U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

GEOLOGIC RADON POTENTIAL OF EPA REGION 2

New Jersey New York

OPEN-FILE REPORT 93-292-B

Prepared in Cooperation with the
U.S. Environmental Protection Agency

1993

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R. Randall Schumann
EDITOR

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards or with the North American Stratigraphic Code.

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THE USGS/EPA RADON POTENTIAL ASSESSMENTS: AN INTRODUCTION

by
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and
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BACKGROUND

The Indoor Radon Abatement Act of 1988 (Public Law 100-551) 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.*

USGS geologists are the authors of the booklets. The booklets are organized by EPA Federal boundaries (Regions). Each Regional booklet consists of several components, the first being this introduction to the project, including a general discussion of radon (occurrence, transport, etc.), and details concerning the types of data used. The second component is a summary chapter outlining the general geology and geologic radon potential of the EPA Region. The third component is an individual chapter for each state in the Region. 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.

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}Rn) is produced from the radioactive decay of radium (^{226}Ra), which is, in turn, a product of the decay of uranium (^{238}U) (fig. 1). The half-life of ^{222}Rn is 3.825 days. Other isotopes of radon occur naturally, but, with the exception of thoron (^{220}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 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

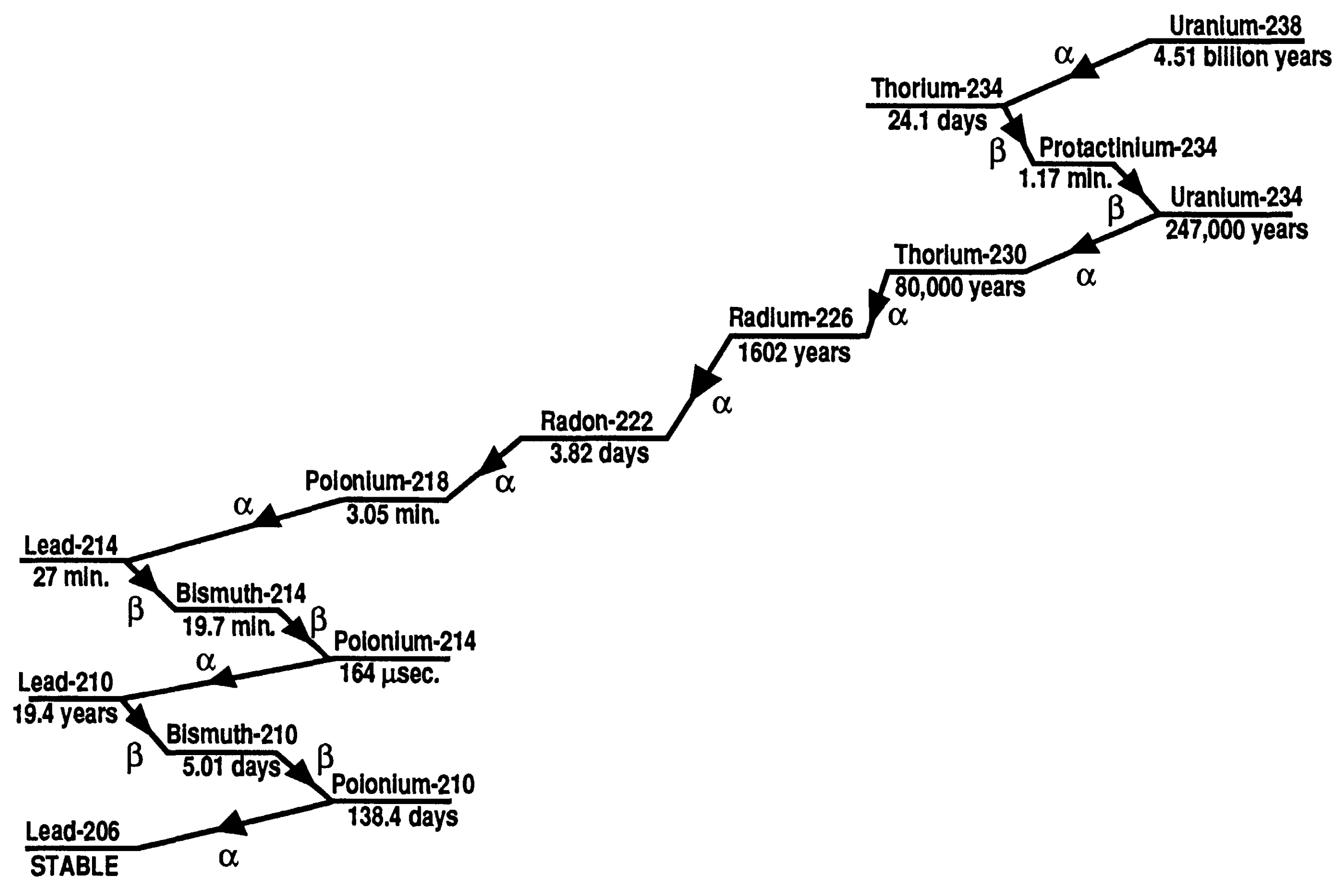

Figure 1. The uranium-238 decay series, showing the half-lives of elements and their modes of decay (after Wanty and Schoen, 1991). α denotes alpha decay, β denotes beta decay.

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 nm = 10^{-9} meters), or about 2×10^{-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}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).

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.

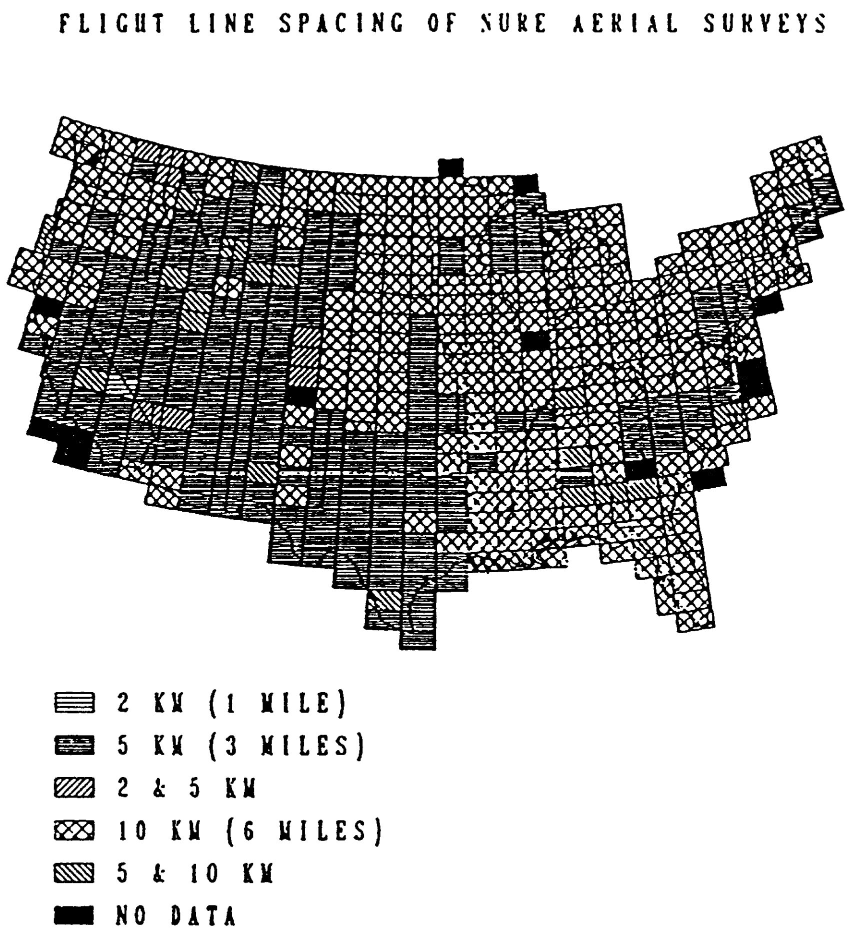

Figure 2. Nominal flightline spacings for NURE aerial gamma-ray surveys covering the contiguous United States (from Duval and others, 1990). Rectangles represent 1°x2° quadrangles.

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.

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

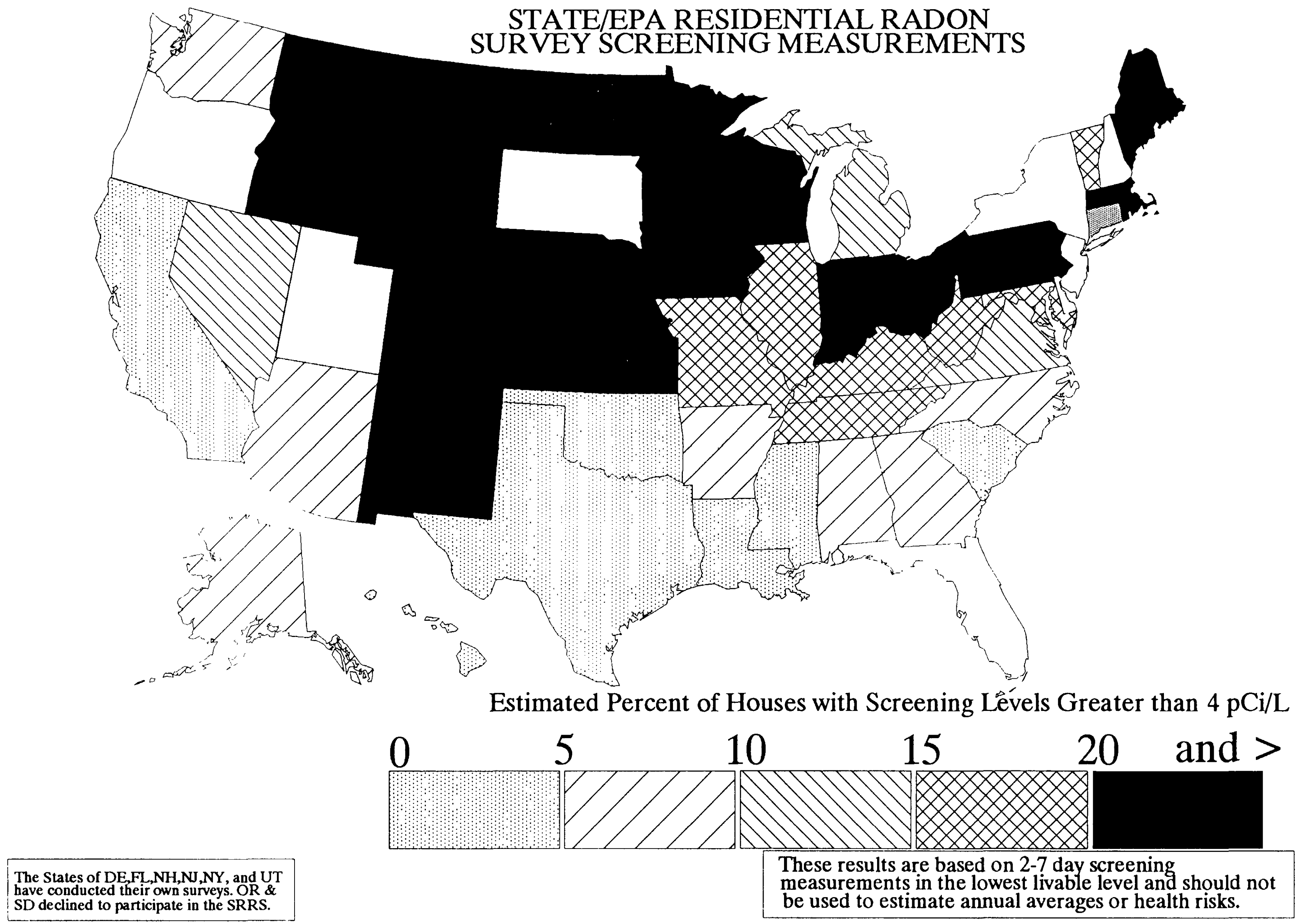

Figure 3. Percent of homes tested in the State/EPA Residential Radon Survey with screening indoor radon levels exceeding 4 pCi/L.

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 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

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.

INCREASING RADON POTENTIAL →

FACTOR	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

INCREASING CONFIDENCE →

FACTOR	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

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.

EPA COUNTY RADON POTENTIAL MAPS

EPA has produced maps of radon potential, referred to as "radon zone maps", using counties as the primary geographic units. The maps were produced by adapting the results of the geologic radon potential evaluations of the approximately 360 geologic provinces defined for the United States, to fit county boundaries. Because the geologic province boundaries cross State and county boundaries, a strict translation of counties from the geologic province map was not possible. When a county fell within varying radon potential areas, the radon potential designation that covers the most area was chosen as the county designation. The geologic province assessments were adapted to a county map format because many planning, outreach, and information programs are based on political boundaries such as counties. The county-based EPA Radon Zone Maps are not included in the USGS geologic radon potential booklets. They are available from EPA headquarters and regional offices or through the state radon program offices.

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APPENDIX A
GEOLOGIC TIME SCALE

Eon or Eonothem	Era or Erathem	Period, System, Subperiod, Subsystem		Epoch or Series		Age estimates of boundaries in mega-annum (Ma)[1]
Phanerozoic[2]	Cenozoic[2] (Cz)	Quaternary[2] (Q)		Holocene		0.010
				Pleistocene		1.6 (1.6–1.9)
		Tertiary (T)	Neogene[2] Subperiod or Subsystem (N)	Pliocene		5 (4.9–5.3)
				Miocene		24 (23–26)
			Paleogene[2] Subperiod or Subsystem (Pɛ)	Oligocene		38 (34–38)
				Eocene		55 (54–56)
				Paleocene		66 (63–66)
	Mesozoic[2] (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 (Ŧr)		Late	Upper	
				Middle	Middle	
				Early	Lower	~240
	Paleozoic[2] (Pz)	Permian (P)		Late	Upper	
				Early	Lower	290 (290–305)
		Carboniferous Systems (C)	Pennsylvanian (Ꝑ)	Late	Upper	
				Middle	Middle	
				Early	Lower	~330
			Mississippian (M)	Late	Upper	
				Early	Lower	360 (360–365)
		Devonian (D)		Late	Upper	
				Middle	Middle	
				Early	Lower	410 (405–415)
		Silurian (S)		Late	Upper	
				Middle	Middle	
				Early	Lower	435 (435–440)
		Ordovician (O)		Late	Upper	
				Middle	Middle	
				Early	Lower	500 (495–510)
		Cambrian (Ꞓ)		Late	Upper	
				Middle	Middle	
				Early	Lower	~570[3]
Proterozoic (Ᵽ)	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)[4]					

[1] 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.

[2] 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.

[3] Rocks older than 570 Ma also called Precambrian (p€), a time term without specific rank.

[4] 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^3 (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^3.

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 (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 ($CaMg(CO_3)_2$), 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 ($CaCO_3$).

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 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.

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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
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Washington	10
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Wisconsin	5
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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.

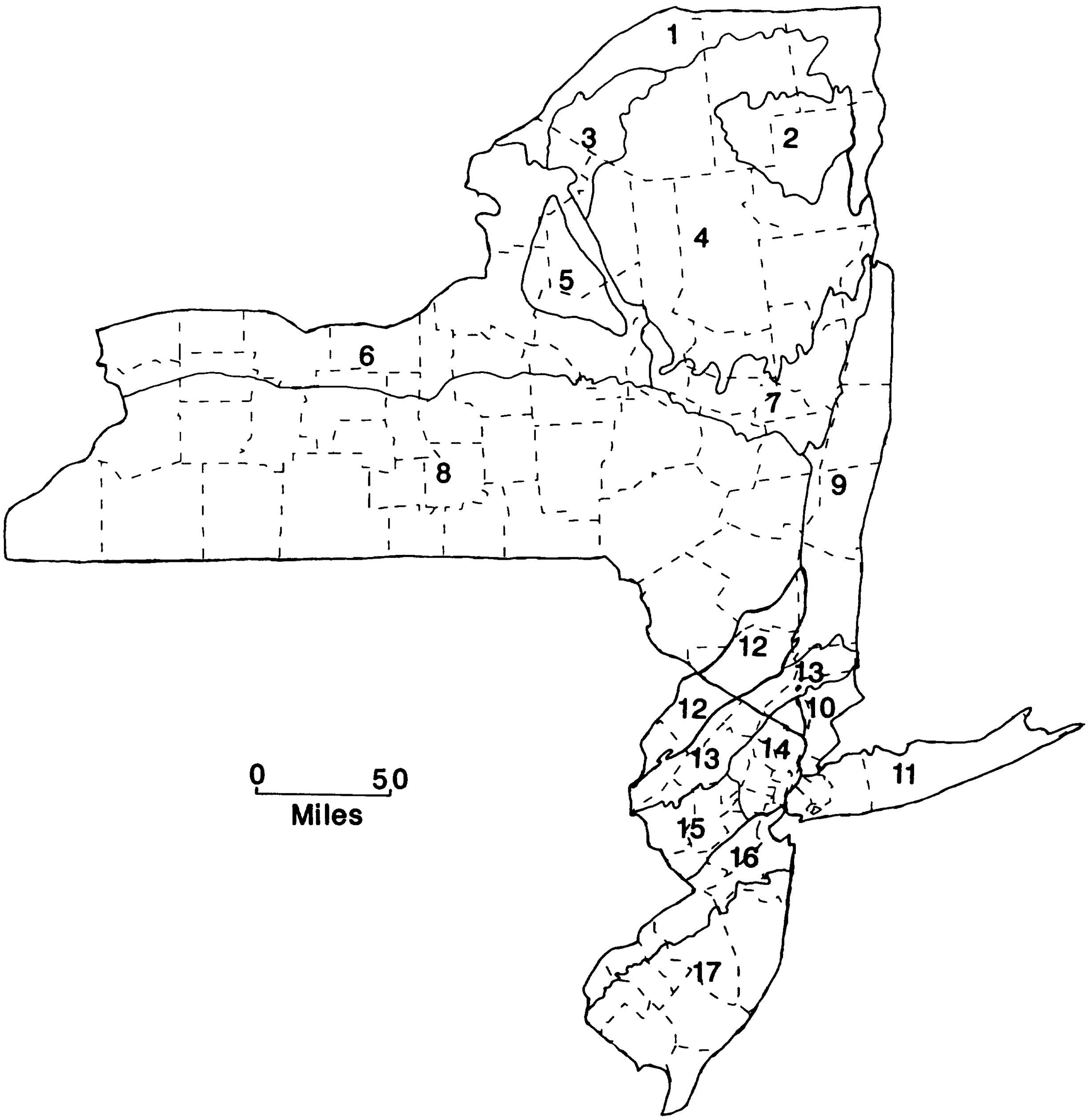

Figure 1. Geologic radon potential areas of EPA Region 2. 1–St. Lawrence-Champlain Lowlands; 2–High Peaks; 3–Northwest Lowlands; 4–Adirondacks; 5–Tug Hill Plateau; 6–Erie-Ontario Lowland; 7–Hudson-Mohawk Lowland; 8–Allegheny Plateau; 9–New England Upland-Taconic Mountains; 10–Manhattan Prong; 11–Atlantic 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.

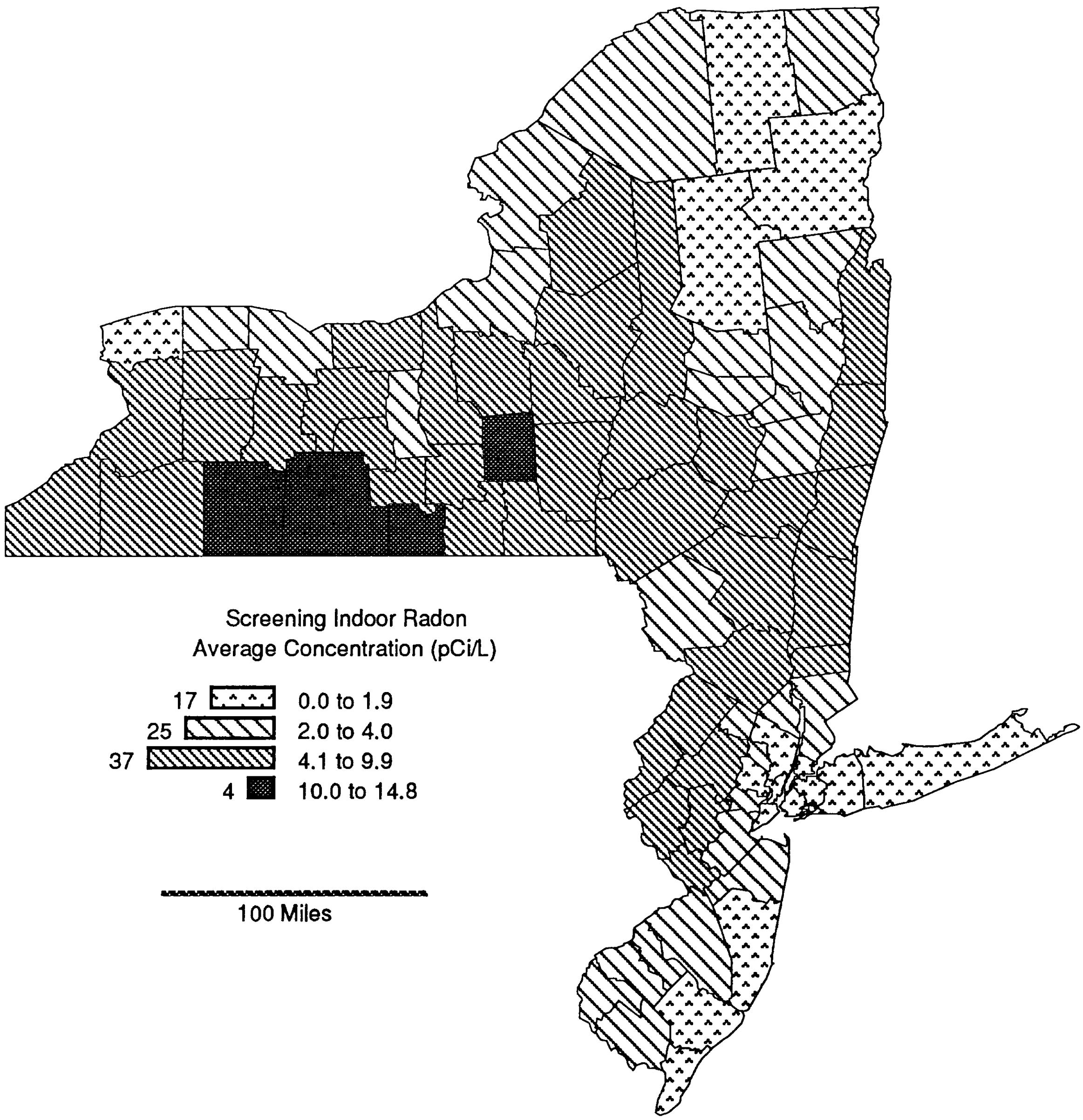

Figure 2. Average screening indoor radon levels, by county, for EPA Region 2. Data are primarily from 2-7 day charcoal canister tests. Data for New York were compiled by the New York State Department of Health; data for New Jersey were compiled by the New Jersey Department of Environmental Protection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

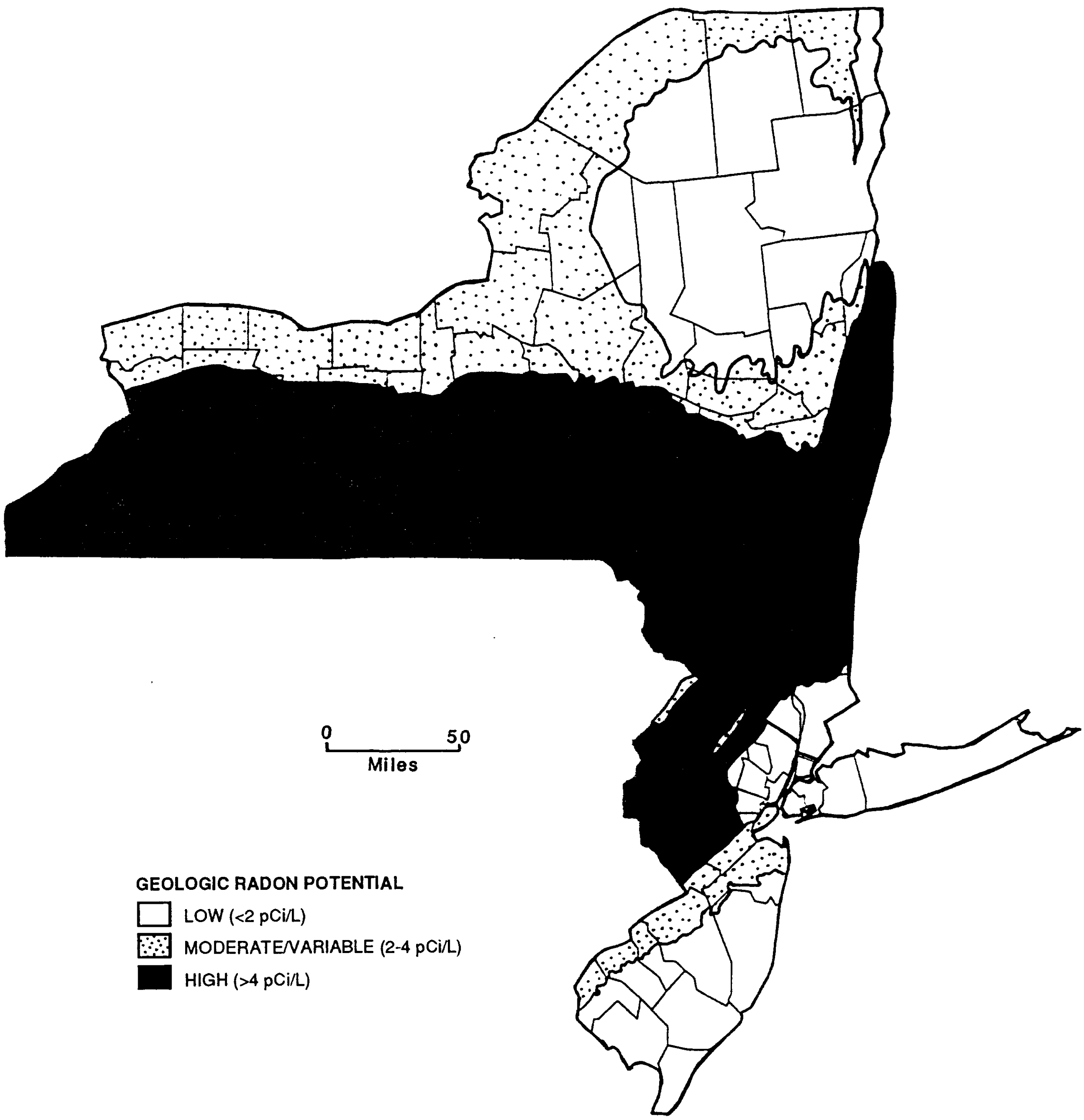

Figure 3. Generalized map showing geologic radon potential of EPA Region 2. For more detail, refer to the individual state geologic radon potential chapters.

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 Steuban–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 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 ≤ 1.5 pCi/L and average indoor radon ≤ 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 ≤ 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
Linda C.S. Gundersen and R. Randall Schumann
U.S. Geological Survey

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.

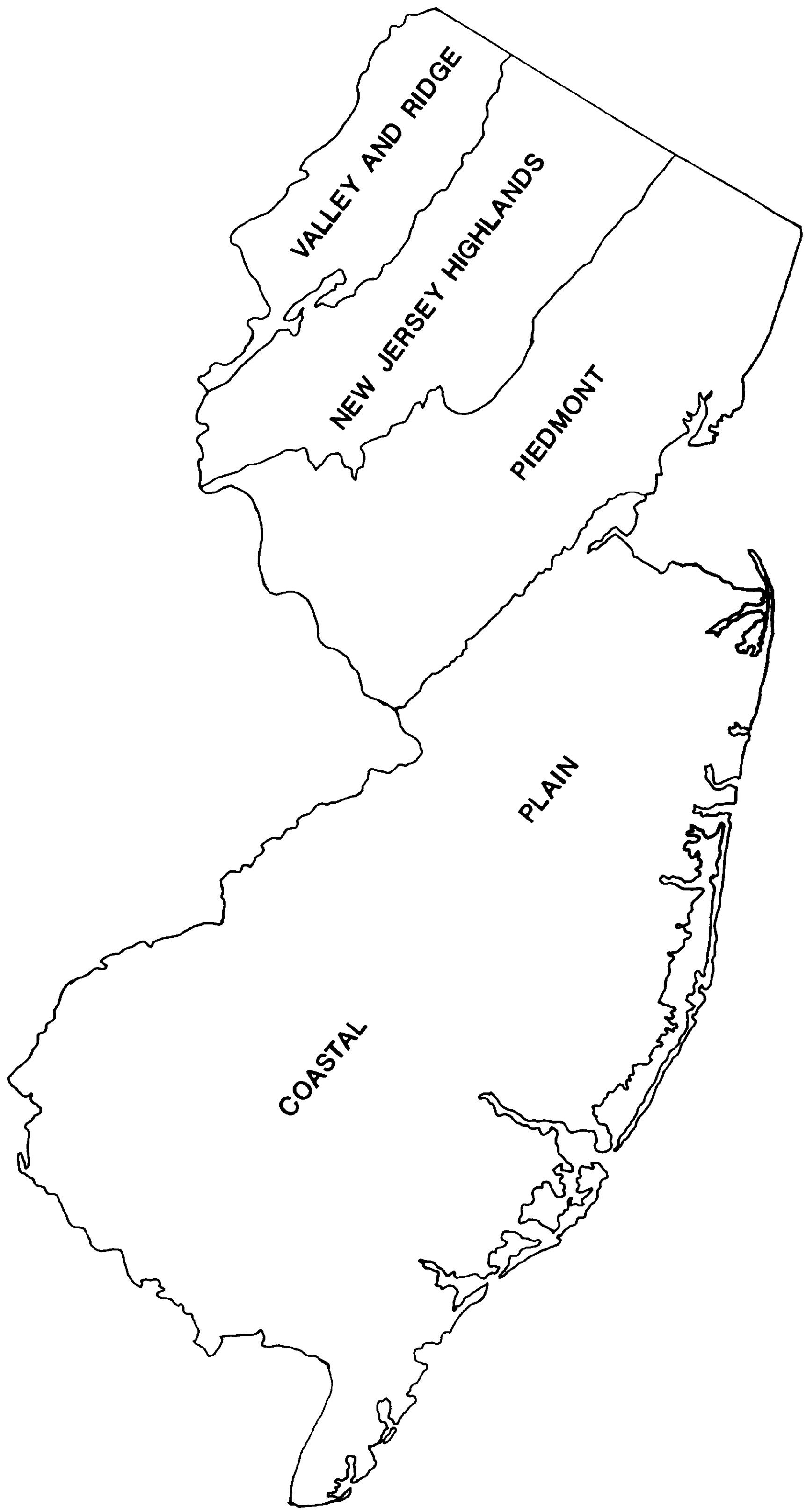

Figure 1. Physiographic provinces of New Jersey.

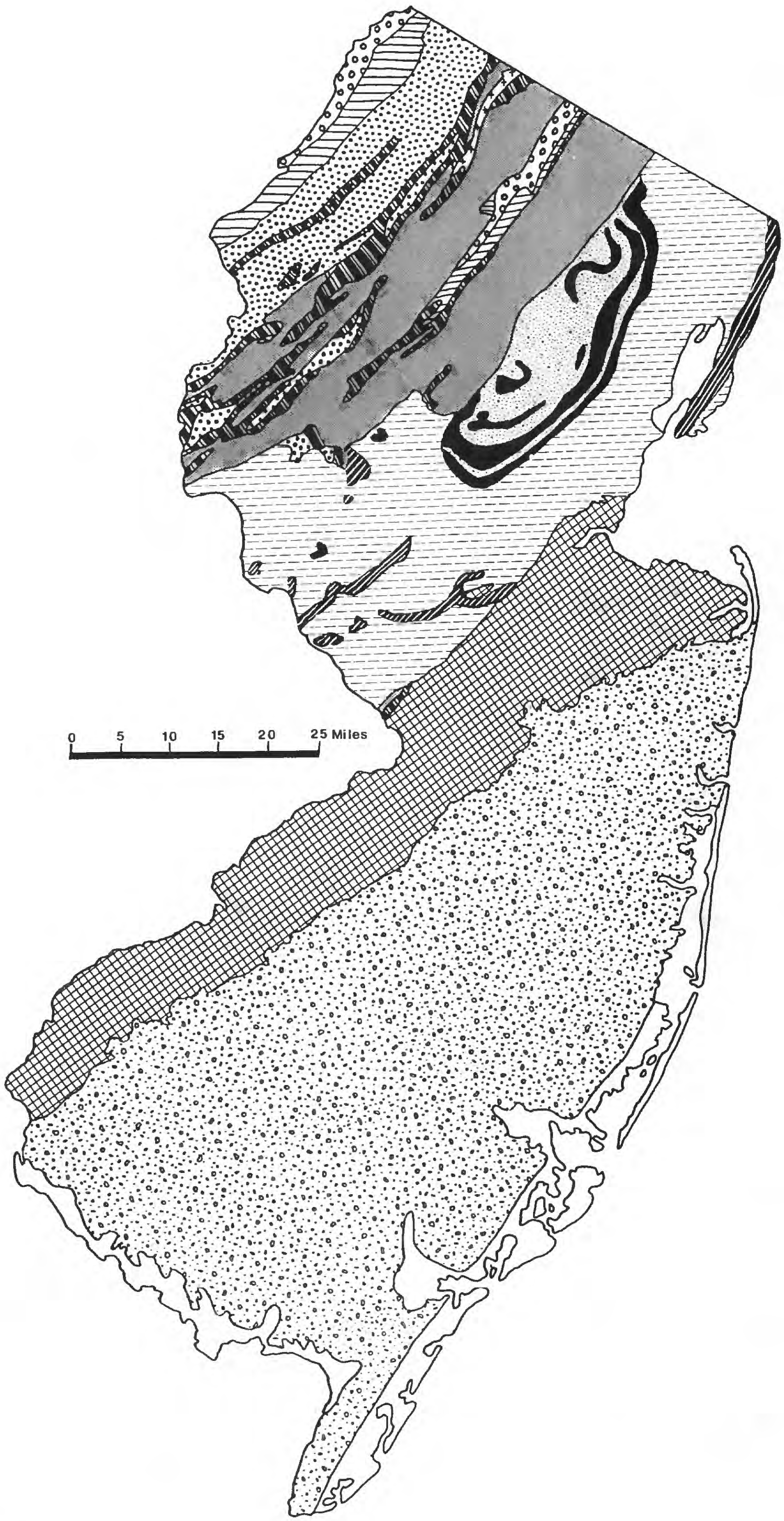

Figure 2. Generalized geologic map of New Jersey (redrawn from New Jersey Geological Survey, 1984).

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

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

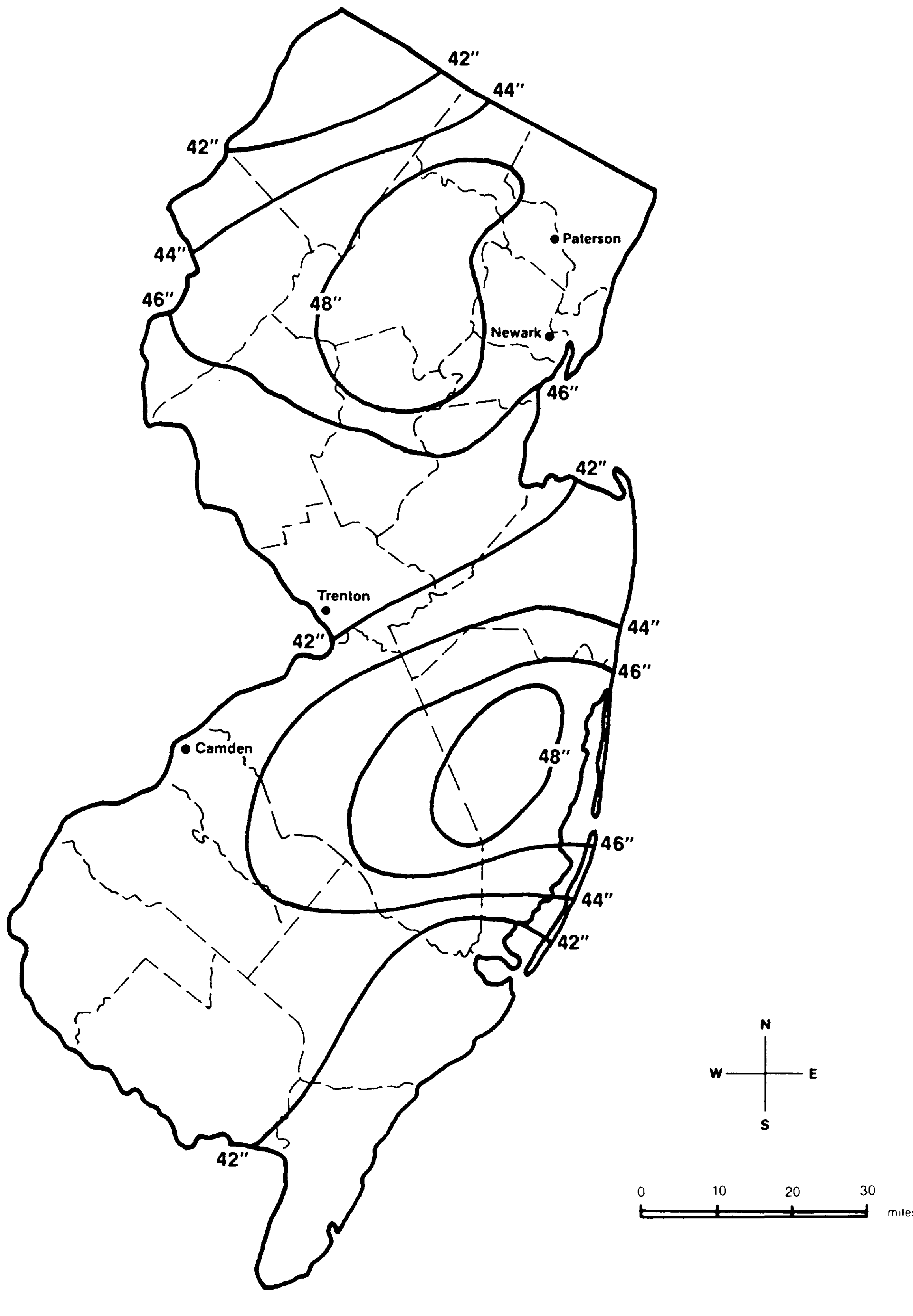

Figure 4. Average annual precipitation in New Jersey (from Facts on File, 1984).

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 quartzo-feldspathic 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 quartzo-feldspathic 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 intertounging 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).

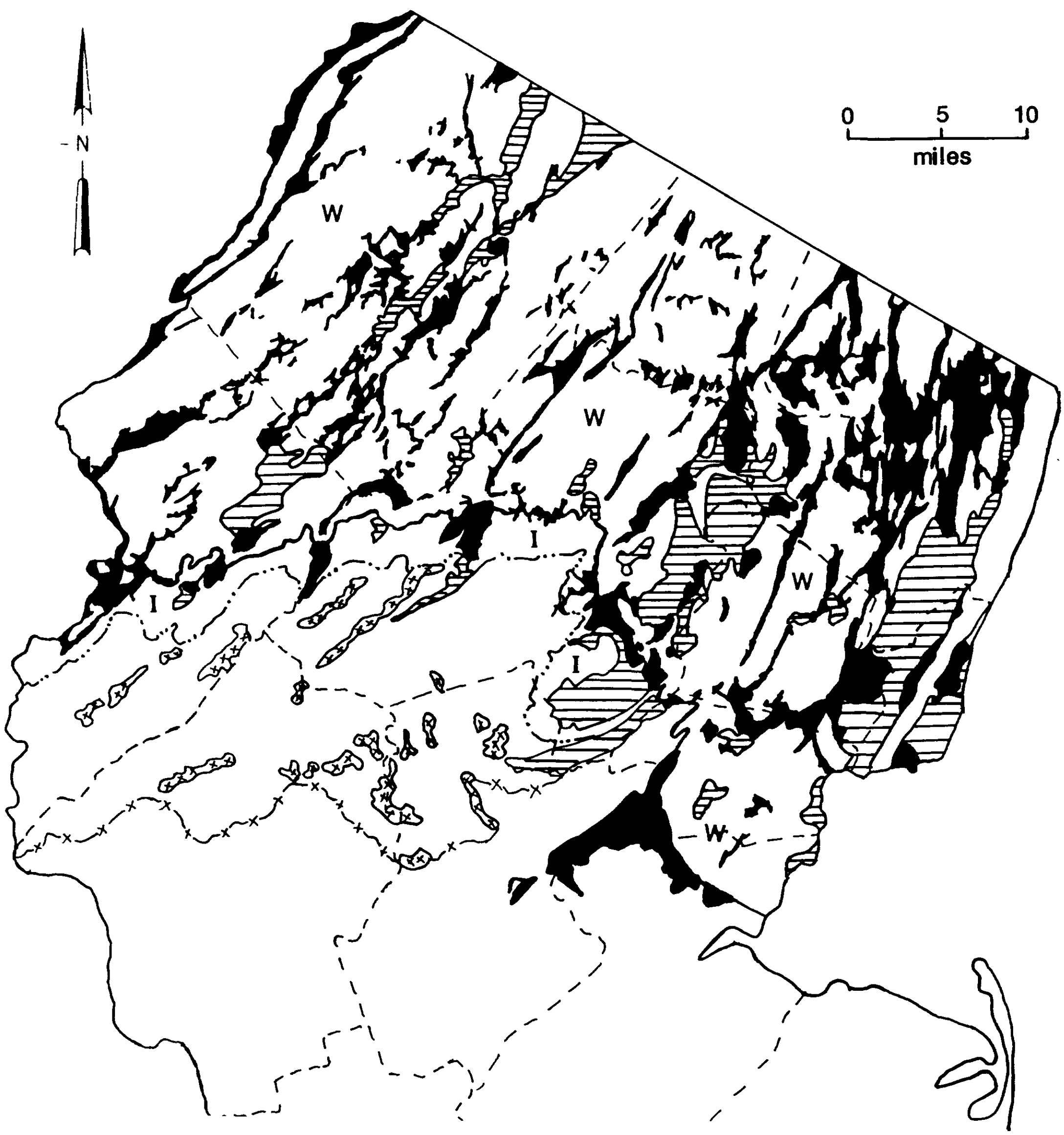

Figure 5. Map of northern New Jersey showing Pleistocene glacial deposits (modified from B.D. Stone, written communication, 1992, and information in Stone and others, 1989).

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

[W] Wisconsinan till—non-stratified, poorly sorted mixture of sand, silt, clay, and some gravel

[I] Illinoian till—non-stratified, poorly sorted mixture of sand, silt, clay, and some gravel

[x x x] 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

—x— 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.

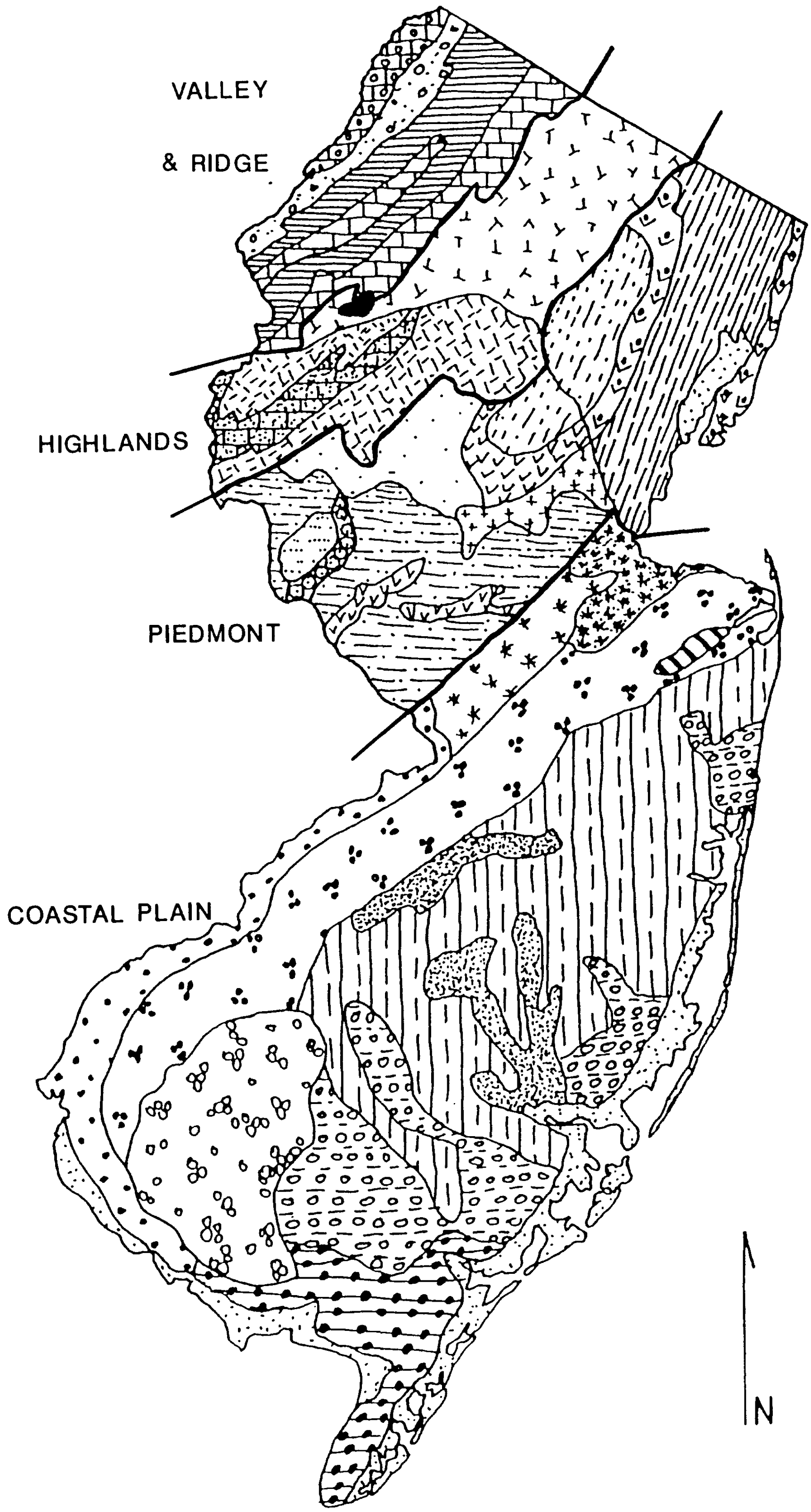

Figure 6. Generalized soil map of New Jersey (modified from Tedrow, 1986).

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

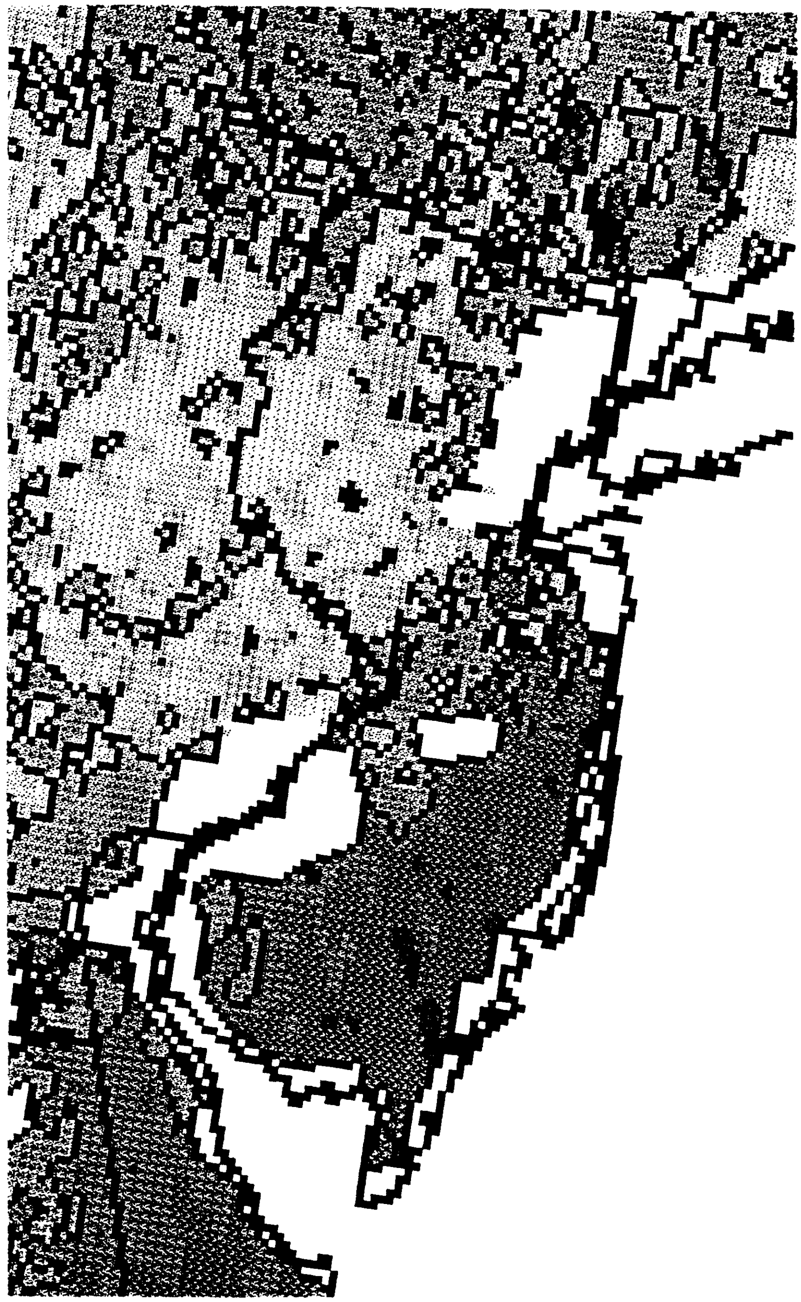

Figure 7. Aerial radiometric map of New Jersey (after Duval and others, 1989). Contour lines at 1.5 and 2.5 ppm equivalent uranium (eU). Pixels shaded at 0.5 ppm eU increments; darker pixels have lower eU values; white indicates no data.

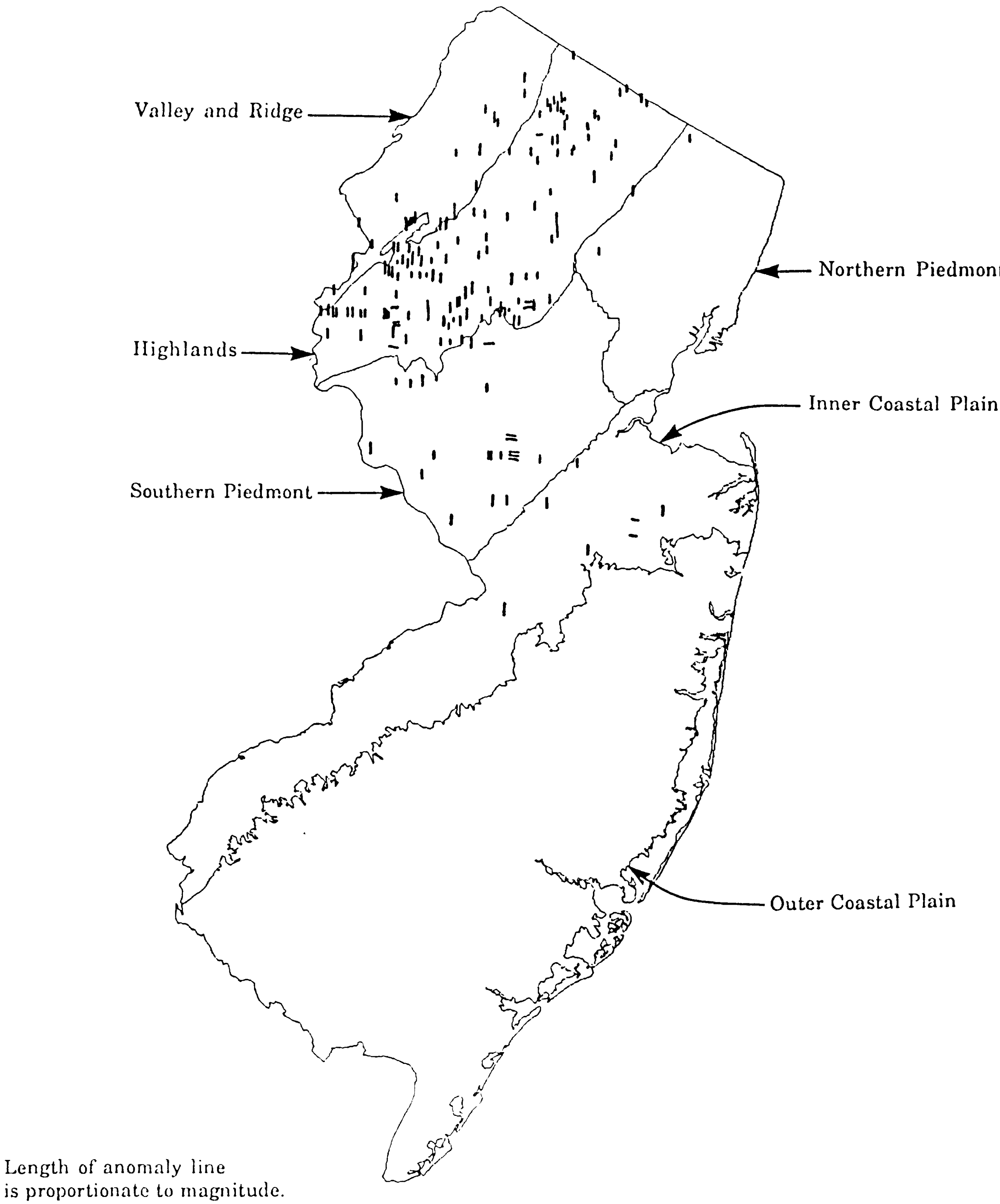

Figure 8. Map showing locations of NURE anomalies greater than 2.4 ppm equivalent uranium (from Muessig and Bell, 1988)

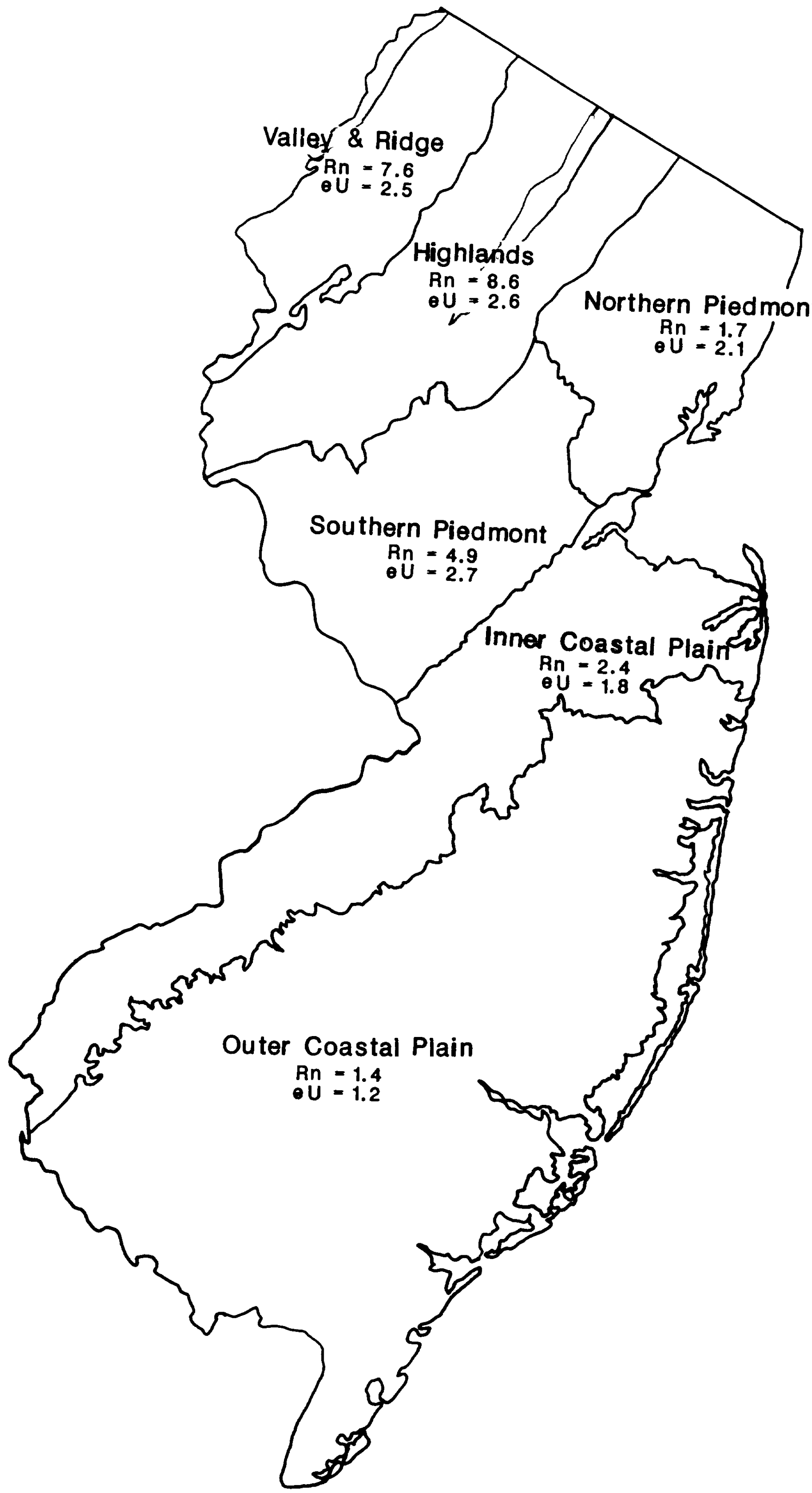

Figure 9. Map of New Jersey showing average NURE equivalent uranium (in ppm) and average indoor radon level (in pCi/L), by province (After Camp Dresser McKee, 1989, and Muesseg and Bell, 1988).

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 trondjhemitic 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 ($CaCO_3$) that makes up the majority of the rock. When the $CaCO_3$ 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 $CaCO_3$ 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.

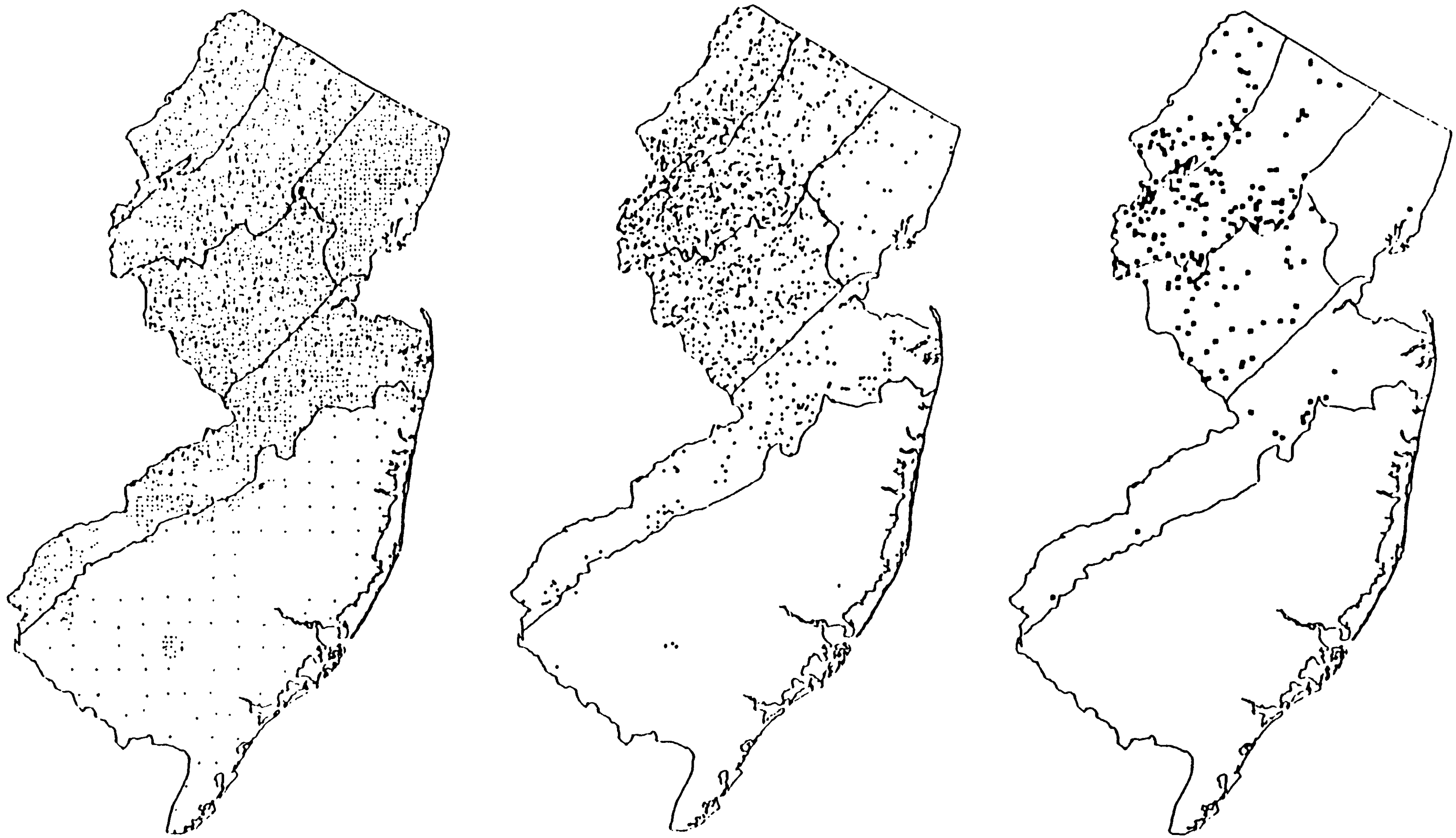

Figure 10. Maps showing statewide indoor radon survey results (from Camp Dresser McKee, 1989).

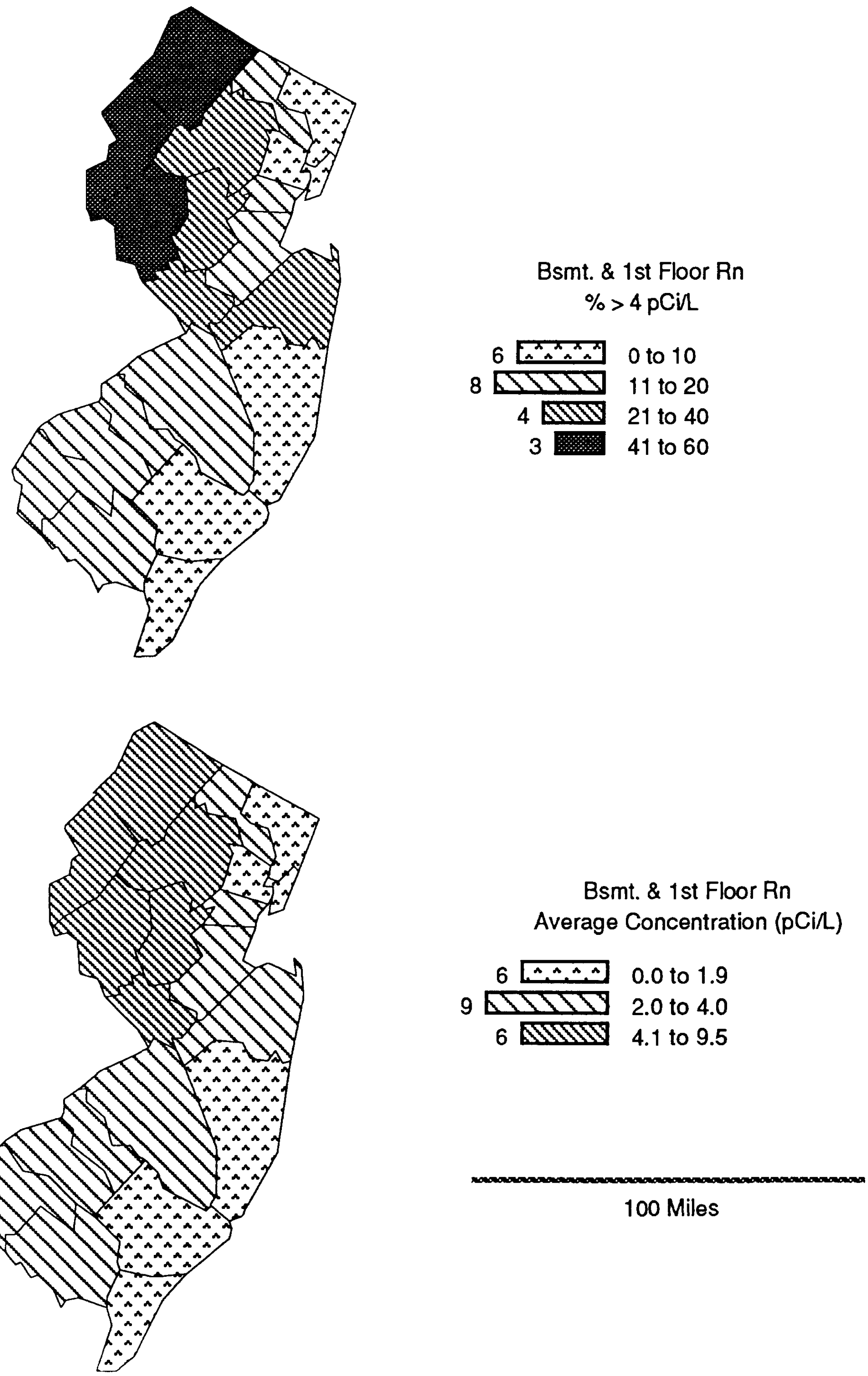

Figure 11. Screening indoor radon data compiled by the New Jersey Department of Environmental Protection and Energy from vendor reports collected by NJDEP from 1986 through 1992. Data represent primarily 2-7 day charcoal canister measurements, although some alpha-track and e-perm detector data are also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

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

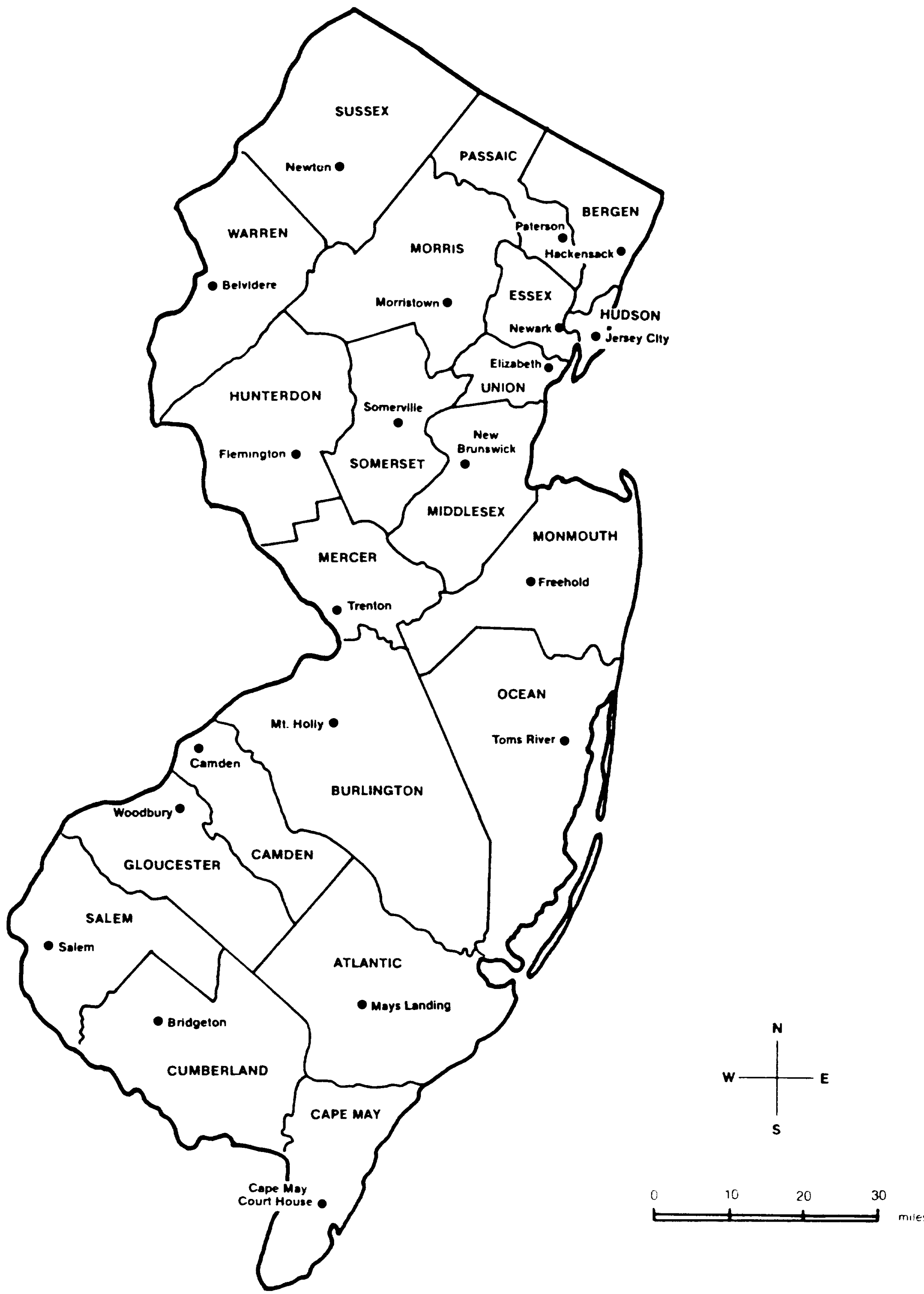

Figure 12. New Jersey counties (from Facts on File, 1984).

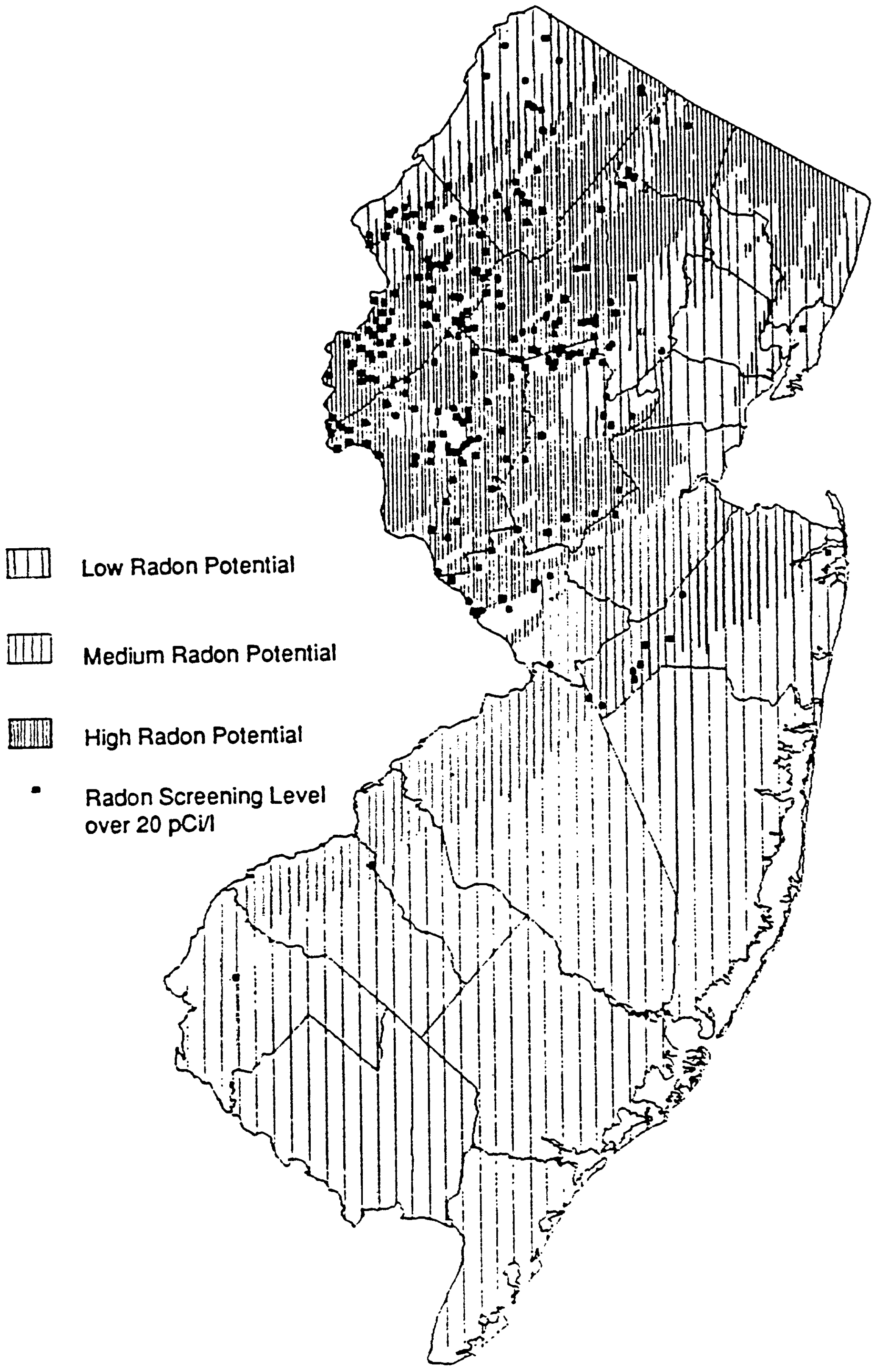

Figure 13. Map showing radon potential areas of New Jersey identified by the New Jersey DEP (from Camp Dresser McKee, 1989).

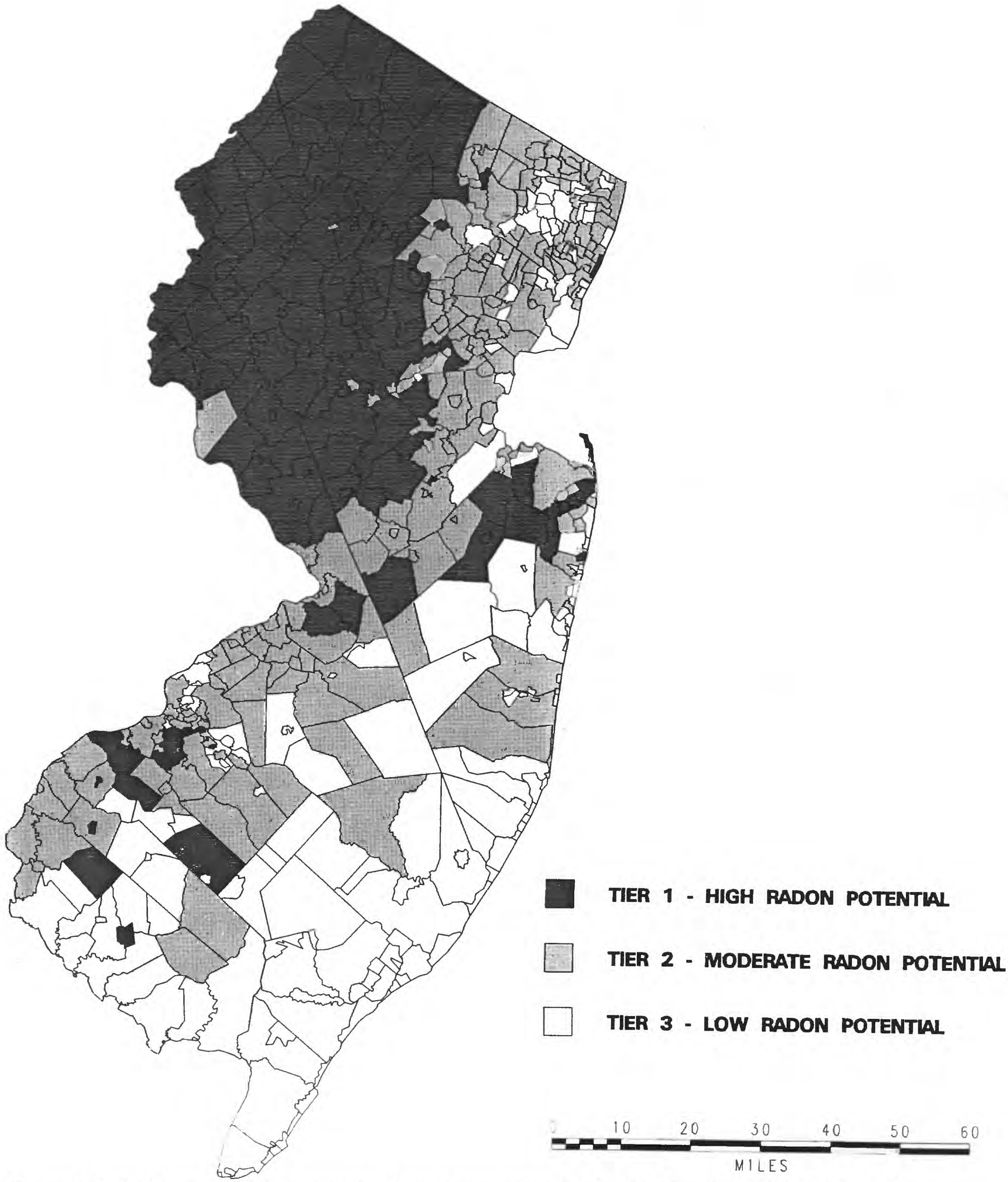

Figure 14. Radon potential tier map for New Jersey compiled by the New Jersey Department of Environmental Protection and Energy. Tiers rankings are based on indoor radon data from more than 150,000 homes compiled from vendor records and the State's radon testing program. Tier 1 municipalities are those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

FACTOR	New Jersey Highlands RI	New Jersey Highlands CI	Cambrian and Ordovician Valley and Ridge RI	Cambrian and Ordovician Valley and Ridge CI	Southern Piedmont RI	Southern Piedmont 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

FACTOR	Silurian and Devonian Valley and Ridge/Green Pond Outlier RI	Silurian and Devonian Valley and Ridge/Green Pond Outlier CI	Northern Piedmont RI	Northern Piedmont CI	Inner Coastal Plain Cretaceous-Lower Tertiary RI	Inner Coastal Plain Cretaceous-Lower Tertiary 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

FACTOR	Outer Coastal Plain Upper Tertiary-Quaternary RI	Outer Coastal Plain Upper Tertiary-Quaternary 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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PRELIMINARY GEOLOGIC RADON POTENTIAL ASSESSMENT OF NEW YORK

by Linda C.S. Gundersen and R. Randall Schumann
U.S. Geological Survey

INTRODUCTION

The State of New York has been conducting radon studies since the late 1970s. Since 1985, the State has had a diverse radon program including information and outreach, radon testing, training for contractors in radon mitigation and detection, and technical and financial assistance (Laymon and others, 1990). As part of their testing program, New York State now has a database of over 50,000 random and non-random charcoal canister indoor radon measurements. These data indicate that several areas of New York have the potential for elevated indoor radon levels. Examination of these data in the context of geology, soil parameters, and aerial radioactivity suggest that certain surficial deposits and rocks of the Allegheny Plateau, Hudson Highlands, Taconic Mountains, and Valley and Ridge have the potential to produce elevated levels of indoor radon (> 4 pCi/L). Surficial deposits and rocks of the Hudson-Mohawk Lowland, Erie-Ontario Lowlands, the Champlain and St. Lawrence Lowlands, and the Northwest Lowlands of the Adirondacks are generally more moderate in radon potential but may be locally high where glacial deposits are highly permeable. Surficial deposits and rocks of the Adirondacks, the Triassic Lowlands, Manhattan Prong, and the Atlantic Coastal Plain are relatively low in radon potential.

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

PHYSIOGRAPHIC AND GEOGRAPHIC SETTING

The physiography of New York (fig. 1) is in part a reflection of the underlying bedrock geology (fig. 2) and the extensive glaciation of the State. Several of the provinces shown in figure 1 have been slightly modified from the classically defined physiographic provinces by using geologic boundaries in order to make better geologic sense for this radon potential assessment. The St. Lawrence and Champlain Lowlands are in the most northerly region of New York and grade from a nearly level marine plain in the east to gently rolling hills with relief of approximately 100 feet in the west. The lowlands are underlain by Cambrian and Ordovician sandstone, dolomite, and limestone. The Adirondack Highlands include the highest mountains in the State, especially in the High Peaks region, which is underlain by resistant anorthosite rock. Mt. Marcy is the highest peak, at over 5000 feet in elevation above sea level. Average relief in the Adirondack Highlands is 1000-2000 feet. The Northwest Lowlands are an area of lowlands in the northwestern part of the Adirondacks that are underlain by metamorphosed sedimentary rocks.

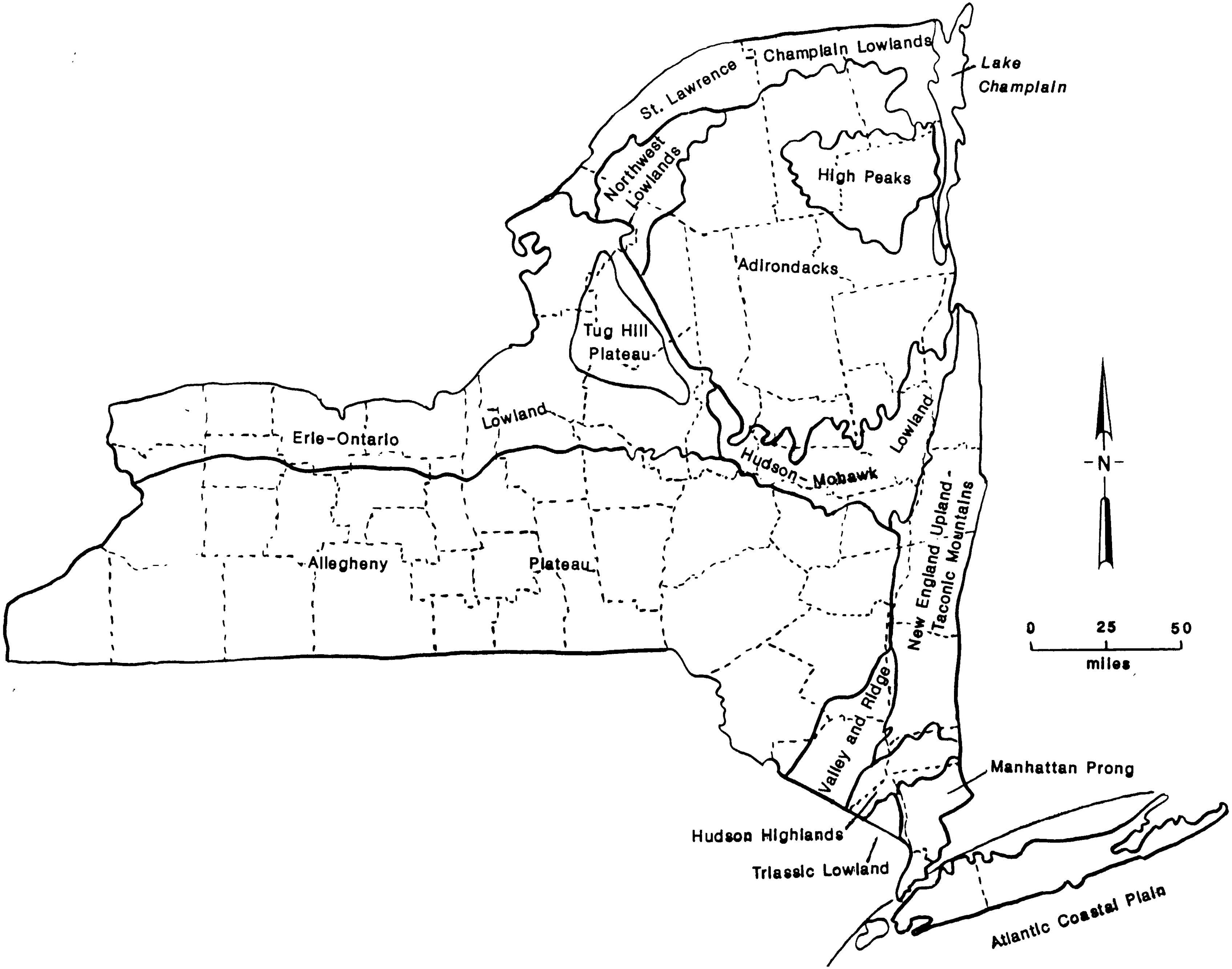

Figure 1. Physiographic/Geologic Provinces and subprovinces of New York.

Figure 2. Generalized bedrock geologic map of New York (redrawn from Rogers and others, 1990). It is recommended that the reader refer to Rogers and others (1990) and other geologic maps published by the New York State Geological Survey (for example, Fisher and others, 1970) for more detail.

EXPLANATION
GENERALIZED GEOLOGIC MAP OF NEW YORK

ATLANTIC COASTAL PLAIN

Quaternary Till, gravel, sand, and mud; **Recent** marine deposits–sand, mud, and clay; small outcrops of **Cretaceous Monmouth and Raritan Formations**–sand and mud

TRIASSIC LOWLAND

TRIASSIC-JURASSIC

Newark Supergroup–arkose, mudstone, and siltstone

Conglomerate facies of Newark Supergroup (Hammer Creek Formation)

Palisades Diabase

ALLEGHENY PLATEAU

DEVONIAN

Conewango Group–shale, siltstone, and sandstone in the west, grades to shale, sandstone, and conglomerate to the east; **Coneaut Group**–shale and siltstone in the west, replaced by shale and sandstone to the east; includes isolated outcrops of the Pennsylvanian **Pottsville and** Mississippian **Pocono Groups** (shale, sandstone, and conglomerate) along the Pennsylvania border

Dc **Canadaway Group**–interbedded shales and siltstones with some sandstone

Java Group–shale and sandstone; **West Falls Group**–shale, sandstone, and siltstone

D **Sonyea Group**–shale; **Genesee Group**–shale, sandstone, and limestone in the west, grades to shale, sandstone, and siltstone to east; **Tully Limestone**

Hamilton Group–shale, sandstone, siltstone, and limestone

Onadaga Formation-limestone; **Tristates Group**-limestone, sandstone, and shale; **Helderberg Group**–limestone and dolostone

SILURIAN

S **Rondout Formation, Binnewater Sandstone, High Falls Shale, Warwarsing, Decker, and Bossardville Limestones, Poxono Island Formation**–dolostone, limestone, shale, and sandstone

Bloomsburg, Guymard, and Shawangunk Formations and Otisville Shale–quartzite, shale, sandstone, and conglomerate

ERIE-ONTARIO LOWLAND

SILURIAN

Salina Group–dolostone, limestone, shale, gypsum, salt

Lockport Group–dolostone and limestone

Clinton Group–shale, sandstone, limestone, dolostone, hematite

Medina Group–sandstone, shale

ORDOVICIAN

Queenston Formation–shale, siltstone

Oswego Sandstone

Lorraine Group–sandstone, siltstone, and shale

Trenton and Black River Groups–limestone, dolostone, shale, and chert

ST. LAWRENCE LOWLAND

ORDOVICIAN

Trenton, Black River, and Chazy Groups–limestone, dolostone, shale, and chert

CAMBRIAN-ORDOVICIAN

Beekmantown Group and Theresa Formation–limestone, dolostone and sandstone

CAMBRIAN

Potsdam Sandstone–quartz sandstone and conglomerate

HUDSON-MOHAWK LOWLAND

ORDOVICIAN

Austin Glen, Mount Merino, and Indian River Formations–graywacke, shale, slate, and chert

Schenectady Formation–graywacke, sandstone, siltstone, and shale

Utica and Snake Hill Formations-black shale and siltstone

CAMBRIAN-ORDOVICIAN

Beekmantown Group and Theresa Formation–limestone, dolostone, and sandstone

CAMBRIAN

Potsdam Sandstone-quartz sandstone and conglomerate

NEW ENGLAND UPLAND AND VALLEY AND RIDGE

DEVONIAN

Hamilton Group-shale, sandstone, and conglomerate

SILURIAN-DEVONIAN

Green Pond Conglomerate, Longwood Shale, Poxono Island Formation, Decker Limestone, Helderberg and Tristates Groups-limestone, shale, dolomite, sandstone, and conglomerate

ORDOVICIAN

Waloomsac, Snake Hill, and Balmville Formations- black shale and slate, graywacke and metagraywacke, melange, limestone, and limestone conglomerate

Austin Glen, Mount Merino, and Indian River Formations (Livingston thrust slice)–graywacke, shale, slate, chert; includes pillow lava at Stark's Knob, Saratoga County

CAMBRIAN-ORDOVICIAN

Stockbridge and Wappinger Groups–limestone, dolostone, sandstone, siltstone, shale, and quartzite

Nassau, Hatch Hill, Deep Kill, Mount Merino, Indian River Formations (Giddings Brook thrust slice)–slate, shale, quartzite; includes limestone, dolomite, chert, conglomerate, and graywacke

CAMBRIAN

Everett Schist (Everett thrust slice)–schist with minor metagraywacke lenses

Bomoseen and Nassau Formations (Chatham thrust slice)–black shale and quartzite

Bomoseen and Nassau Formations (Dorset Mountain thrust slice)–slate with graywacke sandstone, and quartzite

Rensselaer Graywacke (Rensselaer thrust slice)–graywacke and shale

Austerlitz Phyllite (Berlin thrust slice)–phyllite with minor quartzite

PROTEROZOIC

Calcitc and dolmitic marble, calcsilicate rock, interlayered gneisses

MANHATTAN PRONG

ORDOVICIAN

Cortlandt mafic complex–diorite with hornblende, hornblende norite, hornblendite, pyroxenite, and minor amounts of other mafic rocks

Bedford Gneiss–biotite-quartz-plagioclase gneiss and interlayered amphibolite

Harrison Gneiss–biotite-hornblende-quartz-plagioclase gneiss

Staten Island Serpentinite

CAMBRIAN-ORDOVICIAN

Hartland Formation–amphibolite and pelitic schist

Inwood Marble and Lowerre Quartzite

CAMBRIAN

Manhattan Formation–pelitic schist and amphibolite

PROTEROZOIC

Yonkers, Pound Ridge, and Fordham Gneisses–granite gneiss, hornblende gneiss, biotite gneiss, and amphibolite

HUDSON HIGHLANDS

PROTEROZOIC

Leucocratic gneiss

Calcitic and dolomitic marble, calcsilicate rock, and interlayered gneisses

Pyroxene-hornblende granitic gneiss (charnockite)

Biotite granitic gneiss and hornblende granitic gneiss

Interlayered hornblende granitic gneiss and amphibolite

Hornblende granitic gneiss

Biotite-quartz-plagioclase gneiss with subordinate biotite granitic gneiss, amphibolite, and calcsilicate rock

Biotite-quartz-feldspar gneiss with garnet, sillimanite, cordierite, graphite, sulfides, and minor marble and calcsilicate rock

Garnet-quartz-feldspar gneiss with minor marble, amphibolite, and rusty gneiss

ADIRONDACKS

PROTEROZOIC

Biotite and/or hornblende granitic gneiss, biotite-quartz-plagioclase gneiss, other metasedimentary rocks, amphibolite, migmatite

Leucocratic gneiss

Metasedimentary rocks–dominantly calcitic and dolomitic marble, calcsilicate rock, quartzite, and interlayered gneisses

Mangerite or charnockite with plagioclase crystals from anorthosite

Interlayered hornblende granitic gneiss and amphibolite

Hornblende syenitic gneiss (mangerite)

Metagabbro and amphibolite

Olivine-bearing granitic gneiss

Metanorthosite and anorthositic gneiss

Biotite-quartz-plagioclase gneiss and migmatite, may contain garnet

Tonalitic gneiss

Southwest of the Adirondacks lies the Tug Hill Plateau, an isolated upland in the Erie-Ontario Lowlands. Elevation varies from 1000 to 2000 feet and relief is low. The Tug Hill Plateau is underlain mostly by Ordovician quartzite. The Erie-Ontario Lowland lies south of Lake Erie and Lake Ontario and has a maximum elevation of 1500 feet. The land rises gently eastward and southward away from the lakes. Glacial drumlin fields and moraines produce local topography. Just south of the Adirondacks are the Hudson-Mohawk Lowlands, which are underlain primarily by Ordovician shales and limestones with low relief. The southern part of the Hudson-Mohawk Lowlands, especially the area of the Wallkill Valley, has been designated part of the northern extent of the Valley and Ridge Province for the purposes of this report. The Allegheny Plateau (part of the Appalachian Plateau) includes almost all of central and southern New York west of the Catskills and is underlain by Silurian, Devonian and very small amounts of Mississippian and Pennsylvanian sedimentary rocks, primarily by shales, siltstones, and sandstones of Devonian age. The Catskills and Shawangunk Mountains provide moderate to high relief in the eastern part of the plateau. The highest elevation is 4,202 feet in the Catskill Mountains. The rest of the Plateau consists of flat-topped divides with steep to rounded glacial valleys in the north and gentler hills to the south. The New England Upland contains several diverse mountain and hilly terrains, including the Taconic Mountains, the Hudson Highlands, and the Manhattan Prong. These areas are all underlain by complexly folded and faulted sequences of metamorphosed rock and the topography is hilly. Maximum relief is seen in the Hudson Highlands, with elevations from approximately sea level in the Hudson River Valley to over 1500 feet above sea level in the adjacent mountains. The Triassic Lowland is underlain by sandstone and shale and bordered by the distinct, prominent diabase of the Palisades sill on the east and by the sill and a border fault to the north. The Triassic Lowland lies entirely within Rockland County. Staten Island and Long Island are in the Atlantic Coastal Lowlands. The islands are covered by glacial drift and are generally flat-lying with minor, locally hilly terrain.

In 1990, the population of New York was 17,990,455, with 84 percent of the population living in urban areas (fig. 3). The population distribution is approximately 365 per square mile. The climate of New York is variable due to the diverse physiography. The mountainous areas and much of central and northern New York have cold winters with significant snow. Precipitation varies from 40 to 56 inches, with the highest precipitation in the Adirondacks and Catskill Mountains (fig. 4).

GEOLOGIC SETTING

The geology of New York is complex, and the names of rock formations and the way rocks are grouped have changed with time. This description of the geology tries to convey the major rock types of an area, especially as they pertain to the radon problem. Descriptions in this report are derived from the following references: Fisher and others (1970); Broughton and others (1976); Weiner and others (1984); Rankin and others (1989); Drake and others (1989); and Rogers and others (1990). A general geologic map is given in figure 2. It is suggested, however, that the reader refer to the more detailed state geologic maps as well as the numerous detailed geologic maps and reports available from the New York Geological Survey.

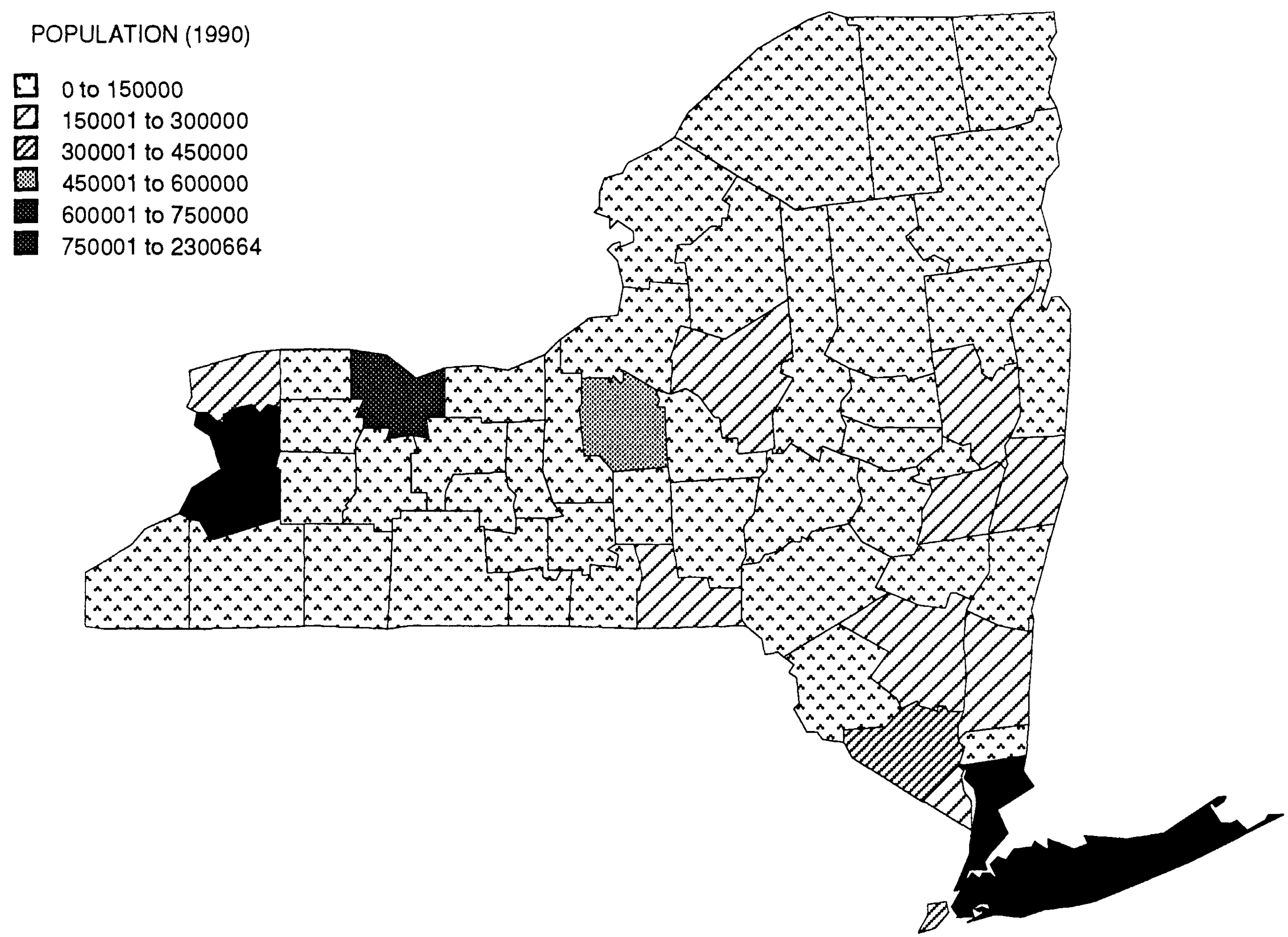

Figure 3. Population of counties in New York (1990 U.S. Census data).

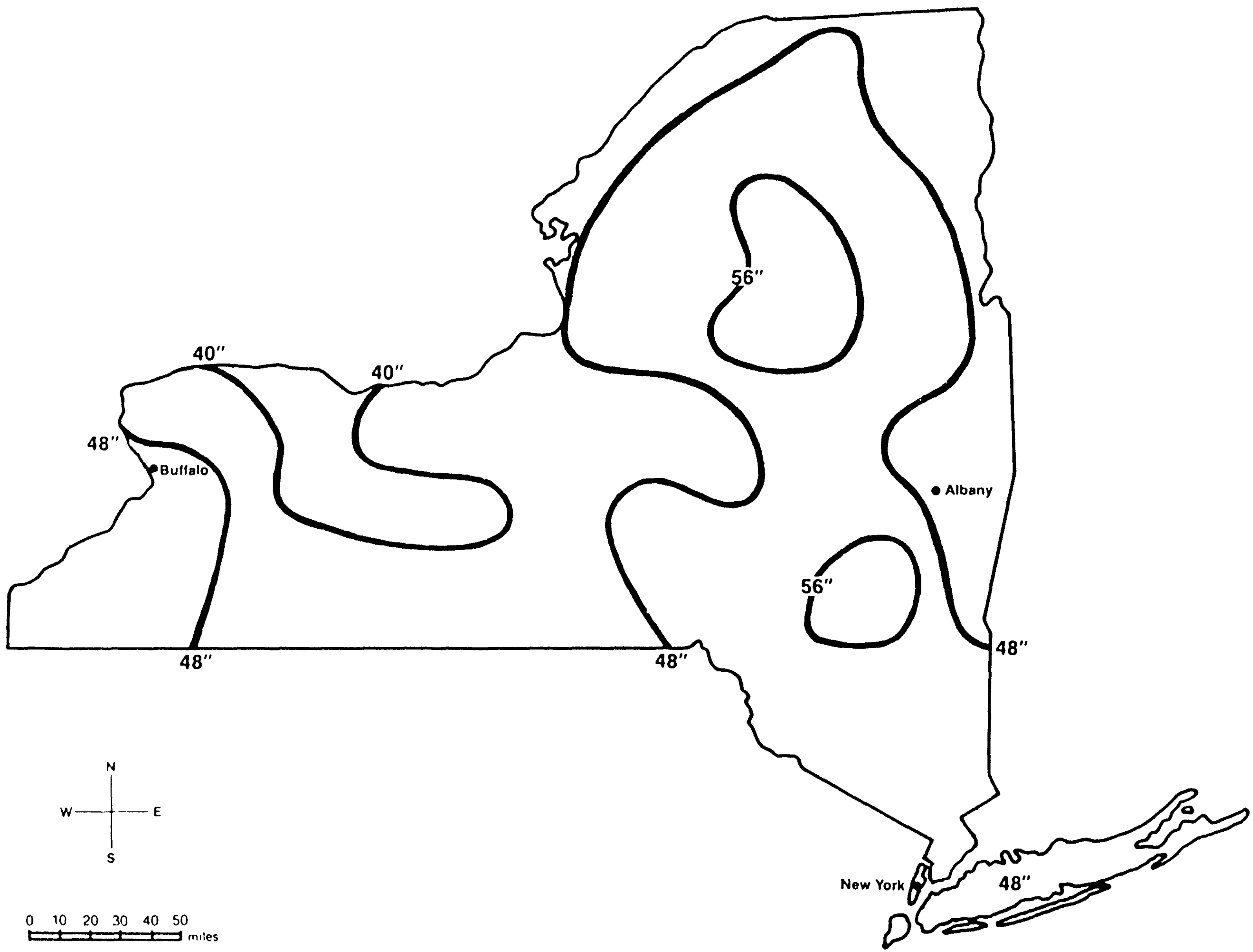

Figure 4. Average annual precipitation in New York (from Facts on File, 1984).

Erie Ontario Lowland and Hudson-Mohawk Lowland Provinces

Most of the Erie-Ontario Lowland and the Hudson-Mohawk Lowland are underlain by sandstone, shale, and limestone. These rocks crop out in east-west trending belts across the State to the Hudson-Mohawk Lowland, where the rocks underlie irregular northeast-trending areas disrupted by faults. The eastern part of the Erie-Ontario Lowland comprises a broad syncline of sandstone and shale that plunges to the southwest and forms the Tug Hill Plateau.

Sandstone and conglomerate of the Cambrian Potsdam Formation underlie small areas along the contact with Proterozoic rocks of the Adirondacks. The Potsdam is overlain by narrow, discontinuous belts of dolomite, sandstone, and shale of the Theresa Formation. Limestone and dolomite of the Cambrian-Ordovician Beekmantown Group and the Ordovician Black River and Trenton Groups overlie the Theresa Formation where present, and unconformably overlie rocks of the Adirondacks elsewhere. The Beekmantown Group is restricted to a belt of outcrops along the northern and western edge of the Hudson-Mohawk Lowland, whereas the Black River and Trenton Groups are most prominent in the eastern and northern portion of the Erie-Ontario Lowland. The basal unit of the Black River Group also contains interbedded shale and arkosic sandstone and the uppermost unit of the Trenton Group contains black shales intercalated with the limestone.

The Ordovician carbonate rocks just described are overlain by Ordovician black and gray shale and siltstone. In the Erie-Ontario Lowland, the shales and siltstones are represented by the Lorraine Group, and are equivalent to black shale and siltstone of the Snake Hill Formation that underlies about two-thirds of the Hudson-Mohawk Lowland. The Snake Hill is overlain by graywacke and sandstone interbedded with gray to black siltstone and shale of the Schenectady Formation, which underlies a large area in the western part of the Hudson-Mohawk Lowland. The Lorraine Group in the Erie-Ontario Lowland is overlain by marine sandstone, siltstone, and shale of the Ordovician Oswego Sandstone. The top of the Ordovician is the Queenston Formation, consisting of red siltstone, shale, and minor sandstone.

Silurian rocks unconformably overlie the Ordovician rocks and comprise much of the western part of the Erie-Ontario Lowland. At their base, the Silurian rocks are sandstone, siltstone, and shale of the Medina Group, overlain by shale and carbonates of the Clinton Group, then carbonates of the Lockport Group, and finally, gypsiferous shale and carbonates of the Salina Group. The Silurian rocks progressively onlap onto the Ordovician rocks to the east.

Allegheny Plateau Province

The Allegheny Plateau is underlain predominantly by marine to fluvial Devonian shales, sandstones, and minor limestones forming broad east-west trending belts that narrow to the east. In general, each stratigraphic unit is coarser grained in the east, grading into finer, shaly rocks to the west. The oldest rocks of this province are in the southeast where Silurian clastic rocks comprise a narrow belt forming the Shawangunk Mountains. These rocks include quartz-pebble conglomerate and sandstone of the Shawangunk Formation overlain by the Otisville Shale, Guymard Quartzite, and red shale and sandstone of the Bloomsburg Formation. These are overlain by a narrow band of Silurian dolomite, limestone, and shale.

The Devonian Helderberg Group, Ulster Group, and the Onondaga Limestone form a narrow belt along most of the northern and eastern margins of the Allegheny Plateau. The Helderberg Group is dolomite and fossiliferous limestone, becoming shaly at the top of the unit. The Helderberg is conformably overlain by gray to black shaly limestone, limestone, shale, and siltstone of the Ulster Group. To the west, quartz sandstone of the Oriskany Sandstone unconformably overlies progressively older rocks of the Helderberg Group. The fossiliferous Onondaga Limestone conformably overlies the Ulster Group and unconformably overlies the Oriskany Sandstone and the sandy, silty Bois Blanc Limestone in the west.

The Onondaga Limestone is conformably overlain by the Devonian Hamilton Group, which forms a prominent belt parallel to the limestones. The Hamilton Group is dominated by black shales (including the Marcellus, Skaneateles, Ludlowville, Panther Mountain, and Moscow Formations). Limestone interbeds become numerous upsection and to the west and the shales also grade upward and eastward into shale, siltstone, and sandstone. Conglomerate and sandstone of the Skunnemunk Formation occur in the southeasternmost exposures of the Hamilton Group.

In the Finger Lakes region, the Hamilton Group is unconformably overlain by a very thin, discontinuous belt of Tully Limestone. In the east, the Hamilton Group is conformably overlain by deltaic and marine shale, siltstone, and sandstone of the Devonian Genesee and Sonyea Groups which unconformably overlie the Hamilton Group and Tully Limestone to the west. These rock units form a broad belt comprising nearly a quarter of the area of the province. The Genesee Group is more sandstone rich to the east and upsection and is more limestone rich and shaly near the base and to the west. The Sonyea Group is also more sandstone and siltstone rich to the east and contains more black shale to the west.

The Devonian West Falls Group and the overlying Java Group form a broad belt in the southeastern margin of the province that thins to the west. The West Falls Group in the east is dominated by fluvial sandstone, siltstone, and conglomerate. To the west these rocks grade into marine sandstone, siltstone, and shale. In the westernmost outcrops, the West Falls Group is dominated by black shale. The easternmost Java Group consists of marine sandstone, siltstone, and shale and to the west it consists of marine black shale and gray siltstone. The Devonian Canadaway Group comprises a broad belt of outcrop that narrows to the west where it forms a thin band along the border of Lake Erie. In the east, the Canadaway is interbedded marine sandstone, siltstone, and shale. In the west, the Canadaway is black shale and siltstone.

The Devonian Conneaut and Conewango Groups comprise a broad belt restricted to the southwestern corner of the province. The Conneaut is composed of marine shelf sandstone, siltstone, and shale in the east and interbedded gray siltstone and shale in the west. The Conewango Group is also composed of marine shelf sandstone, siltstone, shale, and conglomerate to the east and siltstone and shale to the west. The Mississippian Pocono Group overlies the Conewango Group and is overlain by the Pennsylvanian Pottsville Group. These Mississippian and Pennsylvanian rocks underlie a few small areas in the southwestern part of the province. The Pocono Group is largely represented by fossiliferous marine sandstone and shale of the Knapp Formation. The Pottsville Group is represented by quartz-pebble conglomerate of the Olean Conglomerate.

St. Lawrence Lowlands Province

The St. Lawrence Lowlands are underlain by Cambrian sandstone and Cambrian-Ordovician carbonates that form broad northeast-trending belts. These rocks unconformably overlie the Adirondack province rocks and also crop out in small, fault-bounded areas along the Lake Champlain shore.

The oldest rocks of this province are Cambrian quartz sandstone and quartz-pebble conglomerate of the Potsdam Formation. The Potsdam occurs discontinuously along the boundary with the Adirondacks and forms a broad band in the eastern part of the lowlands. The Potsdam is overlain by a thick sequence of dolomite and limestone which includes the Cambrian Theresa

Formation and the Ordovician Beekmantown Group. The Theresa Formation consists of dolomite and sandstone, whereas the Beekmantown Group is predominantly limestone and dolomite. These rocks form a broad belt along the northern part of the lowlands and underlie several small areas along the Lake Champlain shore. The Beekmantown Group is unconformably overlain by limestone of the Ordovician Chazy Group, which is unconformably overlain by limestone and dolomite of the Ordovician Black River and Trenton Groups. These rocks underlie only a few small areas along the shore of Lake Champlain.

Valley and Ridge Province

The Valley and Ridge, as defined in this report, is underlain by marine black and gray shale, siltstone, and sandstone, with minor carbonates and metamorphic rocks. These rocks are complexly folded and faulted into a series of northeast-trending belts. Proterozoic rocks underlie two small areas that project northward from New Jersey in the southeastern part of the province and are described in the section on the Hudson Highlands. The Proterozoic rocks are unconformably overlain by a belt of dolomite, limestone, and minor shale of the Cambrian-Ordovician Wappinger Group. A thin belt of Cheshire Quartzite underlies the carbonates in the New Milford area. Black shales with minor sandstone of the Ordovician Snake Hill Formation underlie a broad area occupying the eastern two-thirds of the province. These rocks are overlain by graywacke sandstone and black to gray siltstone and shale of the Quassaic Formation and other Martinsburg Formation equivalents that underlie much of the southwestern part of the province.

Two narrow belts of Silurian to Devonian rocks are exposed along the southeastern edge of the province and include the Greenpond Conglomerate; Longwood Shale; limestone, dolomite, and shale of the Poxono Island Formation; Decker Limestone; limestone, dolomite, and sandstone of the Helderberg Group; and shale, sandstone, and conglomerate of the Tristates Group. This sequence is overlain by a broader belt of black shale grading upward into siltstone, sandstone, and conglomerate of the Devonian Hamilton Group.

The Adirondacks

The Adirondacks are a complex sequence of Proterozoic sedimentary, volcanic, and igneous plutonic rocks. These rocks were all deformed several times and metamorphosed. The High Peaks in the east-central portion of the Adirondacks are underlain by anorthosite, an igneous rock comprised almost entirely of plagioclase with minor amounts of pyroxene, garnet, and hornblende. Approximately 15 percent of the Adirondacks is underlain by anorthosite. Surrounding the High Peaks are granitic gneisses, charnockite, syenite, amphibolite, and variable metasedimentary gneiss, especially in the northwestern part of the Adirondacks. Charnockitic gneiss and quartz-poor gneiss (known as syenite) occur in several prominent complexes around the High Peaks and in areas to the north, west, and south. These rocks underlie about a quarter of the Adirondacks and are infolded with metasedimentary rocks and granitic gneiss. Granitic gneiss bodies are scattered throughout the Adirondacks and make up approximately a quarter of the area. Large areas of metasedimentary rocks lie in the outermost rim of the Adirondacks, especially in the northwest and southeast . In total, metasedimentary rocks underlie a third of the Adirondacks. The largest body of metasedimentary rocks is in the Northwest Lowlands, which is west of the Carthage-Colton zone, a broad mylonite zone in the northwestern Adirondacks. The Northwest Lowlands has broad valleys underlain by carbonate and calc-silicate rocks (Gouverneur Marble) and intervening ridges consisting of metasedimentary, metavolcanic, and igneous gneiss. Metasedimentary and igneous gneisses are host to base metal deposits, most commonly iron.

New England Upland Province and Taconic Mountains

The northern New England Upland is mostly underlain by Cambrian and Ordovician sedimentary rocks that are intensely deformed by folds and faults into a series of fault-bounded thrust slices. These thrust slices are elongated to the northeast and form the Taconic Mountains. The grade of metamorphism increases from west to east.

The oldest rocks in the province are Proterozoic leucocratic gneiss that underlie a small area in east Dutchess County. They are unconformably overlain by the Poughquag Quartzite, followed by dolomite, limestone, and minor shale of the Cambrian Stissing Formation and the Cambrian-Ordovician Wappinger Group. These rocks underlie a large irregular area in south-central Dutchess County and a discontinuous irregular narrow band that trends northeastward from southwestern Dutchess County to east-central Columbia County. Similar-aged marble of the Stockbridge Group forms a parallel band in eastern Dutchess County and northeastern Columbia County. The Wappinger and Stockbridge Groups are conformably overlain by slate, phyllite, schist, and metagraywacke of the Walloomsac Formation, which underlies a large irregular area in most of Dutchess County and eastern Columbia and Rensselaer Counties. In the southwestern part of the province the carbonates are overlain by shale and siltstone of the Snake Hill Formation.

The thrust fault sequence of rocks consists of Cambrian black slate and shale with thin quartzite interbeds of the Cambrian Bomoseen and Nassau Formations. These are overlain by black shale with limestone and conglomerate interbeds of the Ordovician Hatch Hill and Deep Kill Formations, followed by red and green shale and chert of the Indian Rivers Formation and black shale and chert of the Mount Merino Formation. Graywacke sandstone with black to gray siltstone and shale of the Austin Glen Formation comprises the top of this sequence. Each of the different thrust fault slices contains portions of this sequence and varies from slice to slice.

The Hudson Highlands

The mountains of the Hudson Highlands are part of the central and southern portion of the New England Upland and are also part of the Reading Prong. They are divided into a western highlands and an eastern highlands and consist of complexly folded and faulted metamorphic and igneous rocks that are host to numerous iron deposits. The western Hudson Highlands extend from the central portion of the New York-New Jersey border, north and east across the Hudson River to the Canopus fault zone. These rocks contain approximately equal amounts of hornblende granite gneiss, metasedimentary and metavolcanic gneiss, and a thick sequence of quartz-feldspar and charnockitic gneiss, thought to be the base of the sequence. The Storm King and Canada Hill Granites intrude this sequence. The Storm King Granite is the more extensive granite of the two and is predominantly a hornblende-microcline granite with aplite and alaskite. The Canada Hill granite was formed by local melting of the rock and contains large bodies of biotite gneiss with local xenotime and monazite concentrations. The westernmost Hudson Highlands are composed of two small bodies of Proterozoic rock in the southeastern part of the Valley and Ridge, west of Green Pond Mountain. The western body is underlain by metasedimentary biotite gneiss with quartzite, quartz-feldspar gneiss, calc-silicate rocks, and a calcitic and dolomitic marble (Franklin Marble) interlayered with calc-silicate gneiss. Metasedimentary biotite gneiss and granitic gneiss also underlie a series of tiny lenticular hills along the eastern margin of the Valley and Ridge. The eastern body is underlain by a sequence of metasedimentary, metavolcanic, and calc-silicate rocks, including biotite gneiss, quartz-plagioclase gneiss, amphibolite, and pyroxene gneiss.

East of the Canopus fault, the Hudson Highlands are underlain predominantly by biotite granodioritic gneiss and migmatite called the Reservoir Granite. Metasedimentary biotite gneiss, amphibolite, calc-silicate gneiss, pyroxene gneiss, quartz-feldspar gneiss, and small bodies of ultramafic rock also occur in the eastern Highlands.

The Manhattan Prong

Locally along the eastern margin of the eastern Hudson Highlands, the Cambrian Lowerre Quartzite of the Manhattan Prong lies unconformably on the Hudson Highland gneiss. In much of the Manhattan Prong, however, it is the Yonkers, Pound Ridge, and Fordham gneiss which underlies the Lowerre Quartzite and Inwood Marble. The folded and faulted Fordham gneiss and Manhattan Formation are the most extensive units in the prong. The Fordham gneiss is subdivided into several units consisting of quartz-feldspar gneiss with variable amounts of biotite, hornblende, garnet, sillimanite, and lesser layers of amphibolite, marble, and calc-silicate rock. The Manhattan Formation is predominantly a quartz-muscovite-biotite schist, with minor amphibolite, marble, and quartzite. The northwestern portion of the prong is intruded by hornblende norite and diorite of the Cortlandt Complex.

Triassic Lowlands (Piedmont)

Late Triassic-early Jurassic continental sedimentary and igneous rocks of the Newark Supergroup are restricted to the Newark basin. 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 westward into New Jersey. Only the northeastern corner of the Newark basin is exposed in New York. The basal Triassic Stockton Formation forms a narrow band along the southeastern side of the basin and consists of fluvial arkosic sandstone, conglomerate, and siltstone. It is more conglomeratic along its basal contact with older rocks to the southeast. The Stockton in New York is overlain by the Triassic Passaic Formation which forms most of the rest of the basin fill. In New York, the Passaic Formation consists of lacustrine black shale and red siltstone interbedded with deltaic gray arkosic sandstones in the lower part and fluvial red lithic sandstones and conglomerates in the upper part. The Orange Mountain Basalt occurs in two small synclinal folds along the border fault and consists of tholeiitic basalt flows. Jurassic diabase dikes and sheets intrude the sedimentary rocks, most notably the Palisades sill which intrudes roughly along the contact of the Stockton and Passaic Formations.

Atlantic Coastal Plain

The Atlantic Coastal Plain in New York covers Long Island and part of Staten Island. Sediments of this area include glacial deposits and Cretaceous to Recent marine deposits. The oldest sediments are Late Cretaceous in age and include marine sand and clay of the Raritan, Monmouth, and Magothy Formations. These units are exposed in small outcrops along the northern coast of Long Island. Recent dune and beach sands, intertidal muds, marsh mud, and clay are common on shorelines and cover much of eastern Long Island.

GLACIAL GEOLOGY

Except for the southern part of Cattaragus County in western New York, and the southern half of Long Island, all of New York was covered by glaciers at least once, and most areas several times, during the Pleistocene Epoch. Almost all of the glacial deposits exposed at the surface in New York (fig. 5) were deposited by late Wisconsinan glaciers approximately 30,000 to 11,000 years ago (Cadwell, 1988). However, older glacial deposits are locally found underlying

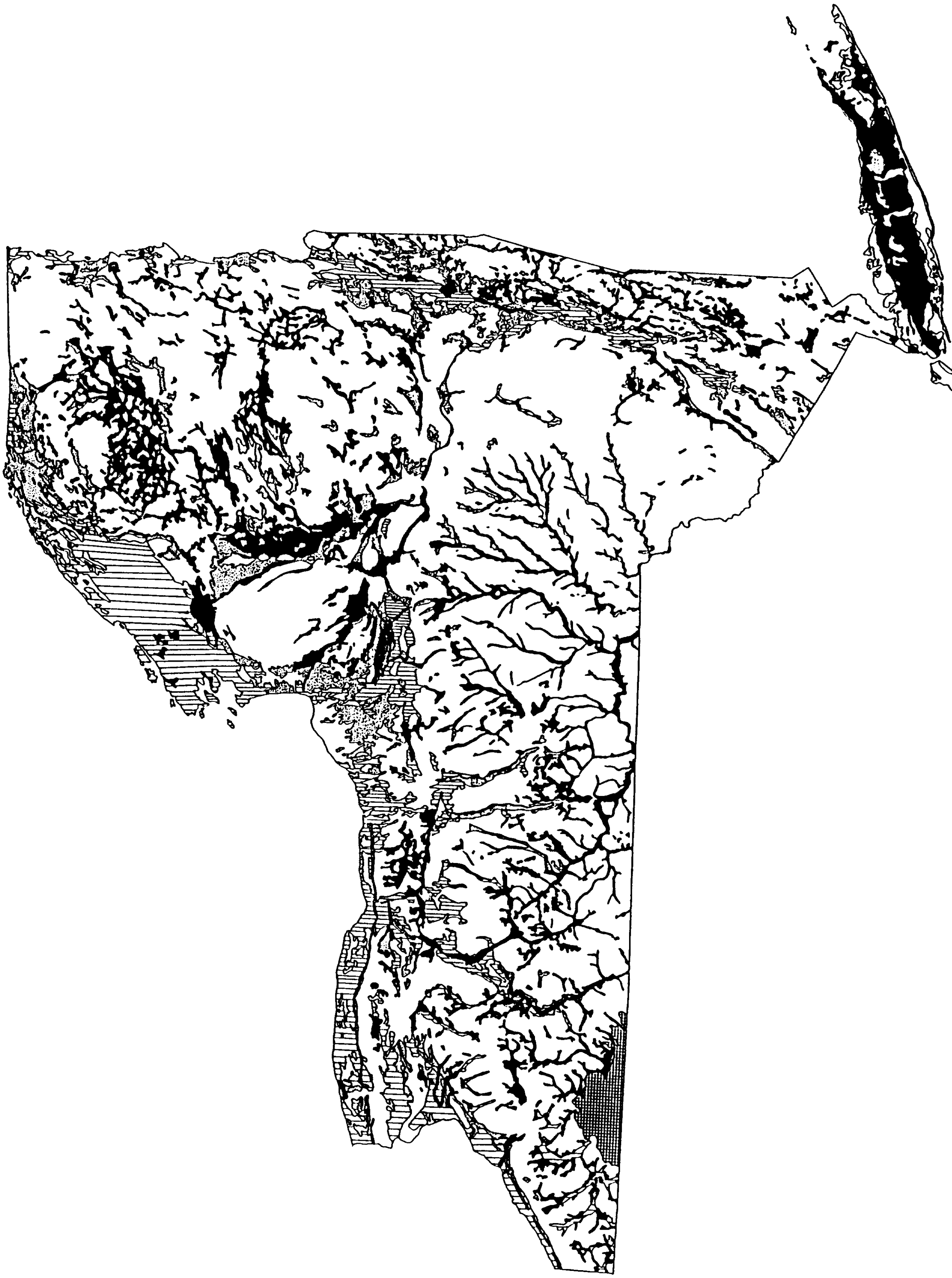

Figure 5. Generalized glacial map of New York (after Richmond and Fullerton, 1991, 1992; and Cadwell and Pair, 1991).

GENERALIZED GLACIAL MAP OF NEW YORK

EXPLANATION

Ice-contact stratified deposits—sorted and stratified gravel, sand, and silt, includes deposits of kames, kame moraines, kame terraces, outwash, glaciolacustrine and marine deltas, eskers; locally includes alluvium

Silt and clay glacial lake and marine deposits—sorted and stratified fine sand, silt, and clay of lake bottoms and shallow marine environments

Sandy glacial lake and marine deposits—sorted and stratified fine to coarse sand of shallow lake and marine environments and beaches

Till—unstratified, poorly sorted to unsorted mixture of gravel, sand, silt, and clay

Unglaciated area

Wisconsinan-age deposits or intermixed with younger outwash or moraine deposits. New York was occupied by three main glacial lobes during late Wisconsin time—the Ontario-Erie lobe in western New York, the Ontario lobe in the central part of the State (Fullerton, 1986; Richmond and Fullerton, 1991), and the Hudson-Champlain lobe in eastern New York (Cadwell and Dineen, 1987; Cadwell, 1989). Much of the glacial drift is locally derived and generally reflects the lithology of the underlying parent bedrock, although most tills include lesser amounts of material derived from bedrock source areas to the north.

Glacial deposits in New York can be generally classified into five categories: till, moraines, kame deposits, outwash and alluvium, and glacial lake deposits. Till varies from 1 to 50 meters thick and commonly covers flat or upland areas. The tills have variable texture, from clay through silt and sandy clay to boulder clay, and have generally low permeability. Tills are sandy in areas underlain by sandstone, granite, or gneiss (Cadwell and Dineen, 1987). Till moraines and kame moraines were formed at the margins of the retreating ice bodies. Moraines are linear or arcuate ridges of material that is variable in sorting and in grain size, typically containing sand to boulders; they usually contain less fine-grained material and thus are generally more permeable than till, especially kame moraines. Kame deposits (which include kames, eskers, and kame deltas) are composed of coarse to fine gravel and sand left by rivers and streams flowing along the margins, surface, or beneath the glacial ice. These deposits have moderate to high permeability, but may have lower permeability where they are locally cemented. River valleys are typically filled with alluvium or outwash sand and gravel deposits. Lacustrine (lake) deposits are composed of clay, silt, and locally, sand and are formed in valleys dammed by glacial ice. These deposits generally have low to moderate permeability. Glacial lake deposits often occupy low-lying areas, including the Erie-Ontario, St. Lawrence, Hudson-Mohawk, and Champlain Lowlands. Lacustrine beach and delta deposits occur locally at the margins of former glacial lakes and are composed of permeable sand and gravel. The following summary of surficial geology of New York is condensed and generalized from the surficial geologic map of New York and other reports (Cadwell, 1988, 1989; Cadwell and Pair, 1991; Cadwell and Dineen, 1987; Muller and Cadwell, 1986). The reader is urged to consult these maps and reports for more detailed information.

Glaciers in eastern New York moved primarily north-south or northeast-southwest. The Adirondack Mountains diverted the continental ice sheet to the east and west while valley glaciers formed in the mountains (Muller, 1965). The glaciers moved southward along the Hudson-Mohawk Valley, terminating on Long Island and in northern New Jersey. As the Hudson-Champlain lobe retreated northward, a glacial lake called Lake Albany formed, filling the entire Hudson Valley. At its maximum extent, Lake Albany reached a length of about 224 km and a width of 13-20 km (Cadwell and Dineen, 1987). As a result, much of the floor of the Hudson Valley is occupied by glaciolacustrine silts and clays. Lacustrine delta deposits composed of sand and gravel are found along Kinderhook Creek, the Hoosic River, in the Batten Kill, and along the Mohawk River. The Champlain Valley was occupied at various times by three glacial lakes: Quaker Springs, Coveville, and Fort Ann (Connally and Sirkin, 1973).

Till of variable thickness covers much of eastern New York. Deposits of drift in the valleys are thicker (up to 100 m) than those in the uplands (generally less than 5 m). Coarse-grained glacial drift partly fills most valleys in the Adirondacks. Glacial deposits are thin or absent in parts of the Taconic Mountains, Hudson Highlands, and Catskill Mountains. Moraines run the length of Long Island and indicate the maximum advances of the Hudson-Champlain lobe on western Long Island and the Connecticut and Rhode Island lobes on central and eastern Long Island (Cadwell, 1989).

Glacial erosion and deposition in central and western New York were most extensive in the Erie-Ontario Lowland and in the east-west belt of arcuate uplands that includes the northern part of the Finger Lakes. To the south, glacial modification of the landscape becomes progressively less intense (Muller and Cadwell, 1986). Except for bedrock exposures in uplands of the Finger Lakes region and on steeper slopes in the south-central and western parts of the State, the landscape of central and western New York is covered by a mantle of glacial deposits ranging in thickness from a few meters in upland areas to several hundred meters in valley bottoms. As the late Wisconsinan ice margin retreated north of the bedrock divide comprising the Finger Lakes region, meltwater was impounded in the many glacially-carved valleys that are now the Finger Lakes. Several minor ice advances failed to extend south of the divide, and these fluctuations built a complex of coarse-grained, poorly sorted moraines, called the Valley Heads Moraine, which extends in an arcuate east-west belt along the southern edge of the Finger Lakes (Muller and Cadwell, 1986).

As a result of these processes, the character of the glacial deposits in central and western New York changes from mostly till in the south, with alluvium, outwash, and abundant kame terraces filling stream valleys, to moraines and kame deposits in the Finger Lakes region, with bedrock exposures in the uplands and deposits of glacial Lake Newberry in the troughs of the Finger Lakes, to deposits of glacial Lake Iroquois in the Erie-Ontario Lowland. Lacustrine clays are the primary deposit type along the shores of Lakes Erie and Ontario, surrounding the southern part of Lake Oneida, and at the northern ends of most of the Finger Lakes. Sandy lake deposits surround the northern, eastern, and western sides of Lake Oneida, the northern ends of Seneca and Keuka Lakes, and are found south and west of Rochester. Interspersed with deposits of Lake Iroquois are outwash, kames, moraines, drumlins, and other features typical of kame-and-kettle topography (Muller and Cadwell, 1986).

SOILS

Three main orders—Alfisols, Inceptisols, and Spodosols—represent most of the soils in New York, although Entisols, Ultisols, and Histosols are also found in significant amounts (U.S. Soil Conservation Service, 1987; Cline and Marshall, 1977). Figure 6 is a generalized map showing soils of New York. The following discussion is condensed primarily from Cline and Marshall (1977); the reader is urged to consult this report or U.S. Soil Conservation Service county soil surveys for more detailed maps and descriptions of soils for specific areas within the State.

Soils in the Adirondacks are mostly Spodosols, soils with light-colored, eluvial near-surface horizons and accumulations of iron and humus in the subsurface. These acidic soils are derived from mafic metamorphic rocks; metasediments; some granites and granitic gneisses; and glacial deposits derived from these rocks. Most of the Spodosols in New York are coarse loamy or sandy in texture, and those developed in glacial till are stony or bouldery. Most of these soils have significant clay accumulations or fragipans in the subsurface, causing them to be poorly drained and slowly permeable (Cline and Marshall, 1977), although most of these soils likely have moderate to high permeability below the B horizon. Wet soils occur in northern Franklin and Clinton Counties, in a north-south trending band in central Lewis County, and in northwestern Lewis County and adjacent areas in Jefferson County. Some parts of the Adirondacks and Hudson Highlands have rock outcrops at the surface with no discernible soil cover.

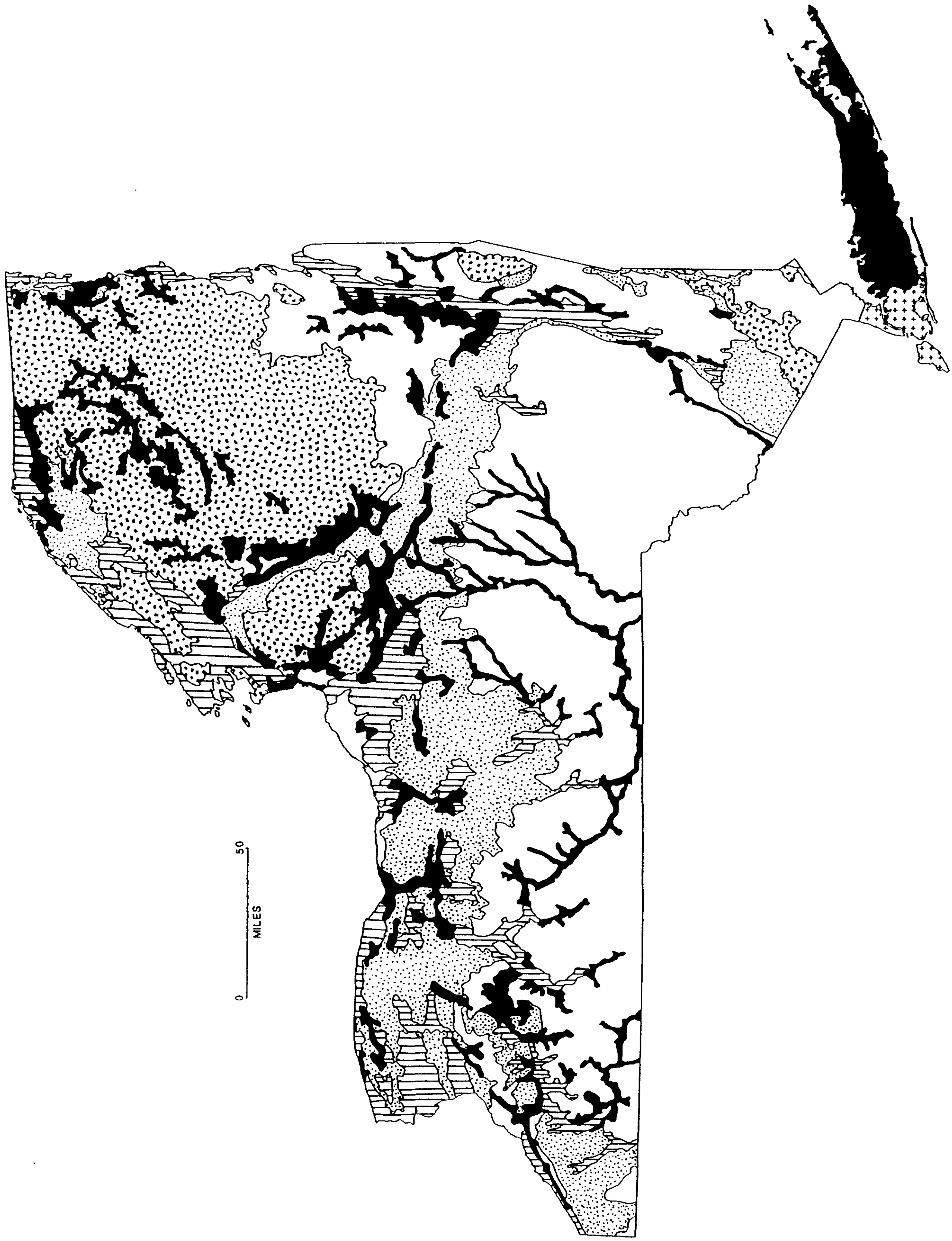

Figure 6. Generalized soils map of New York (modified from Cline and Marshall, 1977).

GENERALIZED SOIL MAP OF NEW YORK
EXPLANATION

Clayey and loamy soils, and soils with fragipans developed on glacial till derived from limestone and shale – *low permeability*

Coarse-textured, shallow, stony soils, and deeper soils with fragipans, developed on glacial till derived from shale, siltstone, sandstone, and conglomerate – *low to moderate permeability*

Stony, coarse-loamy and sandy soils with fragipans developed on glacial till derived from metamorphic rocks – *low permeability*. Includes large areas of bedrock with little or no soil cover

Sandy and gravelly soils developed on glacial outwash, kames, moraines, deltas, and alluvium – *dominantly high permeability, locally moderate permeability*

Clayey and silty soils with clayey subsurface horizons developed on glacial lake deposits – *low to locally moderate permeability*

Urban land – unknown or variable soil characteristics

Soils in the St. Lawrence Lowland, the northern part of the Erie-Ontario Lowland, the Champlain and Hudson Valleys, and northward-draining valleys of the Allegheny Plateau are Alfisols derived from glacial lake and marine sediments. These soils are commonly calcareous and have clayey subsurface horizons. Because of their silty to clayey texture and the presence of clay horizons, these soils have low permeability; however, soils formed on dominantly silty lake deposits have moderate permeability. With the exception of the northern part of the Erie-Ontario Lowland from eastern Orleans County to Oswego County and the southern part of the Hudson River valley, these soils are classified as occasionally to typically wet .

Soils in the remainder of the Erie-Ontario Lowland, the Mohawk Valley, and the Finger Lakes region of the Allegheny Plateau are Alfisols developed on glacial till derived from limestone, dolomite, and shale. These soils are commonly calcareous and contain subsurface clay horizons. Soil texture ranges from loamy to finely loamy in soils developed from carbonate-rich till to clayey in soils developed on shale-rich tills. Most of these soils are slowly permeable, but a few of these soils north of the Finger Lakes region are classified as moderately permeable. Soils in the eastern Mohawk Valley, parts of the Finger Lakes region, and in the western part of the Allegheny Plateau are classified as commonly wet.

Soils of the Allegheny Plateau are shallow to deep Inceptisols developed on glacial till derived from sandstone and shale, including black shale. These soils are generally acidic throughout the profile and contain cambic horizons, leached zones with thin iron oxide coatings on sand and silt grains. Approximately half of the soils in this area have fragipans in the subsurface that act as a barrier to air and water migration in the soil. Soil texture ranges from sandy and gravelly in soils developed on coarse-grained till to clayey in soils developed on shale-rich till. Soil permeability ranges from moderately high to low and generally follows soil texture, i.e., coarser-grained soils generally have higher permeability, except those soils with fragipans, which are uniformly poorly drained and are considered to have low permeability. Wet soils are common in the western and central parts of the Allegheny Plateau region. Soils in the New England Upland are similar to those in the Allegheny Plateau except that they are developed on glacial till derived from carbonate rocks and metasedimentary rocks as well as sandstones and shales. Soils classified as wet are less common in the New England Upland than in the Allegheny Plateau region.

Soils of the Valley and Ridge are acidic Alfisols with fragipans and clayey horizons. These soils are developed on glacial till derived from limestone, dolomite, sandstone, siltstone, and shale. These soils have generally poor internal drainage and low permeability, and are typically wet unless situated on slopes. However, soils derived from coarser-grained parent materials may have moderate to locally high permeability beneath the fragipan. Soils of this same classification also occur in the southern Finger Lakes region and in the western part of the Allegheny Plateau.

Soils in the Triassic Basin are acidic Inceptisols with fragipans below cambic horizons. These soils are developed on glacial till derived from sandstone, siltstone, shale, metasedimentary rocks, and intrusive igneous rocks. They are poorly drained and have low overall permeability due to the presence of fragipans, but may have moderate permeability beneath the fragipan layer. Soils of the Manhattan Prong are acidic Inceptisols with cambic horizons developed on glacial till derived from sandstone, shale, marble, gneiss, schist, amphibolite, and quartzite. Soil cover ranges from shallow to none (rock outcrops). These soils are generally sandy to gravelly and have moderate to high permeability. Soils of Long Island and the New York City area are Inceptisols developed on glacial outwash, alluvium, and marine sediments. They are typically sandy to gravelly, well drained, and rapidly permeable.

RADIOACTIVITY

An aeroradiometric map of New York (fig. 7) was compiled from spectral gamma-ray data acquired during the U.S. Department of Energy's National Uranium Resource Evaluation (NURE) program (Duval and others, 1989). For the purposes of this report, low equivalent uranium (eU) on the map is defined as less than 1.5 parts per million (ppm), moderate eU is defined as 1.5-2.5 ppm, and high eU is defined as greater than 2.5 ppm. In figure 7, low eU (<1.5 ppm), is found throughout the Erie-Ontario Lowland. The Adirondacks have generally low surface eU with the exception of the metasedimentary rocks that form the outer edge of the Adirondacks, especially in the Northwest Lowlands. The Tug Hill Plateau and Champlain Lowland are also low in radioactivity. The St. Lawrence Lowland has low to moderate eU. Moderate eU covers much of the Allegheny Plateau with some low eU areas along the northern edge of the plateau. Moderate to high eU is found throughout the New England Upland, the Hudson-Mohawk Lowland, the Hudson Highlands, part of the Triassic Lowland, and the Manhattan Prong. High eU is associated with the Catskill Mountains of the Allegheny Plateau, the southern Allegheny Plateau, the Valley and Ridge, parts of the Hudson Highlands, and parts of the Taconic Mountains.

INDOOR RADON

As part of their statewide indoor radon testing program, a number of different indoor radon surveys have been conducted and compiled by the State of New York since 1985. For the assessment done by the authors of this report, volunteer basement and first-floor indoor radon data from 39,070 charcoal canister tests across New York State were used. These data were supplied by the New York State Department of Health, duplicates were eliminated from the original data set and the resulting data set is given in Table 1. These data are also presented in map format in figure 8. A map of county names is included for reference (fig. 9). The average for the State in this data set is 5.2 pCi/L. Thirty percent of the measurements were greater than 4 pCi/L and 5 percent of the measurements exceeded 20 pCi/L The data were compiled over several years and several seasons. Because these data are statistically non-random, the arithmetic mean will tend to be biased towards higher readings (Cohen, 1990). However, these data do emphasize distinct areas of low and high radon in the State and provide some distinction within the higher radon categories, especially when comparing the average and geometric means for each county. Areas of the State with county indoor radon geometric means greater than 4 pCi/L occur in the Allegheny Plateau and New England Upland, particularly the Taconic Mountains. Geometric means between 2 and 4 pCi/L occur in the Allegheny Plateau, Hudson-Mohawk Lowlands, Tug Hill Plateau, and Hudson Highlands. Geometric means less than 2 pCi/L occur in the St. Lawrence-Champlain Lowlands, the High Peaks, and much of the Adirondacks, much of the Erie-Ontario Lowlands, the Manhattan Prong, the Triassic Lowlands, and the Atlantic Coastal Plain.

New York State has also conducted a statewide random survey of more than 2000 homes using alpha-track detectors (Perritt and others, 1988). They divided New York into seven areas (fig. 10) based on geologic and geographic factors and placed several detectors in each home for several periods of time. Table 2 shows the statistics for two-month winter alpha-track data placed in the living area of the home. Table 3 shows 12-month alpha track data placed in the living area of the homes. Table 4 shows 12-month alpha track data placed in the basement of the same homes. Areas 1, 2, and 7 were consistently above the average for the State for each data set. The highest average alpha-track measurements were found in area 1, the eastern-southern tier underlain by the

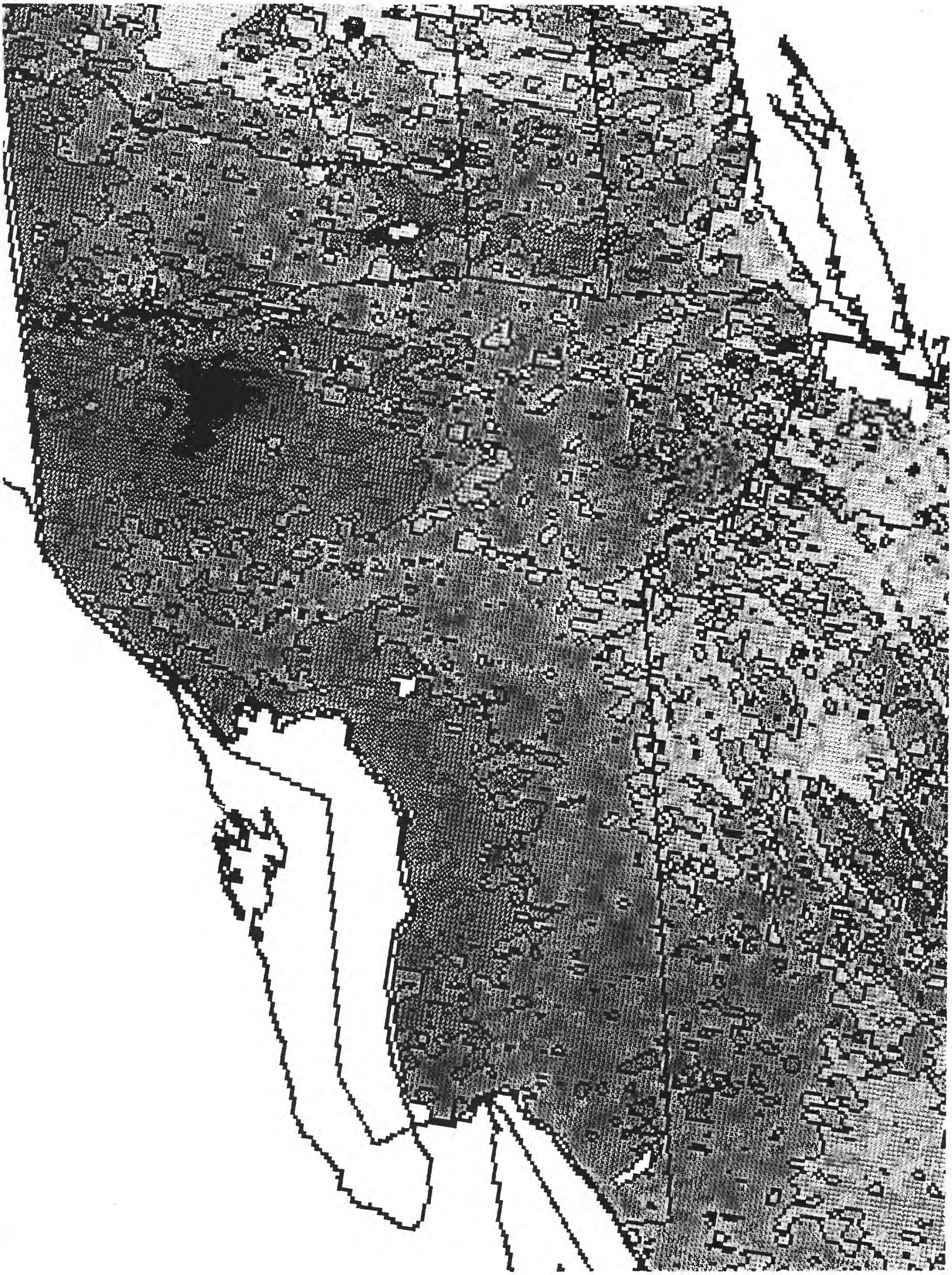

Figure 7. Aerial radiometric map of New York (after Duval and others, 1989). Contour lines at 1.5 and 2.5 ppm equivalent uranium (eU). Pixels shaded at 0.5 ppm eU increments; darker pixels have lower eU values; white indicates no data.

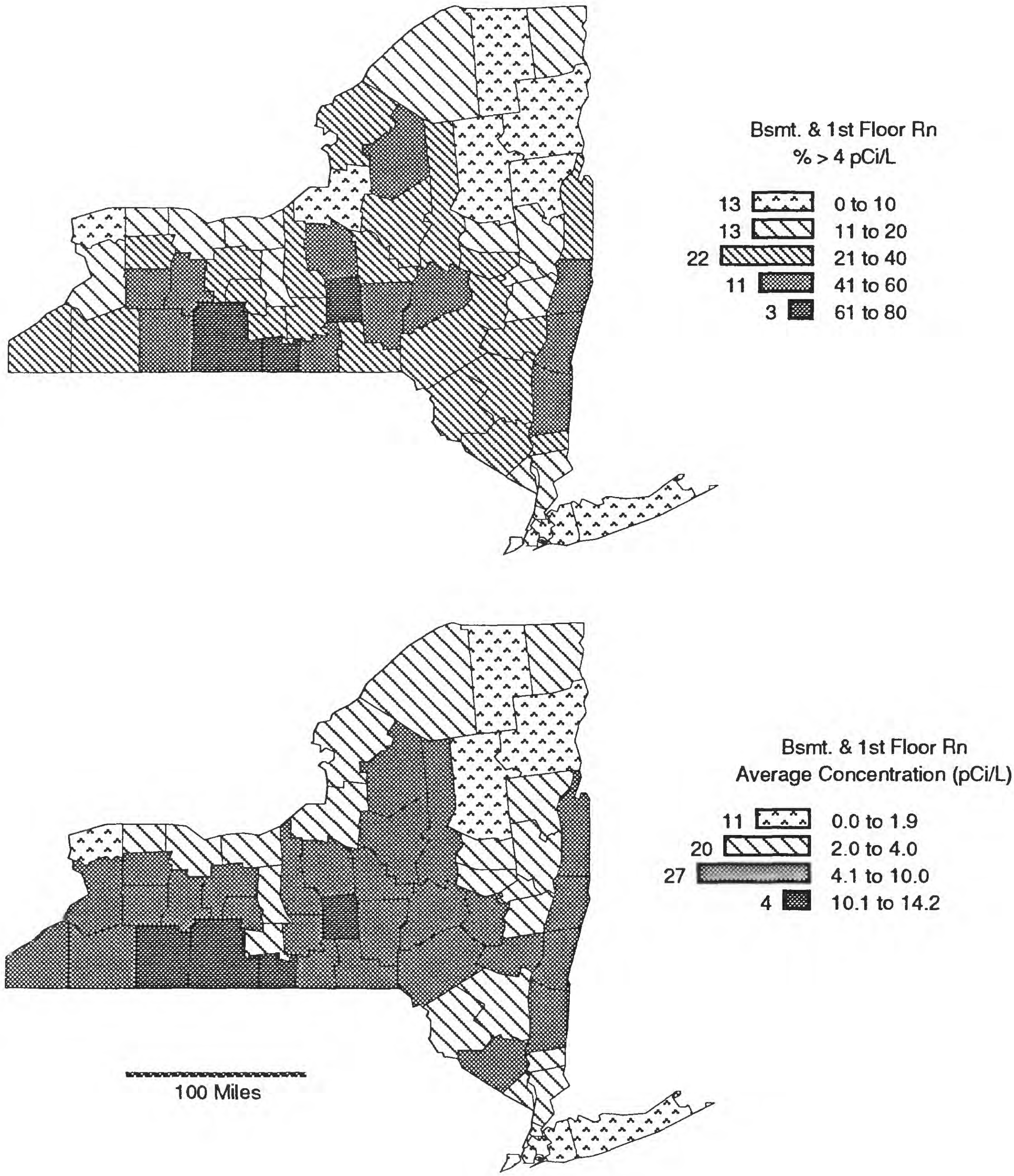

Figure 8. Screening indoor radon measurements from 39,070 homes, compiled by the New York State Department of Health. Data are from 2-7 day charcoal canister measurements. Histograms in map legends show the number of counties in each category.

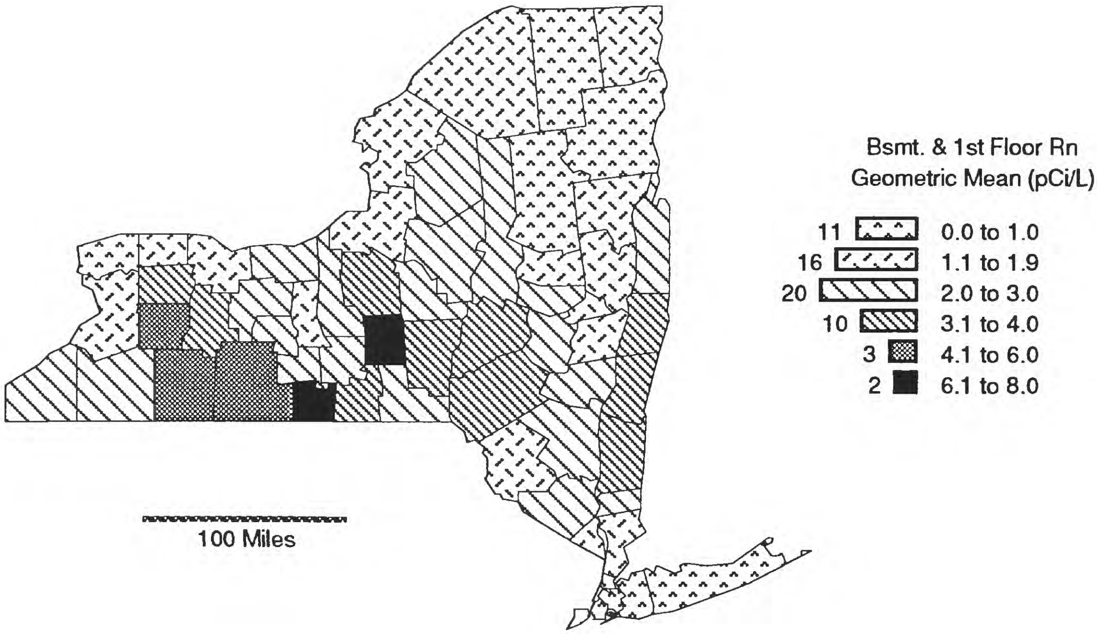

Fig. 8 continued

Table 1. Screening indoor radon data compiled by the New York State Department of Health. Data represent 1-7 day charcoal canister measurements from the lowest level of each home tested.

COUNTY	NO. OF MEAS.	AVERAGE	STD. DEV.	MEDIAN	GEOM. MEAN	MAX	%>4 pCi/L	%>20 pCi/L
Albany	1183	3.7	8.3	1.5	1.6	100.6	19	3
Allegany	212	10.2	14.0	4.7	4.6	113.7	55	17
Bronx	1123	1.4	2.0	0.8	0.8	21.9	5	0
Broome	1826	5.7	13.1	2.4	2.6	319.9	35	5
Cattaraugus	394	6.5	12.4	2.7	3.0	119.4	40	6
Cayuga	440	4.4	7.0	2.5	2.5	81.9	31	3
Chautauqua	651	5.3	9.4	1.9	2.2	102.1	31	4
Chemung	1195	12.4	13.6	7.6	6.9	98.4	69	21
Chenango	255	8.5	13.8	3.6	3.8	105.5	47	11
Clinton	132	2.2	3.3	1.3	1.2	23.2	13	1
Columbia	304	7.0	18.0	3.8	3.6	298.0	49	6
Cortland	380	14.2	15.1	9.9	8.0	107.4	73	23
Delaware	348	7.0	13.8	2.8	3.1	152.4	39	7
Dutchess	2454	6.3	8.0	4.1	3.8	135.2	51	4
Erie	4671	4.4	14.2	1.1	1.3	371.9	18	4
Essex	122	1.5	2.7	0.9	0.9	26.3	5	1
Franklin	71	1.3	1.3	0.9	0.8	6.2	3	0
Fulton	103	2.1	2.3	1.4	1.3	13.5	12	0
Genesee	339	7.7	20.6	3.1	3.4	322.7	39	8
Greene	137	4.4	8.4	2.1	2.1	72.4	28	3
Hamilton	20	1.6	1.5	1.0	1.0	5.5	10	0
Herkimer	147	4.6	6.1	2.5	2.5	44.2	33	3
Jefferson	127	3.0	4.2	1.6	1.5	28.8	23	1
Kings	1123	1.4	2.0	0.8	0.8	21.9	5	0
Lewis	56	4.4	4.9	2.5	2.5	26.4	41	2
Livingston	139	6.2	9.3	3.5	3.4	76.6	47	4
Madison	265	4.8	6.8	2.7	2.6	57.7	35	4
Monroe	1298	2.8	8.4	1.4	1.5	214.4	12	2
Montgomery	147	3.6	4.5	1.9	2.0	32.7	31	1
Nassau	589	1.2	1.2	1.0	0.9	9.6	3	0
New York	1123	1.4	2.0	0.8	0.8	21.9	5	0
Niagara	712	1.7	2.2	1.0	1.0	17.3	8	0
Oneida	729	5.1	7.6	2.5	2.6	79.0	35	4
Onondaga	4749	8.5	16.2	3.6	3.7	341.8	47	10
Ontario	352	5.3	10.1	2.4	2.7	125.0	32	5
Orange	1098	4.5	6.8	2.5	2.4	85.5	33	3
Orleans	476	3.2	6.3	1.7	1.7	86.4	18	2
Oswego	170	2.0	2.9	1.2	1.3	29.6	9	1
Otsego	494	8.0	17.4	4.2	3.8	299.7	52	7
Putnam	624	4.0	5.6	2.3	2.2	47.5	31	2
Queens	1123	1.4	2.0	0.8	0.8	21.9	5	0
Rensselaer	648	6.4	9.4	3.5	3.3	103.2	46	5
Richmond	1123	1.4	2.0	0.8	0.8	21.9	5	0

Table 1 (continued).

COUNTY	NO. OF MEAS.	AVERAGE	STD. DEV.	MEDIAN	GEOM. MEAN	MAX	%>4 pCi/L	%>20 pCi/L
Rockland	2469	2.2	4.3	1.3	1.3	123.7	11	1
St. Lawrence	195	2.3	4.5	1.4	1.3	56.8	12	1
Saratoga	578	3.2	5.1	1.8	1.8	56.9	20	1
Schenectady	506	3.0	6.0	1.7	1.7	84.9	19	1
Schoharie	151	5.4	8.8	2.8	2.7	58.9	38	5
Schuyler	70	4.0	3.4	3.1	2.7	18.5	40	0
Seneca	144	2.5	2.9	1.7	1.6	19.5	15	0
Steuben	593	11.2	14.6	5.8	5.5	133.4	63	17
Suffolk	356	1.6	2.6	1.1	1.0	42.6	6	0
Sullivan	154	3.1	4.6	1.8	1.7	38.0	21	2
Tioga	541	8.3	14.9	3.7	3.8	236.8	48	9
Tompkins	460	4.4	5.8	2.6	2.7	54.6	32	2
Ulster	596	4.0	7.9	2.3	2.2	114.3	28	2
Warren	121	2.1	2.5	1.4	1.3	20.1	10	1
Washington	119	4.7	7.1	2.1	2.3	43.6	29	3
Wayne	142	3.8	5.8	1.8	2.0	35.3	20	4
Westchester	2365	2.4	3.8	1.5	1.5	95.4	13	1
Wyoming	233	8.9	14.7	3.9	4.1	137.4	48	12
Yates	97	5.8	9.3	2.8	2.8	69.0	38	5

Figure 9. New York counties (from Facts on File, 1984).

Table 2. Weighted summary statistics for the New York State short-term, living-area radon study, overall and by geographic region. Values in pCi/L (from Perritt and others, 1988).

REGION	SAMPLE SIZE	POPULATION ESTIMATE	MEAN	STD. ERROR	MEDIAN	90th PERCENTILE	MAXIMUM
State	2401	2,600,830	1.39	0.05	0.86	2.51	39.8
Eastern & Southern Tier	346	82,929	3.34	0.30	1.31	8.81	39.8
Central & Western	767	1,078,804	1.58	0.10	0.95	3.21	28.4
North-eastern	545	137,452	1.09	0.08	0.81	1.86	21.6
Eastern	276	374,910	1.82	0.18	1.06	3.42	20.9
Staten Island	51	58,676	0.75	0.06	0.63	1.22	2.4
Long Island	335	563,816	0.87	0.04	0.73	1.75	3.4
New York City	81	304,243	0.81	0.08	0.78	1.46	2.4

Table 3. Weighted summary statistics for the New York State long-term, living-area radon study, overall and by geographic region. Values in pCi/L (from Perritt and others, 1988).

REGION	SAMPLE SIZE	POPULATION ESTIMATE	MEAN	STD. ERROR	MEDIAN	90th PERCENTILE	MAXIMUM
State	2043	2,598,722	1.13	0.05	0.6	2.2	38.3
Eastern & Southern Tier	307	81,810	2.65	0.26	1.2	6.0	38.3
Central & Western	655	1,075,537	1.33	0.08	0.8	2.7	21.7
North-eastern	465	137,475	0.88	0.06	0.6	1.7	9.5
Eastern	238	377,165	1.51	0.15	0.9	3.2	16.2
Staten Island	41	58,408	0.55	0.06	0.4	1.1	2.3
Long Island	273	563,816	0.68	0.04	0.5	1.2	7.4
New York City	64	304,512	0.64	0.10	0.5	1.4	5.1

Table 4. Weighted summary statistics for the New York State long-term, basement radon study, overall and by geographic region. Values in pCi/L (from Perritt and others, 1988).

REGION	SAMPLE SIZE	POPULATION ESTIMATE	MEAN	STD. ERROR	MEDIAN	90th PERCENTILE	MAXIMUM
State	1716	2,187,865	2.68	0.13	1.4	5.3	115.0
Eastern & Southern Tier	262	70,186	6.58	0.69	3.6	14.7	115.0
Central & Western	561	912,234	3.05	0.25	1.5	6.7	52.9
North-eastern	371	112,241	2.56	0.35	1.3	4.4	65.7
Eastern	199	300,925	4.02	0.36	2.2	9.0	31.5
Staten Island	35	46,836	1.35	0.17	1.2	3.2	3.6
Long Island	231	461,512	1.49	0.08	1.2	2.9	6.5
New York City	57	283,929	1.30	0.13	1.1	2.4	3.5

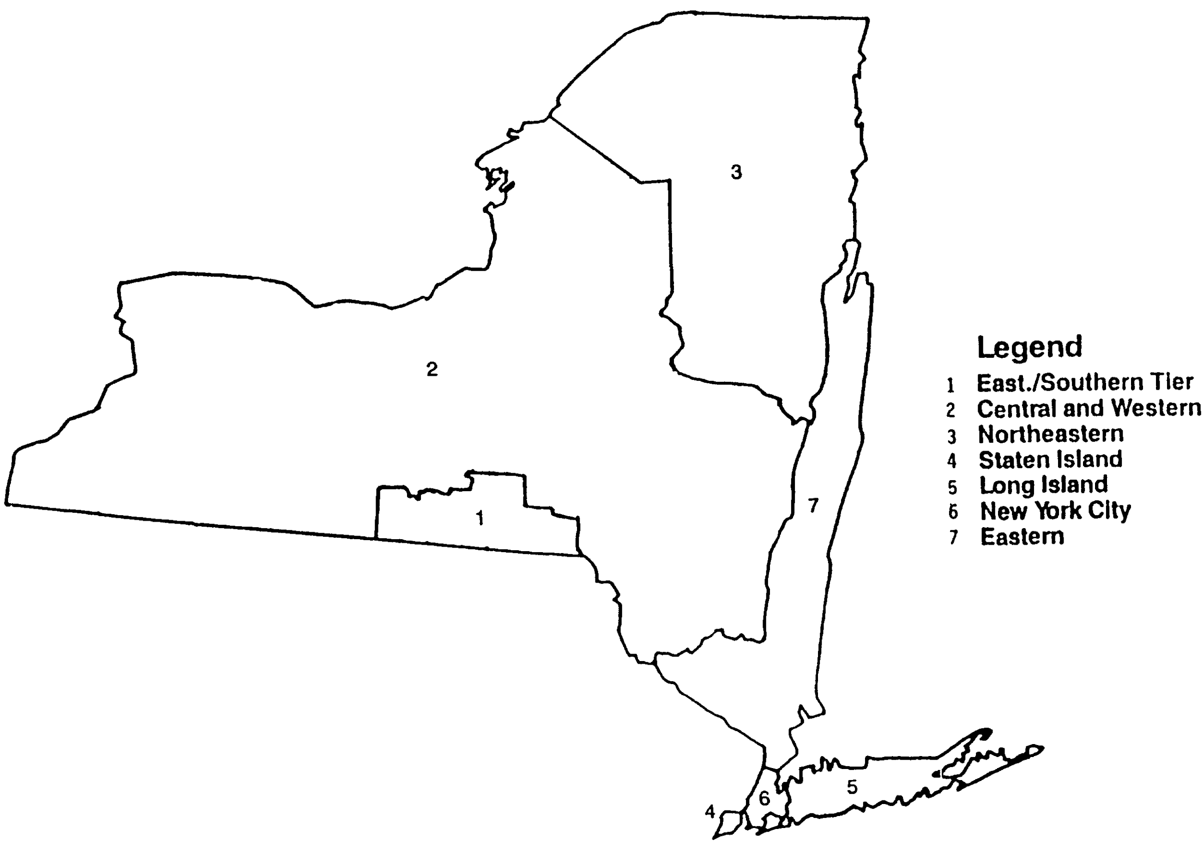

Figure 10. Map showing the 7 geographic regions used in the above tables by Perritt and others (1988).

shales and sandstones of the West Falls, Sonyea, and Genesee Groups. Coarse glacial gravel deposits in valleys are also common in this area. The area with the second highest average measurements is area 7, which is underlain by metamorphic, igneous, and deformed sedimentary rocks of the Taconic Mountains, Hudson Highlands, Valley and Ridge, and Manhattan Prong, as well as the undeformed sediments of the Triassic Lowlands. Area 2, the central and western area, had alpha-track measurements that averaged greater than the State average. This area is underlain by undeformed shales, sandstones, siltstones, and carbonates. Perritt and others (1988) also noted a distinct difference between the 12-month and 2-month measurements. They observed that the 12-month living area measurements were higher than the 2-month winter living area measurements and that the 12-month basement measurements were the highest in the data set.

GEOLOGIC RADON POTENTIAL

Several studies have been conducted in New York State relating the geology of the State to indoor radon occurrences. The most comprehensive of these was done by the New York State Department of Health (Laymon and others, 1990). In their study, the authors examined the indoor radon, geology, radioactivity, and soil data to arrive at general potential ratings for geologic provinces within the State. Other studies have concentrated on particular areas of the State with high radon (Kunz and others, 1987; Kunz and others, 1989; Laymon and Kunz, 1991; Hand and Banikowski, 1988a, 1988b; Schwenker and others, 1992).

The following section discusses the geologic radon potential of New York in the context of the data presented thus far and radon studies conducted by the State. A scoring system for geologic radon potential is presented in Table 5 following this section. Table 6 lists the counties of the State, the major geologic province and indoor radon average of the county, and highlights counties with more than one province of contrasting radon potential and the possibilities for variations in indoor radon within the county.

The Erie-Ontario Lowland/Tug Hill Plateau

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. Equivalent uranium (fig. 7) is generally low to moderate in this area. Counties in the Erie-Ontario Lowland have indoor radon geometric means less than 2 pCi/L and average concentrations of indoor radon less than 4 pCi/L. Lewis County is the exception in that the indoor radon average is 4.4 and the geometric mean is 2.5 pCi/L. A veneer of impermeable clay covers a significant part of the Erie-Ontario Lowlands but discrete occurrences of very coarse gravel and some of the marine shales may cause some of the moderate and locally high radon measurements found in the area. Laymon and others (1990) ranked the Erie-Ontario Lowlands as having low radon source strength, low permeability, and consequently low radon potential, but the authors indicate that radon potential is high in association with gravels in drumlins, outwash, moraines, till, and beach ridges. 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 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 geology, variably low to high permeability, and low to moderate radioactivity.

The Hudson-Mohawk Lowland

The Hudson-Mohawk Lowland is underlain by sandstone, siltstone, shale and conglomerates of variable age. In this assessment, the lowland has been ranked moderate/variable in radon potential because the geology and glacial deposits of the area are highly variable and radon potential varies likewise from low to high. Equivalent uranium (fig. 7) is generally moderate to locally high in this area. Soils have moderate to locally high permeability. Counties in the Hudson-Mohawk Lowland have indoor radon geometric means in the low to moderate range (less than 3 pCi/L), and average concentrations of indoor radon between 2 and 4 pCi/L (fig. 8). Kunz and others (1989) discovered high levels of indoor and soil radon associated with the coarse gravel deposits in Albany County. In their study, the geometric mean for 675 basement indoor radon measurements in Albany County was 20.2 pCi/L for homes built on glacial gravels. Schwenker and others (1992) have done a detailed study in Albany County using a Geographic Information System mapping program and looking at surficial geology and indoor radon. They confirmed the results of the study by Kunz and others (1989) and further delineated areas of low and moderate radon in the county and the associated glacial deposits. Schwenker and others (1992) found indoor radon geometric means for lacustrine delta and kame deposits were 3.6 pCi/L and 3.2 pCi/L respectively. Homes built on recent floodplain deposits and lacustrine silt and clay had indoor radon geometric means of 1.5 pCi/l and 1.1 pCi/L respectively. The indoor radon geometric means for lacustrine sand and dune sand were both 0.9 pCi/L. The New York State Department of Health is intending to extend their Geographic Information Systems-based study of indoor radon to the rest of New York State.

Laymon and others (1990) have suggested that the Hudson-Mohawk Lowland is highly variable in radon potential but that the gravelly kame and till deposits found above the valley bottoms and gravel concentrations in sandy glacial deposits are high in radon potential. They also note that the region is underlain predominantly by shale with average to below-average radium concentrations and that indoor radon over the shales is generally low.

The St. Lawrence and Champlain Lowlands

The St. Lawrence and Champlain Lowlands are underlain by sedimentary rocks of Cambrian through early Ordovician age with relatively low radon potential. However, some of the very coarse gravel deposits have moderate to high radon potential. Equivalent uranium (fig. 7) is generally low with a few moderate areas. Counties in the lowlands have indoor radon geometric means less than 2 pCi/L and average concentrations of indoor radon less than 3 pCi/L. The Cambrian rocks are dominantly conglomerates and coarse sandstones, known as the Potsdam Sandstone. In the basal conglomerate of the Potsdam, local accumulations of monazite, a uranium- and thorium-bearing mineral, occur. The rest of the section consists of siltstone, dolomite, limestone, shale, and sandstone that are relatively low in uranium. 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. Laymon and others (1990) ranked the St. Lawrence-Champlain Lowlands as having low radon source strength, low permeability, and consequently low radon potential. They also indicate that 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 are ranked moderate in radon potential.

The Allegheny Plateau

The Allegheny Plateau is underlain by sedimentary rocks, predominantly shales, limestones, and sandstones. Soils in the southern 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 moderate to low in radon potential, especially areas in the Catskill Mountains. Equivalent uranium (fig. 7) 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 portions of the plateau have high radon potential in association with coarse kame, till, and other gravel deposits which are restricted generally to valleys. Two belts of uraniferous black shale cross central and southern New York and cause significant high indoor radon from Onondaga County to Erie County. The Marcellus Shale and West Falls Group shales appear to be the source for this radon. Uranium and radium concentrations in these shales are high (Laymon and others, 1990) but variable. Laymon and others (1990) also note that other black shales and related sedimentary rocks in the plateau do not appear to have as high a uranium content. Studies of radon in Onondaga County by Laymon and Kunz (1991) indicate that high indoor radon is related to the uraniferous Marcellus Shale and also related to gravelly glacial deposits and high permeability zones around the substructure of houses built into limestone bedrock. Hand and Banikowski (1988a, 1988b) speculate that elevated indoor radon concentrations near the contact between the Onondaga limestone and the Marcellus Shale are due to remobilization of uranium from the shale into the fractured limestone. Of the northern counties in the Allegheny Plateau, Seneca County is the only county with an indoor radon average less than 4 pCi/L and it is considered moderate in 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.

According to Kunz and others (1989) and Laymon and others (1990), gravelly glacial deposits are the cause of most of the high radon found in the southern plateau, probably due to high permeability and radon emanation. Their field studies indicate that gravelly soils with a silty loam matrix are probably the source for the highest indoor radon. Because the alluvial valley and moraine deposits are discrete bodies (fig. 5), 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 comes 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. Since many of the uplands are highly fractured shales, there is a geologic potential for elevated indoor radon.

Devonian sandstones in the eastern portion of the plateau and Catskill Mountains are variable in uranium concentrations—some may locally contain up to 53 ppm (Way and Freidman, 1980), but generally the sandstones are in the 1-2 ppm range. 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. This county is considered to have moderate radon potential.

Most counties in the Allegheny Plateau have indoor radon geometric means in the 2-4 pCi/L range and county averages $\geq$ 4 pCi/L. Four counties—Allegany, Chemung, Cortland, and Steuban—have indoor radon county averages exceeding 10 pCi/L.

The New England Upland-Hudson Highlands, Taconic Mountains, and Manhattan Prong

The Hudson Highlands, which are the northeastern extension of the Reading Prong, has been ranked high in radon potential, but the radon potential is actually highly variable. These mountains contain a wide variety rock types and compositions. Equivalent uranium (fig. 7) 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-ray anomalies are well documented in the Hudson Highlands by McKeown and Klemic (1953); Prucha (1956), Klemic and others (1959), Grauch and Zarinski (1976), Grauch (1978), and Gundersen (1984, 1986). Uraninite and other U-bearing minerals form layers and disseminations in several kinds of host rocks, including magnetite deposits, pegmatites, intrusive granitic rocks, marble, veins, and biotite-garnet gneiss with layers of monazite and xenotime. Uranium mineralization in the gneisses and magnetite deposits is often conformable with the compositional layering and is localized. These uranium deposits appear to be the cause for local occurrences of very high indoor radon levels. Faults and shear zones in the Highlands are also host to uranium mineralization and are well known throughout the Appalachians for causing high indoor radon levels (Gundersen, 1991). New York State has compiled a brittle structures map for the State (Isachsen and McKendree, 1977) and faults may be an important radon source in parts of the Adirondacks and New England Uplands.

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 concentrations of uranium in these rocks is so variable, indoor radon is likewise highly variable. The Hudson Highlands underlie parts of Putnam and Orange Counties that have county indoor radon geometric means of 2.4 and 2.8 pCi/L respectively (Table 1) and county indoor radon averages greater than 4 pCi/L. Laymon and others (1990) have ranked the Hudson Highlands 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 (fig. 7). 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 ≤ 1.5 pCi/L and average indoor radon ≤ 2.4 pCi/L (fig. 8). Laymon and others (1990) ranked the Manhattan Prong low in radon potential and we concur in this assessment.

The Taconic Mountains-New England Upland 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 (fig. 7) is moderate to locally high. Soil permeability is low to moderate, with locally high permeability in glacial gravels. Laymon and others (1990) classified the region as having moderate potential but he also states that little is known about the indoor radon in the area. In their limited studies, Kunz and others (1989) showed that high indoor radon appears to be related to highly permeable glacial and fluvial sediments along the valleys of the New England Upland.

Adirondack Mountains

The High Peaks and most of the central Adirondacks are made up of anorthosite and charnockitic gneiss, both of which are low in uranium and unlikely to cause radon problems. The rim of the Adirondacks are predominantly metasedimentary and metavolcanic rocks noted for base metal deposits, several of which have known local uranium occurrences and have locally high radon potential. The iron deposits in eastern Essex County between Crown Point and Westport are locally enriched in uranium, as are granitic and syenitic gneiss in Clinton County and granitic gneiss and pegmatite at the Benson Mines in St. Lawrence County (McKeown and Klemic, 1953). Laymon and others (1990) note that mine tailings from the Essex County deposits contain as much as 204 ppm of uranium and that building blocks for local homes were made from this material, but they do not indicate whether high radon was found in these homes. Four uranium occurrences have also been identified in Lewis County associated with magnetite and sulfide deposits in granitic gneiss, pegmatite, and amphibolite (Grauch and Zarinski, 1976).

Equivalent uranium (fig. 7) 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 sand 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 ≤ 1.5 pCi/L in Essex, Hamilton, and Franklin Counties, but greater than 2 pC/L for Herkimer, Warren, St. Lawrence, and Lewis Counties. These counties also lie partially in other geologic provinces. Laymon and others (1990) have ranked the Adirondacks low in radon potential, with the uranium occurrence areas having locally high radon potential. 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.

Valley and Ridge

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 can be locally low to moderate. Cambrian and Ordovician rocks are a marine shelf sequence with basal Cambrian sandstones and conglomerates followed by a highly variable sequence of interbedded shales and limestones. Recent studies of indoor radon and soil radon in Orange County by J. Driscoll and A.E. Gates of Rutgers University and L.C.S. Gundersen of the U.S. Geological Survey (unpublished data) indicate that 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 they form in the valleys of the area are elevated in uranium. The studies also indicate that indoor radon (3 month alpha-track) is elevated (> 4 pCi/L) in basements of homes built in limestone soils of the Wallkill Valley, in black shale bedrock, and especially in glacial gravel deposits of black shales. Equivalent uranium (fig. 7) is moderate to high in the Valley and Ridge. Indoor radon in Orange County (Table 1) averages 4.5 pCi/L and the geometric mean is 2.4 pCi/L.

The Triassic Lowland

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. There are no uranium occurrences reported in the Newark Supergroup of New York. 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 (fig. 7) is low to moderate in the Triassic Lowlands. Soil permeability is generally low to moderate. The Triassic Lowlands have been ranked low in radon potential.

Atlantic Coastal Plain

Long Island, in the Atlantic Coastal Plain Province, is made up of glacial deposits and marine sediments with little or no known uranium concentrations. 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. Laymon and others (1990) ranked the Atlantic Coastal Plain as low in radon potential because of the low radium content of the soils; however, they did note that a number of boulders in the moraines 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 high radon.

SUMMARY

For the purpose of this assessment, New York has been divided into ten geologic radon potential areas and each area assigned a Radon Index (RI) and a Confidence Index (CI) score (Table 5). The RI is a relative measure of radon potential based on geology, soils, radioactivity, architecture, and indoor radon. The CI is a measure of the relative confidence of the RI assessment based on the quality and quantity of the data used to assess geologic radon potential (see the Introduction chapter to this regional booklet for more information). The radon potential areas are shown in figure 11.

Indoor radon data for New York, when compared with geology, indicate that certain surficial deposits and rocks of the Allegheny Plateau, Hudson Highlands, Taconic Mountains and Valley and Ridge Provinces have the potential to produce high levels of indoor radon (> 4 pCi/L). Surficial deposits and rocks of the Hudson-Mohawk Lowland, Erie-Ontario Lowlands, the Champlain and St. Lawrence Lowlands, and the Northwest Lowlands of the Adirondacks are generally more moderate in radon potential but may be locally high where glacial deposits are highly permeable. Surficial deposits and rocks of the Adirondacks, the Triassic Lowlands, Manhattan Prong, and the Atlantic Coastal Plain are relatively low in radon potential.

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

TABLE 5. RI and CI scores for geologic radon potential areas of New York.

FACTOR	St. Lawrence-Champlain Lowland RI	CI	Erie-Ontario Lowland RI	CI	Hudson-Mohawk Lowland/Northwest Lowlands RI	CI	Allegheny Plateau RI	CI
INDOOR RADON	2	2	2	2	2	2	2	2
RADIOACTIVITY	1	2	1	2	2	2	2	2
GEOLOGY	2	3	2	3	2	3	3	3
SOIL PERM.	1	3	1	3	2	3	2	3
ARCHITECTURE	3	-	3	-	3	-	3	-
GFE POINTS	0	-	0	-	0	-	0	-
TOTAL	9	10	9	10	11	10	12	10
	Mod	High	Mod	High	Mod	High	High	High

FACTOR	Taconic Mts.-New England Upland RI	CI	Manhattan Prong RI	CI	Hudson Highlands RI	CI	Adirondack Mountains High Peaks RI	CI
INDOOR RADON	3	2	1	2	2	2	1	2
RADIOACTIVITY	2	2	1	2	2	2	1	2
GEOLOGY	2	2	2	2	2	3	1	3
SOIL PERM.	2	3	2	3	2	3	2	3
ARCHITECTURE	3	-	2	-	3	-	3	-
GFE POINTS	0	-	0	-	2	-	0	-
TOTAL	12	9	8	9	13	10	8	10
	High	Mod	Low	Mod	High	High	Low	High

FACTOR	Valley and Ridge RI	CI	Triassic Lowland RI	CI	Atlantic Coastal Plain RI	CI
INDOOR RADON	3	2	1	2	1	2
RADIOACTIVITY	2	2	1	2	1	1
GEOLOGY	2	3	1	3	1	3
SOIL PERM.	2	3	2	3	2	3
ARCHITECTURE	3	-	3	-	2	-
GFE POINTS	0	-	0	-	0	-
TOTAL	12	10	8	10	7	9
	High	High	Low	High	Low	Mod

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

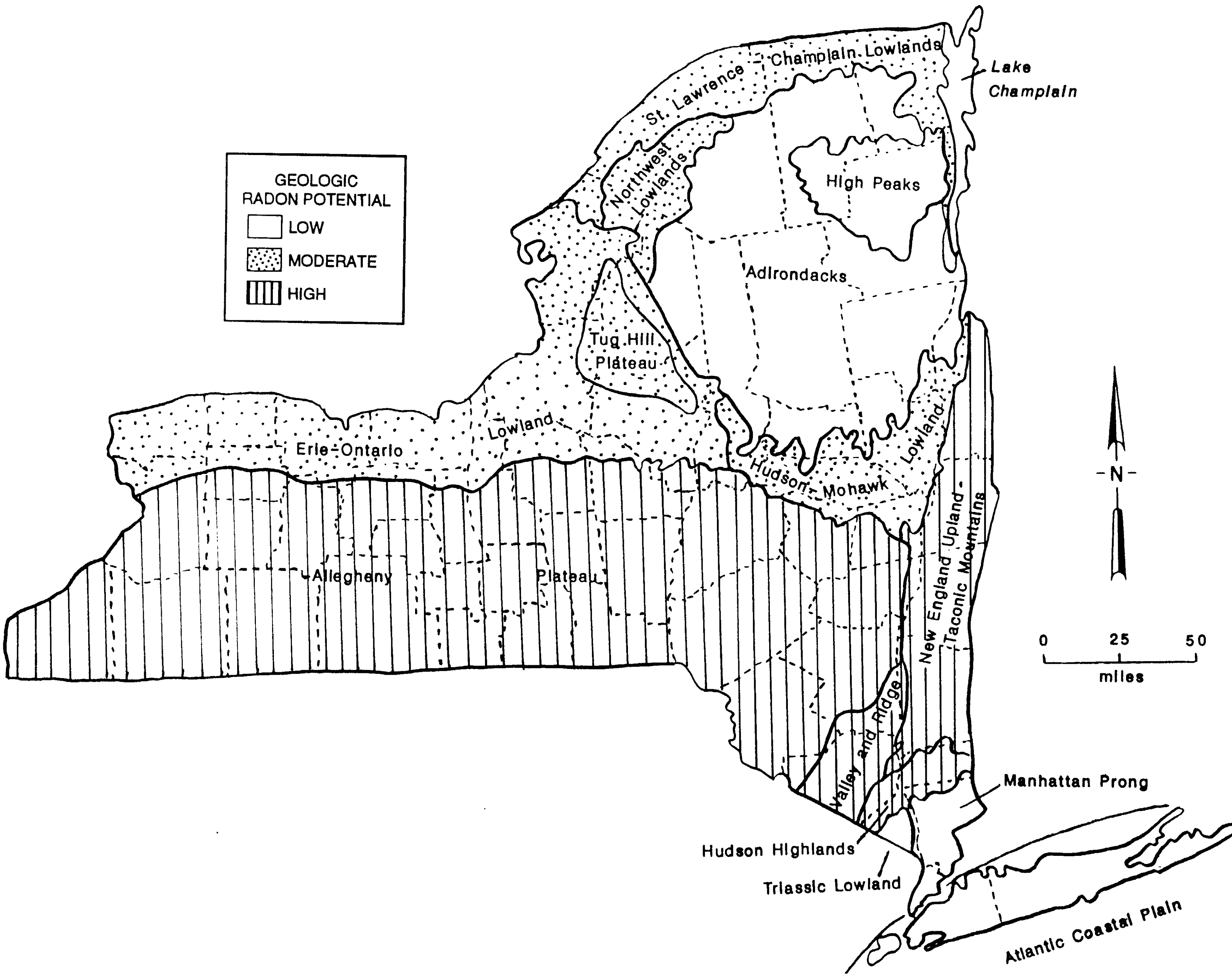

Figure 11. Geologic radon potential areas of New York. See Table 5 for rankings of areas.

Table 6. Geologic radon potential and screening indoor radon averages for counties in New York. "Dominant Geologic Province" indicates the geologic province occupied by all or most of the county. A * indicates counties located in 2 or more provinces with different geologic radon potential. An # indicates counties in which the geologic radon potential ranking differs from the rank based on screening indoor radon average. The variability of the geology in these counties affects the indoor radon levels and more detailed information from state and local officials should be used when assessing these areas.

COUNTY	DOMINANT GEOLOGIC PROVINCE	GEOL. RADON POTENTIAL	INDOOR Rn RANK (EPA)	INDOOR Rn AVERAGE
Albany	Hudson-Mohawk Lowland *	MODERATE	MODERATE	3.7
Allegany	Allegheny Plateau	HIGH	HIGH	10.2
Broome	Allegheny Plateau	HIGH	HIGH	5.7
Cattaraugus	Allegheny Plateau	HIGH	HIGH	6.5
Cayuga	Allegheny Plateau *	HIGH	HIGH	4.4
Chautauqua	Allegheny Plateau	HIGH	HIGH	5.3
Chemung	Allegheny Plateau	HIGH	HIGH	12.4
Chenango	Allegheny Plateau	HIGH	HIGH	8.5
Clinton	St. Lawrence-Champlain Lowland *	MODERATE	MODERATE	2.2
Columbia	New England Upland-Taconics	HIGH	HIGH	7.0
Cortland	Allegheny Plateau	HIGH	HIGH	14.2
Delaware	Allegheny Plateau	HIGH	HIGH	7.0
Dutchess	New England Upland-Taconics	HIGH	HIGH	6.3
Erie	Allegheny Plateau *	HIGH	HIGH	4.4
Essex	Adirondacks	LOW	LOW	1.5
Franklin	St. Lawrence-Champlain Lowland *	LOW	LOW	1.3
Fulton	Adirondacks *	LOW #	MODERATE	2.1
Genesee	Allegheny Plateau *	HIGH	HIGH	7.7
Greene	Allegheny Plateau *	HIGH	HIGH	4.4
Hamilton	Adirondacks	LOW	LOW	1.6
Herkimer	Adirondacks *	LOW #	HIGH	4.6
Jefferson	Erie-Ontario Lowland *	MODERATE	MODERATE	3.0
Lewis	Tug Hill Plateau *	MODERATE #	HIGH	4.4
Livingston	Allegheny Plateau *	HIGH	HIGH	6.2
Madison	Allegheny Plateau *	HIGH	HIGH	4.8
Monroe	Erie-Ontario Lowland *	MODERATE	MODERATE	2.8
Montgomery	Hudson-Mohawk Lowland	MODERATE	MODERATE	3.6
Nassau	Coastal Plain	LOW	LOW	1.2
Niagara	Erie-Ontario Lowland	MODERATE #	LOW	1.7
Oneida	Erie-Ontario Lowland *	MODERATE #	HIGH	5.1
Onondaga	Allegheny Plateau *	HIGH	HIGH	8.5
Ontario	Allegheny Plateau *	HIGH	HIGH	5.3
Orange	Valley and Ridge *	HIGH	HIGH	4.5
Orleans	Erie-Ontario Lowland	MODERATE	MODERATE	3.2
Oswego	Erie-Ontario Lowland *	MODERATE	MODERATE	2.0
Otsego	Allegheny Plateau	HIGH	HIGH	8.0
Putnam	Hudson Highlands *	HIGH #	MODERATE	4.0
Rensselaer	New England Upland-Taconics	HIGH	HIGH	6.4
Rockland	Triassic Lowland *	LOW #	MODERATE	2.2
St. Lawrence	St. Lawrence-Champlain Lowland *	MODERATE	MODERATE	2.3
Saratoga	Hudson-Mohawk Lowland *	MODERATE	MODERATE	3.2
Schenectady	Hudson-Mohawk Lowland	MODERATE	MODERATE	3.0
Schoharie	Allegheny Plateau *	HIGH	HIGH	5.4
Schuyler	Allegheny Plateau	HIGH #	MODERATE	4.0

Table 6 (continued).

COUNTY	DOMINANT GEOLOGIC PROVINCE	GEOL. RADON POTENTIAL	INDOOR Rn RANK (EPA)	INDOOR Rn AVERAGE
Seneca	Allegheny Plateau *	HIGH #	MODERATE	2.5
Steuben	Allegheny Plateau	HIGH	HIGH	11.2
Suffolk	Coastal Plain	LOW	LOW	1.6
Sullivan	Allegheny Plateau	HIGH #	MODERATE	3.1
Tioga	Allegheny Plateau	HIGH	HIGH	8.3
Tompkins	Allegheny Plateau	HIGH	HIGH	4.4
Ulster	Allegheny Plateau *	HIGH #	MODERATE	4.0
Warren	Adirondacks *	LOW #	MODERATE	2.1
Washington	New England Upland-Taconics *	HIGH	HIGH	4.7
Wayne	Erie-Ontario Lowland	MODERATE	MODERATE	3.8
Westchester	Manhattan Prong *	LOW #	MODERATE	2.4
Wyoming	Allegheny Plateau	HIGH	HIGH	8.9
Yates	Allegheny Plateau	HIGH	HIGH	5.8
New York City	Coastal Plain	LOW	LOW	1.4

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