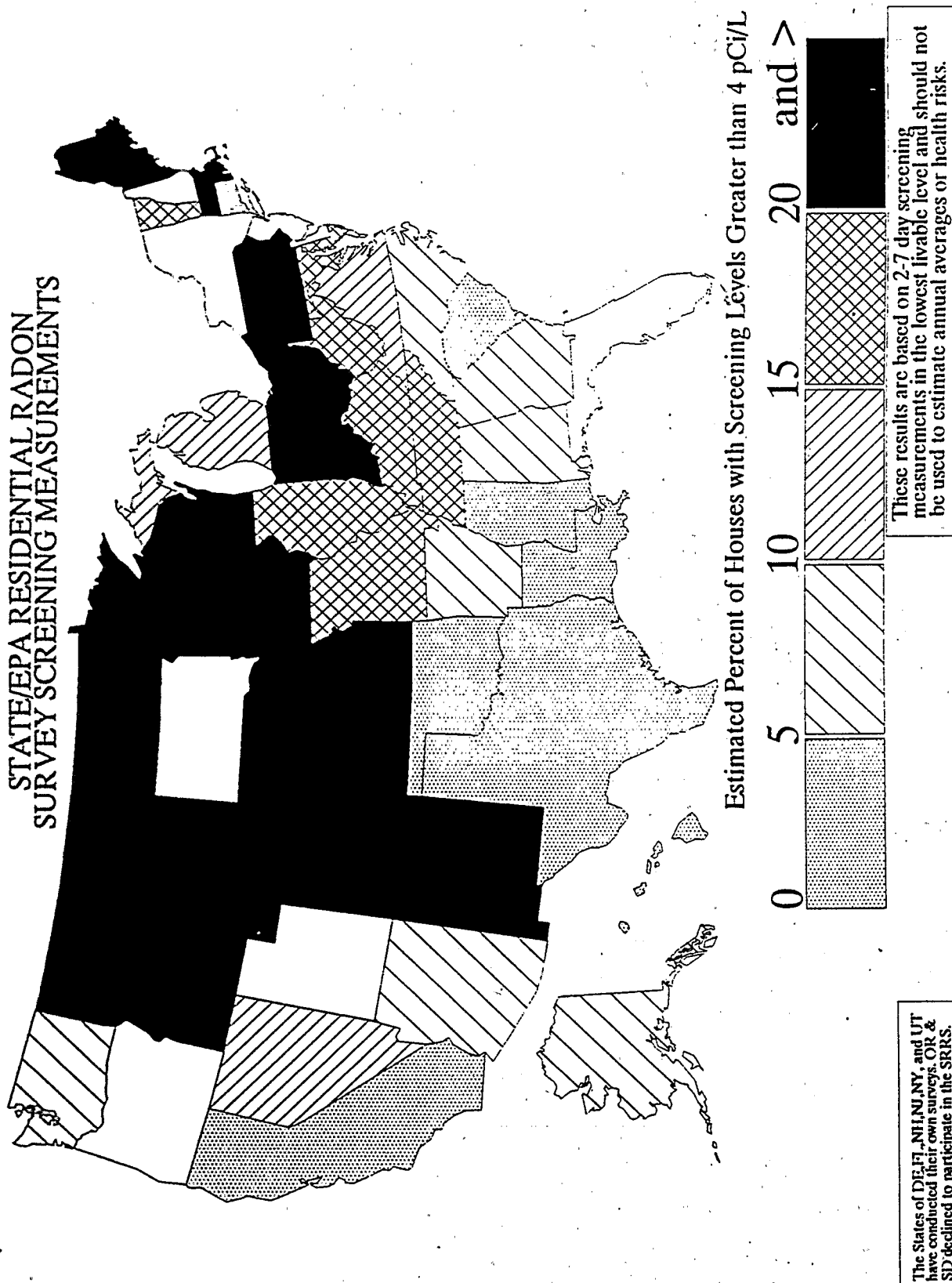


Figure 3. Percent of homes tested in the State/EPA Residential Radon Survey with screening indoor radon levels exceeding 4 pCi/L.

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 (Tr)		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			
			Mississippian (M)	Early	Lower	-330		
				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 (E)	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?		
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 (pC), 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		
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## EPA REGION 2 GEOLOGIC RADON POTENTIAL SUMMARY

by

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EPA Region 2 includes the states of New Jersey and New York. 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 2 is given in the individual state chapters. The individual chapters describing the geology and radon potential of the states in EPA Region 2, though much more detailed than this summary, are still 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 likely will be found.

Figure 1 shows the geologic radon potential areas in Region 2, combined and summarized from the individual state chapters in this booklet. These areas are based on the major geologic provinces in these states. Figure 2 shows average screening indoor radon levels by county. The data for New York were compiled by the New York State Department of Health and data for New Jersey were compiled by the New Jersey Department of Environmental Protection and Energy. Figure 3 is a generalized geologic radon potential map of EPA Region 2.

### NEW JERSEY

The New Jersey Highlands have been ranked high in geologic radon potential. Screening measurements of indoor radon in this area averaged 8.6 pCi/L. Uranium in rocks of the New Jersey Highlands is well documented in the literature. Uraninite and other U-bearing minerals form layers and disseminations in several kinds of host rocks, including intrusive granitic rocks, magnetite deposits, pegmatites, marble, veins, faults, shear zones, and feldspathic metasedimentary gneiss. Soil permeability is generally moderate to high with a few areas of low permeability. Glacial deposits in the New Jersey Highlands are, for the most part, locally derived and, in some areas, they enhance radon potential because of high permeability. In other areas, glacial deposits may blanket more uraniferous bedrock and effectively lower the radon potential.

The Valley and Ridge Province has been divided into two sections for this assessment. Silurian and Devonian rocks of the Valley and Ridge and the Green Pond outlier have been ranked moderate in radon potential. The Silurian and Devonian rocks are predominantly conglomerate, sandstone, shale, and limestone that generally have low to moderate equivalent uranium associated with them. The shales and local uranium mineral accumulations in the sandstones are the most likely source of radon problems. A few homes with indoor radon concentrations greater than 20 pCi/L were measured in the Silurian and Devonian rocks.

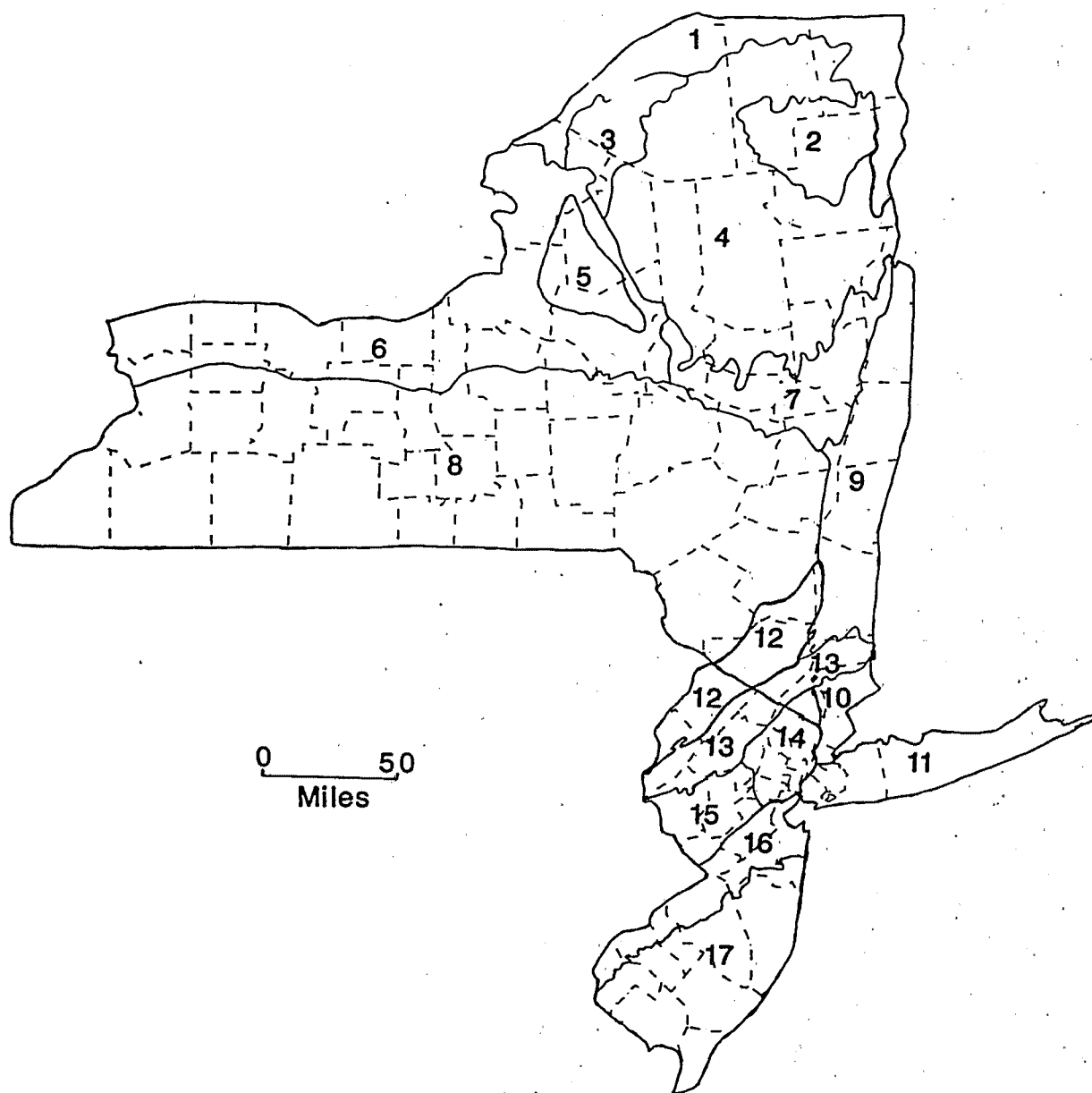


Figure 1. Geologic radon potential areas of EPA Region 2. 1-St. Lawrence-Champlain Lowlands; 2-High Peaks; 3-Northwest Lowlands; 4-Adirondacks; 5-Tug Hill Plateau; 6-Erie-Ontario Lowland; 7-Hudson-Mohawk Lowland; 8-Allegheny Plateau; 9-New England Upland-Taconic Mountains; 10-Manhattan Prong; 11-Atlantic Coastal Plain; 12-Valley and Ridge; 13-New Jersey Highlands-Hudson Highlands; 14-Triassic Lowland (NY)/northern Piedmont (NJ); 15-southern Piedmont; 16-Inner Coastal Plain; 17-Outer Coastal Plain.



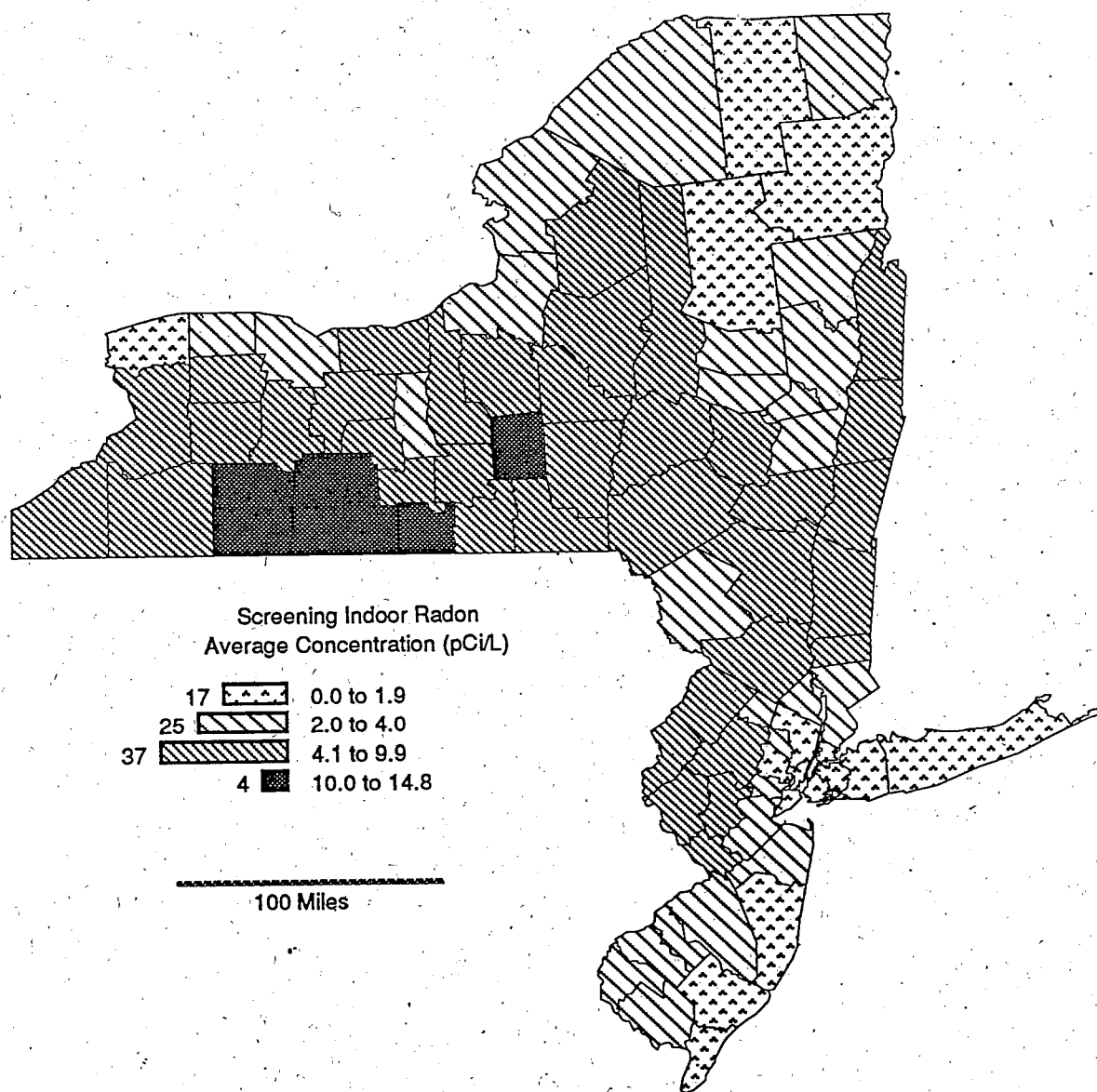


Figure 2. Average screening indoor radon levels, by county, for EPA Region 2. Data are primarily from 2-7 day charcoal canister tests. Data for New York were compiled by the New York State Department of Health; data for New Jersey were compiled by the New Jersey Department of Environmental Protection and Energy. Histograms in map legend show the number of counties in each category.

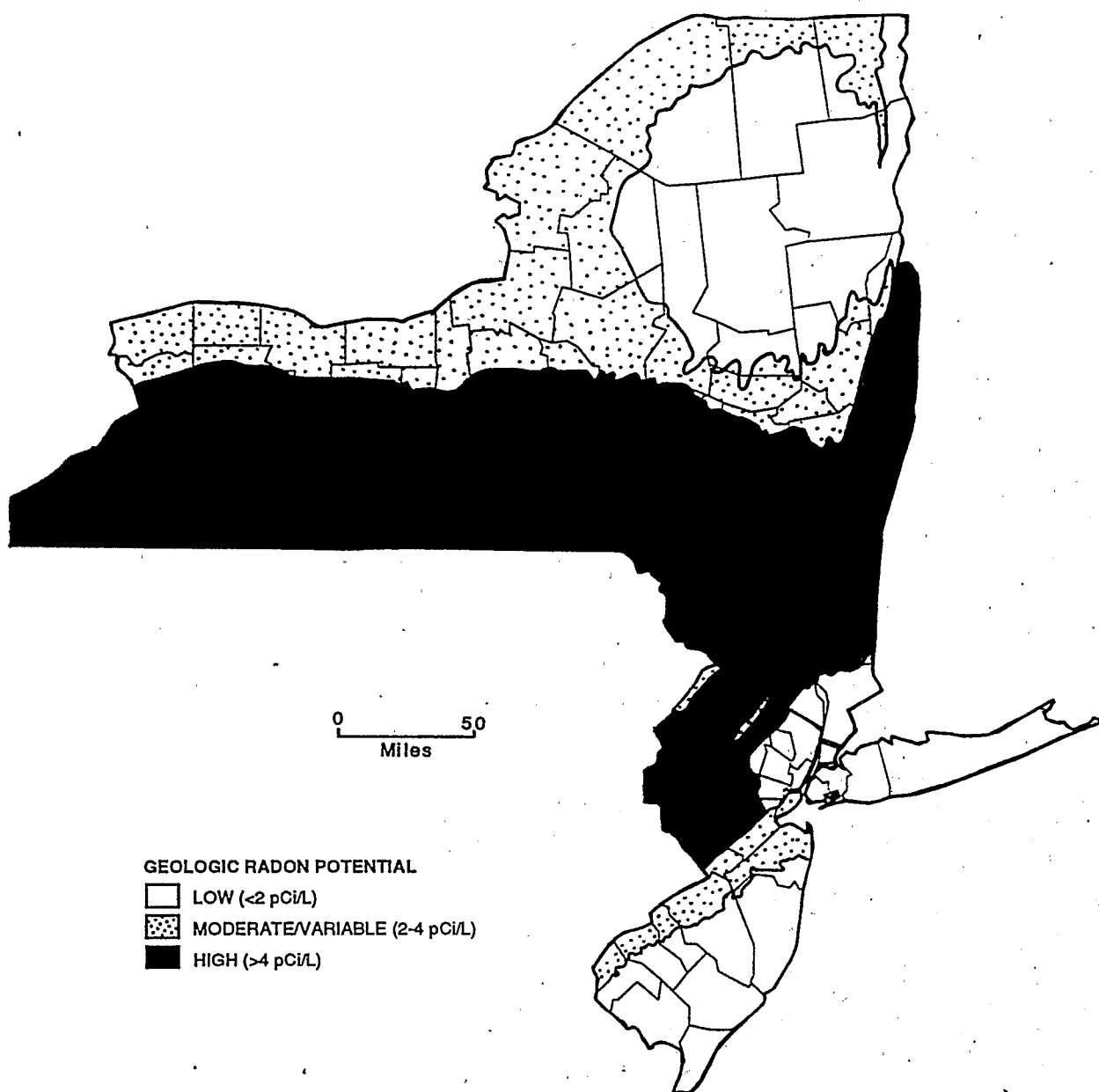


Figure 3. Generalized map showing geologic radon potential of EPA Region 2. For more detail refer to the individual state geologic radon potential chapters.

The Cambrian-Ordovician rocks of the Valley and Ridge have been ranked high in geologic radon potential. The Hardyston Quartzite is known to have local uranium and uranium mineral deposits, and the black shales and carbonate soils are also sources of indoor radon. Screening measurements of indoor radon in the Valley and Ridge averaged 7.6 pCi/L. Equivalent uranium is generally moderate to high over the Cambrian and Ordovician sedimentary rocks. Soil permeability is generally moderate.

The northern and southern Piedmont provinces together form the Newark Basin. The basin is underlain by Triassic sandstone, siltstones, and shales; Jurassic basalt and diabase; and Jurassic siltstone, shales, and sandstones. Of all these rock types, the black shales have the greatest potential to be a source of radon problems. Black shales are not as abundant in the northern Piedmont as in the southern Piedmont. The average screening indoor radon level in the northern Piedmont is 1.7 pCi/L; indoor radon levels greater than 4 pCi/L are probably associated with the black shales of the lower Passaic Formation and uranium mineralization along the northern border fault and in adjacent rocks. Sands and conglomerates of the upper Passaic Formation with low geologic radon potential dominate the northwestern part of the northern Piedmont. Jurassic basalts and interbedded sands and shales with low to moderate radon potential make up the western half of the northern Piedmont. Low to moderate radon potential is expected for the eastern half of the northern Piedmont, which is underlain by sands interbedded with lacustrine shales of the Passaic Formation and diabase of the Palisades sill that intrudes along the Lockatong Formation-Stockton Formation contact. This thin layer of Lockatong Formation may be responsible for the single indoor radon level greater than 20 pCi/L found near here. The northern Piedmont has been ranked low in geologic radon potential overall. The southern Piedmont is underlain by the uraniferous black shales and siltstones of the lower Passaic Formation, the uraniferous black shales of the Lockatong Formation, and the uraniferous black shales and locally uraniferous sandstones of the Stockton Formation. Average indoor radon for the southern Piedmont is 4.9 pCi/L. Equivalent uranium is also moderate to high. Soil permeability is low to moderate. The southern Piedmont has been ranked high in geologic radon potential.

The Inner Coastal Plain Province, underlain by Cretaceous and Early Tertiary sediments, is ranked moderate in radon potential. Screening measurements of indoor radon in the Inner Coastal Plain averaged 2.4 pCi/L. Equivalent uranium is generally moderate. Soil permeability is moderate to high. Soil radon studies indicate that the glauconitic sediments are significant sources of radon. The highest soil radon concentrations and radioactivity were found in the glauconitic sands of the Cretaceous Englishtown and Navesink Formations, the Mount Laurel Sand, and the Tertiary Hornerstown Sand.

The Outer Coastal Plain has been ranked low in radon potential. Soil radon studies of the Tertiary Kirkwood Formation, Cohansey Sand, and Pleistocene residuum indicate that they are relatively poor sources of radon. Equivalent uranium is generally low. Soil permeability is moderate to high and the average indoor radon for the province is low (1.4 pCi/L).

## NEW YORK

The Erie-Ontario Lowland and Tug Hill Plateau are underlain by a flat-lying sedimentary sequence with abundant limestone, dolomite, shale, sandstone, and distinctive salt deposits. Counties in the Erie-Ontario Lowland generally have indoor radon geometric means of less than 2 pCi/L and average indoor radon concentrations of less than 4 pCi/L. A veneer of impermeable clay covers a significant portion of the Erie-Ontario Lowland and generates low to moderate indoor

radon levels. Discrete occurrences of very coarse gravel and some marine shales may cause some of the moderate and locally high radon levels found in the area. Although the Erie-Ontario Lowlands have low radon source strength, low permeability, and consequently low radon potential, radon potential is high in association with gravels in drumlins, outwash, moraines, till, and beach ridges in the region. Significant accumulations of these coarse glacial deposits occur in Wayne County and in the eastern portion of the province around the Tug Hill Plateau. We have assigned an overall moderate/variable radon potential to the area based on the majority of county indoor radon averages being greater than 2 pCi/L, the variably low to high radon source potential of the underlying geology, variably low to high soil permeability, and low (<1.5 ppm eU) to moderate (1.5-2.5 ppm eU) radioactivity.

The Hudson-Mohawk Lowland is underlain by sandstone, siltstone, shale, and conglomerate of variable ages. In this assessment, the lowland has been ranked generally moderate or variable in radon potential, as the geology and glacial deposits of the area are highly variable and radon potential varies likewise from low to high. Equivalent uranium is generally moderate to locally high (>2.5 ppm eU) in this area. Soils have moderate to locally high permeability. The region is underlain predominantly by shale with average to below-average radium concentrations and indoor radon over the shale is generally low. High levels of indoor and soil radon are associated with gravelly kame and till deposits found above valley bottoms and with gravel concentrations in sandy glacial deposits, generally moderate radon levels are associated with lacustrine delta and kame deposits, and generally low levels are associated with Recent floodplain deposits, lacustrine silt and clay, lacustrine sand, and dune sand.

The St. Lawrence and Champlain Lowlands are underlain by sedimentary rocks of Cambrian through early Ordovician age with relatively low geologic radon potential. However, some of the very coarse gravel deposits have moderate to high radon potential. Equivalent uranium is generally low with a few moderate areas. Counties in the lowlands have indoor radon geometric means less than 2 pCi/L and basement average concentrations of indoor radon less than 3 pCi/L. A veneer of impermeable clay covers much of the area; however, areas of highly permeable, very coarse glacial gravels and gravel in beach ridges may cause some of the moderate to high radon levels found in the area. Local occurrences of elevated (>4 pCi/L) indoor radon are associated with gravels in drumlins, outwash, moraines, till, and beach ridges. Because of these highly permeable deposits and county average radon greater than 2 pCi/L, these provinces have been ranked moderate in radon potential.

The Allegheny Plateau is underlain by sedimentary rocks, predominantly shales, limestones, and sandstones. Soils in the southern part of the plateau have low to moderate permeability except for glacial gravel deposits, primarily in valleys, which have high permeability. In the northern plateau, the soils have low permeability, with the exception of local glacial gravels. The plateau has been ranked high in radon potential overall. However, parts of the Allegheny Plateau are low to moderate in radon potential, especially areas in the Catskill Mountains. Equivalent uranium is generally moderate in the plateau and is high along the south-central border with Pennsylvania. The radioactivity pattern may correspond to the geometry of the Valley Heads Moraine in the Finger Lakes region, with thinner till and progressively higher radioactivity south of the moraines. The central and southern parts of the plateau have high radon potential in association with coarse kame, till, and other gravel deposits which are generally restricted to valleys. Two belts of uraniferous black shale, the Marcellus Shale and West Falls Group shales, cross central and southern New York and cause significant high indoor radon from Onondaga County to Erie County. Other black shales and related sedimentary rocks in the plateau do not appear to have as

high uranium contents. Elevated indoor radon concentrations near the contact between the Onondaga limestone and the Marcellus Shale may be due to remobilization of uranium from the shale into the fractured limestone. Of the northern counties in the Allegheny Plateau, only Seneca County has an indoor radon average less than 4 pCi/L and it is considered to have moderate radon potential. The northern, more populous portion of Seneca County is underlain by glacial clays and the rest of the county is covered by till. Gravelly glacial deposits are the cause of most of the high radon found in the southern plateau, probably due to high permeability and high radon emanation coefficients. Because the alluvial valley and moraine deposits are discrete bodies, categorizing whole counties as high in radon potential may not be accurate. In addition, many towns are built in the valleys, on the deposits most likely to cause high radon, and most of the indoor radon data available for the counties is from these towns. Further work is needed outside of the towns located in the valleys to accurately evaluate the uplands and counties as a whole. Because many of the uplands are underlain by highly fractured shales, there is a geologic potential for elevated indoor radon. Most counties in the Allegheny Plateau have indoor radon geometric means in the 2-4 pCi/L range and county averages greater than 4 pCi/L. Four counties—Allegany, Chemung, Cortland, and Steuben—have county indoor radon averages greater than 10 pCi/L. Sullivan County, which is mostly located in the Catskill Mountains, has lower indoor radon than surrounding counties with an average of 3.1 pCi/L and geometric mean of 1.7 pCi/L. This county is considered to be moderate in radon potential.

The Hudson Highlands, which are the northeastern extension of the Reading Prong, have been ranked high in radon potential, but the radon potential is actually highly variable. These mountains consist of a wide variety of rock types. Equivalent uranium is generally moderate with local lows and highs. Soils are thin and stony with locally thick accumulations of low-permeability till. Numerous uranium localities and associated gamma-radioactivity anomalies are well documented in the Hudson Highlands. These uranium deposits appear to be the cause for localized occurrences of very high indoor radon levels. Faults and shear zones in the Highlands also host uranium mineralization and are well known throughout the Appalachians for causing high indoor radon levels. Faults may also be an important radon source in parts of the Adirondacks and New England Upland. Rock types which tend to be low in uranium in the Hudson Highlands include amphibolitic gneisses, quartz-poor gneisses, and some marbles. Because the composition and location of very high uranium concentrations in these rocks is so variable, indoor radon is highly variable. The Hudson Highlands underlie parts of Putnam and Orange Counties, which have county indoor radon geometric means of 2.4 and 2.8 pCi/L respectively, and county indoor radon averages greater than 4 pCi/L. The Hudson Highlands are high in radon potential because of the very high indoor radon levels found in some homes, because many of the homes are built into bedrock, and because high levels of radon in well-water also occur.

The Manhattan Prong is made up of metamorphic and igneous rocks with generally low amounts of uranium and low radon potential. No direct correlation between any of the Manhattan Prong rocks and indoor radon has been made. Equivalent uranium is generally low to moderate. Soils have low to moderate permeability. Counties underlain by the Manhattan Prong (Westchester County and most of New York City) have indoor radon geometric means  $\leq 1.5$  pCi/L and average indoor radon  $\leq 2.4$  pCi/L.

The New England Upland-Taconic Mountains area is underlain predominantly by slate, phyllite, graywacke, and limestone. This area has been ranked high in radon potential. The county geometric means for indoor radon in this province are greater than 2 pCi/L and the county averages are greater than 4 pCi/L. Equivalent uranium is moderate to locally high. Soil

permeability is low to moderate, with locally high permeability in glacial gravels. High indoor radon levels appear to be related to highly permeable glacial and fluvial sediments along the valleys.

The High Peaks and most of the central Adirondacks are made up of anorthosite and gneiss, both of which are low in uranium and unlikely to cause radon problems. The rim of the Adirondacks is composed predominantly of metasedimentary and metavolcanic rocks, several of which contain local uranium occurrences and have locally high radon potential. Equivalent uranium in the Adirondacks is low over the High Peaks and surrounding charnockitic rocks. Moderate and locally high equivalent uranium is associated with the Northwest Lowlands and scattered areas in metasedimentary rocks and iron deposits in the southeastern and eastern rim of the Adirondacks. Soils have low to moderate permeability with locally high permeability in sandy and gravelly glacial deposits. Most counties in the Adirondack Mountains have geometric means of indoor radon less than 2 pCi/L. Average indoor radon is  $\leq 1.5$  pCi/L in Essex, Hamilton, and Franklin Counties, but greater than 2 pCi/L for Herkimer, Warren, St. Lawrence, and Lewis Counties. These counties also lie partially in other geologic provinces. We rank the High Peaks and Adirondacks low in radon potential but rank the Northwest Lowlands moderate in radon potential due to the high radioactivity, local occurrence of uranium, local glacial gravel deposits, the sheared and faulted metamorphic rocks, and higher indoor radon in St. Lawrence County.

In the Valley and Ridge section, sedimentary rocks of Cambrian through Ordovician age comprise the underlying bedrock and have been ranked high in radon potential but may be locally low to moderate. Cambrian and Ordovician rocks consist of a marine shelf sequence with basal Cambrian sandstones and conglomerates followed by a highly variable sequence of interbedded shales and carbonate rocks. Many of the black shales in this sequence are elevated in uranium ( $>2$  ppm) and, although the limestones are relatively low in uranium, the local residual soils formed on limestones in the valleys of the area may be elevated in uranium. Indoor radon is elevated ( $> 4$  pCi/L) in basements of homes built on limestone soils of the Wallkill Valley, on black shale bedrock, and especially in glacial gravel deposits containing black shale.

The Triassic Lowland is underlain by fluvial quartz sands, minor siltstones and shales, and Jurassic basalt and diabase, and underlies most of Rockland County. Of these rock types, the shales have the potential to be a source of radon problems; however, they are not abundant. Black shales and gray sandstones in the lower Passaic Formation are similar to uranium-bearing units in the same formation in New Jersey, but they make up a minor part of the section. Rockland County has a basement indoor radon average of 2.2 pCi/L and a geometric mean of 1.3 pCi/L. Equivalent uranium is low to moderate for the Triassic Lowlands. Soil permeability is generally low to moderate. The Triassic Lowlands have been ranked low in radon potential.

Long Island, in the Atlantic Coastal Plain Province, is made up of glacial deposits and marine sediments containing little or no uranium. Indoor radon measurements are among the lowest in the State. Counties of the Atlantic Coastal Plain have indoor radon geometric means less than 2 pCi/L and average concentrations of indoor radon less than 2 pCi/L. Permeability is moderate to high with local areas of low permeability. A number of boulders in the glacial moraines on Long Island have high levels of radioactivity and coarse gravels and sands of the glacial outwash may also have isolated uranium concentrations, making them local sources of elevated radon.

# PRELIMINARY GEOLOGIC RADON POTENTIAL ASSESSMENT OF NEW JERSEY

by

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## INTRODUCTION

In 1986, the New Jersey Department of Environmental Protection and Energy (NJDEPE) initiated the Statewide Scientific Study of Radon. In this comprehensive study, over 6000 homes and buildings were sampled for indoor radon and an extensive database of geologic, soil, political, demographic, meteorological, building features, and resident behavior information was collected and compared with the indoor radon data (Camp Dresser and McKee Inc., 1989). Models for radon potential and risk exposure were also developed from these data. Since the completion of that study, the NJDEPE has also compiled a separate indoor radon database which now includes 151,453 individual measurements. **The State of New Jersey has classified all municipalities of the state as having high, moderate, or low potential for elevated radon based on this database. State law requires that residential and school structures built in municipalities that the State has classified with a high radon potential use construction techniques that minimize radon entry and facilitate post-construction removal of radon. Please contact the New Jersey Radon Program at 800-648-0934 (New Jersey only) or 609-987-6396 for information.**

The NJDEPE study found the highest average indoor radon levels in the New Jersey Highlands and the Valley and Ridge. More than half of the indoor radon measurements in these two provinces exceeded 4 pCi/L. The Southern Piedmont also had high average indoor radon (4.9 pCi/L). In every province of the State at least 5 percent of the readings were 4 pCi/L or more, and at least one home in every province had indoor radon levels exceeding 30 pCi/L. The study found that geology exerts a strong influence on indoor radon and that aerial radiometric data provide very good correlations with indoor radon. When the data collected in the NJDEPE study and the updated indoor radon database are analyzed using the geologic radon indexes developed by the U.S. Geological Survey (USGS) for the U.S. Environmental Protection Agency (EPA) the results are very similar. The Cambrian-Ordovician sedimentary rocks of the Valley and Ridge, the gneisses of the New Jersey Highlands, and the Triassic sedimentary rocks of the Southern Piedmont score high in radon potential. The Cretaceous and Lower Tertiary sediments of the Inner Coastal Plain and the Silurian-Devonian sedimentary rocks of the Valley and Ridge and the New Jersey Highlands score moderate in radon potential. The Northern Piedmont is highly variable, generally low to moderate in radon potential, with a few locally high areas in the Lockatong and Lower Passaic Formations. The Tertiary and Quaternary sediments of the Outer Coastal Plain score low in radon potential.

The scale of the USGS 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. 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.

## PHYSIOGRAPHIC AND GEOGRAPHIC SETTING

The physiography of New Jersey (fig. 1) is in part a reflection of the underlying bedrock geology (fig. 2). New Jersey has four major physiographic regions: The Appalachian Valley and Ridge Region; The New Jersey Highlands; the Piedmont; and the Atlantic Coastal Plain. The Valley and Ridge Province covers 635 square miles in the northwestern part of the State. It is characterized by a series of parallel ridges and valleys that trend in a northeast-southwest direction. The ridges are frequently underlain by sandstones and conglomerates, whereas the valleys are underlain by limestones and shales. Elevation rises to more than 1800 feet above sea level at Kittatinny Mountain. The New Jersey Highlands Province (also known as the Reading Prong) covers about 900 square miles of rugged, mountainous terrain. It is underlain by Precambrian igneous and metamorphic rocks as well as inliers of Lower and Middle Paleozoic sedimentary rocks. The highest elevation in the Highlands is 1496 feet in the north near Vernon, while some of the intermontane valleys are as low as 200 feet above sea level. The Piedmont Lowland Province lies just southeast of the Highlands (fig. 1) and covers 1500 square miles of broad piedmont plain and rolling lowland. The highest elevation is 879 feet in the basaltic ridges of the Watchung Mountains. The average elevation of the Piedmont is between 200 and 400 feet above sea level. The Coastal Plain Province covers over three-fifths (4500 square miles) of the State. It is a broad, belted plain that slopes gently towards the Atlantic Ocean. This province is bounded to the north by the "fall line" where it intersects the Piedmont. The fall line is marked by a distinct change in water velocity and by waterfalls along the stream and river drainages, giving the boundary its name. Relief is low and elevation is less than 200 feet above sea level. Cuestas, or ridges of more resistant sediments, give the Coastal Plain a distinctive topography.

In 1990, the population of New Jersey was 7,730,188, including 89 percent urban population (fig. 3). The population density is approximately 991 per square mile. The climate is moderate and precipitation averages 46 to 50 inches per year (fig. 4).

## GEOLOGIC SETTING

A generalized geologic map of New Jersey is shown in figure 2 (New Jersey Geological Survey, 1984). The following descriptions are intended to present a general overview of the geology of New Jersey and are derived from a number of sources, including numerous papers in Subitzky (1969) and in Kroll and Brown (1990); Wolfe (1977); Drake (1984); Drake and others (1990); Volkert and Drake (1990); and Smoot (1991). The New Jersey Geological Survey is currently completing a series of new geologic maps covering the entire State. It is recommended that the reader refer to these new maps and other detailed geologic maps and information available from the New Jersey Geological Survey (Dombroski, 1990; Harper, 1991).

### The Coastal Plain Province

The Coastal Plain is underlain by Cretaceous and Tertiary marine and fluvial sand, clay, and gravel forming a clastic wedge that thickens seaward. The surface expression of the gently dipping Cretaceous and lower Tertiary sediments is a series of northeast-trending belts with the oldest belt to the northwest and progressively younger belts southeastward. In the eastern part of the province, the latest Tertiary deposits form sheets covering the older sediments that are irregularly eroded to expose the underlying deposits.



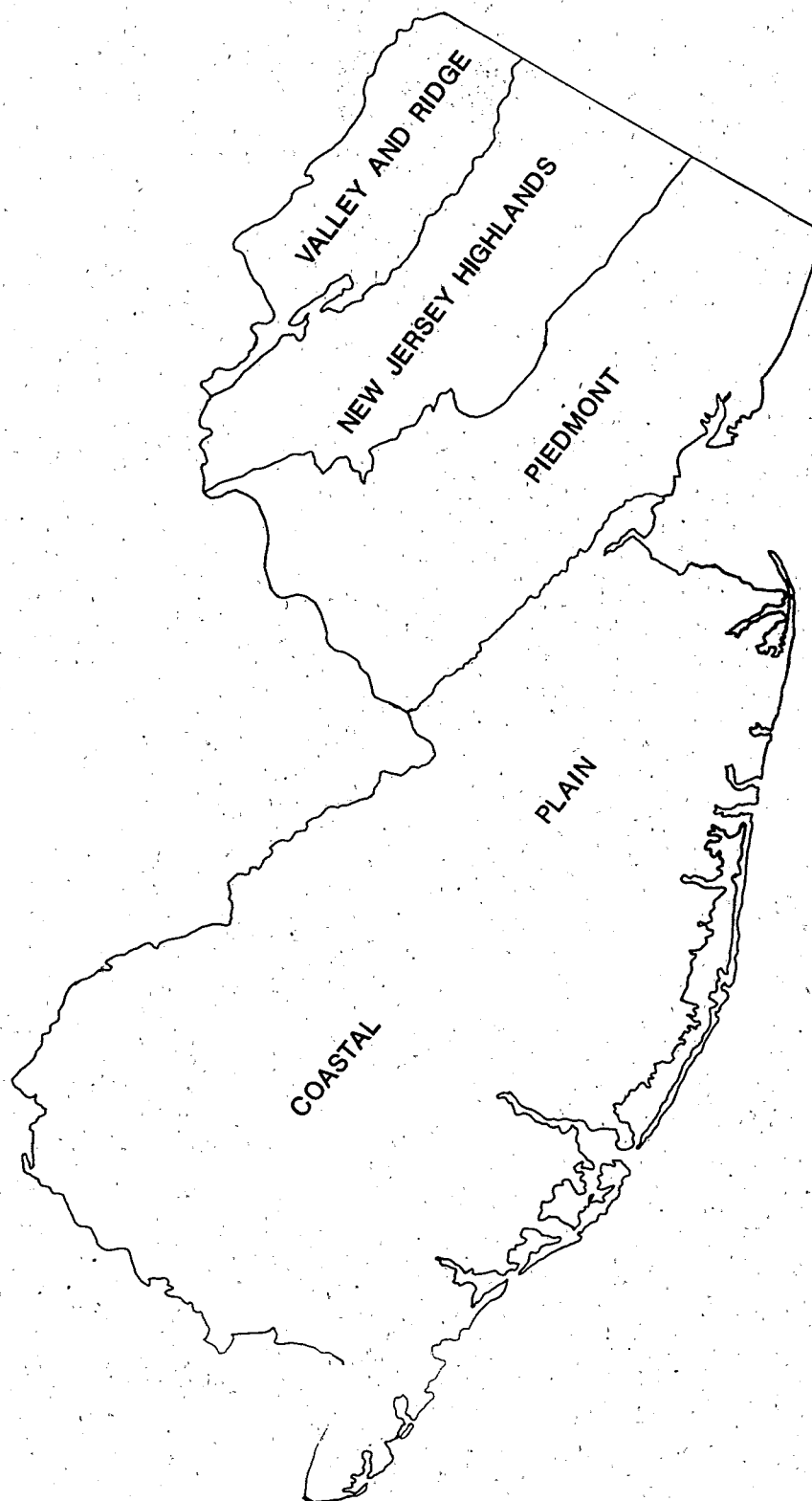


Figure 1. Physiographic provinces of New Jersey.

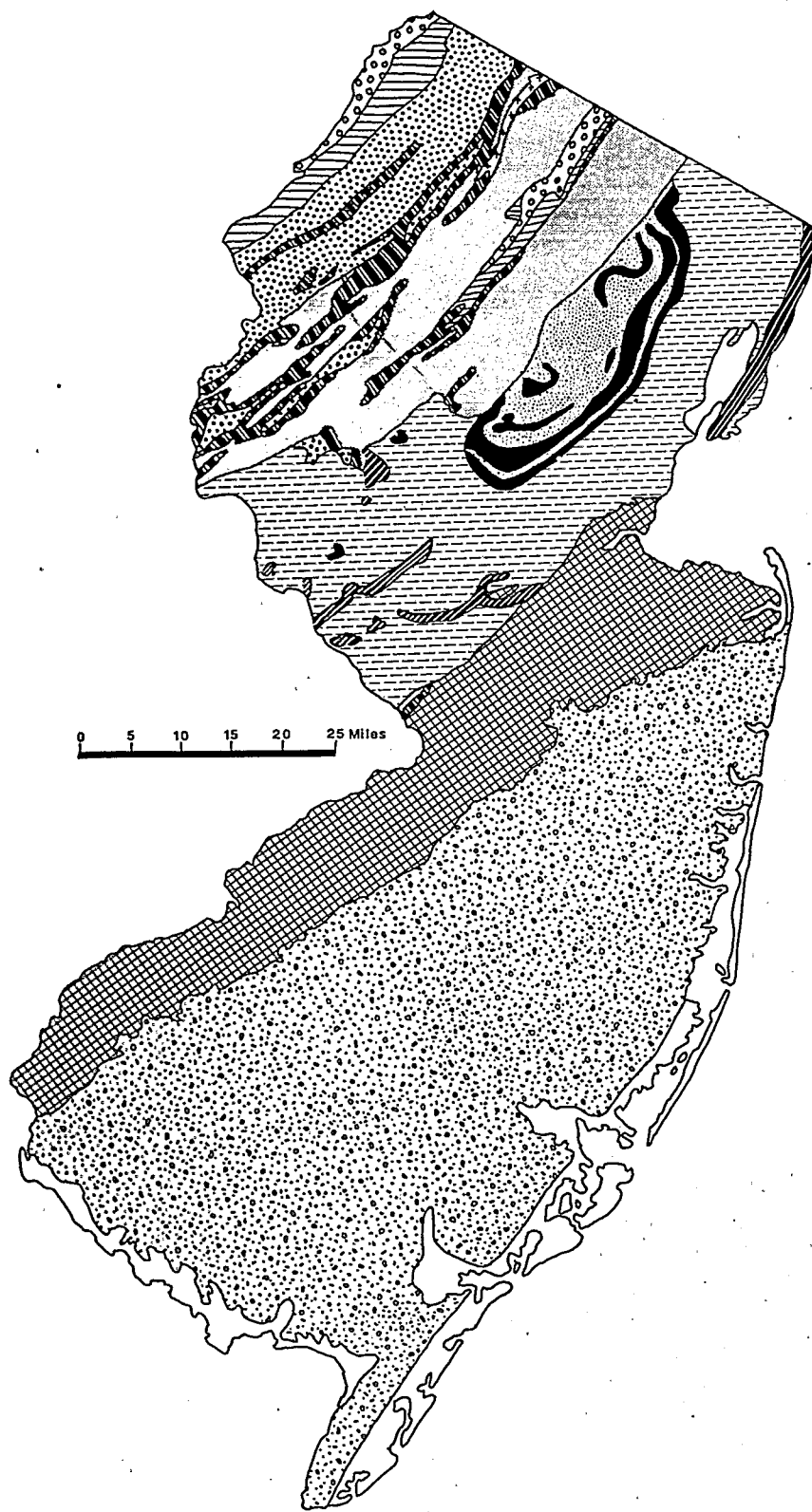











Figure 2. Generalized geologic map of New Jersey (redrawn from New Jersey Geological Survey, 1984).





# GENERALIZED GEOLOGIC MAP OF NEW JERSEY

## EXPLANATION

### SEDIMENTARY ROCKS

-  Holocene: beach and estuarine deposits
-  Tertiary: sand, greensand, marl, and clay
-  Cretaceous: sand, clay, greensand, and marl
-  Jurassic: siltstone, shale, sandstone, and conglomerate
-  Triassic: siltstone, shale, sandstone, and conglomerate
-  Devonian: conglomerate, sandstone, shale, and limestone
-  Silurian: conglomerate, sandstone, shale, and limestone
-  Ordovician: shale and sandstone
-  Cambrian-Ordovician: limestone and sandstone

### IGNEOUS AND METAMORPHIC ROCKS

-  Jurassic: basalt
-  Jurassic: diabase
-  Precambrian: marble
-  Precambrian: gneiss and granite

POPULATION (1990)

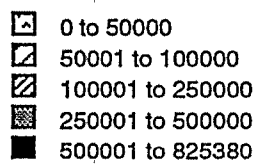


Figure 3. Population of counties in New Jersey (1990 U.S. Census data).

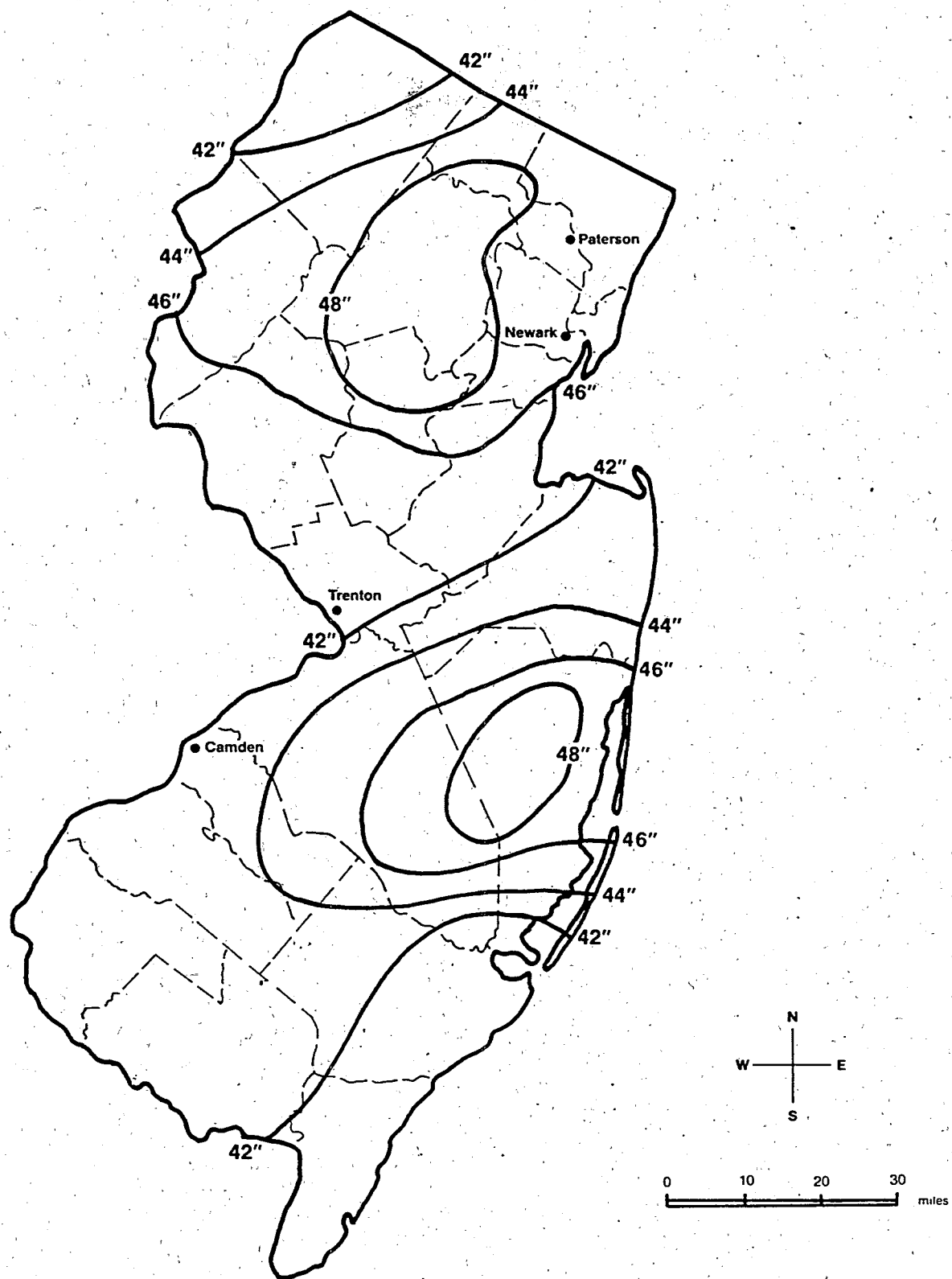


Figure 4. Average annual precipitation in New Jersey (from Facts on File, 1984).

The oldest Cretaceous sediments are fluvial and shallow marine interbedded sand and variegated clayey silt and silty clay of the Raritan Formation, which form a broad band of outcrop. The Raritan Formation is overlain by a series of fine-grained marine deposits that form narrow outcrop belts, including fossiliferous, locally glauconitic, clayey silt and sand of the Magothy Formation; black, sandy glauconitic clay and local fine glauconitic sand of the Merchantville Clay; and fossiliferous, gray to black clayey silt of the Woodbury Clay. The fine-grained marine sequence is overlain by an upward-coarsening marine to fluvial sequence of the Englishtown Formation that forms a narrow outcrop belt. To the north, the Englishtown consists of cross-stratified sands, in places gravelly, interbedded with carbon-rich silt, and to the south it consists of marine gray, fossiliferous silty sand. Glauconite lentils and siderite concretions are common near the top. The Englishtown is overlain by an upward-coarsening sequence of marine clay to sand composed of the Marshalltown and Wenonah Formations and Mount Laurel Sand. The Marshalltown is a silty, glauconitic clay with fine quartz sand interbeds; the Wenonah is a fine, micaceous silty sand that is slightly glauconitic; and the Mount Laurel Sand is a fine to coarse quartz sand that is slightly glauconitic. The Navesink Formation is a coarse-grained, clayey, glauconitic sand that is locally shelly at the base, and it overlies the Mount Laurel Sand. The Navesink Formation is overlain by an upward-coarsening sequence of the Red Bank Sand that forms a broad outcrop belt in the north-central part of the province and pinches out in the central part of the province. The base of the Red Bank is dark-gray, fossiliferous silty sand that is locally cemented with iron oxide. The Red Bank grades up into a slightly glauconitic quartz sand, and glauconitic, sideritic sand of the Tinton Sand. In Gloucester and Salem Counties, the Red Bank and Tinton Sands grade into a glauconitic, clayey and silty sand of the New Egypt Formation.

The lower Tertiary deposits are glauconitic sand similar to those of Cretaceous age, whereas the upper Tertiary is characterized by quartz sand. The Hornerstown Sand is the basal Tertiary unit that forms a continuous narrow outcrop band consisting of fine- to coarse-grained, locally clayey, glauconitic sand. The Hornerstown is overlain by the Vincentown Formation, which forms a narrow outcrop band that becomes broader in the east-central part of the province. The Vincentown is predominantly quartz sand that is glauconitic near the base. To the south, the lower part of the Vincentown is a fossiliferous, glauconitic sand that grades upward into a calcareous quartz sand. Glauconitic sand and mud of the Manasquan and Shark River Formations discontinuously overlie the Vincentown. The Kirkwood Formation overlies the Manasquan, Shark River, and Vincentown, and comprises a broad outcrop band that narrows to the southwest. The Kirkwood is a cross-bedded, locally conglomeratic, marine quartz sand with lenses of dark porcelaneous phosphatic clay. The Cohansey Sand overlies the Kirkwood and comprises about one-third of the Coastal Plain, forming a broad sheet to the south and irregular erosional remnants on the Kirkwood to the north. To the north, the Cohansey consists of fluvial and marine, cross-bedded quartz sand and gravelly sand, whereas to the south it is composed of quartz sand interbedded with thick dark-gray clay.

### New Jersey Highlands

The Reading Prong of the New Jersey Highlands is underlain by the oldest rocks in New Jersey, consisting of approximately equal parts of metavolcanic, metasedimentary, and granitic intrusive rocks.

At the base of the section is the Losee Metamorphic Suite which generally consists of rocks dominated by sodic plagioclase and quartz with locally abundant biotite and minor hornblende, magnetite, augite, and hypersthene. Texture of the rocks varies from massive to well-layered and

foliated. Pegmatite and amphibolite layers are sparse to moderately common. The Losee Metamorphic Suite is thought to be partly metavolcanic in origin and contains probable trondhjemitic to tonalitic intrusions. The Losee is distributed throughout the New Jersey Highlands, especially in the central and eastern sections. Physically overlying the Losee Metamorphic Suite is a sequence of metasedimentary rocks varying from calcareous to quartzofeldspathic in composition. The calcareous metasedimentary rocks include calcitic and dolomitic marble, pyroxene gneiss, epidote-bearing gneiss, and variable gneisses containing pyroxene, scapolite, and allanite. The Franklin Marble crops out along the northern border of the New Jersey Highlands, is the largest area of marble in the Highlands, and hosts well-known zinc deposits. The metasedimentary quartzofeldspathic rocks vary in composition, commonly containing biotite and various amounts of garnet, graphite, sillimanite, and magnetite. Amphibolite and magnetite deposits are locally associated with all of the above rock units. Metasedimentary rocks are most abundant in the northern and western parts of the New Jersey Highlands.

Igneous intrusive rocks in the New Jersey Highlands are dominated by the Byram Intrusive Suite and the Lake Hapatacong Intrusive Suite, and are distributed throughout the Highlands. These two intrusive suites are granitic, syenitic, or monzonitic in composition and consist of varying amounts of quartz, several kinds of feldspar, and minor mafic minerals, predominantly hornblende and clinopyroxene, respectively. Quartz-poor rocks of the Lake Hapatacong Suite are monzonitic, and are common in north-central New Jersey.

Several kinds of migmatitic rocks not belonging to the Byram Intrusive Suite are found throughout the Highlands, but seem more abundant in north-central New Jersey. Charnockitic rocks are widely distributed in the Highlands, but are most abundant in north-central New Jersey. These rocks appear granitic, but often have distinct alternating light and dark layers, as well as discontinuous layers of amphibolite.

Along the central axis of the New Jersey Highlands is an area of Devonian and Silurian sandstones, shales, siltstones, minor carbonates, and conglomerates referred to as the Green Pond outlier (Herman and Mitchell, 1989). The most prominent units include the Silurian Green Pond Conglomerate, Longwood Shale, carbonates of the Poxono Island and Berkshire Valley Formations, the Devonian Connelly Conglomerate, shales of the Esopus Formation, Kanouse Sandstone, Cornwall Shale, Bellvale Sandstone, and Skunnemunk Conglomerate.

#### Appalachian Valley and Ridge Province

The Valley and Ridge is underlain by northeast-southwest trending belts of limestone, shale, and sandstone. Along the contact with the Reading Prong, faults and folds complexly join rocks characteristic of the two regions, making the boundary poorly defined.

The oldest rocks of the Appalachian Valley and Ridge are Cambrian in age. These form a series of narrow, fault-repeated belts along the southeastern edge of the province. The basal Hardyston Quartzite and the overlying interbedded dolomite and phyllite of the Leithsville Formation form very narrow bands. Most of the area is underlain by Cambrian rocks, including a broad central belt of rocks called the Allentown Dolomite.

Ordovician rocks form a broad belt covering the eastern half of the Valley and Ridge. The basal Ordovician is composed of very narrow belts of limestone and dolomite of the Beekmantown Group, including the Stonehenge Formation, Rickenbach Formation, Epler Formation, Ontelaunee Formation, and the Kittatinny Supergroup. The Beekmantown Group is overlain by sandy and clayey limestone of the Jacksonburg Limestone, which forms a series of very narrow outcrop

belts. Most of the Ordovician outcrop area is underlain by Martinsburg Formation, consisting of black shale with interbeds of graywacke, sandstone, and siltstone.

The Silurian rocks form an outcrop belt parallel to the northwestern edge of the province comprising narrow bands of progressively younger units. The basal Shawangunk Formation unconformably overlies the Ordovician Martinsburg Formation and consists of fluvial quartz conglomerate grading up into deltaic sandstone and siltstone. This is overlain by red sandstone, siltstone, and shale of the Bloomsburg Redbeds. This is overlain by green to gray shale with sandstone and limestone interbeds of the Poxono Island Formation, followed by clayey limestone of the Bossardville Limestone. The Bossardville is overlain by calcareous quartz sandstone, siltstone, and limestone of the Decker Formation. Interbedded clay-rich limestone and dolomite and calcareous shale of the Rondout Formation comprise the youngest Silurian rocks.

The Devonian rocks of the Valley and Ridge in New Jersey are restricted to a belt along the northwest margin of the province, forming narrow bands of formations. The basal part of the section is limestone, clayey or shaly limestone, and calcareous shale of the Helderburg Group, including the Coeymans and New Scotland Formations, the Minnisink Limestone, and the Port Ewen Shale. The Helderburg Group is overlain by the Oriskany Group, consisting of silty limestone of the Glenarie Formation, the Shriver Chert, and the Ridgely Sandstone. The Glenarie Formation is the only unit found to the northeast, whereas the Ridgely Sandstone and Shriver Chert dominate in the southwest. The Oriskany Group is overlain by gray to black siltstone and calcareous siltstone of the Esopus and Schoharie Formations. Limestone and shaly limestone of the Buttermilk Falls Limestone overlie these units. The uppermost rocks are black shale of the Marcellus Formation.

#### Piedmont (Newark Basin)

Late Triassic-early Jurassic continental sedimentary and igneous rocks of the Newark Supergroup are restricted to the Newark basin, which forms a broad northeast-trending belt across the north-central part of the State. The Newark basin is a half graben with a faulted northwestern margin. The strata dip toward the border fault and are folded into a broad syncline that extends eastward into New York and another syncline near the Pennsylvania border that extends westward into Pennsylvania. The stratigraphic sequence of the basin is repeated in two fault blocks that extend into Pennsylvania. The basal Triassic Stockton Formation forms a narrow band along the southeastern side of the basin and is repeated in the two fault blocks. The Stockton 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 Stockton is overlain by the Triassic Lockatong Formation, which forms a very narrow band in the northeastern part of the basin and pinches out. The Lockatong forms broader bands to the southwest, where it is repeated in the fault blocks. The Lockatong consists of lacustrine black and red shales and siltstones with interbedded arkosic sandstones. The Triassic to Jurassic Passaic Formation overlies the Lockatong and forms a broad belt of outcrop that underlies most of the basin in New Jersey. The Passaic consists of red and black lacustrine shale and siltstone intertonguing with sandstone and conglomerate. The Passaic Formation is overlain by a Jurassic sequence of tholeiitic basalt flows and sedimentary rocks, deformed by synclines along the border fault, and in fault slices that repeat the stratigraphic section. The Jurassic sequence consists of the Orange Mountain Basalt, Feltville Formation, Preakness Basalt, Towaco Formation, Hook Mountain Basalt, and Boonton Formation. The Feltville, Towaco, and Boonton Formations consist of lacustrine black and red shales interbedded with sandstones. The basalts and the Feltville and Towaco Formations form



narrow outcrop bands, but the Boonton underlies an extensive area in the core of the large syncline along the border fault. Along the northwestern faulted margin of the basin, all of the formations intertongue with alluvial fan conglomerates containing clasts of the older rocks immediately outside of the basin. Jurassic diabase dikes and sheets intrude the sedimentary rocks. The most prominent diabase body is the Palisades sill, which intrudes approximately along the contact of the Stockton and Lockatong Formations near the Hudson River. It also forms a large sheet that intrudes along the contact of the Lockatong and Passaic Formations near the Delaware River. Smaller diabase sheets are folded into synclines along the fault contacts.

## GLACIAL GEOLOGY

Glacial deposits of pre-Illinoian, Illinoian, and Wisconsinan ages occur in northern New Jersey (Fullerton, 1986; Stone and others, 1989). The Wisconsinan terminal moraine forms a nearly continuous ridge of thick till across the State from Perth Amboy north to Denville and west to Belvidere (Minard and Rhodehamel, 1969). Pre-Illinoian and Illinoian-age glacial deposits south of the moraine are generally discontinuous and weathered to a much greater extent than the Late Wisconsinan glacial deposits north of the moraine (Minard and Rhodehamel, 1969). Late Wisconsinan till underlies much of the landscape north of the terminal moraine.

Glacial deposits in New Jersey are divided into three main classes: till, glaciofluvial deposits, and glaciolacustrine deposits (fig. 5). Till is a non-stratified deposit consisting of a poorly sorted mixture of sand, silt, clay, and some gravel. Thickness of till in northern New Jersey ranges from zero to as much as 76 m, but is generally less than 6 m. Till thickness averages less than 1 m on uplands and 1-3 m beneath stratified meltwater deposits in valleys, and bedrock is exposed in many places. Till is commonly more than 30 m thick in drumlins in the Newark Basin area and the Great Valley and 6-20 m thick on the terminal moraine (B.D. Stone, personal communication, 1993). The composition of the till generally reflects the underlying bedrock, although boulders from more distant source areas, called erratics, occur in all glaciated areas. In the Valley and Ridge province, much of the glacial deposits are composed of shale, slate, and graywacke in the valleys, and sandstone and conglomerate on many of the ridgetops. Limestone and dolostone are a major components of the tills in carbonate valleys such as Kittatinny Valley (Wolfe, 1977). In the Highlands, Precambrian gneiss is the major source component of the tills. In the Piedmont, the tills are derived primarily from shale, sandstone, conglomerate, basalt, and diabase of the Triassic Newark Group (Minard and Rhodehamel, 1969).

Glacial landforms associated with till include drumlins and moraines. Moraines are broad ridges of till that form at the margin of a glacier. A terminal moraine averaging 1.5 km in width and from 8 to 90 m high extends from Perth Amboy north to Denville and west to Belvidere. To the north, recessional moraines mark former marginal positions of the retreating ice. A discontinuous recessional moraine crosses Sussex County from Ogdensburg to Culvers Lake, about 32 km north of the terminal moraine, and continues up Kittatinny Mountain, where it joins another moraine. Other small recessional moraines are found in Sussex County (Witte, 1991) and discontinuous moraines are also found in northern Morris and Passaic Counties (Stanford and others, 1990). Drumlins are streamlined, elongate hills of till that have their long axes oriented parallel to the direction of glacial movement. Drumlins are found principally in northern Bergen County (Salisbury, 1902), near Culvers Lake in Kittatinny Valley, and on Kittatinny Mountain north of Culvers gap (Stanford and others, 1990).

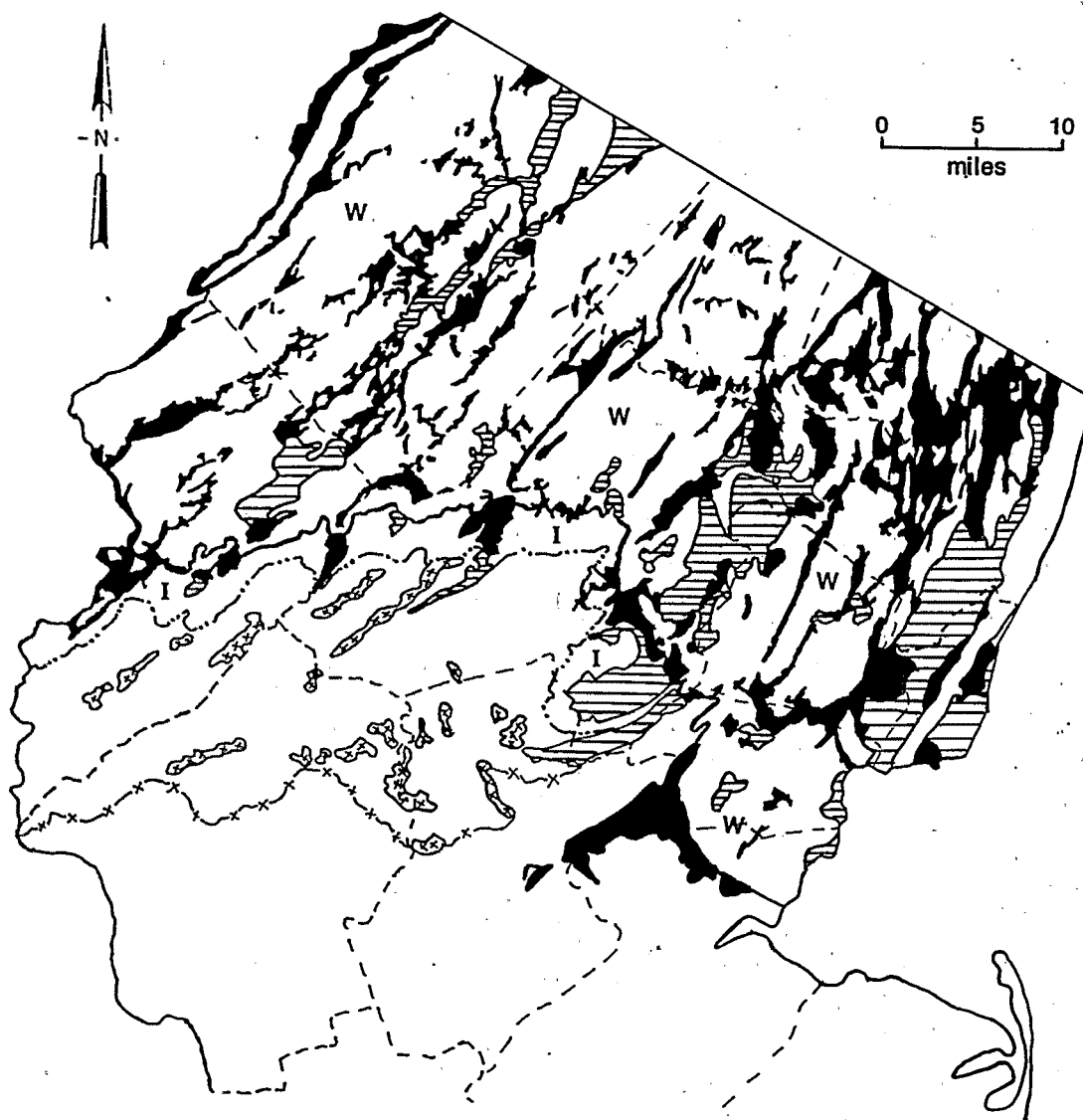










Figure 5. Map of northern New Jersey showing Pleistocene glacial deposits (modified from B.D. Stone, written communication, 1992, and information in Stone and others, 1989).

## GENERALIZED MAP OF GLACIAL DEPOSITS IN NEW JERSEY

### EXPLANATION

-  Glaciofluvial deposits—coarse-grained, sorted and stratified sand and gravel in outwash, glaciolacustrine deltas and fans, and eskers
-  Glacial lake bottom deposits—stratified and sorted fine-grained sand, silt, and clay
-  Wisconsinan till—non-stratified, poorly sorted mixture of sand, silt, clay, and some gravel
-  Illinoian till—non-stratified, poorly sorted mixture of sand, silt, clay, and some gravel
-  Pre-Illinoian till—deeply weathered, non-stratified, poorly sorted mixture of sand, silt, clay, and some gravel
-  Limit of Late Wisconsinan glacial deposits
-  Limit of Illinoian glacial deposits
-  Maximum extent of Pleistocene glacial deposits; excluding glacial and postglacial meltwater deposits that form coarse-grained terrace deposits in valleys south of the glaciated area

Glaciofluvial deposits are stratified coarse-grained sand and gravel deposited by glacial meltwater streams. Outwash plains, flat plains of coarse sand and gravel, occur near Plainfield and in several valleys south of the terminal moraine. Deposits of other glaciofluvial features such as eskers and kames, generally referred to as ice-contact stratified deposits, occur locally in northern New Jersey (Stone and others, 1989).

Glaciolacustrine (glacial lake) deposits consist of stratified, fine-grained sand, silt, and clay deposited on the bottoms of glacial lakes that were dammed by outwash, moraines, or stagnant ice. One of the largest glacial lakes was Lake Passaic, which occupied the upper Passaic valley between the New Jersey Highlands and the Second Watchung Mountain. At its maximum extent, glacial Lake Passaic was about 30 km long, 13-16 km wide, and 50-60 m deep, with a maximum depth of about 73 m (Salisbury and Kummel, 1895). Other glacial lakes include Lake Hackensack, which occupied an area east of the Watchung Mountains, north of Staten Island, and west of the Palisades, and now comprises the Hackensack Meadowlands; and many smaller lakes that occupied valleys obstructed by glacial drift, outwash, or stagnant ice, many of which still exist as modern lakes in the lower parts of glacial lake basins or in large kettles. Deposits of features related to glacial lakes, such as coarse-grained lacustrine deltas, fans, or wave-cut outwash terraces, are mapped with glaciofluvial features on figure 5. Glaciolacustrine delta and fan deposits are stratified silt, sand, and gravel that were deposited where a glacial meltwater river entered a glacial lake.

## SOILS

Soils of six orders—Ultisols, Inceptisols, Alfisols, Entisols, Spodosols, and Histosols—represent most of the soils in New Jersey (Tedrow, 1986). Ultisols are soils with a horizon containing an appreciable amount of translocated clay and they often have a moist or wet substratum. Inceptisols are described as soils with weakly developed horizons in which materials have been altered or removed and may contain horizons of accumulated silica, iron, or bases, but they generally do not have clayey subsurface horizons. Alfisols are mineral soils with argillic (clayey) subsurface horizons or fragipans, and may contain plinthic (iron-rich) or calcic horizons in the subsurface. Entisols are mineral soils with no discernible pedogenic horizons because their parent material is inert (such as quartz sand) or because the soils are very young. Spodosols are mineral soils containing spodic horizons, subsurface accumulations of organic matter and compounds of aluminum and iron. Spodosols may also have argillic horizons or fragipans beneath the spodic horizon. Histosols are organic soils such as peats or mucks which occur along coastlines or in river valleys (Soil Survey Staff, 1975). Figure 6 is a generalized map showing soil regions of New Jersey. The reader is urged to consult U.S. Soil Conservation Service county soil surveys or county engineering soil reports published by Rutgers University for more detailed maps and descriptions of soils for specific areas within the State.

The following discussion is condensed mostly from Tedrow (1961, 1986). Soils of the Valley and Ridge, northern New Jersey Highlands, and northern Piedmont provinces are derived primarily from glacial deposits, but some of the descriptions given in Tedrow (1961, 1986) are based on the characteristics of bedrock and thus do not necessarily reflect the character of the surficial deposits in much of northern New Jersey. General descriptions of the characteristics of glacially-derived surficial deposits are given in the previous section; for more detailed soil information, the reader should consult the previously-mentioned information sources.

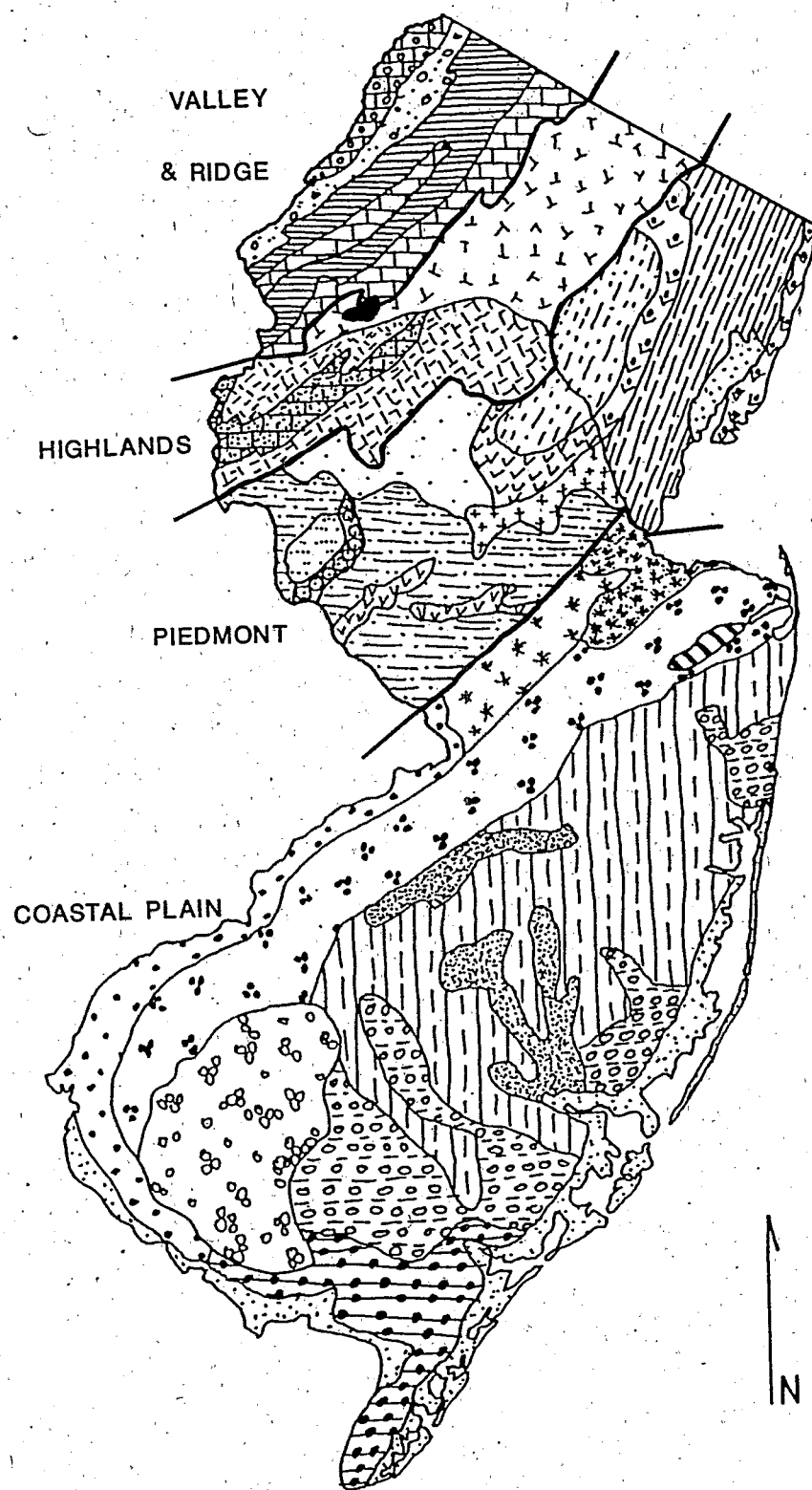


Figure 6. Generalized soil map of New Jersey (modified from Tedrow, 1986).

# GENERALIZED SOIL MAP OF NEW JERSEY EXPLANATION

## SOILS OF THE VALLEY AND RIDGE—soils formed on glacial till and sedimentary rocks



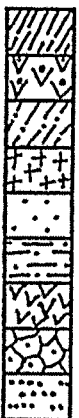
1. silt loams with moderate permeability
2. stony sandy loams and loams with firm, compact substrata; moderate permeability
3. clayey and silty loams with moderate to high permeability
4. clays and clay loams, locally gravelly; low to moderate permeability

## SOILS OF THE NEW JERSEY HIGHLANDS—soils developed on glacial till and crystalline rocks



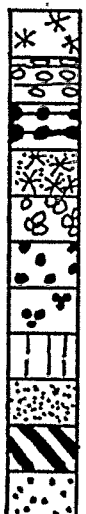
5. stony, loamy soils, some with firm substrata; low to moderate permeability
6. organic-rich muck; moderate to high permeability, wet
7. gravelly silt loams with moderate to high permeability, locally low permeability
8. silt loams with moderate permeability

## SOILS OF THE PIEDMONT—soils formed on till, glacial lake sediments, and outwash



9. silty, sandy, and gravelly loams with moderate to high permeability
10. stony silt loams with low to moderate permeability
11. clayey and silty loams with low to moderate permeability
12. sandy and gravelly soils with moderate to high permeability
13. loams with low to moderate permeability
14. silt loams with hard, compact substrata; moderate permeability
15. stony silt loams with moderate permeability
16. loams and silt loams with moderate permeability
17. wet, compact, silt loams with low to moderate permeability

## SOILS OF THE COASTAL PLAIN—soils developed on sedimentary rocks and loose sediments



18. sands and clayey sands with moderate to locally low permeability
19. sand with moderate to high permeability
20. sand with moderate to high permeability
21. sandy, silty, and clayey loams with moderate to high permeability, clayey soils have low perm.
22. sands and silts with clayey substrata; moderate permeability
23. fine sandy and silty soils with somewhat compact substrata; low to moderate permeability
24. medium sands with small quantities of silt and clay; moderate to high permeability
25. sand with moderate to high permeability
26. wet, sandy soils with a thick organic surface layer; moderate permeability
27. sandy loams with moderate to high permeability
28. wet, organic soils of tidal marshes with low to moderate permeability

Soils of the Valley and Ridge Province include silty, sandy, and gravelly soils. Most of the soils in the Valley and Ridge are developed on glacial till, outwash, and alluvium. Bedrock outcrops occur on ridgetops and in some valleys in the Valley and Ridge. Unit 1 (fig. 6) consists of deep, well-drained, loose, friable, silt loam soils formed on glacial drift derived from sandstone and limestone. Unit 2 consists of deep, well-drained, stony sandy loams and loams derived primarily from sandy glacial till. The soils have a loose surface layer and a firm, compact substratum. Unit 3 consists of shallow to deep, well-drained, clayey and silty loams developed on glacial till derived mainly from shale, limestone, and slate. Unit 4 consists of deep, well-drained, clayey and loamy soils developed on limestone- and dolostone-derived glacial till.

Soils of the New Jersey Highlands consist mostly of loose, friable, sandy and loamy soils developed on glacial till derived from crystalline rocks. Soil unit 5 (fig. 6) consists of deep, well-drained, loose, friable, stony, loamy soils developed on glacial till derived from crystalline rocks. Some soils in this map unit have a firm, but not clay-rich, substratum. Bedrock outcrops occur on ridgetops and in some valleys in this soil area. Unit 6 is organic-rich muck that accumulates in poorly drained, low-lying areas. Muck occurs in many areas of New Jersey that are too small to be shown on figure 6. Soils of unit 7 are deep, well-drained, gravelly silt loams formed on extensively weathered pre-Wisconsinan glacial drift derived from crystalline rocks. Unit 8 consists of deep, well-drained, silt loam soils with well-developed clayey B horizons formed in weathered glacial deposits derived largely from limestone.

Soils of the Piedmont are clayey, silty, sandy, and gravelly soils formed on till, glacial lake sediments, and outwash. Unit 9 consists of deep, well-drained, sandy and gravelly loams developed on glacial till containing red shale as a major source component, and poorly drained silty and clayey soils developed on glaciolacustrine deposits. Peat soils occur locally. Unit 10 consists of relatively shallow, well-drained, acidic, stony, silt loams developed on glacial till and volcanic bedrock. This unit is mostly confined to traprock ridges such as the Watchung Mountains, Snake Mountain, and the Palisades. Soils of unit 11 are deep, poorly drained, clayey and silty loams developed on glacial lake sediments. Most of these soils are slowly permeable, wet, and subject to flooding. Unit 12 soils are deep, well-drained, sandy and gravelly soils developed on glacial outwash. These soils are generally highly permeable but they have locally high water tables. Soils of unit 13 are deep, well-drained, loamy soils formed on weathered pre-Wisconsinan glacial drift derived largely from red shale and some crystalline rocks. The soils may be firm, especially when dry. Unit 14 consists of shallow, well-drained, silty loams formed on red shale. The subsoil may be hard and compact, especially when dry. Shale fragments are common. Some soils in this map area are silty loams derived from windblown silts. Soil unit 15 consists of deep, well-drained, moderately acid, stony silt loams on traprock ridges. These soils have strongly developed iron-rich horizons in the subsurface. Unit 16 consists of deep, moderately acid, well-drained loams and silt loams formed on deeply weathered gray sandstone. Soils of unit 17 are wet, compact, silt loams formed on argillite. These soils have low permeability and poor drainage.

The Coastal Plain is covered by sandy, silty, and clayey soils developed on sedimentary rocks and unconsolidated sediments. Soil unit 18 consists of deep, poorly- to well-drained, loose, sandy soils. Small areas within this map unit are composed of poorly drained and well-drained clayey sands. Unit 19 consists of well-drained, highly permeable, very sandy soils that commonly have a thin bleached layer at the surface. Soils of unit 20 are deep, well-drained, acidic sands with a water table that is typically within 0.75 m of the surface. Most of the area is flat-lying and less than 6 m above tidewater (Tedrow, 1961). Unit 21 soils occur in a complex pattern in Middlesex and Monmouth Counties. Soils of this unit are sandy and well-drained in higher areas, whereas

those in lower areas are poorly drained and high in silt and clay. Soils of unit 22 are well-drained, acid, loose sands and silts with a hard, reddish, sandy clay texture below 0.75 m that imparts a low permeability to the soil. In low-lying areas these soils tend to be wet. Unit 23 consists of well-drained, fine sandy and silty soils confined to low terraces along the Delaware River. They are loose and friable at the surface, but somewhat compact at depth. Soils of this unit that are less than about 2 meters above river level tend to be wet. Unit 24 soils are deep, well-drained, medium sands with small quantities of silt and clay formed on Coastal Plain deposits containing glauconite. Unit 25 consists of deep, acid, sandy soils with little silt and clay formed on dry sands. Soils of unit 26 are poorly drained, wet, sandy soils formed in sandy depressions and along water courses in the pine region and cedar swamps of New Jersey. The soils commonly have a thick organic layer at the surface, with brown sand occurring at a depth of 0.75-1.5 m. Unit 27 consists of soils formed on red sands of the Coastal Plain. They are deep, well-drained, sandy loams with little profile development. Soil unit 28 consists of wet, organic soils of tidal marshes in the coastal areas of the State. The thickness of these saline marsh peats and mucks commonly exceeds 8 m. Coastal beach sands, which occur directly adjacent to the shoreline, are included in this unit.

## RADIOACTIVITY

An aeroradiometric map of New Jersey compiled from National Uranium Resource Evaluation program (NURE) flightline data (Duval and others, 1989) is given in figure 7. Low radioactivity (<1.5 ppm eU) is associated with the Tertiary and Quaternary sediments of the Outer Coastal Plain and some of the Silurian and Devonian sedimentary rocks of the Valley and Ridge. Moderate radioactivity (1.5-2.5 ppm) covers much of the Inner Coastal Plain and the Jurassic sedimentary rocks of the Piedmont. High radioactivity (> 2.5 ppm) is associated with Cambrian and Ordovician sedimentary rocks of the Valley and Ridge, gneisses of the New Jersey Highlands, and Triassic sedimentary rocks of the southern Piedmont. Muessig (1989) and Muessig and Bell (1988) give an excellent review of the NURE radiometric anomalies, the geology associated with them, and the correlation with indoor radon. The individual anomaly map they have derived from the NURE data is shown in figure 8. The authors have concluded that geology and NURE radiometric data correlate well with indoor radon. South of the glacial limit, bedrock geology has a strong influence over the pattern of the NURE aerial radiometric data. North of the glacial limit, the glacial deposits, their morphology, and their source rock appear to be the principal geologic controls on NURE anomalies. Bedrock geology is locally important in areas with thin or no glacial cover. Muessig and Bell (1988) compared geologic provinces, NURE data, and indoor radon from the NJDEPE study; their comparison is illustrated in figure 9. The provinces shown in figure 9 include important sub-provinces: the Piedmont has been subdivided into a northern and southern portion along the limit of glaciation and the Coastal Plain has been subdivided into an Inner and Outer Coastal Plain along the Vincentown-Kirkwood Formation contact. Provinces with the highest average indoor radon also had the highest average equivalent uranium. The Valley and Ridge and the New Jersey Highlands were the two highest provinces.

Cluster areas, those areas within the State in which clusters of homes with very high indoor radon levels occur, were also examined by Muessig and Bell (1988). Nine areas with anomalously high indoor radon were ground-truthed by geologic mapping, soil sampling, and ground radiometric traverses. All the localities were within or immediately adjacent to airborne radiometric anomalies exceeding 6 ppm equivalent uranium. Muessig and Bell (1988) concluded that high radioactivity, uranium, radium, and thorium concentrated in some of the faults and breccia zones



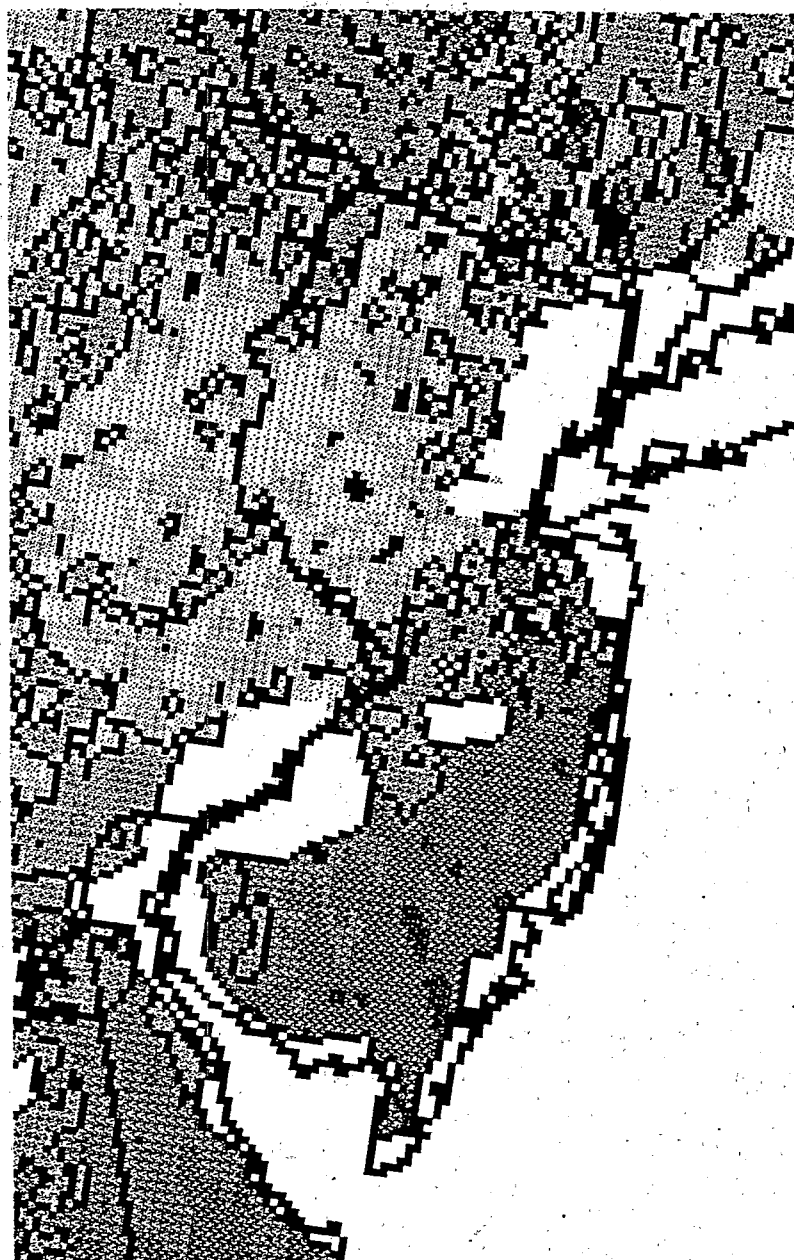


Figure 7. Aerial radiometric map of New Jersey (after Duval and others, 1989). Contour lines at 1.5 and 2.5 ppm equivalent uranium (eU). Pixels shaded at 0.5 ppm eU increments; darker pixels have lower eU values; white indicates no data.

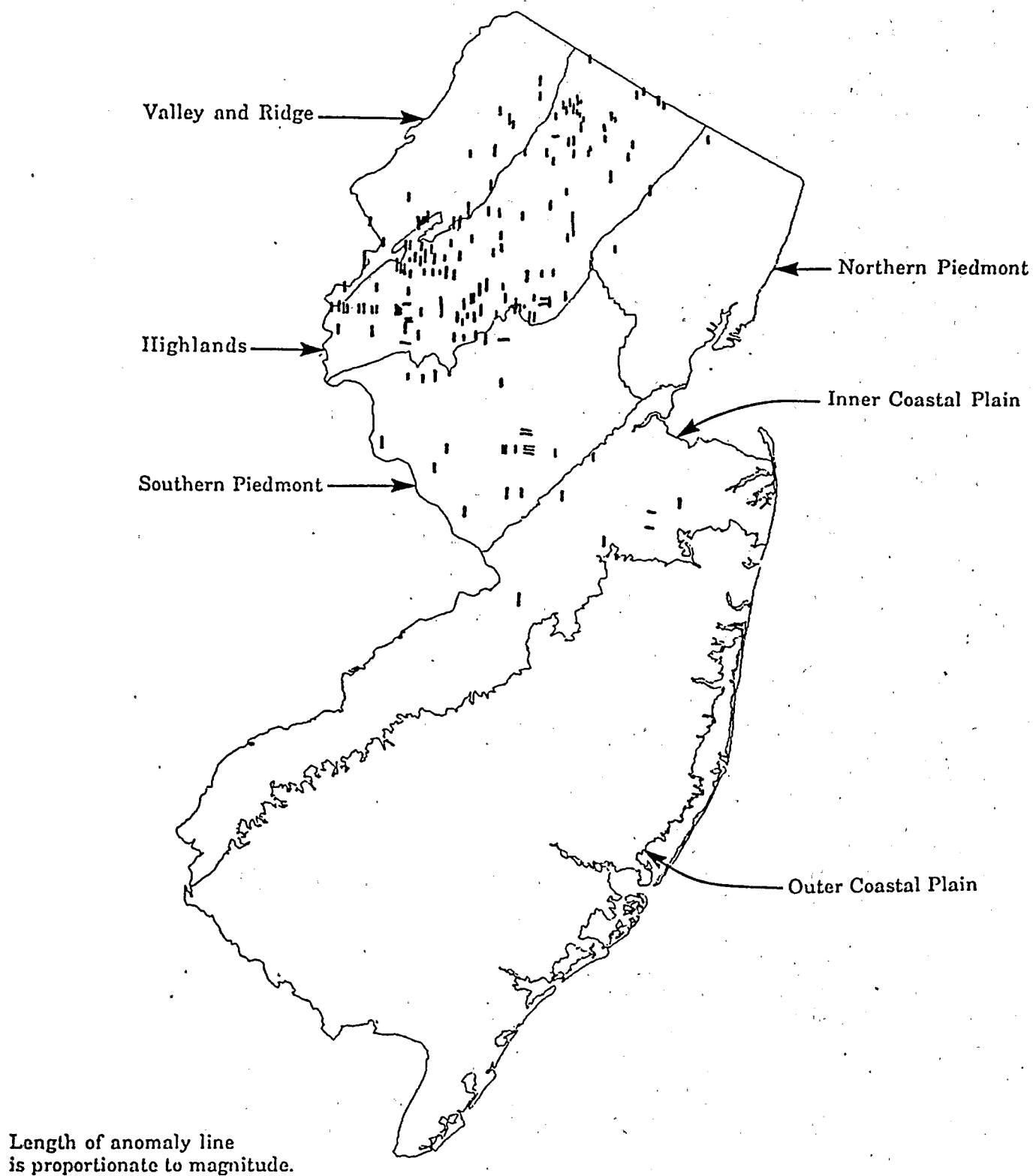


Figure 8. Map showing locations of NURE anomalies greater than 2.4 ppm-equivalent uranium (from Muessig and Bell, 1988)

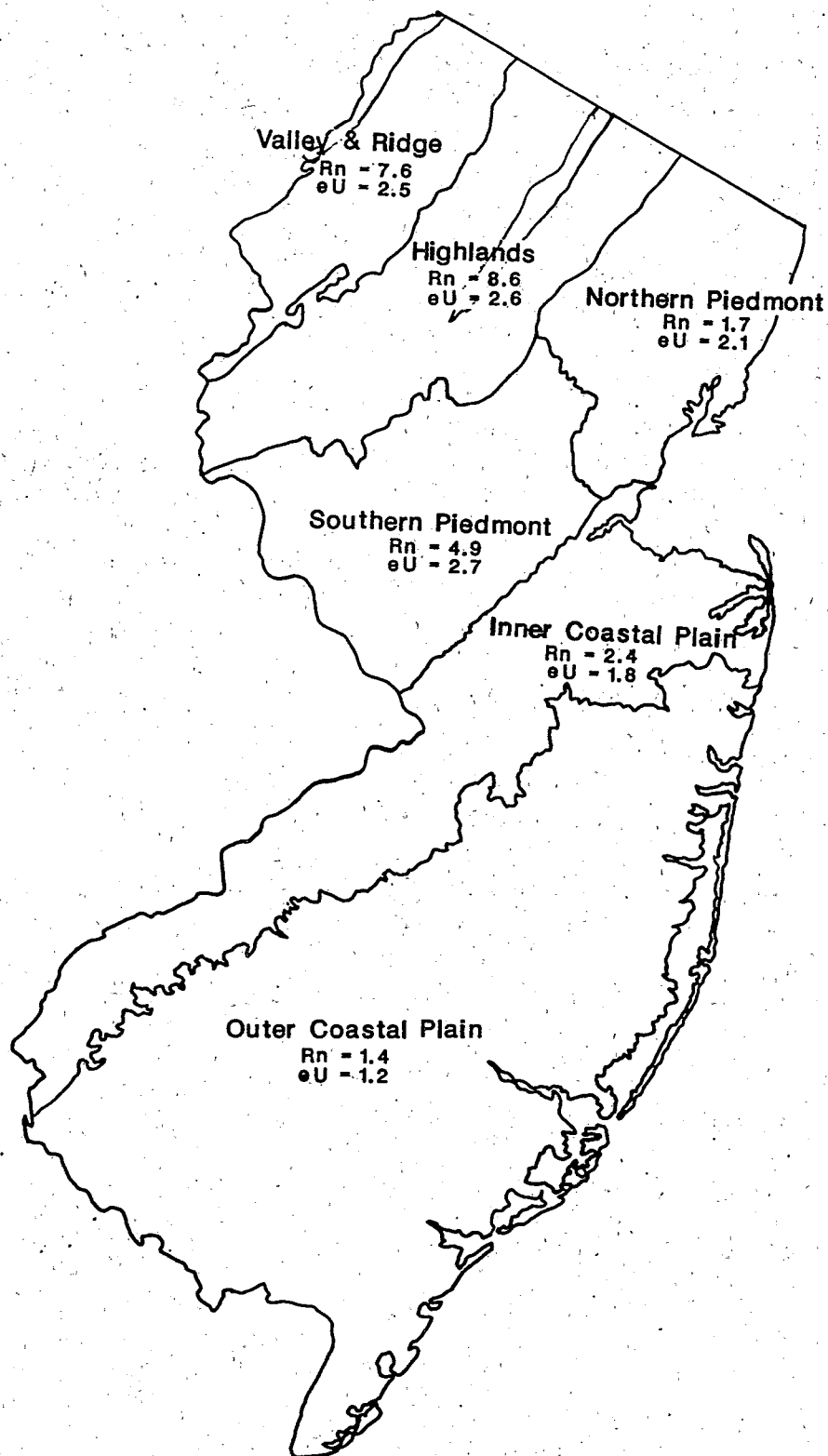


Figure 9. Map of New Jersey showing average NURE equivalent uranium (in ppm) and average indoor radon level (in pCi/L), by province (After Camp Dresser McKee, 1989, and Muesseg and Bell, 1988).

within limestone are the source of high indoor radon in the Clinton cluster. In the Montgomery, Ewing, and Princeton clusters, situated over Triassic sediments of the Piedmont province, uranium in the black shales of the Lockatong Formation and uranium along the contact between the Lockatong and Stockton Formations are the cause of high indoor radon. Precambrian granitic gneisses are the source of high indoor radon in the Bethlehem, Hampton, Bernardsville, and Washington clusters. Muessig and Bell (1988) indicate that uranium-rich hornblende granite and alaskite are the principal sources of the radon in Bethlehem, Hampton, and Bernardsville. In Washington, the source of the indoor radon is a 9.5-km-long belt of monazite, a thorium phosphate mineral that also contains uranium. The Mansfield cluster has complicated geology, with a fault zone separating two distinctly different geologic areas. Homes in the northern portion of the cluster have faults and fractures in granite alaskite as the source of the radon, and homes in the southern part of the area have black, uniformly uraniferous shales of the Ordovician Martinsburg Formation as the source of the high indoor radon levels.

Uranium occurrences in the State are well documented. Bell (1983) has published a comprehensive review and map of all the known radioactive mineral occurrences in New Jersey. The sizes of the occurrences range from single outcrops to mineral belts several kilometers long. Other sources of information on the radioactivity of rocks in New Jersey include: Grauch and Zarinsky (1976), Turner-Peterson (1980), Olsen (1988), Gundersen (1986), Volkert (1987), Muessig (1989), and Muessig and others (1992). Most occurrences of uranium enrichment are located in the New Jersey Highlands. Uraninite and other U-bearing minerals form layers and disseminations in several kinds of host rocks in the Highlands, including magnetite deposits, pegmatites, intrusive granitic rocks, marble, veins, faults, shear zones, and biotite-garnet gneiss with layers of monazite and xenotime. Uranium mineralization in the gneisses and magnetite deposits may be conformable with the compositional layering. General rock types with overall elevated uranium include quartz-potassium feldspar gneiss, biotite-garnet gneiss, and most granite, especially hornblende-bearing granite (Volkert, 1987; Muessig, 1989; Muessig and others, 1992). Rock types which tend to be low in uranium include amphibolitic gneisses, most marbles, and tonalitic, syenitic, and trondjemitic gneisses. Pegmatites and migmatitic rocks of the Byram Intrusive Suite may also be elevated in uranium.

In several parts of the New Jersey Highlands and in the Valley and Ridge section, sedimentary rocks of Cambrian through Devonian age comprise the underlying bedrock. Cambrian and Ordovician rocks are a marine shelf sequence with basal Cambrian sandstones and conglomerates followed by a highly variable sequence of interbedded shales, dolomites, and limestones. Uranium-bearing minerals are found in the basal conglomerates of the Cambrian Hardyston Quartzite. Many of the black shales in the Paleozoic section, such as the Ordovician Martinsburg Formation, are elevated in uranium (Muessig, 1988). Carbonate rocks are usually low in radionuclide elements, but the soils developed from carbonate rocks are often elevated in uranium and radium. Carbonate soils are derived from the dissolution of the calcium carbonate ( $\text{CaCO}_3$ ) that makes up the majority of the rock. When the  $\text{CaCO}_3$  has been dissolved away, the soils are enriched in the remaining impurities, predominantly base metals, including radionuclides (Schultz and others, 1992). Rinds containing high concentrations of uranium and uranium minerals can be formed on the surfaces of rocks involved with  $\text{CaCO}_3$  dissolution and karstification. Karst and cave morphology is also thought to promote the flow and accumulation of radon. Some of the Cambrian-Ordovician dolomites of New Jersey have been faulted and hydrothermal deposition of uranium has occurred locally, as in the Clinton cluster of high indoor radon (McKeown and Klemic, 1953; Popper and Blauvelt, 1980; Muessig, 1989; Muessig and

Bell, 1988; Henry and others, 1991). Two belts of Silurian and Devonian sedimentary rocks are found in the northwesternmost part of the State in the Valley and Ridge, and in the north-central part of the State within the New Jersey Highlands. These rocks are composed of conglomerate, sandstone, shale, and minor limestone. The sandstones and conglomerates are generally low in uranium or have very local uranium occurrences in some of the conglomerates and channel sandstones. Some of the marine black shales, such as the Marcellus Formation, have elevated uranium (LKB Resources, 1978).

In the Triassic rocks of the Piedmont Province, lacustrine black shales of the Lockatong Formation are the principal uranium-bearing rocks (Muessig, 1989; Muessig and others, 1992). Uranium occurrences have also been noted in the upper Stockton Formation in fluvial sandstones associated with gray shale lenses (Turner-Peterson, 1980) and in black shales of the Lower Passaic Formation (Olsen, 1988). There may also be elevated uranium associated with black shales and gray sandstones of the upper Passaic, Feltville, Towaco, and Boonton Formations (Smoot, J.P., pers. comm., 1992). Thermally-altered Paleozoic limestone or conglomerates consisting of limestone clasts near diabase bodies, as in the area northeast of the Delaware River along the border fault of the basin, may also have elevated uranium concentrations (Robinson, 1988).

In 1988, the U.S. Geological Survey and the U.S. Environmental Protection Agency initiated a program to assess the radon potential of the Coastal Plain sediments in the United States (Gundersen and others, 1991). In New Jersey, radon in soil gas, surface gamma-ray activity, and permeability were measured, and core and auger samples of soils and sediment were examined. The highest soil-gas radon concentrations and equivalent uranium (eU) concentrations (measured by portable gamma-ray spectrometer) were found in the glauconitic sands of the Cretaceous Englishtown and Navesink Formations, the Mount Laurel Sand, and the Tertiary Hornerstown Sand. In these units, soil radon exceeded 3000 pCi/L and average eU was greater than 2.5 ppm. Units that had the lowest soil radon concentrations and eU include the Cretaceous Red Bank Sand and Magothy Formation, the Tertiary Kirkwood Formation and Cohansey Sand, and Pleistocene residuum. Soil-gas radon concentrations in these units were generally less than 1000 pCi/L and eU was generally less than 1 ppm. Low to moderate soil radon and eU ppm concentrations were measured in the Cretaceous Wenonah and Tertiary Bridgeton Formations, the Cretaceous Woodbury Clay, and the Tertiary Vincentown Formation.

## INDOOR RADON

In 1986, the New Jersey Department of the Environmental Protection and Energy (NJDEPE) initiated the Statewide Scientific Study of Radon. The study was conducted by the NJDEPE, Radiation Protection Element, Bureau of Environmental Radiation, with the assistance of Camp Dresser and McKee, Inc. (CDM). In this comprehensive statistical study, more than 6000 homes and other buildings were randomly sampled for indoor radon using charcoal canisters, and an extensive database of geologic, soil, political, demographic, meteorological, building features, and resident behavior was collected and compared with the indoor radon data. Follow-up detailed sampling was conducted in 200 homes and ground-water sampling was conducted at 300 homes. The State was divided into six geologic provinces (fig. 9) to help organize the sampling and analyses and compare the data on a geologic basis. The highest average indoor radon was found in the New Jersey Highlands and the Valley and Ridge Province. More than half of the indoor radon measurements in these provinces exceeded 4 pCi/L. The Southern Piedmont also had an average exceeding 4 pCi/L. In every province of the State, at least 5 percent of the readings

were 4 pCi/L or more, and at least one home in every province had more than 30 pCi/L. Within each province, variability in measurements was high. Figure 10, taken from the CDM report, illustrates the distribution of indoor radon within several different ranges of values.

Since the completion of the CDM work, the NJDEPE has compiled additional indoor radon data and now has a database of more than 150,000 measurements (Table 1). These data were supplied to the NJDEPE by commercial vendors and are predominantly lowest living area screening measurements made by charcoal canister, although some alpha-track and e-perm measurements are included. Figure 11 shows the NJDEPE indoor radon data by county, and figure 12 is a map of counties and their names for reference. Homes with indoor radon levels greater than 4 pCi/L are most prevalent in the Valley and Ridge, the New Jersey Highlands, and Southern Piedmont. Homes with indoor radon levels greater than 20 pCi/L are restricted to parts of the Valley and Ridge, the Southern Piedmont, the New Jersey Highlands, and certain rock units of the Inner Coastal Plain.

## GEOLOGIC RADON POTENTIAL

A radon potential map was produced by CDM (Camp Dresser and McKee, 1989) from the extensive data collected during the NJDEPE Statewide Scientific Study of Radon. The map is reproduced here as figure 13. Low radon potential has been assigned to the upper Tertiary and Quaternary sediments of the Outer Coastal Plain, the Silurian and Devonian rocks of the Valley and Ridge, and some of the Triassic and Jurassic sedimentary and igneous rocks of the northern and southern Piedmont. High radon potential has been assigned to most of the New Jersey Highlands, the eastern and central portions of the Valley and Ridge Province, and the Triassic sedimentary rocks of the Southern Piedmont and parts of the Northern Piedmont. Moderate radon potential has been assigned to the sediments of the Inner Coastal Plain, some of the Triassic and Jurassic rocks of the Piedmont, some of the Ordovician sedimentary rocks of the Valley and Ridge, and Cambrian-Devonian rocks in the New Jersey Highlands. The NJDEPE has also classified all municipalities of the State as having high, moderate, or low potential for elevated radon based on the data given in Table 1, and this map is reproduced in figure 14.

As part of an Interagency Agreement between the EPA and the USGS, the USGS has prepared geologic radon potential estimates of the land for each state in the United States. In a few states, such as New Jersey, comprehensive radon potential programs have been active since the recognition of indoor radon as a health problem. In the preceding sections, we have presented the results of the NJDEPE Statewide Scientific Study of Radon, which utilized a wide variety of important geologic and cultural data to examine the status of radon problems and health risk in the State, and target future study areas. The following section presents a geologic radon potential assessment of the land in New Jersey, concentrating on the geologic factors and using a semi-quantitative numeric index to rank areas by geologic province. The assessment uses similar data to, and has been greatly augmented by, the NJDEPE study. The results of the USGS assessment are similar to those obtained by CDM, with few differences. The USGS assessment examines only the geologic radon potential of the land and not health risk or exposure. The assessment done by the USGS is presented in Table 2 and discussed in the following section. The USGS has used the same basic subdivisions as Muessig and Bell (1988) and Camp Dresser and McKee, Inc. (1989), and also have separately delineated the Silurian and Devonian-age rocks of the Green Pond outlier and the western Valley and Ridge.

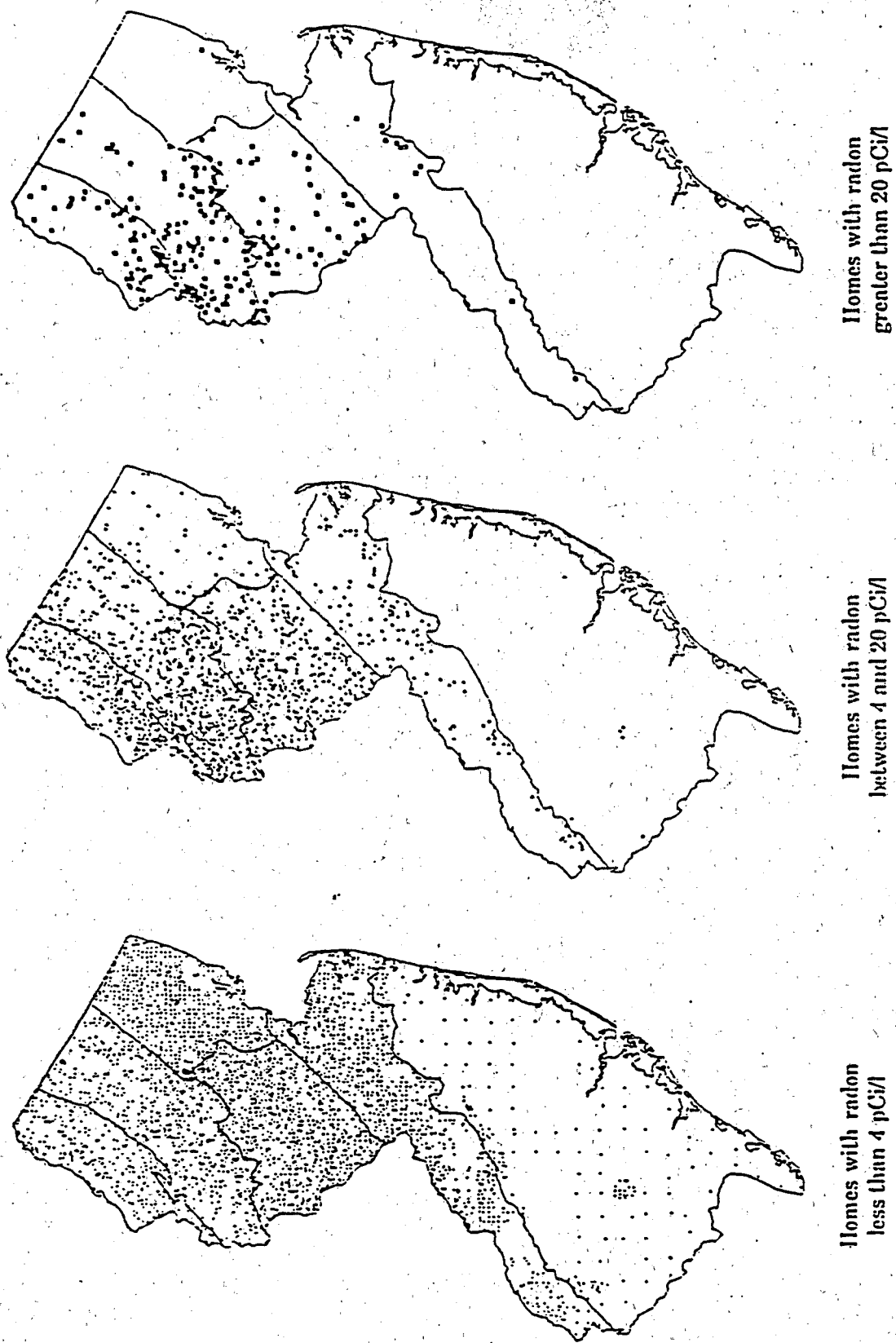


Figure 10. Maps showing statewide indoor radon survey results (from Camp Dresser McKee, 1989).

TABLE 1. Screening indoor radon data for New Jersey compiled by the New Jersey Department of Environmental Protection and Energy. Data are compiled from vendor reports collected by NJDEP from 1986 through 1992 and represent primarily 2-7 day charcoal canister measurements, although some alpha-track and e-perm detector data are also included.

COUNTY	NO. OF MEAS.	ARITHMETIC MEAN	%>4 pCi/L
Atlantic	225	1.3	4
Bergen	14887	1.8	8
Burlington	3631	2.2	12
Camden	4029	2.6	15
Cape May	55	1.1	4
Cumberland	287	3.5	16
Essex	10598	1.9	8
Gloucester	1229	3.0	19
Hudson	1390	1.5	5
Hunterdon	9465	9.4	47
Mercer	11535	6.1	30
Middlesex	12325	2.8	19
Monmouth	11176	4.0	26
Morris	27624	4.5	28
Ocean	997	1.5	4
Passaic	6031	2.6	17
Salem	215	2.6	18
Somerset	16382	5.1	35
Sussex	6536	6.5	41
Union	7855	2.2	11
Warren	4981	9.5	54
STATEWIDE	151,453	4.3	25



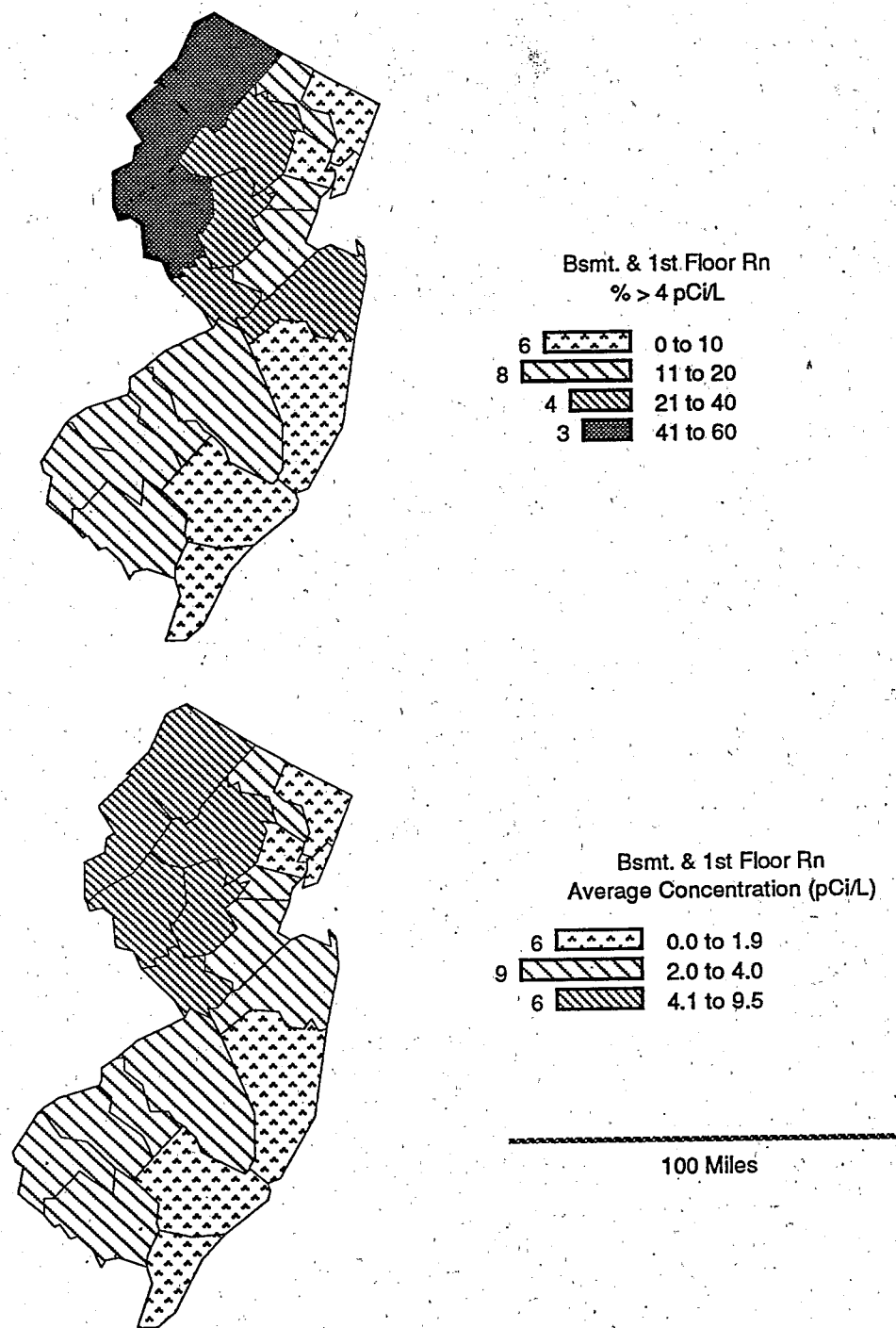


Figure 11. Screening indoor radon data compiled by the New Jersey Department of Environmental Protection and Energy from vendor reports collected by NJDEP from 1986 through 1992. Data represent primarily 2-7 day charcoal canister measurements, although some alpha-track and e-perm detector data are also included. Histograms in map legend show the number of counties in each category.

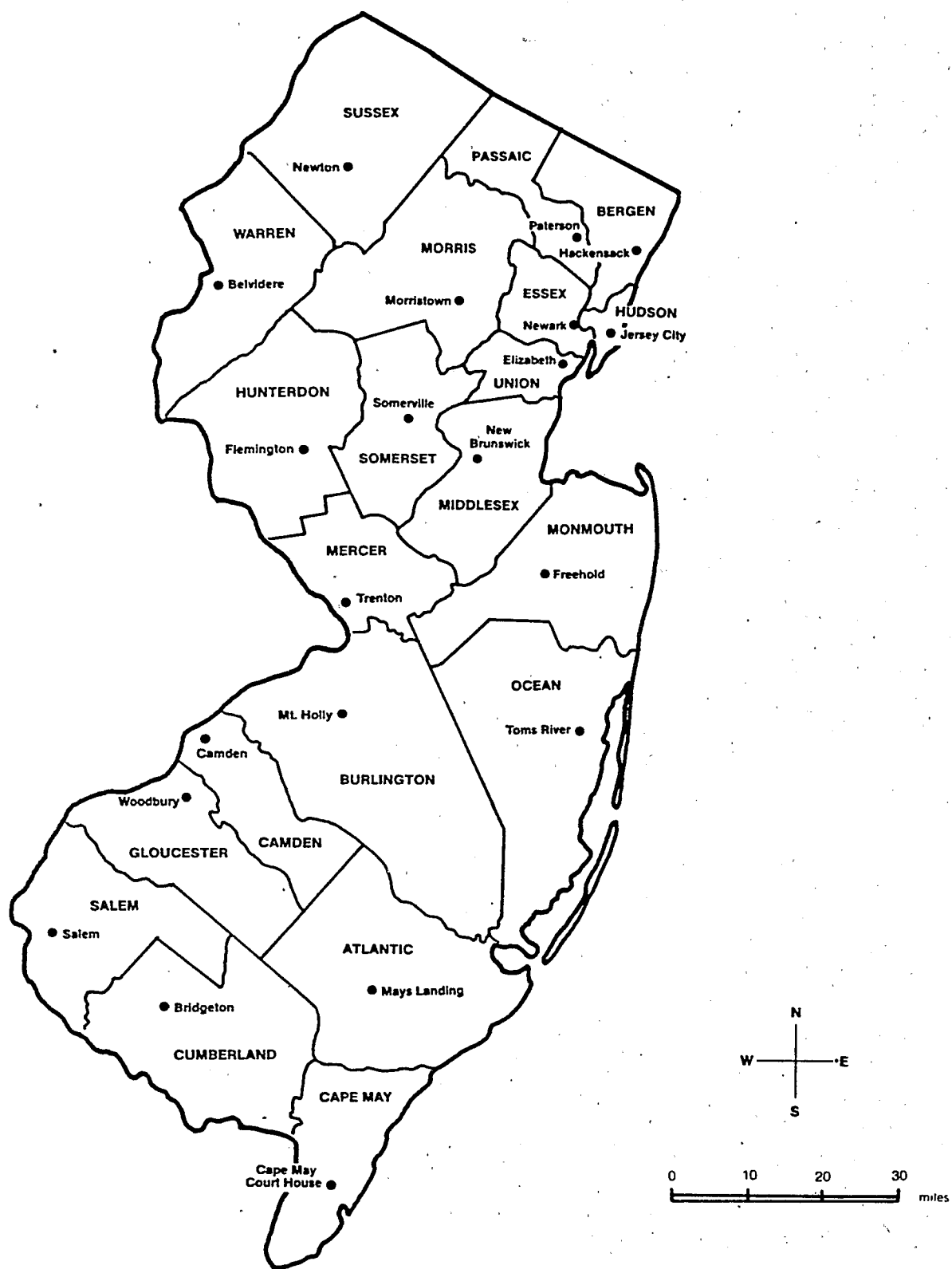


Figure 12. New Jersey counties (from Facts on File, 1984).

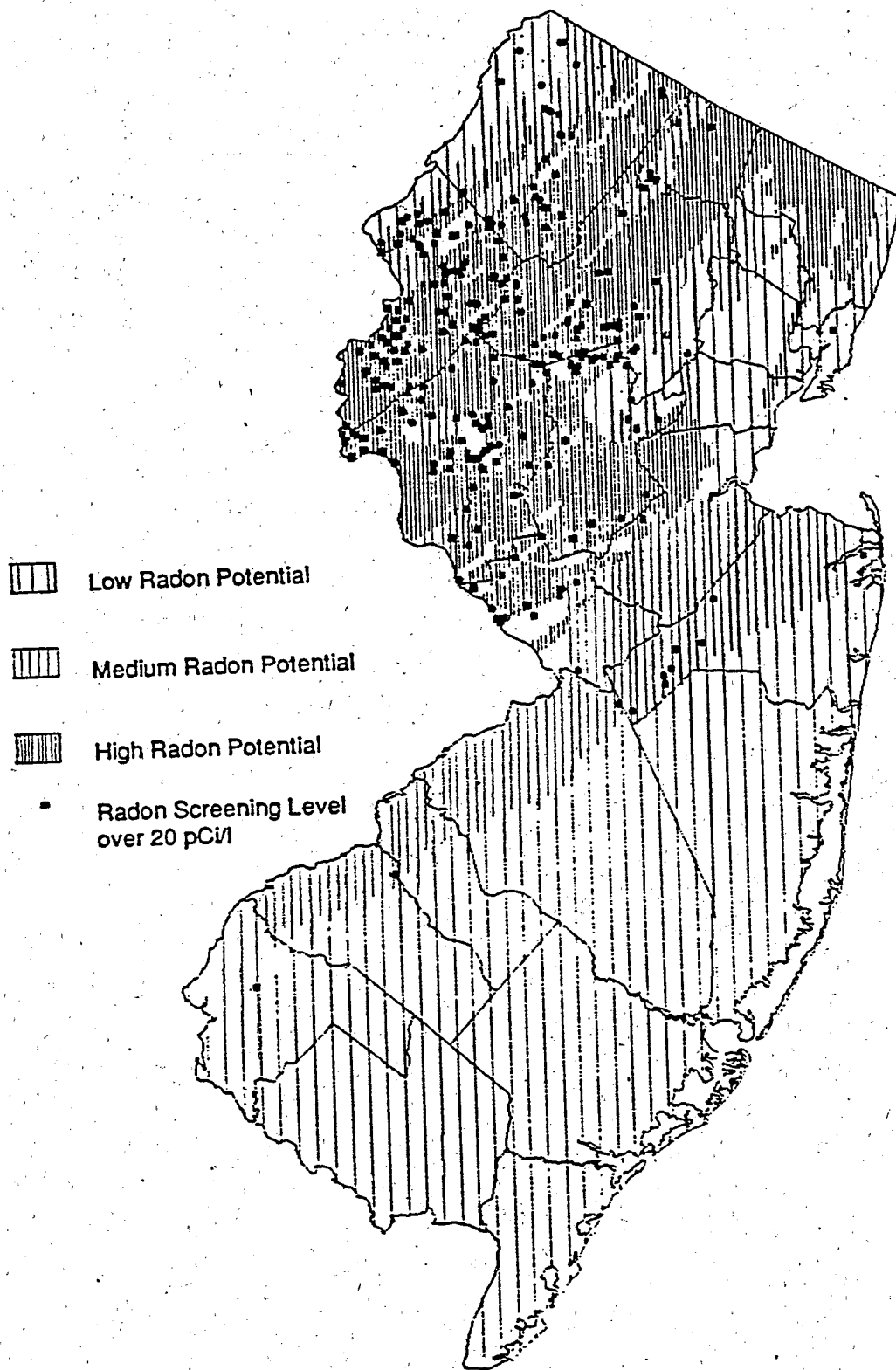


Figure 13. Map showing radon potential areas of New Jersey identified by the New Jersey DEP (from Camp Dresser McKee, 1989).

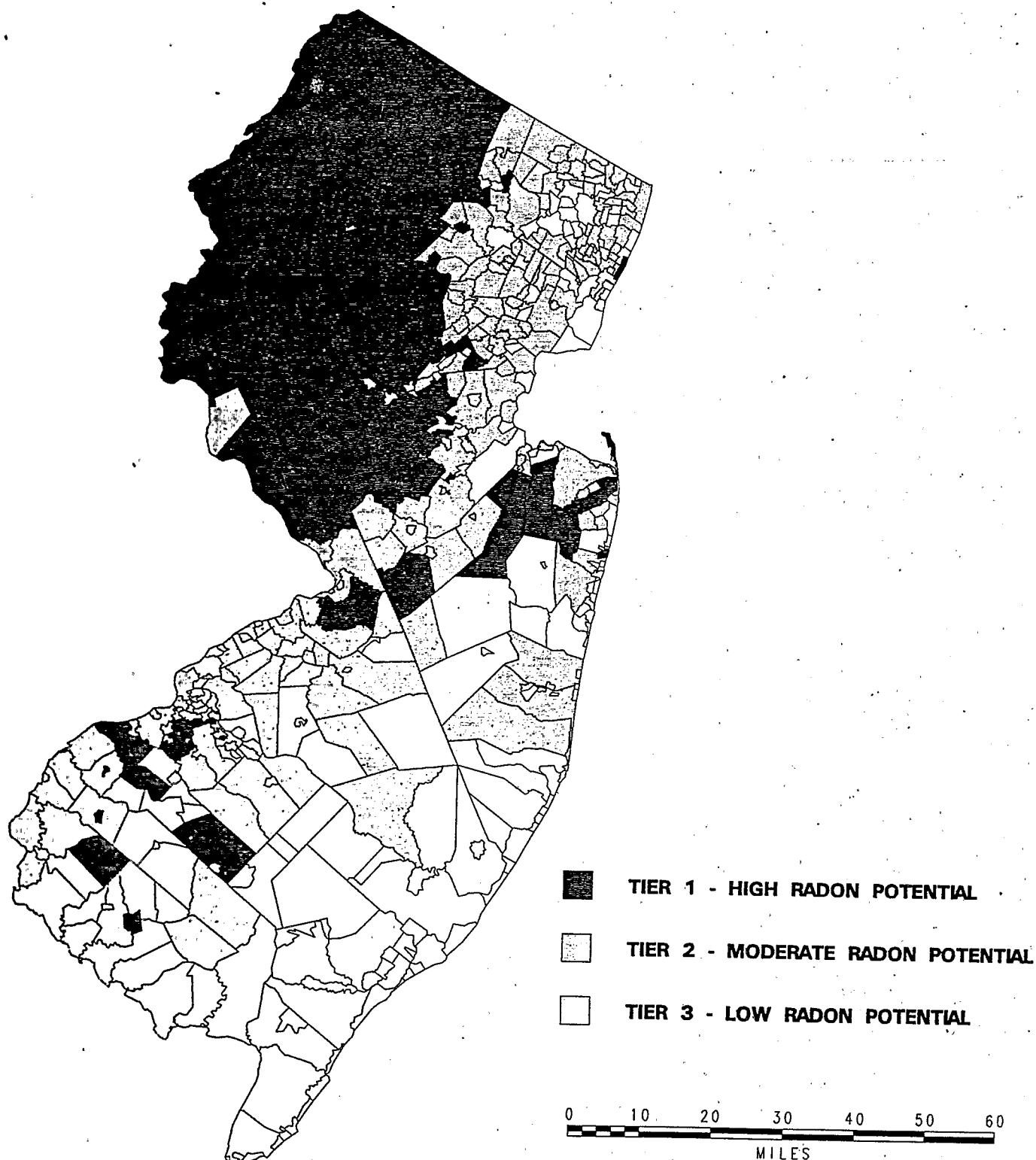


Figure 14. Radon potential tier map for New Jersey compiled by the New Jersey Department of Environmental Protection and Energy. Tiers rankings are based on indoor radon data from more than 150,000 homes compiled from vendor records and the State's radon testing program. Tier 1 municipalities are those in which 25% or more of the homes have indoor radon levels  $\geq 4$  pCi/L, Tier 2 municipalities are those in which 5-24% of the homes have indoor radon levels  $\geq 4$  pCi/L, and municipalities assigned to Tier 3 are those in which 4% or less of the homes have indoor radon levels  $\geq 4$  pCi/L. Map courtesy of Barbara Plunkett and Herbert Roy, NJDEPE.

For the purpose of this assessment, New Jersey has been divided into eight geologic radon potential areas and each area assigned a Radon Index (RI) and a Confidence Index (CI) score (Table 2) using the information outlined in this chapter. Please see the Introduction chapter to this regional book for a detailed explanation of the Indexes. The RI is a semi-quantitative measure of radon potential based on geology, soils, radioactivity, architecture, and indoor radon. The CI is a measure of the relative confidence of the RI assessment based on the quality and quantity of the data used to assess geologic radon potential.

As can be seen in Table 2, the New Jersey Highlands have been ranked high in geologic radon potential. The average screening measurement of indoor radon in this province is expected to be greater than 4 pCi/L. Screening measurements of indoor radon in the Highlands averaged 8.6 pCi/L in the NJDEPE study. The NURE data for the Highlands indicates many high equivalent uranium anomalies (>2.5 ppm). Uranium in rocks of the New Jersey Highlands is well documented in the literature. Uraninite and other U-bearing minerals form layers and disseminations in several kinds of host rocks in the Highlands, including intrusive granitic rocks, magnetite deposits, pegmatites, marble, veins, faults, shear zones, and feldspathic metasedimentary gneiss. Soil permeability is generally moderate to high with a few areas of low permeability. Glacial deposits in the Highlands are, for the most part, locally derived and, in some areas, they enhance radon potential because of high permeability. In other areas, glacial deposits may blanket bedrock and effectively lower the radon potential (Gates and others, 1990).

The Valley and Ridge Province has been divided into two sections for this assessment. The Silurian and Devonian rocks of the Valley and Ridge and the Green Pond outlier have been ranked moderate in radon potential. The Silurian and Devonian rocks generally have low to moderate equivalent uranium associated with them in the NURE data. They are predominantly conglomerate, sandstone, shale, and limestone. The shales and local uranium mineral accumulations in the sandstones are the most likely source of radon problems. Figure 10 indicates that only a few homes with indoor radon greater than 20 pCi/L were measured in the Silurian and Devonian rocks.

The Cambrian-Ordovician rocks of the Valley and Ridge have been ranked high in geologic radon potential. The Hardyston Quartzite is known to have local uranium and uranium mineral deposits, and the black shales and carbonate soils are also sources of indoor radon. Screening measurements of indoor radon in the Valley and Ridge averaged 7.6 pCi/L in the NJDEPE study. Equivalent uranium from the NURE data is generally moderate to high over the Cambrian and Ordovician sedimentary rocks. Permeability is generally moderate.

The northern and southern Piedmont provinces together form the Newark Basin. The basin is underlain by Triassic sandstone, siltstone, and shale, Jurassic basalt and diabase, and Jurassic siltstone, shale, and sandstone. Of all these rock types, the black shales have the greatest potential to be a source of radon problems. Black shales are not as abundant in the Northern Piedmont as in the Southern Piedmont. The average indoor radon from the NJDEPE study for the Northern Piedmont is 1.7 pCi/L. Indoor radon levels between 4 and 20 pCi/L in the Northern Piedmont (fig. 10) are probably associated with the black shales of the lower Passaic Formation and uranium mineralization along the northern border fault and in adjacent rocks. The NURE data are sparse for the northern Piedmont because the aerial radiometric survey was not flown in highly populated urban areas. Sandstones and conglomerates of the upper Passaic Formation with low radon potential dominate the northwestern portion of the Northern Piedmont. Jurassic basalts and interbedded sandstones and shales with low to moderate radon potential make up the western half of the Northern Piedmont. Low to moderate radon potential is expected for the eastern half of the

Northern Piedmont, which is underlain by sandstones interbedded with lacustrine shales of the Passaic Formation and diabase of the Palisades sill that intrudes along the Lockatong Formation-Stockton Formation contact. This thin layer of Lockatong Formation may be responsible for the single reading over 20 pCi/L found near here. Soil permeability is generally low to moderate in the Northern Piedmont. The Northern Piedmont Province has been ranked low in geologic radon potential overall.

The Southern Piedmont is underlain by the uraniferous black shales and siltstones of the Lower Passaic Formation, the uraniferous black shales of the Lockatong Formation, and the uraniferous black shales and locally uraniferous sandstones of the Stockton Formation. Average indoor radon for the Southern Piedmont is high at 4.9 pCi/L. Equivalent uranium from the NURE data is also moderate to high. Soil permeability is low to moderate. The Southern Piedmont has been ranked high in geologic radon potential.

The Inner Coastal Plain Province, consisting of Cretaceous and Lower Tertiary sediments, has been ranked moderate in radon potential. Screening measurements of indoor radon in the Inner Coastal Plain averaged 2.4 pCi/L in the NJDEPE study. Equivalent uranium from the NURE data is generally moderate. Soil permeability is moderate to high. Soil radon studies indicate that the glauconitic sediments are significant sources of radon. The highest soil radon concentrations and eU concentrations were found in the glauconitic sands of the Cretaceous Englishtown and Navesink Formations, the Mount Laurel Sand, and the Tertiary Hornerstown Sand.

The Outer Coastal Plain has been ranked low in geologic radon potential. Soil radon studies of the Tertiary Kirkwood Formation, Cohansey Sand, and Pleistocene residuum indicate that they are poor sources of radon. Equivalent uranium from the NURE data is generally low. Soil permeability is moderate to high and the average indoor radon for the province is low (1.4 pCi/L).

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 that assigned to the area as a whole. Any local decisions about radon should not be made without consulting all available local data. State law requires that residential and school structures built in municipalities that the State has classified with a high radon potential use construction techniques that minimize radon entry and facilitate post-construction removal of radon. For additional information, contact the New Jersey Radon Program at 800-648-0934 (New Jersey only) or 609-987-6396. More detailed information on state or local geology may be obtained from the New Jersey geological survey.

TABLE 2. RI and CI scores for geologic radon potential areas of New Jersey.

		New Jersey Highlands		Cambrian and Ordovician Valley and Ridge		Southern Piedmont	
FACTOR		RI	CI	RI	CI	RI	CI
INDOOR RADON		3	3	3	3	3	3
RADIOACTIVITY		3	3	3	3	3	3
GEOLOGY		2	2	3	2	3	3
SOIL PERM.		2	2	2	2	2	2
ARCHITECTURE		3	-	3	-	3	-
GFE POINTS		2	-	0	-	0	-
TOTAL		15	10	14	10	14	11
		High	High	High	High	High	High

		Silurian and Devonian Valley and Ridge/Green Pond Outlier		Northern Piedmont		Inner Coastal Plain Cretaceous-Lower Tertiary	
FACTOR		RI	CI	RI	CI	RI	CI
INDOOR RADON		2	3	1	3	2	3
RADIOACTIVITY		2	3	1	1	2	2
GEOLOGY		2	2	2	2	2	3
SOIL PERM.		2	3	2	2	2	3
ARCHITECTURE		3	-	2	-	2	-
GFE POINTS		0	-	0	-	0	-
TOTAL		11	11	8	8	10	11
		Mod	High	Low	Mod	Mod	High

		Outer Coastal Plain Upper Tertiary-Quaternary	
FACTOR		RI	CI
INDOOR RADON		1	3
RADIOACTIVITY		1	2
GEOLOGY		1	3
SOIL PERM.		3	3
ARCHITECTURE		2	-
GFE POINTS		0	-
TOTAL		8	11
		Low	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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## 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.)

### NEW JERSEY MAP OF RADON ZONES

The New Jersey Map of Radon Zones and its supporting documentation (Part IV of this report) have received extensive review by New Jersey geologists and radon program experts. The map for New Jersey 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.

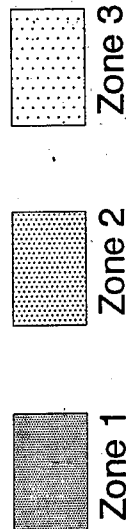
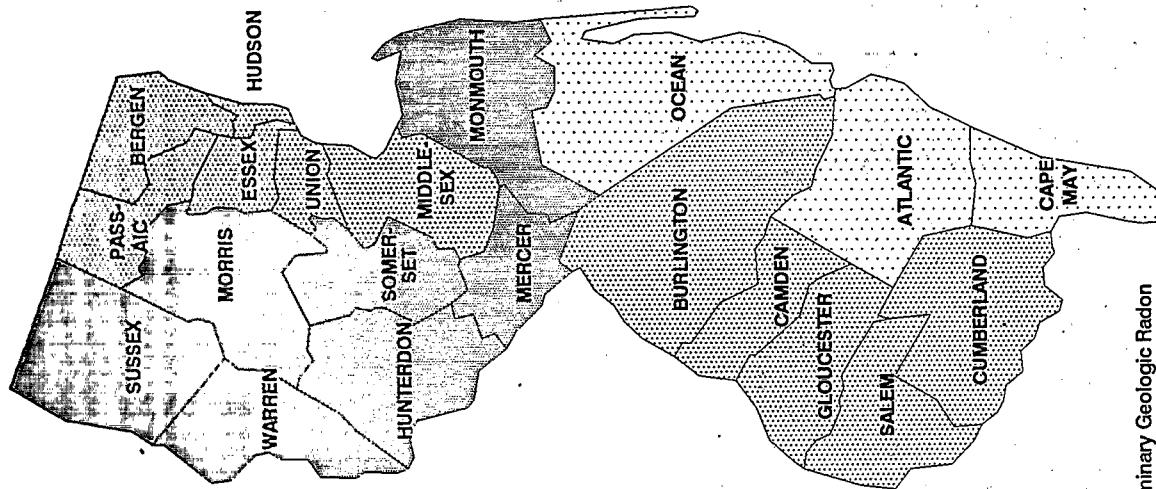
Several counties in New Jersey do not strictly follow the methodology for adapting the geologic provinces to county boundaries. EPA and the State of New Jersey's Department of Environmental Protection and Energy have decided to change several of the county zone designations based on the increased radon potential that is demonstrated by the elevated indoor radon measurements. Cumberland, Cloucester, Salem, Camden, Burlington, Union, Essex, Hudson, Passaic and Bergen have been designated as Zone 2 based on this supplemental data.

Although the information provided in Part IV of this report -- the State chapter entitled "Preliminary Geologic Radon Potential Assessment of New Jersey" -- 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 2 EPA office or the New Jersey radon program for information on testing and fixing homes. Telephone numbers and addresses can be found in Part II of this report.

# NEW JERSEY - 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.*



**IMPORTANT:** Consult the publication entitled "Preliminary Geologic Radon Potential Assessment of New Jersey" 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.