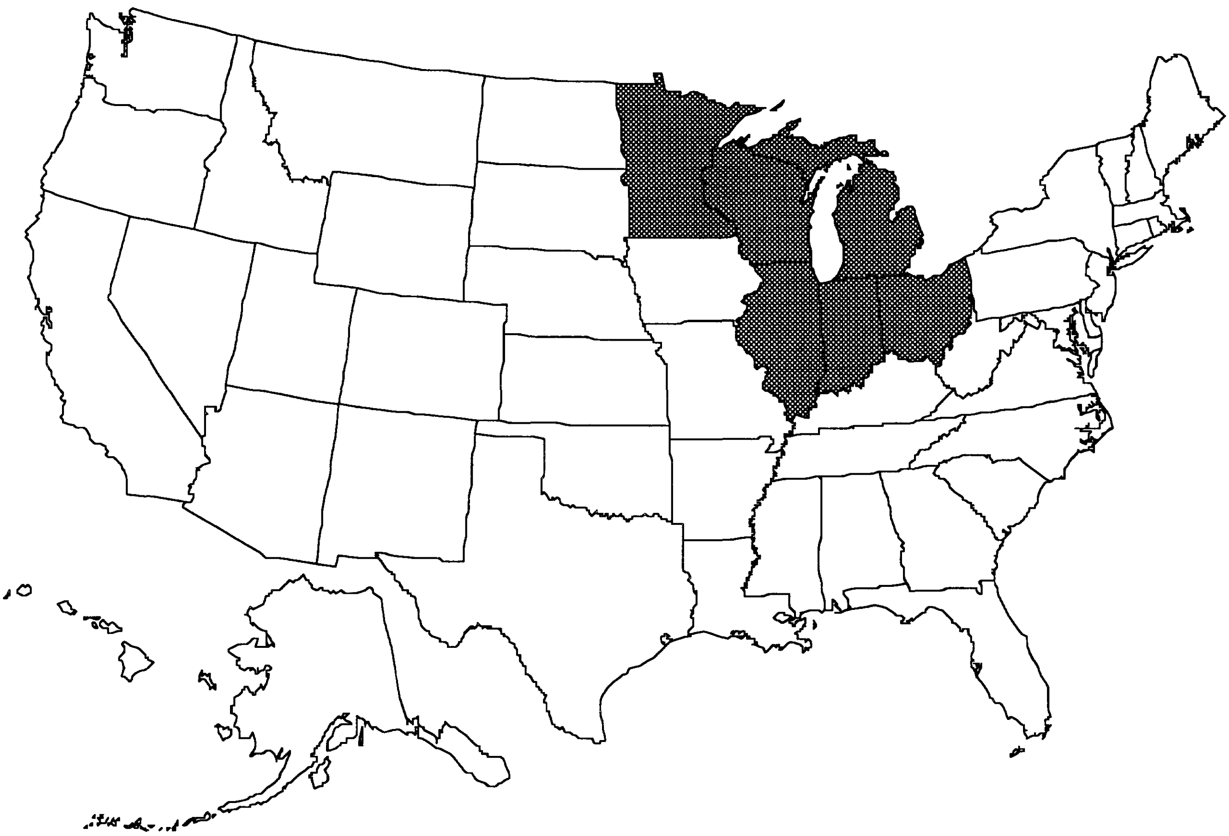
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

# GEOLOGIC RADON POTENTIAL OF EPA REGION 5

Illinois Indiana Michigan Minnesota Ohio Wisconsin



## OPEN-FILE REPORT 93-292-E

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

**1993**

U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

# GEOLOGIC RADON POTENTIAL OF EPA REGION 5

Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin

R. Randall Schumann
*EDITOR*

OPEN-FILE REPORT 93-292-E

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

1993

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.

## CONTENTS

ACKNOWLEDGMENTS

These reports are the culmination of a 3-year cooperative project involving, almost literally, a "cast of thousands." Sharon W. White and R. Thomas Peake of the U.S. Environmental Protection Agency coordinated the project for EPA and provided data, comments, assistance, and support. They did an exemplary job and we appreciate their work and our association with the EPA Radon program. The Association of American State Geologists (AASG), through each of the State geological surveys, provided reviews and information that greatly aided in the preparation of the reports and enhanced the final products. Special thanks are due to the AASG committee, consisting of Walter Schmidt (chairman), Robert Fakundiny, Mark Davis, Michael Mudrey, Jonathan Price, Charles Robertson, and John Rold. We also thank the State radon program representatives, whose comments and technical assistance are greatly appreciated.

Technical assistance in preparation of the maps and materials was ably provided by Michele Killgore, Debra Mickelson, Michele Murray, Mark Pyle, and Sandra Szarzi. We thank Helen Britton, Carole Buntenbah, Marge Cunningham, Marian Nance, and Gwen Pilcher for their assistance in manuscript processing. The project chiefs, Linda Gundersen and Randall Schumann, express thanks to those named here and to many others unnamed, but appreciated nonetheless.

# THE USGS/EPA RADON POTENTIAL ASSESSMENTS: AN INTRODUCTION

*by*
*Linda C.S. Gundersen and R. Randall Schumann*
*U.S. Geological Survey*
*and*
*Sharon W. White*
*U.S. Environmental Protection Agency*

## 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

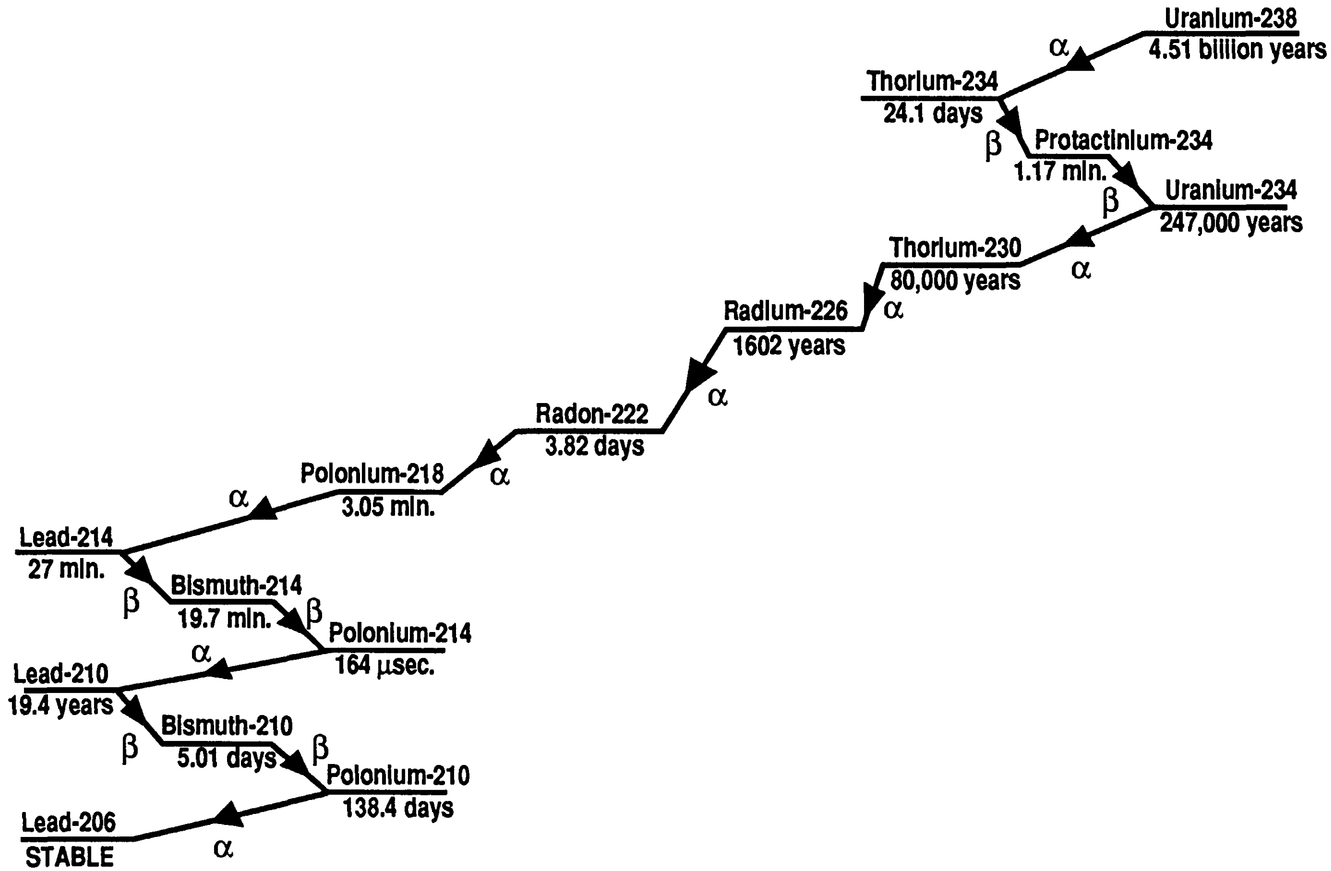



Figure 1. The uranium-238 decay series, showing the half-lives of elements and their modes of decay (after Wanty and Schoen, 1991). α denotes alpha decay, β denotes beta decay.

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 $2x10^{-6}$ 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.

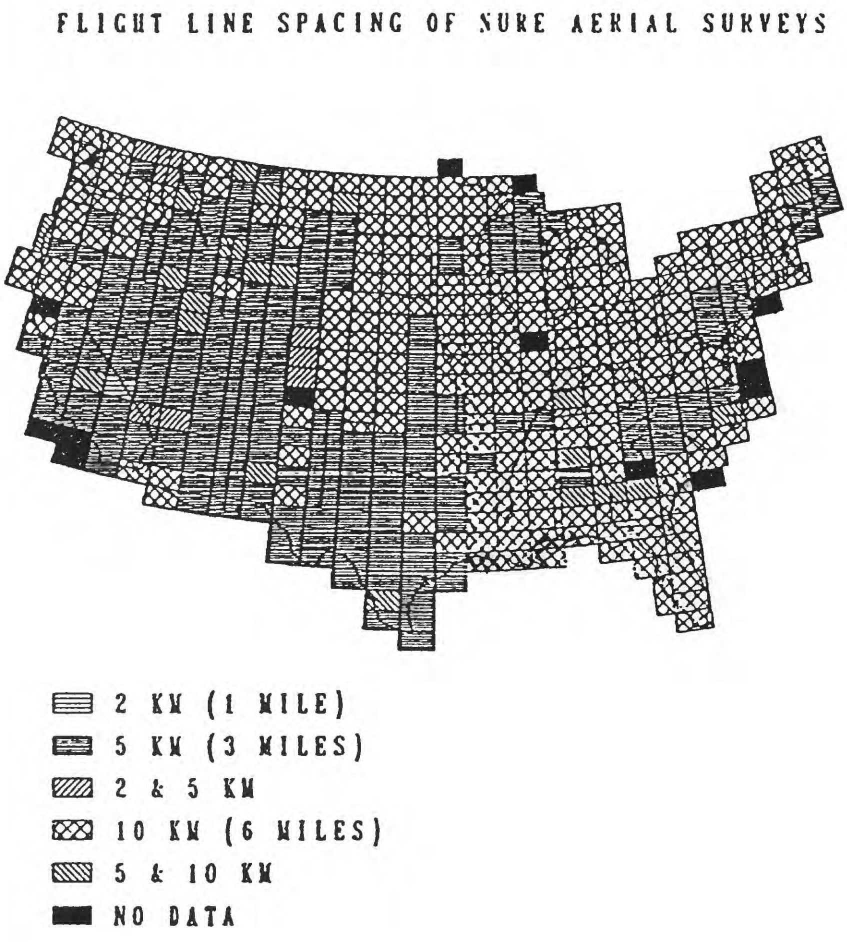



Figure 2. Nominal flightline spacings for NURE aerial gamma-ray surveys covering the contiguous United States (from Duval and others, 1990). Rectangles represent 1°x2° quadrangles.

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

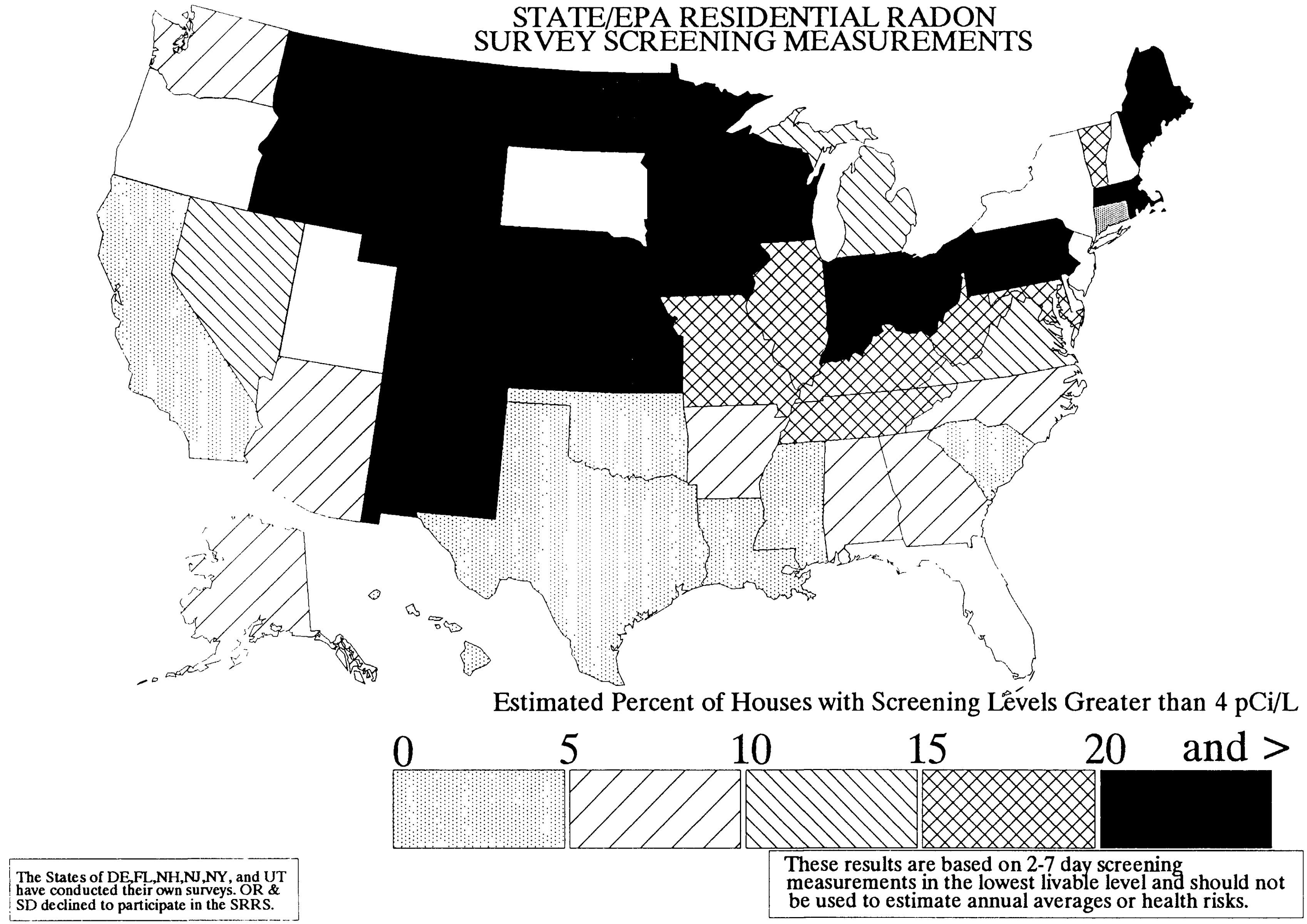



Figure 3. Percent of homes tested in the State/EPA Residential Radon Survey with screening indoor radon levels exceeding 4 pCi/L.

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.

## REFERENCES CITED


Akerblom, G., Anderson, P., and Clavensjo, B., 1984, Soil gas radon--A source for indoor radon daughters: Radiation Protection Dosimetry, v. 7, p. 49-54.

Deffeyes, K.S., and MacGregor, I.D., 1980, World uranium resources: Scientific American, v. 242, p. 66-76.

Durrance, E.M., 1986, Radioactivity in geology: Principles and applications: New York, N.Y., Wiley and Sons, 441 p.

Duval, J.S., 1989, Radioactivity and some of its applications in geology: Proceedings of the symposium on the application of geophysics to engineering and environmental problems (SAGEEP), Golden, Colorado, March 13-16, 1989: Society of Engineering and Mineral Exploration Geophysicists, p. 1-61.

Duval, J.S., Cook, B.G., and Adams, J.A.S., 1971, Circle of investigation of an airborne gamma-ray spectrometer: Journal of Geophysical Research, v. 76, p. 8466-8470.

Duval, J.S., Jones, W.J., Riggle, F.R., and Pitkin, J.A., 1989, Equivalent uranium map of conterminous United States: U.S. Geological Survey Open-File Report 89-478, 10 p.

Duval, J.S., Reimer, G.M., Schumann, R.R., Owen, D.E., and Otton, J.K., 1990, Soil-gas radon compared to aerial and ground gamma-ray measurements at study sites near Greeley and Fort Collins, Colorado: U.S. Geological Survey Open-File Report 90-648, 42 p.

Dziuban, J.A., Clifford, M.A., White, S.B., Bergstein, J.W., and Alexander, B.V., 1990, Residential radon survey of twenty-three States, *in* Proceedings of the 1990 International Symposium on Radon and Radon Reduction Technology, Vol. III: Preprints: U.S. Environmental Protection Agency report EPA/600/9-90/005c, Paper IV-2, 17 p.

Gammage, R.B., Wilson, D.L., Saultz, R.J., and Bauer, B.C., 1993, Subtereanean transport of radon and elevated indoor radon in hilly karst terranes: Atmospheric Environment (in press).

Gundersen, L.C.S., Reimer, G.M., and Agard, S.S., 1988a, Correlation between geology, radon in soil gas, and indoor radon in the Reading Prong, *in* Marikos, M.A., and Hansman, R.H., eds., Geologic causes of natural radionuclide anomalies: Missouri Department of Natural Resources Special Publication 4, p. 91-102.

Gundersen, L.C.S, Reimer, G.M., Wiggs, C.R., and Rice, C.A., 1988b, Map showing radon potential of rocks and soils in Montgomery County, Maryland: U.S. Geological Survey Miscellaneous Field Studies Map MF-2043, scale 1:62,500.

Gundersen, Linda C.S., 1991, Radon in sheared metamorphic and igneous rocks, *in* Gundersen, Linda C.S., and Richard B. Wanty, eds., Field studies of radon in rocks, soils, and water: U.S. Geol. Survey Bulletin no. 1971, p. 39-50.

Henry, Mitchell E., Kaeding, Margret E., and Monteverde, Donald, 1991, Radon in soil gas and gamma-ray activity of rocks and soils at the Mulligan Quarry, Clinton, New Jersey, *in* Gundersen, Linda C.S., and Richard B. Wanty, eds., Field studies of radon in rocks, soils, and water: U.S. Geol. Survey Bulletin no. 1971, p. 65-75.

Klusman, R. W., and Jaacks, J. A., 1987, Environmental influences upon mercury, radon, and helium concentrations in soil gases at a site near Denver, Colorado: Journal of Geochemical Exploration, v. 27, p. 259-280.

Kovach, E.M., 1945, Meteorological influences upon the radon content of soil gas: Transactions, American Geophysical Union, v. 26, p. 241-248.

Kunz, C., Laymon, C.A., and Parker, C., 1989, Gravelly soils and indoor radon, *in* Osborne, M.C., and Harrison, J., eds., Proceedings of the 1988 EPA Symposium on Radon and Radon Reduction Technology, Volume 1: U.S. Environmental Protection Agency Report EPA/600/9-89/006A, p. 5-75--5-86.

Muessig, K., and Bell, C., 1988, Use of airborne radiometric data to direct testing for elevated indoor radon: Northeastern Environmental Science, v. 7, no. 1, p. 45-51.

Ronca-Battista, M., Moon, M., Bergsten, J., White, S.B., Holt, N., and Alexander, B., 1988, Radon-222 concentrations in the United States--Results of sample surveys in five states: Radiation Protection Dosimetry, v. 24, p. 307-312.

Rose, A.W., Washington, J.W., and Greeman, D.J., 1988, Variability of radon with depth and season in a central Pennsylvania soil developed on limestone: Northeastern Environmental Science, v. 7, p. 35-39.

Schery, S.D., Gaeddert, D.H., and Wilkening, M.H., 1984, Factors affecting exhalation of radon from a gravelly sandy loam: Journal of Geophysical Research, v. 89, p. 7299-7309.

Schumann, R.R., and Owen, D.E., 1988, Relationships between geology, equivalent uranium concentration, and radon in soil gas, Fairfax County, Virginia: U.S. Geological Survey Open-File Report 88-18, 28 p.

Schumann, R.R., and Gundersen, L.C.S., 1991, Regional differences in radon emanation coefficients in soils: Geological Society of America Abstracts With Programs, v. 23, no. 1, p. 125.

Schumann, R.R., Peake, R.T., Schmidt, K.M., and Owen, D.E., 1991, Correlations of soil-gas and indoor radon with geology in glacially derived soils of the northern Great Plains, *in* Proceedings of the 1990 International Symposium on Radon and Radon Reduction Technology, Volume 2, Symposium Oral Papers: U.S. Environmental Protection Agency report EPA/600/9-91/026b, p. 6-23--6-36.

Schumann, R.R., Owen, D.E., and Asher-Bolinder, S., 1992, Effects of weather and soil characteristics on temporal variations in soil-gas radon concentrations, *in* Gates, A.E., and Gundersen, L.C.S., eds., Geologic controls on radon: Geological Society of America Special Paper 271, p. 65-72.

Sextro, R.G., Moed, B.A., Nazaroff, W.W., Revzan, K.L., and Nero, A.V., 1987, Investigations of soil as a source of indoor radon, *in* Hopke, P.K., ed., Radon and its decay products: American Chemical Society Symposium Series 331, p. 10-29.

Sterling, R., Meixel, G., Shen, L., Labs, K., and Bligh, T., 1985, Assessment of the energy savings potential of building foundations research: Oak Ridge, Tenn., U.S. Department of Energy Report ORNL/SUB/84-0024/1.

Smith, R.C., II, Reilly, M.A., Rose, A.W., Barnes, J.H., and Berkheiser, S.W., Jr., 1987, Radon: a profound case: Pennsylvania Geology, v. 18, p. 1-7.

Tanner, A.B., 1964, Radon migration in the ground: a review, *in* Adams, J.A.S., and Lowder, W.M., eds., The natural radiation environment: Chicago, Ill., University of Chicago Press, p. 161-190.

Tanner, A.B., 1980, Radon migration in the ground: a supplementary review, *in* Gesell, T.F., and Lowder, W.M. (eds), Natural radiation environment III, Symposium proceedings, Houston, Texas, v. 1, p. 5-56.

U.S. Department of Agriculture, 1987, Principal kinds of soils: Orders, suborders, and great groups: U.S. Geological Survey, National Atlas of the United States of America, sheet 38077-BE-NA-07M-00, scale 1:7,500,000.

U.S. Department of Energy, 1976, National Uranium Resource Evaluation preliminary report, prepared by the U.S. Energy Research and Development Administration, Grand Junction, Colo.: GJO-11(76).

Wanty, Richard B., and Schoen, Robert, 1991, A review of the chemical processes affecting the mobility of radionuclides in natural waters, with applications, *in* Gundersen, Linda C.S., and Richard B. Wanty, eds., Field studies of radon in rocks, soils, and water: U.S. Geological Survey Bulletin no. 1971, p. 183-194.

Washington, J.W., and Rose, A.W., 1990, Regional and temporal relations of radon in soil gas to soil temperature and moisture: Geophysical Research Letters, v. 17, p. 829-832.

White, S.B., Bergsten, J.W., Alexander, B.V., and Ronca-Battista, M., 1989, Multi-State surveys of indoor $^{222}$Rn: Health Physics, v. 57, p. 891-896.

# APPENDIX A
# GEOLOGIC TIME SCALE

| Subdivisions (and their symbols) | | | | | | Age estimates of boundaries in mega-annum (Ma)[1] |
|---|---|---|---|---|---|---|
| Eon or Eonothem | Era or Erathem | Period, System, Subperiod, Subsystem | | Epoch or Series | | |
| 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 (T̄R) | | Late | Upper | |
| | | | | Middle | Middle | |
| | | | | Early | Lower | ~240 |
| | Paleozoic[2] (Pz) | Permian (P) | | Late | Upper | |
| | | | | Early | Lower | 290 (290–305) |
| | | Carboniferous Systems (C) | Pennsylvanian (ℙ) | Late | Upper | |
| | | | | Middle | Middle | |
| | | | | Early | Lower | ~330 |
| | | | Mississippian (M) | Late | Upper | |
| | | | | Early | Lower | 360 (360–365) |
| | | Devonian (D) | | Late | Upper | |
| | | | | Middle | Middle | |
| | | | | Early | Lower | 410 (405–415) |
| | | Silurian (S) | | Late | Upper | |
| | | | | Middle | Middle | |
| | | | | Early | Lower | 435 (435–440) |
| | | Ordovician (O) | | Late | Upper | |
| | | | | Middle | Middle | |
| | | | | Early | Lower | 500 (495–510) |
| | | Cambrian (Є) | | Late | Upper | |
| | | | | Middle | Middle | |
| | | | | Early | Lower | ~570[3] |
| Proterozoic (P̄) | 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 (pЄ), 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.

# APPENDIX C
# EPA REGIONAL OFFICES

**EPA Regional Offices**

EPA Region 1
JFK Federal Building
Boston, MA 02203
(617) 565-4502

EPA Region 2
(2AIR:RAD)
26 Federal Plaza
New York, NY 10278
(212) 264-4110

Region 3 (3AH14)
841 Chestnut Street
Philadelphia, PA 19107
(215) 597-8326

EPA Region 4
345 Courtland Street, N.E.
Atlanta, GA 30365
(404) 347-3907

EPA Region 5 (5AR26)
77 West Jackson Blvd.
Chicago, IL 60604-3507
(312) 886-6175

EPA Region 6 (6T-AS)
1445 Ross Avenue
Dallas, TX 75202-2733
(214) 655-7224

EPA Region 7
726 Minnesota Avenue
Kansas City, KS 66101
(913) 551-7604

EPA Region 8
(8HWM-RP)
999 18th Street
One Denver Place, Suite 1300
Denver, CO 80202-2413
(303) 293-1713

EPA Region 9 (A-3)
75 Hawthorne Street
San Francisco, CA 94105
(415) 744-1048

EPA Region 10
1200 Sixth Avenue
Seattle, WA 98101
(202) 442-7660

| State | EPA Region |
|---|---|
| Alabama | 4 |
| Alaska | 10 |
| Arizona | 9 |
| Arkansas | 6 |
| California | 9 |
| Colorado | 8 |
| Connecticut | 1 |
| Delaware | 3 |
| District of Columbia | 3 |
| Florida | 4 |
| Georgia | 4 |
| Hawaii | 9 |
| Idaho | 10 |
| Illinois | 5 |
| Indiana | 5 |
| Iowa | 7 |
| Kansas | 7 |
| Kentucky | 4 |
| Louisiana | 6 |
| Maine | 1 |
| Maryland | 3 |
| Massachusetts | 1 |
| Michigan | 5 |
| Minnesota | 5 |
| Mississippi | 4 |
| Missouri | 7 |
| Montana | 8 |
| Nebraska | 7 |
| Nevada | 9 |
| New Hampshire | 1 |
| New Jersey | 2 |
| New Mexico | 6 |
| New York | 2 |
| North Carolina | 4 |
| North Dakota | 8 |
| Ohio | 5 |
| Oklahoma | 6 |
| Oregon | 10 |
| Pennsylvania | 3 |
| Rhode Island | 1 |
| South Carolina | 4 |
| South Dakota | 8 |
| Tennessee | 4 |
| Texas | 6 |
| Utah | 8 |
| Vermont | 1 |
| Virginia | 3 |
| Washington | 10 |
| West Virginia | 3 |
| Wisconsin | 5 |
| Wyoming | 8 |

## STATE RADON CONTACTS

May, 1993

**Alabama**
James McNees
Division of Radiation Control
Alabama Department of Public Health
State Office Building
Montgomery, AL 36130
(205) 242-5315
1-800-582-1866 in state

**Alaska**
Charles Tedford
Department of Health and Social Services
P.O. Box 110613
Juneau, AK 99811-0613
(907) 465-3019
1-800-478-4845 in state

**Arizona**
John Stewart
Arizona Radiation Regulatory Agency
4814 South 40th St.
Phoenix, AZ 85040
(602) 255-4845

**Arkansas**
Lee Gershner
Division of Radiation Control
Department of Health
4815 Markham Street, Slot 30
Little Rock, AR 72205-3867
(501) 661-2301

**California**
J. David Quinton
Department of Health Services
714 P Street, Room 600
Sacramento, CA 94234-7320
(916) 324-2208
1-800-745-7236 in state

**Colorado**
Linda Martin
Department of Health
4210 East 11th Avenue
Denver, CO 80220
(303) 692-3057
1-800-846-3986 in state

**Connecticut**
Alan J. Siniscalchi
Radon Program
Connecticut Department of Health Services
150 Washington Street
Hartford, CT 06106-4474
(203) 566-3122

**Delaware**
Marai G. Rejai
Office of Radiation Control
Division of Public Health
P.O. Box 637
Dover, DE 19903
(302) 736-3028
1-800-554-4636 In State

**District of Columbia**
Robert Davis
DC Department of Consumer and Regulatory Affairs
614 H Street NW
Room 1014
Washington, DC 20001
(202) 727-71068

**Florida**
N. Michael Gilley
Office of Radiation Control
Department of Health and Rehabilitative Services
1317 Winewood Boulevard
Tallahassee, FL 32399-0700
(904) 488-1525
1-800-543-8279 in state

**Georgia**
Richard Schreiber
Georgia Department of Human Resources
878 Peachtree St., Room 100
Atlanta, GA 30309
(404) 894-6644
1-800-745-0037 in state

**Hawaii**
Russell Takata
Environmental Health Services Division
591 Ala Moana Boulevard
Honolulu, HI 96813-2498
(808) 586-4700

Idaho
Pat McGavarn
Office of Environmental Health
450 West State Street
Boise, ID 83720
(208) 334-6584
1-800-445-8647 in state

Illinois
Richard Allen
Illinois Department of Nuclear Safety
1301 Outer Park Drive
Springfield, IL 62704
(217) 524-5614
1-800-325-1245 in state

Indiana
Lorand Magyar
Radiological Health Section
Indiana State Department of Health
1330 West Michigan Street
P.O. Box 1964
Indianapolis, IN 46206
(317) 633-8563
1-800-272-9723 In State

Iowa
Donald A. Flater
Bureau of Radiological Health
Iowa Department of Public Health
Lucas State Office Building
Des Moines, IA 50319-0075
(515) 281-3478
1-800-383-5992 In State

Kansas
Harold Spiker
Radiation Control Program
Kansas Department of Health and Environment
109 SW 9th Street
6th Floor Mills Building
Topeka, KS 66612
(913) 296-1561

Kentucky
Jeana Phelps
Radiation Control Branch
Department of Health Services
Cabinet for Human Resources
275 East Main Street
Frankfort, KY 40601
(502) 564-3700

Louisiana
Matt Schlenker
Louisiana Department of Environmental Quality
P.O. Box 82135
Baton Rouge, LA 70884-2135
(504) 925-7042
1-800-256-2494 in state

Maine
Bob Stilwell
Division of Health Engineering
Department of Human Services
State House, Station 10
Augusta, ME 04333
(207) 289-5676
1-800-232-0842 in state

Maryland
Leon J. Rachuba
Radiological Health Program
Maryland Department of the Environment
2500 Broening Highway
Baltimore, MD 21224
(410) 631-3301
1-800-872-3666 In State

Massachusetts
William J. Bell
Radiation Control Program
Department of Public Health
23 Service Center
Northampton, MA 01060
(413) 586-7525
1-800-445-1255 in state

Michigan
Sue Hendershott
Division of Radiological Health
Bureau of Environmental and Occupational Health
3423 North Logan Street
P.O. Box 30195
Lansing, MI 48909
(517) 335-8194

Minnesota
Laura Oatmann
Indoor Air Quality Unit
925 Delaware Street, SE
P.O. Box 59040
Minneapolis, MN 55459-0040
(612) 627-5480
1-800-798-9050 in state

Mississippi

Silas Anderson
Division of Radiological Health
Department of Health
3150 Lawson Street
P.O. Box 1700
Jackson, MS 39215-1700
(601) 354-6657
1-800-626-7739 in state

Missouri

Kenneth V. Miller
Bureau of Radiological Health
Missouri Department of Health
1730 East Elm
P.O. Box 570
Jefferson City, MO 65102
(314) 751-6083
1-800-669-7236 In State

Montana

Adrian C. Howe
Occupational Health Bureau
Montana Department of Health and Environmental Sciences
Cogswell Building A113
Helena, MT 59620
(406) 444-3671

Nebraska

Joseph Milone
Division of Radiological Health
Nebraska Department of Health
301 Centennial Mall, South
P.O. Box 95007
Lincoln, NE 68509
(402) 471-2168
1-800-334-9491 In State

Nevada

Stan Marshall
Department of Human Resources
505 East King Street
Room 203
Carson City, NV 89710
(702) 687-5394

New Hampshire

David Chase
Bureau of Radiological Health
Division of Public Health Services
Health and Welfare Building
Six Hazen Drive
Concord, NH 03301
(603) 271-4674
1-800-852-3345 x4674

New Jersey

Tonalee Carlson Key
Division of Environmental Quality
Department of Environmental Protection
CN 415
Trenton, NJ 08625-0145
(609) 987-6369
1-800-648-0394 in state

New Mexico

William M. Floyd
Radiation Licensing and Registration Section
New Mexico Environmental Improvement Division
1190 St. Francis Drive
Santa Fe, NM 87503
(505) 827-4300

New York

William J. Condon
Bureau of Environmental Radiation Protection
New York State Health Department
Two University Place
Albany, NY 12202
(518) 458-6495
1-800-458-1158 in state

North Carolina

Dr. Felix Fong
Radiation Protection Division
Department of Environmental Health and Natural Resources
701 Barbour Drive
Raleigh, NC 27603-2008
(919) 571-4141
1-800-662-7301 (recorded info x4196)

North Dakota

Arlen Jacobson
North Dakota Department of Health
1200 Missouri Avenue, Room 304
P.O. Box 5520
Bismarck, ND 58502-5520
(701) 221-5188

Ohio

Marcie Matthews
Radiological Health Program
Department of Health
1224 Kinnear Road - Suite 120
Columbus, OH 43212
(614) 644-2727
1-800-523-4439 in state

Oklahoma
Gene Smith
Radiation Protection Division
Oklahoma State Department of Health
P.O. Box 53551
Oklahoma City, OK 73152
(405) 271-5221

Oregon
George Toombs
Department of Human Resources
Health Division
1400 SW 5th Avenue
Portland, OR 97201
(503) 731-4014

Pennsylvania
Michael Pyles
Pennsylvania Department of Environmental Resources
Bureau of Radiation Protection
P.O. Box 2063
Harrisburg, PA 17120
(717) 783-3594
1-800-23-RADON In State

Puerto Rico
David Saldana
Radiological Health Division
G.P.O. Call Box 70184
Rio Pierdras, Puerto Rico 00936
(809) 767-3563

Rhode Island
Edmund Arcand
Division of Occupational Health and Radiation
Department of Health
205 Cannon Building
Davis Street
Providence, RI 02908
(401) 277-2438

South Carolina
Bureau of Radiological Health
Department of Health and Environmental Control
2600 Bull Street
Columbia, SC 29201
(803) 734-4631
1-800-768-0362

South Dakota
Mike Pochop
Division of Environment Regulation
Department of Water and Natural Resources
Joe Foss Building, Room 217
523 E. Capitol
Pierre, SD 57501-3181
(605) 773-3351

Tennessee
Susie Shimek
Division of Air Pollution Control
Bureau of the Environment
Department of Environment and Conservation
Customs House, 701 Broadway
Nashville, TN 37219-5403
(615) 532-0733
1-800-232-1139 in state

Texas
Gary Smith
Bureau of Radiation Control
Texas Department of Health
1100 West 49th Street
Austin, TX 78756-3189
(512) 834-6688

Utah
John Hultquist
Bureau of Radiation Control
Utah State Department of Health
288 North, 1460 West
P.O. Box 16690
Salt Lake City, UT 84116-0690
(801) 536-4250

Vermont
Paul Clemons
Occupational and Radiological Health Division
Vermont Department of Health
10 Baldwin Street
Montpelier, VT 05602
(802) 828-2886
1-800-640-0601 in state

Virgin Islands
Contact the U.S. Environmental Protection Agency, Region II
in New York
(212) 264-4110

Virginia — Shelly Ottenbrite
Bureau of Radiological Health
Department of Health
109 Governor Street
Richmond, VA 23219
(804) 786-5932
1-800-468-0138 in state

Washington — Kate Coleman
Department of Health
Office of Radiation Protection
Airdustrial Building 5, LE-13
Olympia, WA 98504
(206) 753-4518
1-800-323-9727 In State

West Virginia — Beattie L. DeBord
Industrial Hygiene Division
West Virginia Department of Health
151 11th Avenue
South Charleston, WV 25303
(304) 558-3526
1-800-922-1255 In State

Wisconsin — Conrad Weiffenbach
Radiation Protection Section
Division of Health
Department of Health and Social Services
P.O. Box 309
Madison, WI 53701-0309
(608) 267-4796
1-800-798-9050 in state

Wyoming — Janet Hough
Wyoming Department of Health and Social Services
Hathway Building, 4th Floor
Cheyenne, WY 82002-0710
(307) 777-6015
1-800-458-5847 in state

## STATE GEOLOGICAL SURVEYS

May, 1993

Alabama
Ernest A. Mancini
Geological Survey of Alabama
P.O. Box 0
420 Hackberry Lane
Tuscaloosa, AL 35486-9780
(205) 349-2852

Alaska
Thomas E. Smith
Alaska Division of Geological & Geophysical Surveys
794 University Ave., Suite 200
Fairbanks, AK 99709-3645
(907) 479-7147

Arizona
Larry D. Fellows
Arizona Geological Survey
845 North Park Ave., Suite 100
Tucson, AZ 85719
(602) 882-4795

Arkansas
Norman F. Williams
Arkansas Geological Commission
Vardelle Parham Geology Center
3815 West Roosevelt Rd.
Little Rock, AR 72204
(501) 324-9165

California
James F. Davis
California Division of Mines & Geology
801 K Street, MS 12-30
Sacramento, CA 95814-3531
(916) 445-1923

Colorado
Pat Rogers (Acting)
Colorado Geological Survey
1313 Sherman St., Rm 715
Denver, CO 80203
(303) 866-2611

Connecticut
Richard C. Hyde
Connecticut Geological & Natural History Survey
165 Capitol Ave., Rm. 553
Hartford, CT 06106
(203) 566-3540

Delaware
Robert R. Jordan
Delaware Geological Survey
University of Delaware
101 Penny Hall
Newark, DE 19716-7501
(302) 831-2833

Florida
Walter Schmidt
Florida Geological Survey
903 W. Tennessee St.
Tallahassee, FL 32304-7700
(904) 488-4191

Georgia
William H. McLemore
Georgia Geologic Survey
Rm. 400
19 Martin Luther King Jr. Dr. SW
Atlanta, GA 30334
(404) 656-3214

Hawaii
Manabu Tagomori
Dept. of Land and Natural Resources
Division of Water & Land Mgt
P.O. Box 373
Honolulu, HI 96809
(808) 548-7539

Idaho
Earl H. Bennett
Idaho Geological Survey
University of Idaho
Morrill Hall, Rm. 332
Moscow, ID 83843
(208) 885-7991

Illinois
Morris W. Leighton
Illinois State Geological Survey
Natural Resources Building
615 East Peabody Dr.
Champaign, IL 61820
(217) 333-4747

Indiana
Norman C. Hester
Indiana Geological Survey
611 North Walnut Grove
Bloomington, IN 47405
(812) 855-9350

Iowa
Donald L. Koch
Iowa Department of Natural Resources
Geological Survey Bureau
109 Trowbridge Hall
Iowa City, IA 52242-1319
(319) 335-1575

Kansas
Lee C. Gerhard
Kansas Geological Survey
1930 Constant Ave., West Campus
University of Kansas
Lawrence, KS 66047
(913) 864-3965

Kentucky
Donald C. Haney
Kentucky Geological Survey
University of Kentucky
228 Mining & Mineral Resources Building
Lexington, KY 40506-0107
(606) 257-5500

Louisiana
William E. Marsalis
Louisiana Geological Survey
P.O. Box 2827
University Station
Baton Rouge, LA 70821-2827
(504) 388-5320

Maine
Walter A. Anderson
Maine Geological Survey
Department of Conservation
State House, Station 22
Augusta, ME 04333
(207) 289-2801

Maryland
Emery T. Cleaves
Maryland Geological Survey
2300 St. Paul Street
Baltimore, MD 21218-5210
(410) 554-5500

Massachusetts
Joseph A. Sinnott
Massachusetts Office of Environmental Affairs
100 Cambridge St., Room 2000
Boston, MA 02202
(617) 727-9800

Michigan
R. Thomas Segall
Michigan Geological Survey Division
Box 30256
Lansing, MI 48909
(517) 334-6923

Minnesota
Priscilla C. Grew
Minnesota Geological Survey
2642 University Ave.
St. Paul, MN 55114-1057
(612) 627-4780

Mississippi
S. Cragin Knox
Mississippi Office of Geology
P.O. Box 20307
Jackson, MS 39289-1307
(601) 961-5500

Missouri
James H. Williams
Missouri Division of Geology & Land Survey
111 Fairgrounds Road
P.O. Box 250
Rolla, MO 65401
(314) 368-2100

Montana
Edward T. Ruppel
Montana Bureau of Mines & Geology
Montana College of Mineral Science and Technology, Main Hall
Butte, MT 59701
(406) 496-4180

Nebraska
Perry B. Wigley
Nebraska Conservation & Survey Division
113 Nebraska Hall
University of Nebraska
Lincoln, NE 68588-0517
(402) 472-2410

Nevada
Jonathan G. Price
Nevada Bureau of Mines & Geology
Stop 178
University of Nevada-Reno
Reno, NV 89557-0088
(702) 784-6691

New Hampshire
Eugene L. Boudette
Dept. of Environmental Services
117 James Hall
University of New Hampshire
Durham, NH 03824-3589
(603) 862-3160

New Jersey
Haig F. Kasabach
New Jersey Geological Survey
P.O. Box 427
Trenton, NJ 08625
(609) 292-1185

New Mexico
Charles E. Chapin
New Mexico Bureau of Mines & Mineral Resources
Campus Station
Socorro, NM 87801
(505) 835-5420

New York
Robert H. Fakundiny
New York State Geological Survey
3136 Cultural Education Center
Empire State Plaza
Albany, NY 12230
(518) 474-5816

<u>North Carolina</u>
Charles H. Gardner
North Carolina Geological Survey
P.O. Box 27687
Raleigh, NC 27611-7687
(919) 733-3833

<u>North Dakota</u>
John P. Bluemle
North Dakota Geological Survey
600 East Blvd.
Bismarck, ND 58505-0840
(701) 224-4109

<u>Ohio</u>
Thomas M. Berg
Ohio Dept. of Natural Resources
Division of Geological Survey
4383 Fountain Square Drive
Columbus, OH 43224-1362
(614) 265-6576

<u>Oklahoma</u>
Charles J. Mankin
Oklahoma Geological Survey
Room N-131, Energy Center
100 E. Boyd
Norman, OK 73019-0628
(405) 325-3031

<u>Oregon</u>
Donald A. Hull
Dept. of Geology & Mineral Indust.
Suite 965
800 NE Oregon St. #28
Portland, OR 97232-2162
(503) 731-4600

<u>Pennsylvania</u>
Donald M. Hoskins
Dept. of Environmental Resources
Bureau of Topographic & Geologic Survey
P.O. Box 2357
Harrisburg, PA 17105-2357
(717) 787-2169

<u>Puerto Rico</u>
Ramón M. Alonso
Puerto Rico Geological Survey Division
Box 5887
Puerta de Tierra Station
San Juan, P.R. 00906
(809) 722-2526

<u>Rhode Island</u>
J. Allan Cain
Department of Geology
University of Rhode Island
315 Green Hall
Kingston, RI 02881
(401) 792-2265

<u>South Carolina</u>
Alan-Jon W. Zupan (Acting)
South Carolina Geological Survey
5 Geology Road
Columbia, SC 29210-9998
(803) 737-9440

<u>South Dakota</u>
C.M. Christensen (Acting)
South Dakota Geological Survey
Science Center
University of South Dakota
Vermillion, SD 57069-2390
(605) 677-5227

<u>Tennessee</u>
Edward T. Luther
Tennessee Division of Geology
13th Floor, L & C Tower
401 Church Street
Nashville, TN 37243-0445
(615) 532-1500

<u>Texas</u>
William L. Fisher
Texas Bureau of Economic Geology
University of Texas
University Station, Box X
Austin, TX 78713-7508
(512) 471-7721

<u>Utah</u>
M. Lee Allison
Utah Geological & Mineral Survey
2363 S. Foothill Dr.
Salt Lake City, UT 84109-1491
(801) 467-7970

<u>Vermont</u>
Diane L. Conrad
Vermont Division of Geology and Mineral Resources
103 South Main St.
Waterbury, VT 05671
(802) 244-5164

<u>Virginia</u>
Stanley S. Johnson
Virginia Division of Mineral Resources
P.O. Box 3667
Charlottesville, VA 22903
(804) 293-5121

<u>Washington</u>
Raymond Lasmanis
Washington Division of Geology & Earth Resources
Department of Natural Resources
P.O. Box 47007
Olympia, Washington 98504-7007
(206) 902-1450

West Virginia — Larry D. Woodfork
West Virginia Geological and
Economic Survey
Mont Chateau Research Center
P.O. Box 879
Morgantown, WV 26507-0879
(304) 594-2331

Wisconsin — James Robertson
Wisconsin Geological & Natural
History Survey
3817 Mineral Point Road
Madison, WI 53705-5100
(608) 263-7384

Wyoming — Gary B. Glass
Geological Survey of Wyoming
University of Wyoming
Box 3008, University Station
Laramie, WY 82071-3008
(307) 766-2286

EPA REGION 5 GEOLOGIC RADON POTENTIAL SUMMARY

*by*
*R. Randall Schumann, Douglass E. Owen, and Sandra L. Szarzi*
*U.S. Geological Survey*

EPA Region 5 comprises the states of Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin. 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 chapter. More detailed information on the geology and radon potential of each state in Region 5 is given in the individual state chapters. The individual chapters describing the geology and radon potential of the six states in EPA Region 5, though much more detailed than this summary, still are generalized assessments and there is no substitute for having a home tested. Radon levels, both high and low, can be quite localized, and within any radon potential area homes with indoor radon levels both above and below the predicted average will likely be found.

Radon potential in EPA Region 5 is controlled by three primary factors. Bedrock geology provides the source material for the overlying glacial deposits, and in areas with no glacial cover, directly provides the parent material for the soils. Glacial geology (fig. 1) is an important factor because glaciers redistributed the bedrock and glacially-derived soils have different soil characteristics from soils developed on bedrock. Climate, particularly precipitation and temperature, in concert with the soil's parent material, controls soil moisture, the extent of soil development and weathering, and the types of weathering products that form in the soils. The following is a brief, generalized discussion of the bedrock and glacial geology of EPA Region 5 as they pertain to indoor radon. More detailed discussions may be found in the individual state geologic radon potential chapters.

Western and southern Minnesota are underlain by deposits of the Des Moines and Red River glacial lobes. Des Moines lobe tills are silty clays and clays derived from Upper Cretaceous sandstones and shales, which have relatively high concentrations of uranium and high radon emanating power. Deposits of the Red River lobe are similar to those of the Des Moines lobe, but also contain silt and clay deposits of glacial Lake Agassiz, a large glacial lake that occupied the Red River Valley along the Minnesota-North Dakota border. The Upper Cretaceous Pierre Shale provides good radon source material because, as a whole, it contains higher-than-average amounts of uranium (average crustal abundance of uranium is about 2.5 parts per million). Glacial deposits of the Red River and Des Moines lobes generate high (> 4 pCi/L) average indoor radon concentrations (fig. 2) and have high geologic radon potential (fig. 3). Northern Wisconsin, the western part of the Upper Peninsula of Michigan, and part of northern Minnesota are underlain by glacial deposits of the Lake Superior lobe. Parts of northern Minnesota are also underlain by deposits of the Rainy and Wadena lobes (fig. 1). The underlying source rocks for these tills are Precambrian volcanic rocks, metasedimentary and metavolcanic rocks, and granitic plutonic rocks of the Canadian Shield. The volcanic, metasedimentary, and metavolcanic rocks have relatively low uranium contents, and the granitic rocks have variable, mostly moderate to high, uranium contents. The sandy tills derived from the

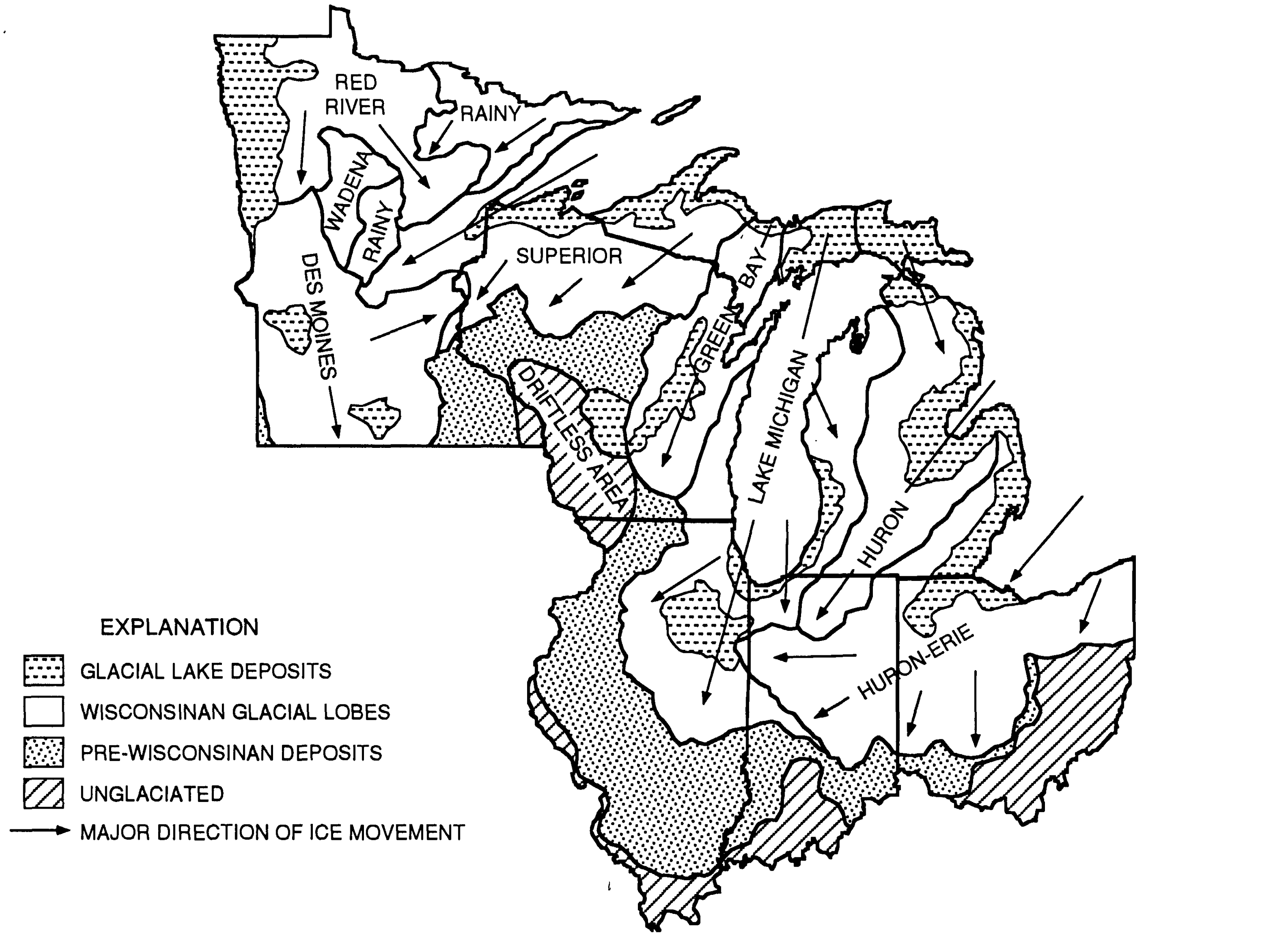



Figure 1. Generalized glacial geologic map of EPA Region 5 showing names of major Wisconsin-age glacial lobes.

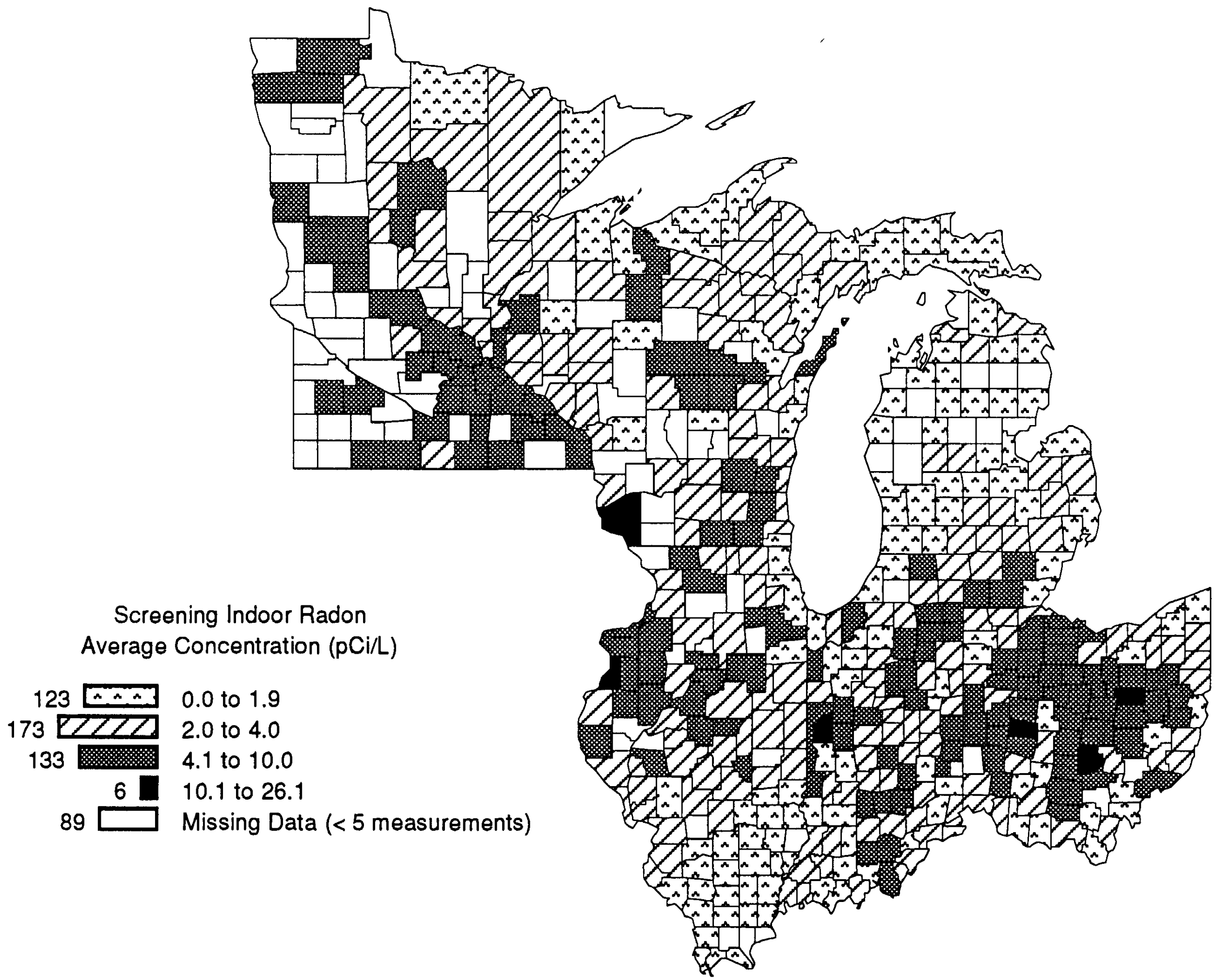



Figure 2. Screening indoor radon data for counties with 5 or more measurements in EPA Region 5. Data are from the EPA/State Residential Radon Survey and represent 2-7 day charcoal canister measurements. Histograms in map legends show the number of counties in each category. The number of samples in each county may not be sufficient to statistically characterize the average radon levels in the counties, but they do suggest general trends.

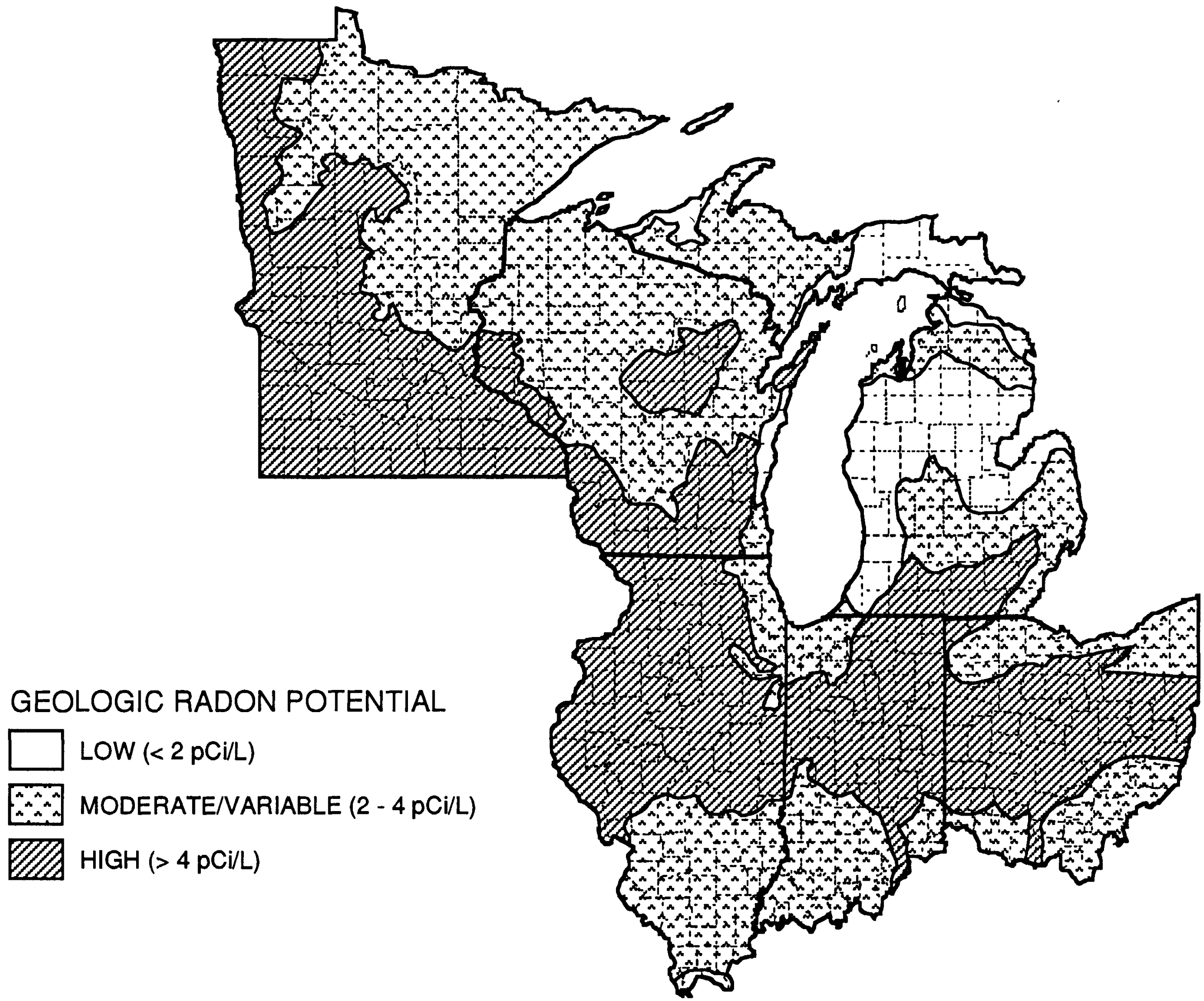



Figure 3. Geologic radon potential areas of EPA Region 5.

volcanic, metasedimentary, and metavolcanic rocks have relatively high permeability, but because of their lower uranium content of and lower emanating power, they have mostly moderate to locally high radon potential (fig. 3). Sandy, granite-rich tills in northern Minnesota generally have high radon potential. Granites and granite gneisses, black slates and graphitic schists, and iron-formation are associated with anomalous uranium concentrations and locally high radon in northern Wisconsin and adjacent northwestern Michigan. In central Wisconsin, uraniferous granites of the Middle Proterozoic Wolf River and Wausau plutons are exposed at the surface or covered by a thin layer of glacial deposits and cause some of the highest indoor radon concentrations in the State. An area in southwestern Wisconsin and adjacent smaller parts of Minnesota, Iowa, and Illinois, is called the "Driftless Area" (fig. 1). It is not covered by glacial deposits but parts of the area were likely overrun by glaciers at least once. The Driftless Area is underlain by Cambrian and Ordovician limestone, dolomite, and sandstone with moderate to high radon potential.

Glacial deposits in southern Wisconsin, northern and central Illinois, and western Indiana are primarily from the Green Bay and Lake Michigan lobes. The Green Bay and Lake Michigan lobes advanced from their source in the Hudson Bay region of Canada and moved southward, terminating in Illinois and Iowa. These tills range from sandy to clayey and are derived primarily from shales, sandstones, and carbonate rocks of southern Wisconsin, the western Michigan Basin, and the northern Illinois Basin. A small part of eastern Illinois and much of western Indiana are covered by deposits of the Huron-Erie lobe, and west-central Illinois is covered by glacial deposits of pre-Wisconsinan, mostly Illinoian, age. The Huron-Erie lobe entered Illinois from the east and moved westward and southwestward into the State. Huron-Erie lobe and pre-Wisconsinan glacial deposits are derived from Paleozoic shale, sandstone, siltstone, carbonate rocks, and coal of the Illinois Basin, and they are commonly calcareous due to the addition of limestones and dolomites of northern Indiana and Ohio and southern Ontario. In contrast, Lake Michigan lobe deposits contain significant amounts of dark gray to black Devonian and Mississippian shales of the Michigan Basin, accounting for the high clay content of Lake Michigan lobe tills. Unglaciated southernmost Illinois is part of the Mississippi Embayment of the Coastal Plain and has low geologic radon potential.

Wisconsin-age glacial deposits in Indiana were deposited by three main glacial lobes—the Lake Michigan lobe, which advanced southward as far as central Indiana; the Huron-Erie lobe; and the Saginaw sublobe of the Huron lobe (labeled Huron lobe on fig. 1), which advanced from the northeast across northern Ohio and southern Michigan, respectively. Michigan lobe deposits are clayey near Lake Michigan, sandy and gravelly in an outwash and morainal area in northwestern Indiana, and clayey to loamy in west-central Indiana. Saginaw sublobe deposits are loamy and calcareous and are derived primarily from carbonate rocks and shale. The Huron-Erie lobe advanced from the northeast and covered much of northern and central Indiana at its maximum extent. Eastern Indiana and western Ohio are underlain by tills of the Huron-Erie lobe that are derived in part from black shales of the Devonian Ohio Shale and Devonian-Mississippian New Albany Shale, but also include Paleozoic limestone, dolomite, sandstone, siltstone, and gray shale. Black shales and carbonates underlie and provide source material for glacial deposits in a roughly north-south pattern through central Ohio, including the Columbus area, and extend south of the glacial limit, where the black shales form a prominant arcuate pattern in northern Kentucky that curves northward into southern Indiana and underlies glacial deposits in east-central Indiana. The overall radon potential of this area is high. Eastern Ohio is underlain by Devonian to Permian shales and limestones with moderate to high radon potential.

The Michigan Basin covers all of the Southern Peninsula and the eastern half of the Northern Peninsula of Michigan, as well as parts of eastern Wisconsin and northeastern Illinois, northern Indiana, and northwestern Ohio. Glacial deposits include silty and clayey tills of the Lake Michigan, Huron, and Huron-Erie lobes (fig. 1). Huron lobe tills are sandy to gravelly and calcareous, containing pebbles and cobbles of limestone, dolomite, and some sandstone and shale, with boulders of igneous and metamorphic rocks and quartzite. Tills of the Huron-Erie and Lake Michigan lobes are derived from similar source rocks but are more silty and clayey in texture. Source rocks for these tills are sandstones, gray shales, and carbonate rocks of the Michigan Basin, which are generally poor radon sources. In the Southern Peninsula, the Devonian Bell, Antrim, and Ellsworth Shales, and Mississippian Sunbury Shale locally contain organic-rich black shale layers with higher-than-average amounts of uranium, except for the Antrim Shale, which is organic rich throughout. These shales underlie and constitute source rock for glacial deposits in the northern, southeastern, and southwestern parts of the Southern Peninsula, and are locally exposed at the surface in the northern part of the Southern Peninsula. Because of generally moist soils, soils developed on tills derived from black shales in Michigan generate moderate to locally high radon, with higher values more common in the southern part of the State (fig. 2).

Glaciated areas present special problems for radon-potential assessment because bedrock material in the central United States was commonly transported hundreds of km from its source. Glaciers are quite effective in redistributing uranium-rich rocks; for example, in Ohio, uranium-bearing black shales have been disseminated over much of western Ohio and eastern Indiana, now covering a much larger area than their original outcrop pattern, and display a prominent radiometric high. The physical, chemical, and drainage characteristics of soils formed from glacial deposits vary according to source bedrock type and the glacial features on which they are formed. For example, soils formed from ground moraine deposits tend to be more poorly drained and contain more fine-grained material than soils formed on kames, moraines, or eskers, which are generally coarser and well-drained. In general, soils developed from coarser-grained tills are poorly structured, poorly sorted, and poorly developed, but are generally more highly permeable than the bedrock from which they are derived.

Clayey tills, such as those underlying parts of western and southern Minnesota, have relatively high emanation coefficients and usually have low to moderate permeability, depending on the degree to which the clays are mixed with coarser sediments. Tills consisting of mostly coarse material tend to emanate less radon because larger grains have lower surface area-to-volume ratios, but because these soils have generally high permeabilities, radon transport distances are generally longer. Structures built in these materials are thus able to draw soil air from a larger source volume, so moderately to highly elevated indoor radon concentrations may be achieved from comparatively lower-radioactivity soils. In till soils with extremely high permeability, atmospheric dilution may become significant, and if the soils have low to moderate radium contents, elevated indoor radon levels would be less likely to occur. Soil moisture has a significant effect on radon generation and transport and high levels of soil moisture generally lower the radon potential of an area. The main effect of soil moisture is its tendency to occlude soil pores and thus inhibit soil-gas transport. Soils in wetter climates from northern Minnesota to northern Michigan generally have lower radon potential than soils derived from similar tills in the southern parts of those states or in Indiana and Illinois, in part because of higher soil moisture conditions to the north.

# PRELIMINARY GEOLOGIC RADON POTENTIAL ASSESSMENT OF ILLINOIS

*by*
*R. Randall Schumann*
*U.S. Geological Survey*

## INTRODUCTION

Many of the rocks and soils in Illinois have the potential to generate levels of indoor radon exceeding the U.S. Environmental Protection Agency's guideline of 4 pCi/L. In a survey of 1450 homes conducted during the winter of 1990-91 by the Illinois Department of Nulcear Safety (IDNS) and the EPA, 22 percent of the homes had screening indoor radon levels exceeding this value. Only one percent of the homes tested had screening indoor radon levels exceeding 20 pCi/L. Similar results were reported from statewide survey of indoor radon levels in 4140 homes conducted by the IDNS. Thirty-two percent of the homes tested in the IDNS study had indoor radon levels exceeding 4 pCi/L, and about one percent of the homes had radon levels exceeding 20 pCi/L. While no level of radon can be considered absolutely safe, the Illinois Department of Nulcear Safety predicts, based on these surveys, that there are very few homes in Illinois (less than one percent) in which radon could be considered a severe problem (i.e., exceeding 20 pCi/L).

This is a generalized assessment of geologic radon potential of rocks, soils, and surficial deposits of Illinois. 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 (Illinois Department of Nulcear Safety) 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

Illinois' landscape stretches from the Great Lakes to the Coastal Plain. The State contains part of four major physiographic provinces—the Central Lowland, Interior Low Plateaus, Ozark Plateaus, and the Coastal Plain—with a number of subdivisions (fig. 1). More than three-quarters of Illinois is in the Till Plains section of the Central Lowlands Province. The Till Plains section is subdivided into seven physiographic areas in Illinois (fig. 1). The Rock River Hill Country, Galesburg Plain, Springfield Plain, and Mt. Vernon Hill Country are covered by Pre-Wisconsinan glacial deposits, but their topography is defined more by the topography of the pre-glacial surface than by glacial features which only locally form prominent features in these areas (Willman and others, 1975). The Green River Lowland and Kankakee Plain are lowlands that are partially covered by sand dunes. The Bloomington Ridged Plain occupies much of northeastern Illinois and displays marked glacial topography including morainal ridges, drift plains, and outwash plains. The Wheaton Morainal Country, with topography similar to that of the Bloomington Ridged Plain,

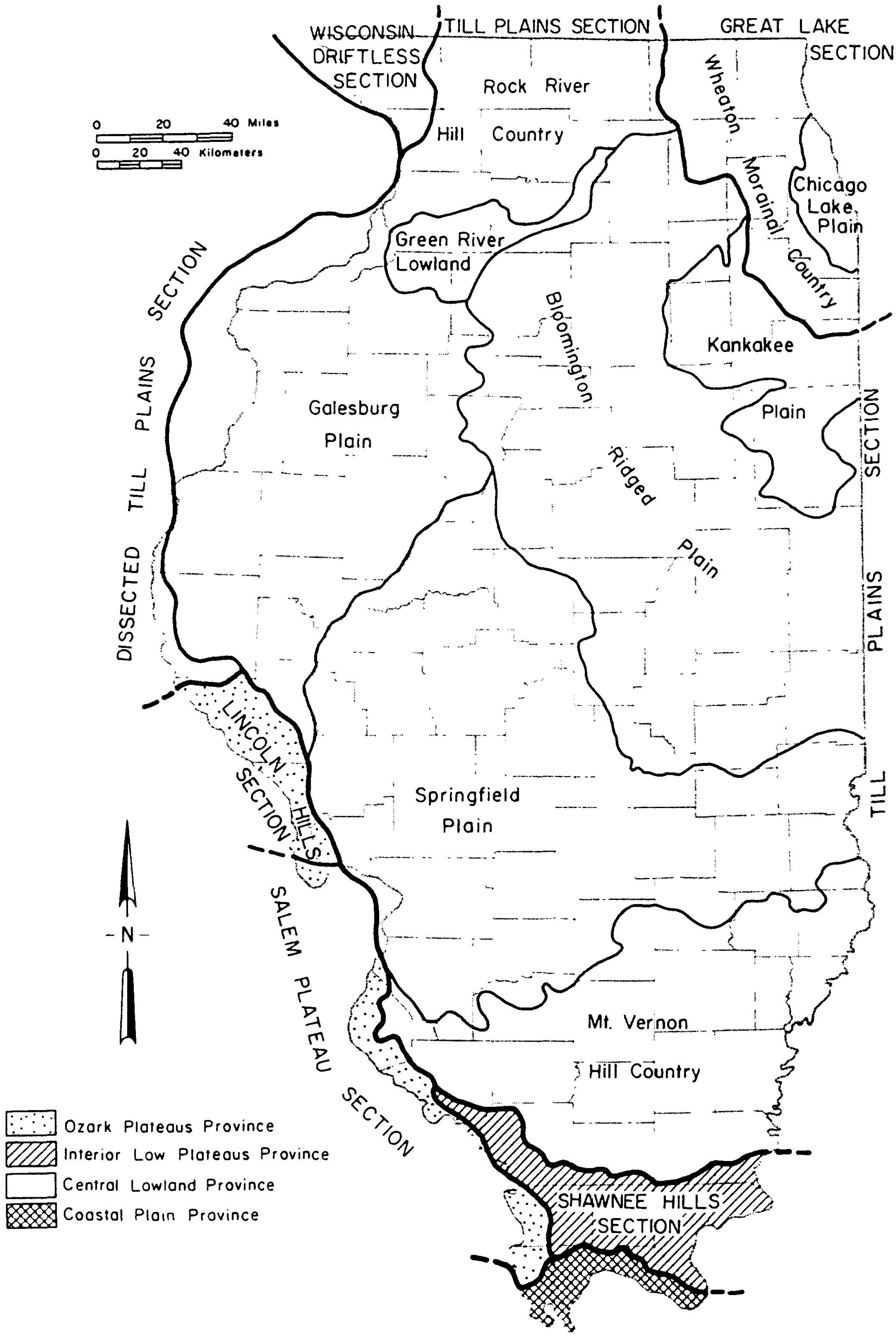



Figure 1. Physiographic regions of Illinois (modified from Willman and others, 1975).

and the Chicago Lake Plain, which was covered by glacial Lake Chicago, belong to the Great Lake Section of the Central Lowland Province. The presumably unglaciated and deeply dissected Wisconsin Driftless Section and a small part of the Dissected Till Plains Section, both in northwestern Illinois, also belong to the Central Lowland Province (Willman and others, 1975).

The Lincoln Hills and Salem Plateau Sections, small parts of subdivisions of the Ozark Plateaus Province, extend into Illinois along the Mississippi River (fig. 1). The Lincoln Hills contains dissected flat-lying rocks, whereas the strata in the Salem Plateau Section are mildly folded and faulted (Willman and others, 1975). The Shawnee Hills Section of the Interior Low Plateaus Province is an unglaciated area containing hills of relatively high relief. The southern tip of Illinois is an area of low, rounded hills which is part of the Coastal Plain Province (fig. 1).

Illinois is divided into 102 counties (fig. 2). Most of the State's population is clustered around urban centers, with the counties in the Chicago area having the highest populations. The southern and western parts of Illinois are largely rural and have lower county populations (fig. 3).

## GEOLOGY

The discussion of geology is divided into three sections: bedrock geology, glacial geology, and a discussion of uranium in rocks and soils. "Bedrock" refers to pre-glacial rock units, which are covered by glacial deposits in most parts of the State. A bedrock geologic map (fig. 4) shows rock units that underlie glacial deposits or are exposed at the surface in some areas. The glacial deposits are composed of material derived from underlying bedrock and from rock units to the north and northeast. The discussion of bedrock geology is summarized from Willman and others (1975). The section on glacial geology is summarized from Willman and Frye (1970), Frye and others (1965), and Richmond and Fullerton (1983, 1991). For more detailed discussions and maps of the geology, the reader is encouraged to consult these and other reports (see the reference list at the end of this chapter for additional suggested references).

*Bedrock geology:* The bedrock geologic setting of Illinois is dominated by the Illinois Basin, a structural and sedimentary basin occupying most of the State. It is bounded on the north by the Kankakee and Wisconsin arches which extend into northern Illinois; on the west by the Mississippi River Arch in Iowa and Missouri; and on the southwest by the Ozark Uplift in Missouri. The Illinois Basin extends into Indiana to the east and into Kentucky and Tennessee to the southeast. With the exception of Pliocene continental sedimentary rocks, all of the pre-glacial bedrock underlying Illinois consists of marine or marginal-marine sedimentary rocks, including limestone, dolomite, sandstone, siltstone, shale, and coal (fig. 4). Most of the rocks are from Cambrian through Pennsylvanian in age. Cretaceous and Tertiary rocks are exposed in a relatively small area in southern Illinois; a small subcrop of Cretaceous rocks underlies glacial drift in western Illinois (fig. 4).

*Glacial geology:* Glaciers advanced into Illinois from three directions during the Pleistocene Epoch. The earliest glaciers (Pre-Illinoian, formerly called Nebraskan and Kansan) advanced from the northwest into western Illinois, and from the north into eastern Illinois. Pre-Illinoian glacial deposits are exposed in Illinois only in a small area in the western part of the State (fig. 5), but they underlie younger deposits throughout much of southern Illinois. Later glaciers (Illinoian and Wisconsinan) advanced from the north and northeast. The Green Bay and Lake Michigan lobes advanced from their source in the Hudson Bay region and moved southward into Illinois. The Erie Lobe (and possibly the Saginaw Lobe) advanced from the Labradorean center, entering Illinois from the northeast (Willman and Frye, 1970). About two-thirds of Illinois is


Figure 2. Illinois counties.

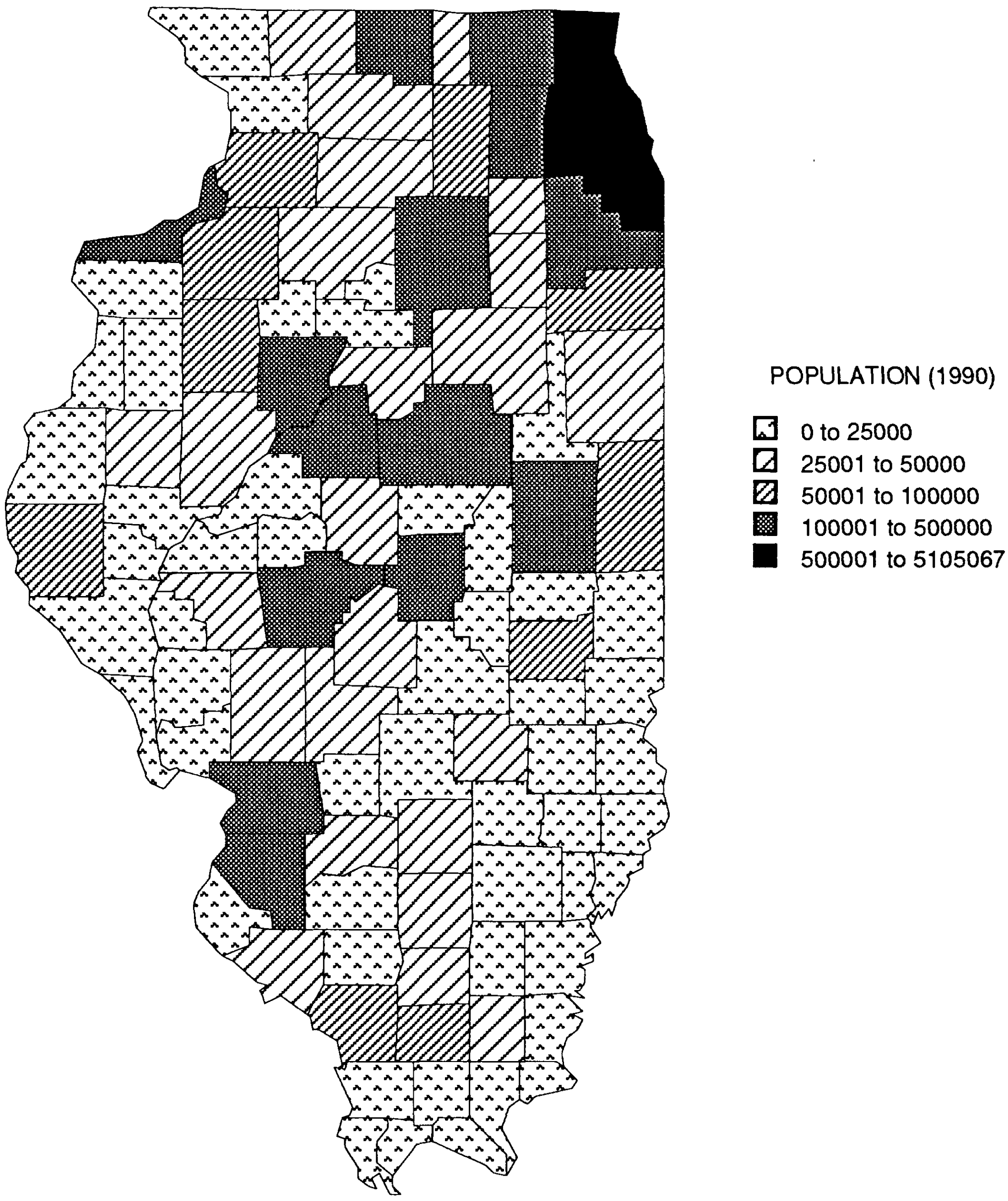



Figure 3. Population of counties in Illinois (1990 U.S. Census data).

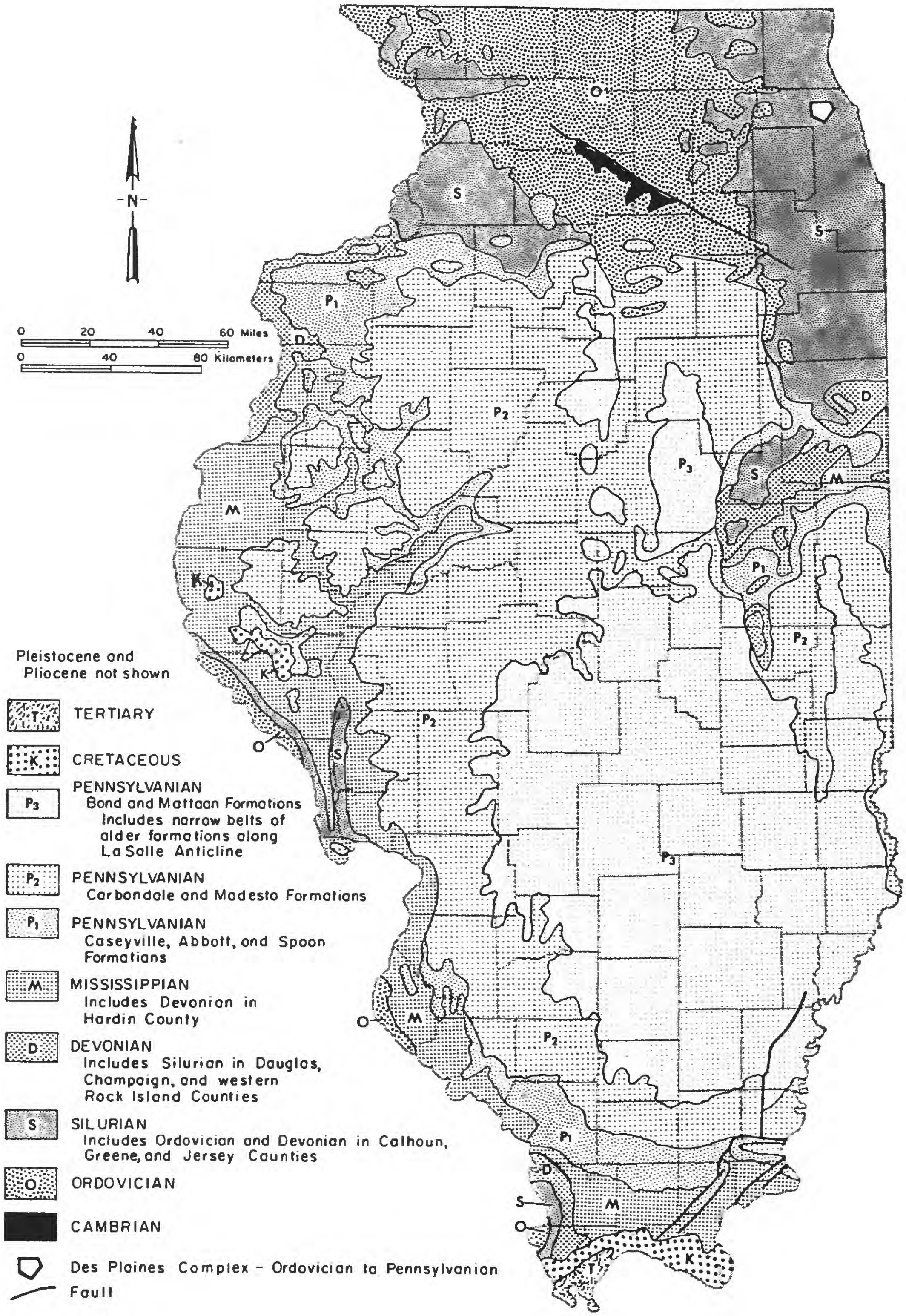



Figure 4. Generalized bedrock geologic map of Illinois (modified from Willman and others, 1975).

# GENERALIZED STRATIGRAPHIC CHART FOR ILLINOIS

| ERA, ERATHEM | PERIOD, SYSTEM | EPOCH, SERIES | ORIGIN AND CHARACTER | GREATEST THICKNESS (ft)[1] | AGE (millions of years)[2] |
|---|---|---|---|---|---|
| CENOZOIC | QUATERNARY | PLEISTOCENE | Continental—glacial, river and stream, wind, lake, swamp, and colluvial deposits and soils | 600 | |
| | | | *Major unconformity* | | 1.5 |
| | TERTIARY | PLIOCENE | Continental — river deposits, mostly gravel, some sand | 50 | |
| | | | *Major unconformity* | | 7 |
| | | EOCENE | Deltaic — mostly sand, some silt | 300 | |
| | | PALEOCENE | Marine — mostly clay, some sand | 150 | |
| | | | *Unconformity* | | 64-65 |
| MESOZOIC | CRETACEOUS | GULFIAN | Deltaic and nearshore marine — sand, some silt and clay, locally lignitic | 500 | |
| | | | *Major unconformity* | | 136 |
| PALEOZOIC | PENNSYLVANIAN | VIRGILIAN<br>MISSOURIAN<br>DESMOINESIAN<br>ATOKAN<br>MORROWAN | Marine, deltaic, continental — cyclical deposits, mostly shale, sandstone, and siltstone with some limestone, coal, clay, black sheety shale; sandstone dominant in lower part, shale above; coal most prominent in middle part, limestone in upper part | 3000 | |
| | | | *Major unconformity* | | 315 |
| | MISSISSIPPIAN | CHESTERIAN | Marine, deltaic — cyclical deposits of limestone, sandstone, shale | 1400 | |
| | | VALMEYERAN | Marine, deltaic — limestone, siltstone, shale, chert, sandstone | 2000 | |
| | | KINDERHOOKIAN | Marine — shale, limestone, siltstone | 150 | 345 |
| | DEVONIAN | UPPER | Marine — shale, limestone | 300 | |
| | | | *Unconformity* | | |
| | | MIDDLE | Marine — largely limestone, some shale | 450 | |
| | | | *Major unconformity* | | |
| | | LOWER | Marine — cherty limestone, chert | 1300 | 395 |
| | SILURIAN | CAYUGAN | Marine — shale, siltstone, limestone | 100 | |
| | | NIAGARAN | Marine — dolomite, limestone, shale, local reefs | 1000 | |
| | | ALEXANDRIAN | Marine — dolomite, limestone, shale | 150 | |
| | | | *Unconformity* | | 430-440 |
| | ORDOVICIAN | CINCINNATIAN | Marine — shale, limestone, siltstone, dolomite | 300 | |
| | | | *Unconformity* | | |
| | | CHAMPLAINIAN | Marine — limestone, dolomite, sandstone | 1400 | |
| | | | *Major unconformity* | | |
| | | CANADIAN | Marine — dolomite, sandstone | 1000 | 500 |
| | CAMBRIAN | CROIXAN | Marine — sandstone, dolomite, shale | 4000 | |
| | | | *Major unconformity* | | 525[4]<br>570[5] |
| PRECAMBRIAN | | | Intrusive igneous rocks — mostly granite | | |

[1] Greatest thickness in one locality.

[2] Radiometric age of beginning of interval. (After Harland [1964] and others. Estimates from chart by Van Eysinga [1972].)

[4] Beginning of Croixan (est.).

[5] Beginning of Cambrian.

Figure 4 (continued) (modified from Willman and others, 1975).

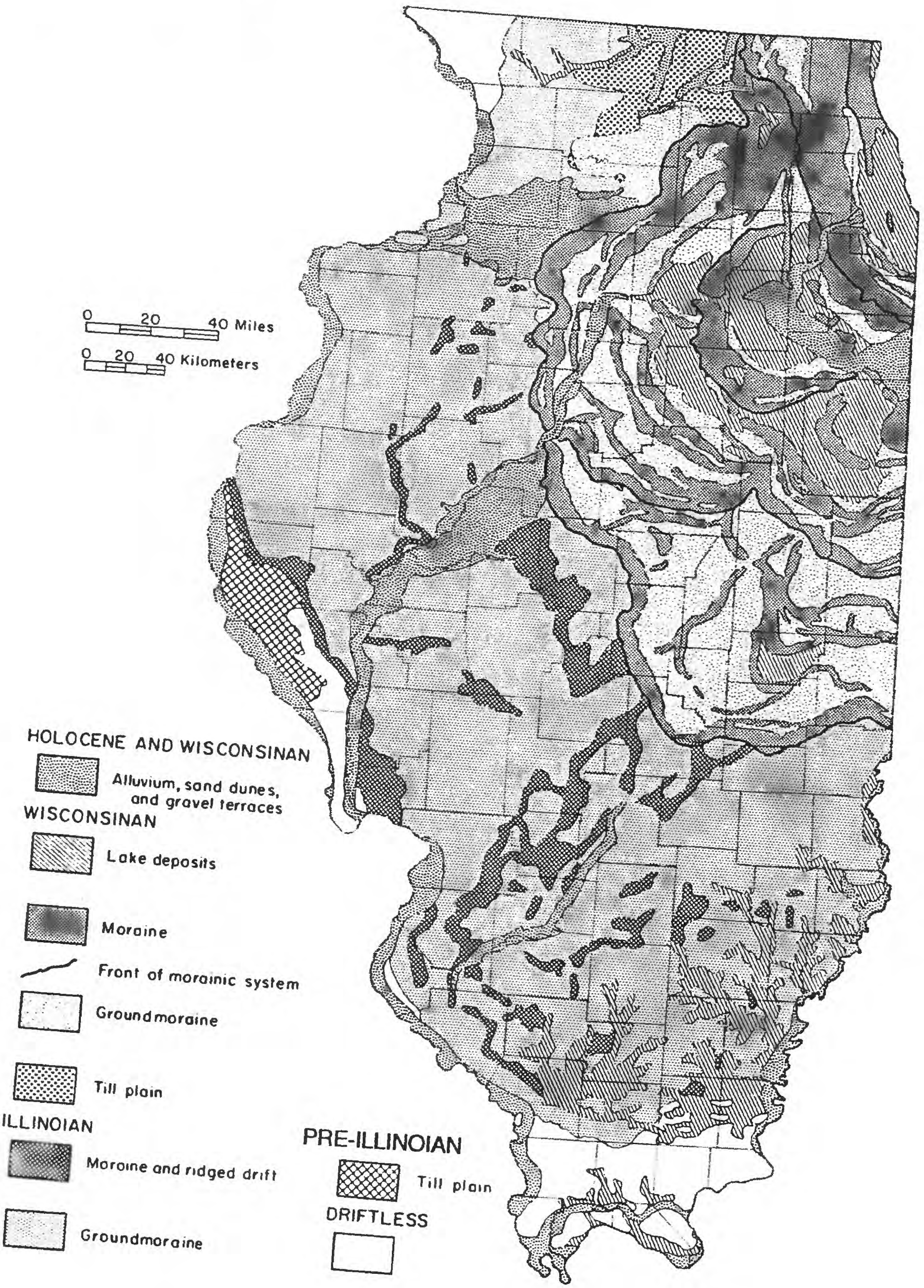



Figure 5. Glacial map of Illinois (modified from Willman and Frye, 1970).

covered by Illinoian-age deposits, about one-third of the State (the northeastern part) is covered by Wisconsinan deposits, and small areas in the northwestern corner, along the western edge, and the southern tip of Illinois are unglaciated (fig. 5). Glaciers from all four northern and northeastern lobes probably advanced into the State during Illinoian time, and the Illinoian deposits are not specifically differentiated by source lobe. During the Wisconsinan Stage, the Lake Michigan and Erie lobes re-entered northeastern Illinois (fig. 6). Glaciers made at least three separate advances into Illinois during Illinoian time and three advances during Wisconsinan time (Willman and Frye, 1970). During Late Wisconsinan time, many lakes were formed in the low areas behind moraines or behind dams of glacial ice. Areas now underlain by glacial lake deposits are shown in figure 7. Lakes Watseka, Wauponsee, Pontiac, and Ottowa (fig. 7) resulted from the Kankakee Flood and their deposits range in texture from silt to boulders. Most of the lakes in southern Illinois are slackwater lakes that left mainly silt deposits derived from windblown silt (loess) and glacial outwash. Lake Chicago (fig. 7) was the glacial predecessor of modern Lake Michigan. Lake Chicago deposits underlie most of the Chicago metropolitan area and consist primarily of silt and clay.

The major bedrock units of Illinois that contributed material to glacial deposits in the State include: (1) Silurian dolomite in the northeast and in a small part of the glaciated area in the northwest; (2) Ordovician dolomite in the north-central part of the State; (3) Ordovician shale (northern Illinois); (4) Mississippian limestones with minor amounts of shale and sandstone in western Illinois; (5) Pennsylvanian rocks throughout the central and southern part of the State, which consist of shale (50 percent), sandstone and siltstone (40 percent), limestone, coal, and other minor constituents (10 percent) (Willman and Frye, 1970). Precambrian igneous and metamorphic rocks from the Canadian Shield in Canada and the Lake Superior region also constitute a significant part of most tills in the State. Major additions to Erie Lobe deposits came from Ordovician, Silurian, and Devonian limestones of northern Indiana and Ohio and southern Ontario, making Erie Lobe deposits more calcareous (calcium carbonate-rich) than Lake Michigan Lobe deposits. Pre-Illinoian glacial deposits from northwestern sources are also notably calcareous. In contrast, Lake Michigan lobe deposits contain significant amounts of dark gray to black Devonian and Mississippian shales of the Michigan Basin, accounting for the high illite (non-expanding clay) content of Lake Michigan Lobe tills. Smectite (swelling clay) in Cretaceous shales is the dominant clay mineral in glacial deposits from northwestern sources (Willman and Frye, 1970).

Loess (windblown silt) was formed as rivers separated the various size fractions (gravel, sand, silt, clay) from glacial drift, and the silt fraction was picked up and transported by wind. Loess deposits from less than one to more than 30 meters thick cover most of Illinois, averaging about 1.5 meters.thick over about 90 percent of the State (Willman and Frye, 1970).

*Uranium geology:* Because no comprehensive studies of uranium contents of glacial deposits and loess in Illinois are known to exist, and because these deposits have underlying bedrock as a major source component (in addition to material derived from the north and northeast), a brief discussion of known concentrations of uranium in rocks and soils of Illinois is presented here in order to provide clues to the sources of radon parent materials (uranium and(or) radium) in surficial deposits. Many rocks throughout the State contain higher-than-average amounts of uranium [average crustal abundance of uranium is approximately 2.5 parts per million (ppm) (Carmichael, 1989)]. Gilkeson and others (1988) list the following typical uranium concentrations for rocks in Illinois: shales, 5-31 ppm; lacustrine sediments of Lake Michigan, 2.3 ppm; limestones, 4.5 ppm; sandstones, 1.5 ppm.

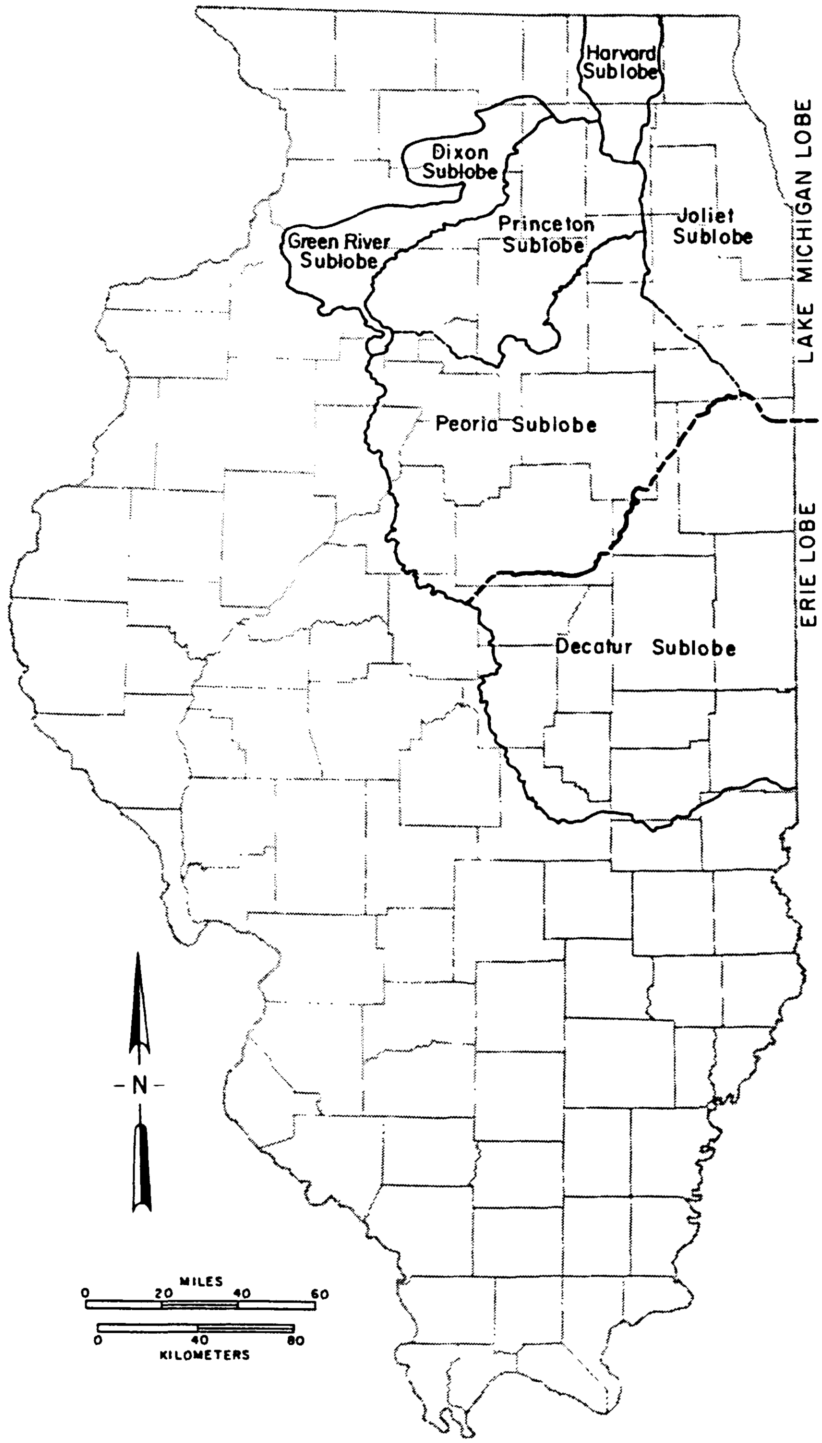



Figure 6. Late Wisconsinan glacial lobes and sublobes in Illinois (modified from Willman and Frye, 1970).

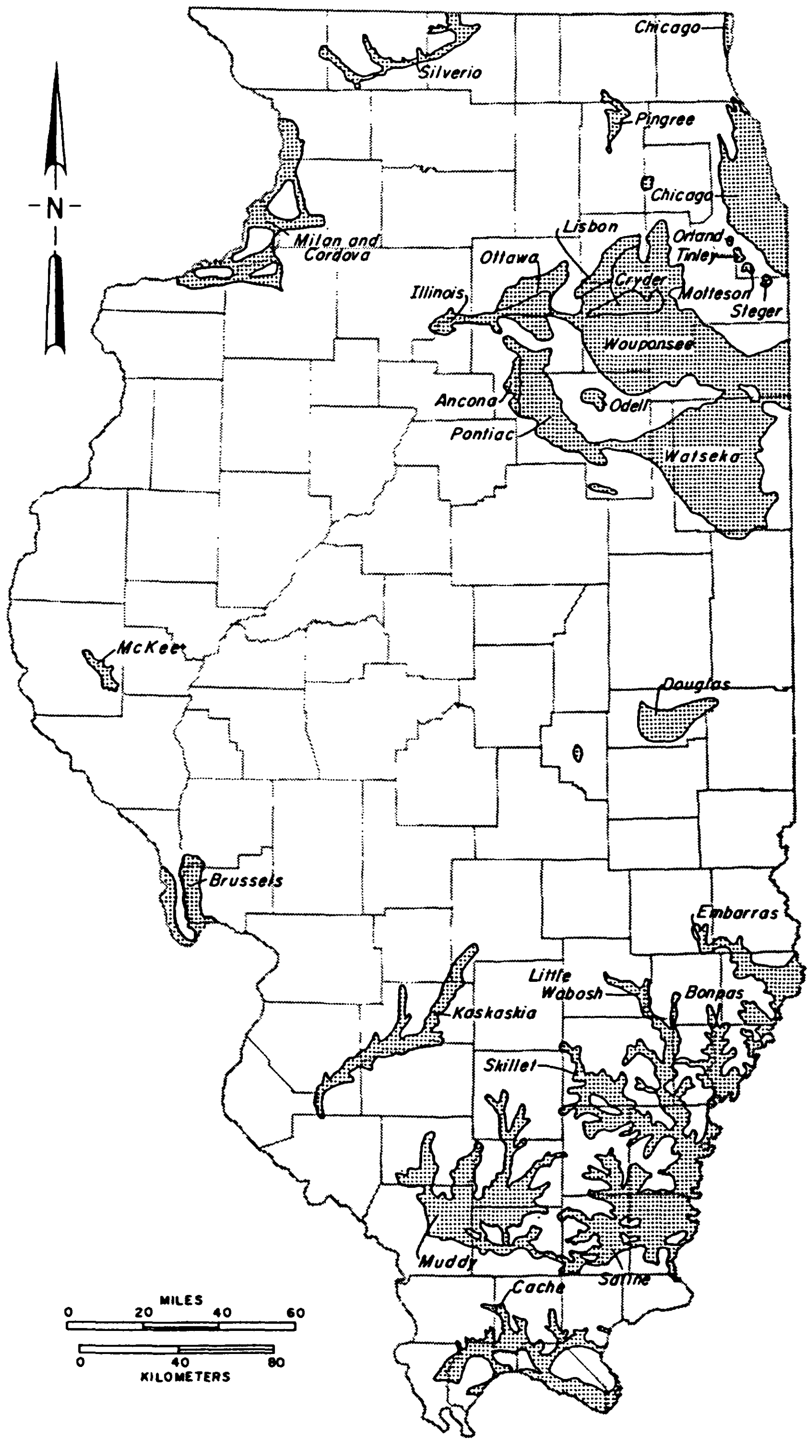



Figure 7. Glacial lake deposits in Illinois (modified from Willman and Frye, 1970).

Black shales, which are fairly common in some parts of the bedrock succession of Illinois, are well-known concentrators of uranium and are known causes of radon problems in a number of areas in the United States. Ostrom and others (1955) collected and analyzed 175 samples of black shales and gray shales from scattered exposures in streams, roadcuts, and open-pit mines in 44 counties covering the lower four-fifths of Illinois. Black shales of Pennsylvanian, Mississippian, and Devonian-Mississippian age had uranium concentrations ranging from near zero to 170 ppm. Uranium is concentrated with organic matter in the shale or in phosphate layers within the shales (Ostrom and others, 1955). Ordovician gray shales contained between 10 and 20 ppm equivalent uranium (Ostrom and others, 1955). Frost and others (1985) found 3-75 ppm uranium in 392 subsurface drillhole samples of the Devonian-Mississippian New Albany Shale Group in Illinois.

Many soils in Illinois contain sufficient uranium to generate indoor radon levels exceeding 4 pCi/L under the proper soil permeability and building construction/ventilation conditions. Out of 153 samples from surface horizons of upland soils across Illinois collected and analyzed by Jones (1991), the average uranium concentration was 3.4 ppm, with a range of 1.2 to 7.7 ppm. There appeared to be no particular correlation of uranium content with soil order, moisture regime, or degree of weathering (Jones, 1991).

## SOILS

Major soil orders in Illinois are shown in figure 8. Mollisols are dark-colored soils formed under grass. They contain a thick (> 25 cm), dark, organic-rich layer at the surface and calcium carbonate ($CaCO_3$) accumulations in the B horizon (Feherenbacher and others, 1984). Mollisols are most extensive in northern and central Illinois (fig. 8). Alfisols in Illinois are generally light-colored soils formed under forest vegetation. The surface layer may be light or dark in color, but it has a low organic matter content. Alfisols have a recognizable B horizon of clay accumulation. Alfisols are most common in southern Illinois, although they are found in most areas of the State (fig. 8). Entisols are generally light-colored, young soils formed mostly in recent alluvium. These soils occur along streams in the southern and western parts of the State and in other very sandy areas such as the dunefields in the northern and central parts of the State (fig. 8). Because they are relatively young, these soils usually have not yet formed distinct horizons. Some of the Entisols in central and northern Illinois and in the Wabash River valley are light-colored, sandy soils with sufficient quantities of weatherable minerals to have formed recognizable horizons (Fehrenbacher and others, 1984). Inceptisols, soils with weakly developed horizons, and Histosols, organic soils (peats and mucks), also occur in Illinois but their areas are too small to be shown on figure 8.

A generalized soil permeability map of Illinois (fig. 9) was compiled from a soil survey report containing maps of soil units and information on soil characteristics, including permeability (Fehrenbacher and others, 1984). The available data, which are shown in figure 9, are for permeability of the soils to water. Permeability to air, which is more relevant to soil-gas radon transport, generally follows that of water permeability except in soils with high soil moisture contents, in which case the water in the soil pores restricts or prevents soil-gas movement. Most of the soils in the southern part of Illinois and some of the soils derived from glacial lake deposits in northeastern Illinois have low permeability. Soils with high permeability occur in the northeastern and central parts of the State (fig. 9). About two-thirds of the soils in Illinois have moderate permeability. More detailed information on permeability of shallow surficial soil and rock units may be found in Keefer and Berg (1990), Berg and Kempton (1988), and Berg and others (1984).

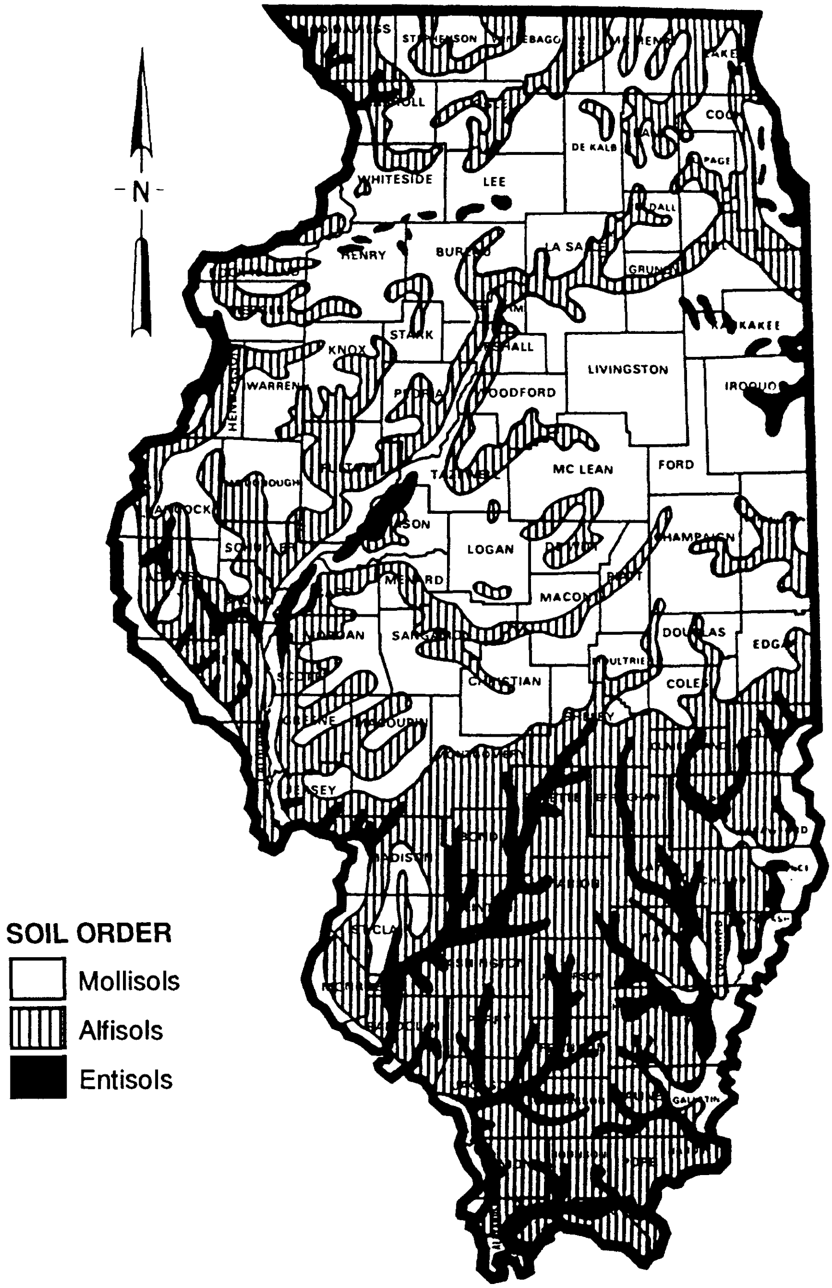



Figure 8. Major soil orders of Illinois (modified from Feherenbacher and others, 1984).

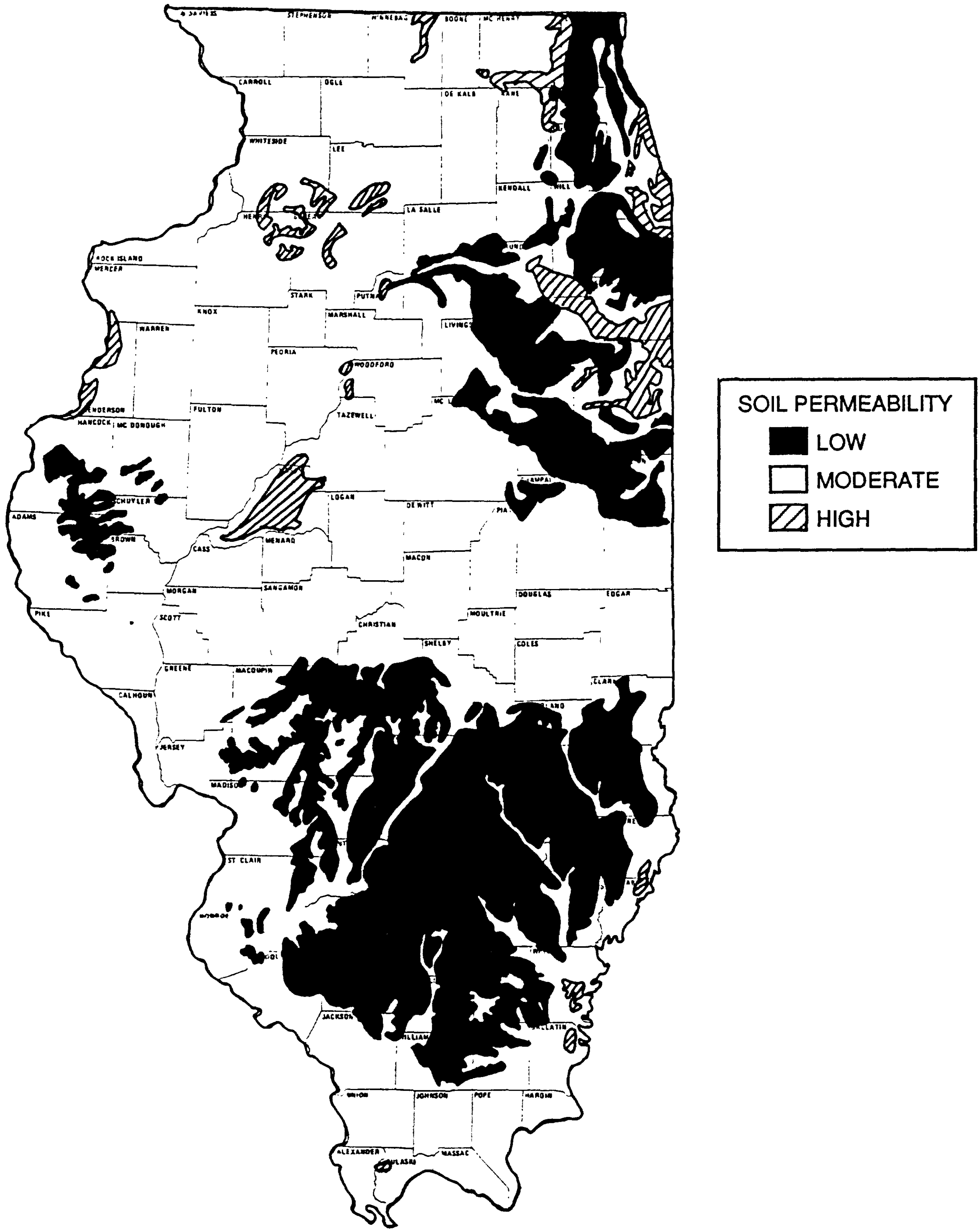



Figure 9. Generalized soil permeability map of Illinois. Data from Feherenbacher and others (1984).

## INDOOR RADON DATA

Screening indoor radon data from 1450 homes sampled in the State/EPA Residential Radon Survey conducted in Illinois during the winter of 1990-91 are listed in Table 1 and shown in figure 10. This survey employed short-term (2-7 day) charcoal canister indoor radon tests. The maximum value recorded in the survey was 92 pCi/L in Madison County. The statewide indoor radon average in this survey was 3.2 pCi/L. A number of counties with average indoor radon levels exceeding 4 pCi/L are found in the northern two-thirds of the State (fig. 10). Counties in which more than 50 percent of the homes tested had screening indoor radon values exceeding 4 pCi/L are restricted to the northern half of the State (fig. 10). Lake and Cook counties, bordering Lake Michigan and including most of the Chicago metropolitan area, have low average indoor radon values (fig. 10). The southern one-third of the State generally has low to moderate average indoor radon values (fig. 10).

The Illinois State Department of Nuclear Safety (IDNS) also conducted statewide indoor radon sampling in 4140 randomly-selected homes during 1987-1991 (Allen and Hamel-Caspary, 1991). This study employed alpha-track detectors placed in the home for a period of 2 weeks to 3 months. The statewide average indoor radon concentration in this study was 3.9 pCi/L, and 32 percent of the homes sampled had indoor radon values exceeding 4 pCi/L (fig. 11 and Table 2). About one percent of the homes tested had indoor radon levels exceeding 20 pCi/L. The data from this survey correspond fairly well with the State/EPA Residential Radon Survey data, although the average values and percent of homes greater than 4 pCi/L are generally somewhat higher for most counties in the IDNS survey than in the State/EPA survey. The pattern of higher radon values in the northern two-thirds of Illinois, generally lower values in the southern one-third of the State, and low to moderate indoor radon levels in the area adjacent to Lake Michigan, is similar for both data sets.

## GEOLOGIC RADON POTENTIAL

An aeroradiometric map of Illinois (fig. 12) compiled from filtered, smoothed, and contoured NURE flightline data (Duval and others, 1989) shows no extremely high or low radioactivity areas within the State. Lower equivalent uranium (eU) areas are associated with alluvium and sand deposits along the drainages of the Illinois, Rock, and Kaskaskia Rivers, and with windblown sand deposits in northeastern Illinois (fig. 7). Areas with eU signatures greater than 2.5 ppm are scattered throughout the northern one-third of the State, and larger areas occur in east-central and southern Illinois which could not be directly correlated with surface features. The pattern of anomalies suggests a possible correlation with glacial lake deposits or areas of thin loess cover or bedrock exposure, but the relatively higher eU values in the southern part of the State are not associated with high radon values; in fact, indoor radon concentrations in the southern one-third of Illinois are generally less than 4 pCi/L.

Most of the State has an eU signature between 1.0 and 2.5 ppm. The radiometric signature of Illinois as a whole appears lower than expected compared to indoor radon, and compared with the radiometric signature of unglaciated areas on a national scale (see Duval and others, 1989). Recent studies (for example, Lively and others, 1991; Schumann and others, 1991) suggest that much of the radium in the near-surface horizons of glacially-derived soils may have been leached and transported downward in the soil profile, giving a low surface radiometric signature while generating significant radon at depth (1-2 m or greater) to produce elevated indoor radon levels.

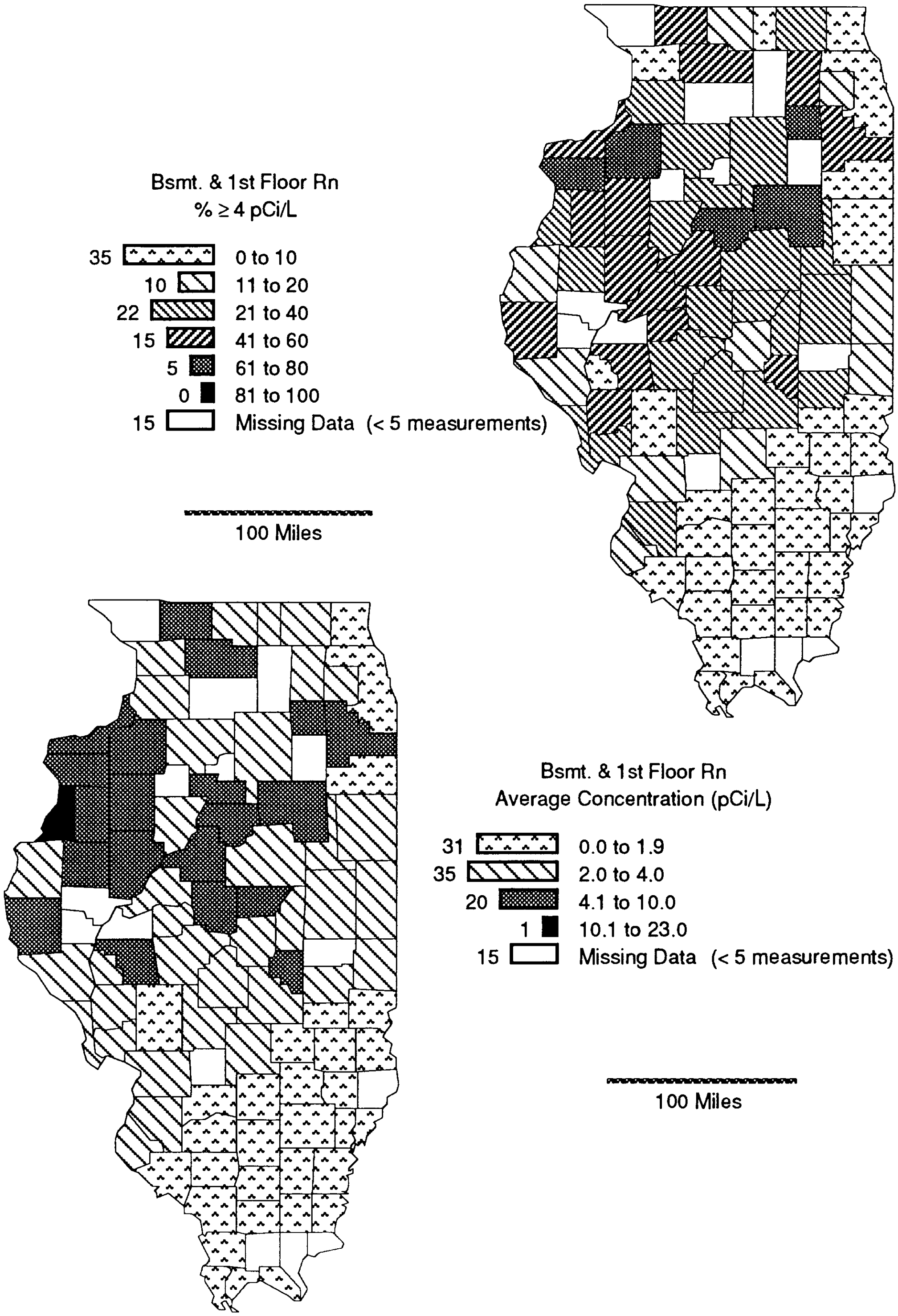



Figure 10. Screening indoor radon data from the EPA/State Residential Radon Survey of Illinois, 1990-91, for counties with 5 or more measurements. Data are from 2-7 day charcoal canister tests. Histograms in map legends show the number of counties in each category. The number of samples in each county (see Table 1) may not be sufficient to statistically characterize the radon levels of the counties, but they do suggest general trends. Unequal category intervals were chosen to provide reference to decision and action levels.

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

| COUNTY | NO. OF MEAS. | MEAN | GEOM. MEAN | MEDIAN | STD. DEV. | MAXIMUM | %>4 pCi/L | %>20 pCi/L |
|---|---|---|---|---|---|---|---|---|
| ADAMS | 22 | 8.4 | 4.0 | 5.0 | 15.3 | 74.6 | 59 | 5 |
| ALEXANDER | 7 | 0.9 | 0.7 | 0.8 | 0.6 | 1.9 | 0 | 0 |
| BOND | 2 | 1.7 | 1.1 | 1.7 | 1.8 | 3.0 | 0 | 0 |
| BOONE | 3 | 2.3 | 2.3 | 2.4 | 0.6 | 2.8 | 0 | 0 |
| BROWN | 1 | 12.8 | 12.8 | 12.8 | 0.0 | 12.8 | 100 | 0 |
| BUREAU | 5 | 3.1 | 2.8 | 2.5 | 1.5 | 5.1 | 40 | 0 |
| CALHOUN | 3 | 2.1 | 1.6 | 1.2 | 2.0 | 4.4 | 33 | 0 |
| CARROLL | 3 | 2.0 | 1.9 | 1.9 | 0.4 | 2.4 | 0 | 0 |
| CASS | 2 | 10.4 | 8.4 | 10.4 | 8.6 | 16.4 | 100 | 0 |
| CHAMPAIGN | 33 | 3.6 | 2.1 | 2.2 | 4.5 | 23.4 | 24 | 3 |
| CHRISTIAN | 13 | 3.3 | 2.0 | 3.2 | 2.7 | 9.8 | 31 | 0 |
| CLARK | 6 | 1.1 | 0.8 | 1.0 | 0.7 | 2.3 | 0 | 0 |
| CLAY | 6 | 0.7 | 0.4 | 0.8 | 0.6 | 1.3 | 0 | 0 |
| CLINTON | 14 | 1.1 | 0.6 | 0.8 | 1.1 | 3.4 | 0 | 0 |
| COLES | 10 | 3.4 | 2.0 | 1.8 | 3.7 | 10.8 | 30 | 0 |
| COOK | 121 | 1.6 | 0.9 | 1.2 | 2.0 | 16.0 | 6 | 0 |
| CRAWFORD | 15 | 1.8 | 0.9 | 0.9 | 3.1 | 12.6 | 7 | 0 |
| CUMBERLAND | 5 | 0.8 | 0.5 | 0.6 | 0.9 | 2.3 | 0 | 0 |
| DE WITT | 11 | 6.4 | 3.5 | 2.6 | 9.3 | 31.2 | 36 | 9 |
| DOUGLAS | 2 | 6.2 | 1.1 | 6.2 | 8.6 | 12.3 | 50 | 0 |
| DU PAGE | 80 | 3.0 | 1.8 | 1.8 | 3.6 | 22.9 | 18 | 1 |
| EDGAR | 7 | 2.0 | 1.1 | 1.7 | 2.2 | 6.6 | 14 | 0 |
| EDWARDS | 3 | 1.4 | 1.3 | 1.5 | 0.5 | 1.8 | 0 | 0 |
| EFFINGHAM | 17 | 1.1 | 0.8 | 0.6 | 1.1 | 4.4 | 6 | 0 |
| FAYETTE | 9 | 2.3 | 1.4 | 1.8 | 2.4 | 8.1 | 11 | 0 |
| FORD | 5 | 2.6 | 1.7 | 1.4 | 2.5 | 6.1 | 40 | 0 |
| FRANKLIN | 19 | 0.9 | 0.6 | 0.8 | 1.0 | 4.4 | 5 | 0 |
| FULTON | 14 | 6.7 | 3.4 | 3.7 | 9.0 | 31.6 | 43 | 14 |
| GALLATIN | 3 | 0.7 | 0.3 | 0.6 | 0.7 | 1.4 | 0 | 0 |
| GREENE | 4 | 4.0 | 3.2 | 4.3 | 2.6 | 6.4 | 50 | 0 |
| GRUNDY | 2 | 5.1 | 5.0 | 5.1 | 0.8 | 5.6 | 100 | 0 |
| HAMILTON | 4 | 0.9 | 0.6 | 0.5 | 1.0 | 2.3 | 0 | 0 |
| HANCOCK | 6 | 3.5 | 0.9 | 1.4 | 6.1 | 15.8 | 17 | 0 |
| HENDERSON | 4 | 23.0 | 5.4 | 2.8 | 41.4 | 85.1 | 25 | 25 |
| HENRY | 14 | 6.5 | 5.0 | 5.3 | 5.5 | 21.0 | 71 | 7 |
| IROQUOIS | 3 | 2.4 | 1.9 | 2.7 | 1.6 | 3.9 | 0 | 0 |
| JACKSON | 16 | 1.2 | 0.8 | 1.0 | 0.9 | 3.2 | 0 | 0 |
| JASPER | 4 | 0.6 | 0.4 | 0.6 | 0.5 | 1.1 | 0 | 0 |
| JEFFERSON | 13 | 0.9 | 0.5 | 0.7 | 0.9 | 2.8 | 0 | 0 |
| JERSEY | 5 | 3.0 | 1.6 | 2.2 | 2.4 | 5.5 | 40 | 0 |
| JO DAVIESS | 1 | 5.3 | 5.3 | 5.3 | 0.0 | 5.3 | 100 | 0 |

TABLE 1 (continued). Screening indoor radon data for Illinois.

| COUNTY | NO. OF MEAS. | MEAN | GEOM. MEAN | MEDIAN | STD. DEV. | MAXIMUM | %>4 pCi/L | %>20 pCi/L |
|---|---|---|---|---|---|---|---|---|
| JOHNSON | 2 | 0.9 | 0.3 | 0.9 | 1.3 | 1.8 | 0 | 0 |
| KANE | 24 | 4.0 | 3.1 | 3.4 | 3.1 | 14.6 | 42 | 0 |
| KANKAKEE | 10 | 1.8 | 1.0 | 1.1 | 2.0 | 6.9 | 10 | 0 |
| KENDALL | 4 | 4.7 | 4.6 | 4.8 | 1.3 | 6.2 | 75 | 0 |
| KNOX | 22 | 5.1 | 3.5 | 3.6 | 4.3 | 17.3 | 36 | 0 |
| LA SALLE | 11 | 4.0 | 3.0 | 2.6 | 4.5 | 17.3 | 27 | 0 |
| LAKE | 29 | 1.6 | 0.8 | 0.9 | 1.9 | 9.4 | 7 | 0 |
| LAWRENCE | 2 | 0.4 | 0.4 | 0.4 | 0.0 | 0.4 | 0 | 0 |
| LEE | 2 | 1.3 | 1.2 | 1.3 | 0.6 | 1.7 | 0 | 0 |
| LIVINGSTON | 5 | 8.6 | 7.5 | 8.5 | 5.0 | 16.4 | 80 | 0 |
| LOGAN | 5 | 4.6 | 3.5 | 2.2 | 3.7 | 9.6 | 40 | 0 |
| MACON | 30 | 2.9 | 2.0 | 2.2 | 2.7 | 13.2 | 17 | 0 |
| MACOUPIN | 20 | 1.7 | 0.7 | 0.8 | 3.0 | 13.8 | 5 | 0 |
| MADISON | 110 | 3.2 | 1.7 | 1.9 | 8.8 | 91.6 | 15 | 1 |
| MARION | 12 | 1.4 | 0.7 | 0.9 | 1.8 | 6.4 | 8 | 0 |
| MARSHALL | 4 | 4.4 | 3.2 | 2.8 | 4.1 | 10.3 | 25 | 0 |
| MASON | 4 | 4.0 | 2.7 | 3.1 | 3.7 | 9.0 | 50 | 0 |
| MASSAC | 7 | 1.1 | 0.8 | 1.0 | 0.7 | 2.0 | 0 | 0 |
| MCDONOUGH | 13 | 5.4 | 3.3 | 2.6 | 6.9 | 22.1 | 23 | 8 |
| MCHENRY | 23 | 3.4 | 2.4 | 2.3 | 2.8 | 10.2 | 35 | 0 |
| MCLEAN | 26 | 3.5 | 2.2 | 2.9 | 2.6 | 10.0 | 35 | 0 |
| MENARD | 5 | 3.6 | 2.9 | 4.5 | 2.0 | 5.4 | 60 | 0 |
| MERCER | 8 | 6.9 | 5.4 | 5.8 | 5.4 | 18.8 | 63 | 0 |
| MONROE | 16 | 2.5 | 2.1 | 1.8 | 1.7 | 5.7 | 19 | 0 |
| MONTGOMERY | 10 | 2.9 | 2.2 | 2.1 | 2.2 | 7.8 | 30 | 0 |
| MORGAN | 12 | 4.8 | 3.9 | 3.9 | 3.5 | 14.2 | 42 | 0 |
| MOULTRIE | 7 | 5.6 | 3.2 | 3.1 | 5.9 | 16.9 | 43 | 0 |
| OGLE | 7 | 4.1 | 3.5 | 3.6 | 2.4 | 7.8 | 43 | 0 |
| PEORIA | 55 | 3.5 | 2.5 | 2.5 | 3.6 | 23.6 | 24 | 2 |
| PERRY | 9 | 1.0 | 0.6 | 0.8 | 0.9 | 3.1 | 0 | 0 |
| PIATT | 4 | 2.6 | 1.3 | 0.8 | 3.8 | 8.3 | 25 | 0 |
| PIKE | 6 | 2.9 | 2.6 | 2.5 | 1.5 | 5.8 | 17 | 0 |
| POPE | 1 | 0.5 | 0.5 | 0.5 | 0.0 | 0.5 | 0 | 0 |
| PULASKI | 5 | 0.9 | 0.3 | 0.3 | 1.7 | 3.8 | 0 | 0 |
| RANDOLPH | 20 | 1.5 | 1.0 | 1.0 | 1.9 | 8.8 | 5 | 0 |
| RICHLAND | 9 | 1.3 | 0.6 | 1.2 | 1.1 | 3.0 | 0 | 0 |
| ROCK ISLAND | 43 | 5.7 | 3.9 | 3.8 | 5.3 | 22.5 | 49 | 2 |
| SALINE | 14 | 0.8 | 0.5 | 0.8 | 0.7 | 2.5 | 0 | 0 |
| SANGAMON | 42 | 3.4 | 2.2 | 2.7 | 3.2 | 20.0 | 26 | 0 |
| SCHUYLER | 1 | 1.3 | 1.3 | 1.3 | 0.0 | 1.3 | 0 | 0 |
| SCOTT | 4 | 2.3 | 1.9 | 2.7 | 1.2 | 3.3 | 0 | 0 |
| SHELBY | 6 | 2.7 | 1.6 | 1.3 | 2.9 | 7.9 | 33 | 0 |
| ST. CLAIR | 78 | 2.7 | 1.9 | 2.2 | 2.6 | 19.5 | 18 | 0 |

TABLE 1 (continued). Screening indoor radon data for Illinois.

| COUNTY | NO. OF MEAS. | MEAN | GEOM. MEAN | MEDIAN | STD. DEV. | MAXIMUM | %>4 pCi/L | %>20 pCi/L |
|---|---|---|---|---|---|---|---|---|
| STARK | 1 | 6.9 | 6.9 | 6.9 | 0.0 | 6.9 | 100 | 0 |
| STEPHENSON | 5 | 8.8 | 2.9 | 5.5 | 11.4 | 28.7 | 60 | 20 |
| TAZEWELL | 41 | 5.8 | 4.4 | 4.2 | 4.1 | 17.3 | 51 | 0 |
| UNION | 9 | 1.4 | 1.1 | 1.1 | 1.0 | 3.3 | 0 | 0 |
| VERMILION | 35 | 2.2 | 1.5 | 2.0 | 1.7 | 7.0 | 20 | 0 |
| WABASH | 6 | 0.6 | 0.5 | 0.5 | 0.3 | 1.1 | 0 | 0 |
| WARREN | 7 | 7.8 | 5.7 | 4.5 | 6.6 | 18.9 | 57 | 0 |
| WASHINGTON | 11 | 0.9 | 0.6 | 0.7 | 0.9 | 3.1 | 0 | 0 |
| WAYNE | 7 | 1.0 | 0.7 | 1.2 | 0.7 | 2.2 | 0 | 0 |
| WHITE | 9 | 1.2 | 0.7 | 1.1 | 1.1 | 3.4 | 0 | 0 |
| WHITESIDE | 8 | 3.1 | 1.6 | 2.5 | 2.9 | 9.1 | 25 | 0 |
| WILL | 21 | 4.9 | 2.5 | 2.6 | 7.4 | 34.9 | 43 | 5 |
| WILLIAMSON | 20 | 1.0 | 0.7 | 0.8 | 1.2 | 5.5 | 5 | 0 |
| WINNEBAGO | 19 | 2.8 | 2.5 | 2.5 | 1.6 | 6.7 | 16 | 0 |
| WOODFORD | 7 | 8.6 | 5.6 | 6.0 | 9.2 | 28.3 | 71 | 14 |

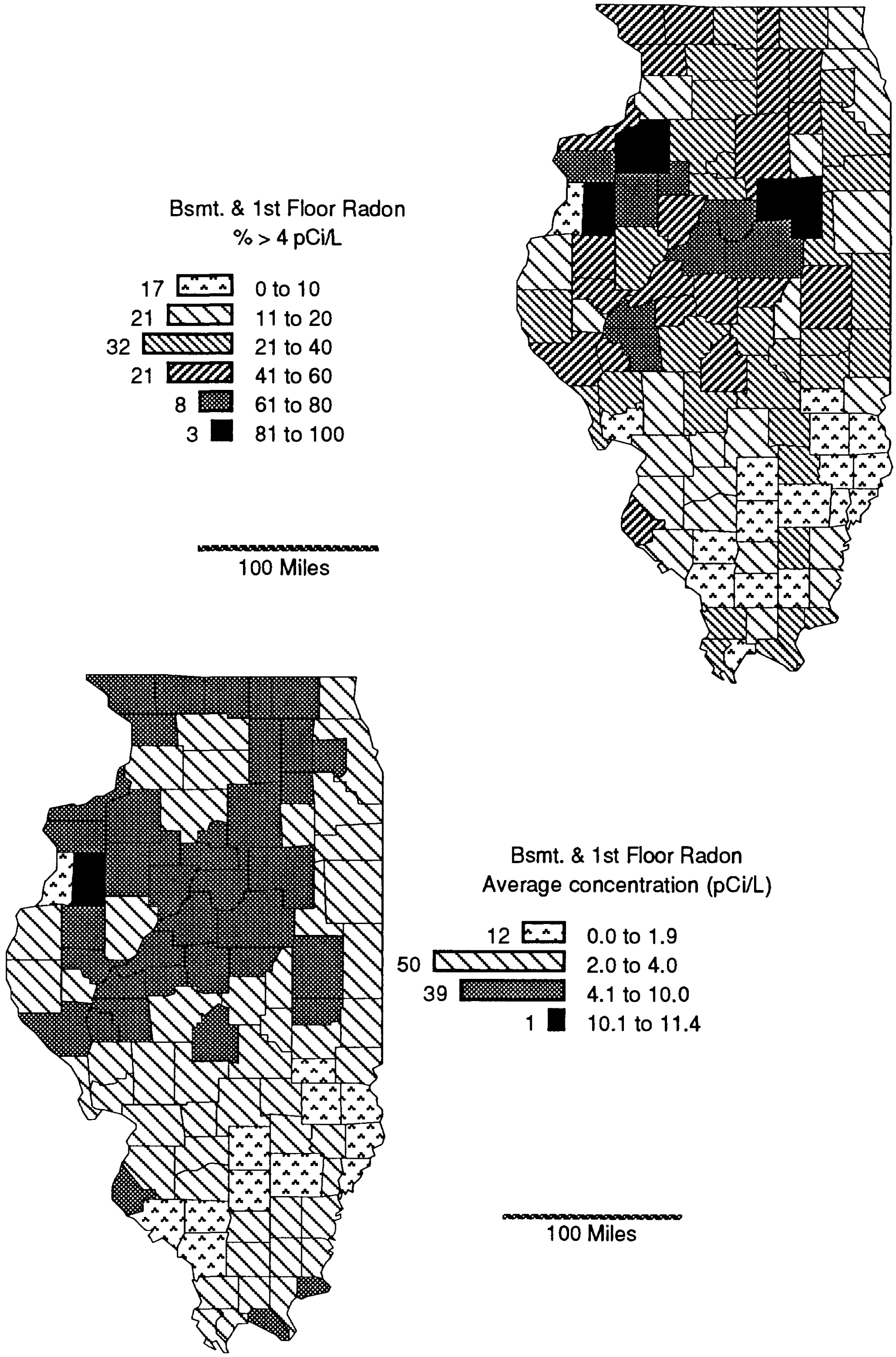



Figure 11. Screening indoor radon data from the Illinois Department of Nuclear Safety indoor radon survey conducted during 1987-1991. Data represent 2-week to 3-month alpha-track detector tests. Histograms in map legends show the number of counties in each category. See Table 2 for additional information from this survey.

TABLE 2. Screening indoor radon data from the IDNS statewide radon survey conducted in Illinois during 1987-91. Data represent 2-week to 3-month alpha-track measurements from the lowest level of each home tested.

| COUNTY | NO. OF MEAS. | MEAN | GEOM. MEAN | MEDIAN | STD. DEV. | MAXIMUM | %>4 pCi/L | %>20 pCi/L |
|---|---|---|---|---|---|---|---|---|
| Adams | 65 | 2.8 | 1.9 | 2.1 | 2.7 | 13.6 | 23 | 0 |
| Alexander | 25 | 3.0 | 2.7 | 3.1 | 1.3 | 5.6 | 24 | 0 |
| Bond | 27 | 2.2 | 1.5 | 1.5 | 1.8 | 6.2 | 19 | 0 |
| Boone | 55 | 5.0 | 4.4 | 4.7 | 2.5 | 13.3 | 62 | 0 |
| Brown | 35 | 3.9 | 2.0 | 2.0 | 9.1 | 55.1 | 23 | 3 |
| Bureau | 24 | 3.0 | 2.6 | 3.1 | 1.6 | 7.0 | 21 | 0 |
| Calhoun | 25 | 3.9 | 3.4 | 3.1 | 2.3 | 10.8 | 32 | 0 |
| Carroll | 28 | 5.1 | 3.5 | 3.4 | 5.5 | 25.4 | 43 | 4 |
| Cass | 28 | 5.2 | 4.6 | 4.7 | 2.5 | 11.3 | 68 | 0 |
| Champaign | 33 | 5.0 | 4.0 | 3.9 | 3.6 | 17.6 | 48 | 0 |
| Christian | 50 | 4.7 | 3.8 | 3.7 | 3.2 | 15.5 | 48 | 0 |
| Clark | 26 | 2.6 | 1.5 | 1.0 | 3.3 | 14.2 | 19 | 0 |
| Clay | 24 | 2.3 | 1.7 | 1.8 | 1.8 | 5.7 | 25 | 0 |
| Clinton | 15 | 2.7 | 2.0 | 1.7 | 2.3 | 8.2 | 20 | 0 |
| Coles | 36 | 3.7 | 2.6 | 2.7 | 3.7 | 18.5 | 33 | 0 |
| Cook | 261 | 2.8 | 2.3 | 2.2 | 1.8 | 11.6 | 19 | 0 |
| Crawford | 30 | 1.5 | 1.1 | 0.8 | 1.7 | 9.7 | 3 | 0 |
| Cumberland | 35 | 1.8 | 1.5 | 1.6 | 1.0 | 4.8 | 3 | 0 |
| DeKalb | 56 | 4.3 | 3.7 | 3.9 | 2.7 | 18.9 | 43 | 0 |
| DeWitt | 27 | 7.5 | 4.2 | 4.9 | 13.9 | 75.6 | 56 | 4 |
| Douglas | 22 | 4.5 | 2.3 | 2.8 | 8.5 | 41.6 | 23 | 5 |
| DuPage | 167 | 4.4 | 3.2 | 3.1 | 6.0 | 64.5 | 31 | 2 |
| Edgar | 31 | 3.0 | 2.3 | 2.0 | 2.7 | 14.3 | 26 | 0 |
| Edwards | 29 | 2.3 | 1.4 | 1.0 | 3.5 | 17.8 | 10 | 0 |
| Effingham | 36 | 3.5 | 2.2 | 1.6 | 4.1 | 19.3 | 28 | 0 |
| Fayette | 40 | 2.9 | 2.5 | 2.5 | 1.7 | 8.4 | 20 | 0 |
| Ford | 28 | 3.3 | 2.5 | 3.3 | 2.2 | 9.1 | 36 | 0 |
| Franklin | 34 | 2.0 | 1.5 | 1.1 | 1.6 | 5.7 | 21 | 0 |
| Fulton | 34 | 3.7 | 2.7 | 2.9 | 3.9 | 18.1 | 29 | 0 |
| Gallatin | 30 | 2.4 | 2.1 | 2.2 | 1.3 | 6.0 | 13 | 0 |
| Greene | 13 | 3.8 | 2.4 | 2.5 | 4.3 | 16.3 | 31 | 0 |
| Grundy | 10 | 2.2 | 1.6 | 1.7 | 1.8 | 5.6 | 20 | 0 |
| Hamilton | 30 | 2.7 | 2.1 | 2.3 | 1.9 | 8.2 | 23 | 0 |
| Hancock | 17 | 2.1 | 1.4 | 1.1 | 2.3 | 8.8 | 18 | 0 |
| Hardin | 29 | 4.4 | 3.7 | 3.2 | 3.3 | 13.5 | 38 | 0 |
| Henderson | 28 | 1.7 | 1.4 | 1.0 | 1.2 | 4.6 | 7 | 0 |
| Henry | 36 | 7.7 | 6.2 | 6.9 | 5.5 | 25.4 | 81 | 6 |
| Iroquois | 30 | 2.9 | 1.9 | 1.7 | 3.3 | 16.9 | 20 | 0 |
| Jackson | 35 | 1.6 | 1.1 | 0.9 | 1.5 | 6.6 | 6 | 0 |
| Jasper | 30 | 1.5 | 1.1 | 1.0 | 1.4 | 7.0 | 7 | 0 |
| Jefferson | 33 | 1.7 | 1.3 | 1.1 | 1.6 | 7.4 | 9 | 0 |
| Jersey | 10 | 3.0 | 2.2 | 2.7 | 2.0 | 8.1 | 10 | 0 |
| Jo Daviess | 21 | 7.1 | 3.6 | 2.8 | 9.5 | 37.5 | 43 | 10 |

TABLE 2 (continued). Indoor radon data from the IDNS statewide radon survey of Illinois.

| COUNTY | NO. OF MEAS. | MEAN | GEOM. MEAN | MEDIAN | STD. DEV. | MAXIMUM | %>4 pCi/L | %>20 pCi/L |
|---|---|---|---|---|---|---|---|---|
| Johnson | 28 | 2.2 | 1.9 | 1.9 | 1.3 | 5.6 | 14 | 0 |
| Kane | 70 | 5.5 | 4.0 | 4.0 | 5.2 | 34.4 | 51 | 3 |
| Kankakee | 35 | 2.7 | 1.8 | 1.7 | 3.0 | 16.8 | 26 | 0 |
| Kendall | 27 | 6.0 | 4.8 | 4.9 | 4.4 | 19.1 | 59 | 0 |
| Knox | 57 | 5.9 | 4.7 | 5.5 | 4.1 | 21.1 | 65 | 2 |
| Lake | 90 | 2.3 | 1.6 | 1.6 | 2.0 | 9.6 | 14 | 0 |
| LaSalle | 86 | 4.6 | 3.7 | 3.8 | 3.1 | 15.5 | 47 | 0 |
| Lawrence | 29 | 1.1 | 1.0 | 0.9 | 0.9 | 5.1 | 3 | 0 |
| Lee | 34 | 3.4 | 2.4 | 2.1 | 3.2 | 15.0 | 24 | 0 |
| Livingston | 26 | 7.7 | 5.9 | 6.0 | 7.4 | 39.8 | 81 | 4 |
| Logan | 57 | 5.0 | 3.9 | 3.9 | 3.7 | 19.2 | 46 | 0 |
| Macon | 72 | 3.0 | 2.0 | 2.0 | 3.3 | 15.7 | 21 | 0 |
| Macoupin | 30 | 2.3 | 1.7 | 1.5 | 1.9 | 7.5 | 20 | 0 |
| Madison | 66 | 2.6 | 1.6 | 1.6 | 4.3 | 34.2 | 11 | 2 |
| Marion | 30 | 1.5 | 1.1 | 1.0 | 1.2 | 4.6 | 10 | 0 |
| Marshall | 26 | 6.0 | 3.5 | 3.3 | 6.9 | 23.4 | 35 | 12 |
| Mason | 29 | 5.9 | 4.8 | 5.0 | 4.0 | 20.8 | 62 | 3 |
| Massac | 26 | 4.5 | 3.2 | 2.9 | 5.7 | 28.1 | 23 | 4 |
| McDonough | 66 | 4.5 | 3.0 | 3.4 | 4.1 | 17.8 | 41 | 0 |
| McHenry | 77 | 4.3 | 3.4 | 3.2 | 3.7 | 23.6 | 30 | 1 |
| McLean | 52 | 6.3 | 4.8 | 5.7 | 4.7 | 23.2 | 62 | 4 |
| Menard | 30 | 4.9 | 3.0 | 3.1 | 4.9 | 20.0 | 43 | 3 |
| Mercer | 28 | 8.5 | 6.5 | 7.8 | 6.1 | 23.1 | 64 | 11 |
| Monroe | 26 | 5.5 | 4.5 | 4.0 | 3.8 | 15.4 | 54 | 0 |
| Montgomery | 32 | 3.5 | 2.4 | 2.5 | 3.3 | 16.9 | 31 | 0 |
| Morgan | 59 | 6.8 | 5.6 | 5.9 | 4.3 | 19.2 | 68 | 0 |
| Moultrie | 26 | 3.0 | 2.2 | 2.2 | 2.7 | 11.0 | 23 | 0 |
| Ogle | 29 | 3.9 | 2.8 | 2.9 | 3.4 | 16.8 | 34 | 0 |
| Peoria | 55 | 5.0 | 3.5 | 3.6 | 4.5 | 22.4 | 42 | 2 |
| Perry | 35 | 1.8 | 1.5 | 1.3 | 1.0 | 4.2 | 6 | 0 |
| Piatt | 35 | 3.2 | 2.5 | 2.6 | 3.0 | 17.9 | 23 | 0 |
| Pike | 27 | 5.5 | 4.2 | 4.4 | 3.9 | 15.9 | 52 | 0 |
| Pope | 30 | 3.8 | 3.1 | 2.6 | 3.2 | 17.6 | 30 | 0 |
| Pulaski | 27 | 2.3 | 2.2 | 2.1 | 0.7 | 4.0 | 4 | 0 |
| Putnam | 26 | 4.5 | 2.4 | 2.5 | 8.4 | 43.8 | 27 | 4 |
| Randolph | 36 | 1.8 | 1.4 | 1.1 | 1.4 | 4.8 | 14 | 0 |
| Richland | 29 | 2.0 | 1.7 | 1.5 | 1.4 | 5.3 | 10 | 0 |
| Rock Island | 66 | 6.0 | 4.1 | 4.7 | 6.5 | 46.2 | 53 | 3 |
| Saline | 26 | 2.1 | 1.8 | 1.7 | 1.2 | 4.9 | 8 | 0 |
| Sangamon | 103 | 3.9 | 3.0 | 2.7 | 3.8 | 23.2 | 29 | 2 |
| Schuyler | 28 | 5.5 | 4.2 | 4.0 | 4.2 | 19.0 | 50 | 0 |
| Scott | 30 | 5.1 | 4.4 | 4.4 | 2.7 | 10.9 | 57 | 0 |
| Shelby | 28 | 3.0 | 2.2 | 2.1 | 2.5 | 10.2 | 21 | 0 |
| St. Clair | 48 | 2.7 | 2.1 | 2.3 | 2.0 | 12.3 | 17 | 0 |
| Stark | 28 | 6.7 | 4.9 | 4.4 | 5.4 | 21.3 | 61 | 4 |

TABLE 2 (continued). Indoor radon data from the IDNS statewide radon survey of Illinois.

| COUNTY | NO. OF MEAS. | MEAN | GEOM. MEAN | MEDIAN | STD. DEV. | MAXIMUM | %>4 pCi/L | %>20 pCi/L |
|---|---|---|---|---|---|---|---|---|
| Stephenson | 56 | 4.6 | 3.7 | 4.3 | 2.9 | 14.9 | 52 | 0 |
| Tazwell | 59 | 5.5 | 4.6 | 4.8 | 3.2 | 14.3 | 64 | 0 |
| Union | 30 | 3.1 | 2.8 | 2.9 | 1.4 | 5.9 | 27 | 0 |
| Vermillion | 36 | 3.9 | 2.9 | 2.5 | 3.1 | 12.8 | 36 | 0 |
| Wabash | 32 | 1.6 | 1.3 | 1.2 | 1.0 | 5.5 | 3 | 0 |
| Warren | 50 | 11.4 | 8.5 | 8.6 | 10.3 | 59.5 | 84 | 16 |
| Washington | 36 | 2.4 | 1.8 | 1.9 | 1.7 | 7.2 | 14 | 0 |
| Wayne | 20 | 1.0 | 0.8 | 0.9 | 0.7 | 3.1 | 0 | 0 |
| White | 32 | 2.0 | 1.6 | 1.7 | 1.5 | 6.4 | 13 | 0 |
| Whiteside | 36 | 2.8 | 2.3 | 2.5 | 1.8 | 8.1 | 19 | 0 |
| Will | 58 | 3.6 | 2.6 | 3.0 | 3.3 | 16.8 | 29 | 0 |
| Williamson | 35 | 2.2 | 1.4 | 0.9 | 2.9 | 11.7 | 9 | 0 |
| Winnebago | 55 | 4.1 | 3.4 | 3.3 | 2.9 | 19.0 | 38 | 0 |
| Woodford | 27 | 9.7 | 7.3 | 8.3 | 7.7 | 33.7 | 78 | 11 |

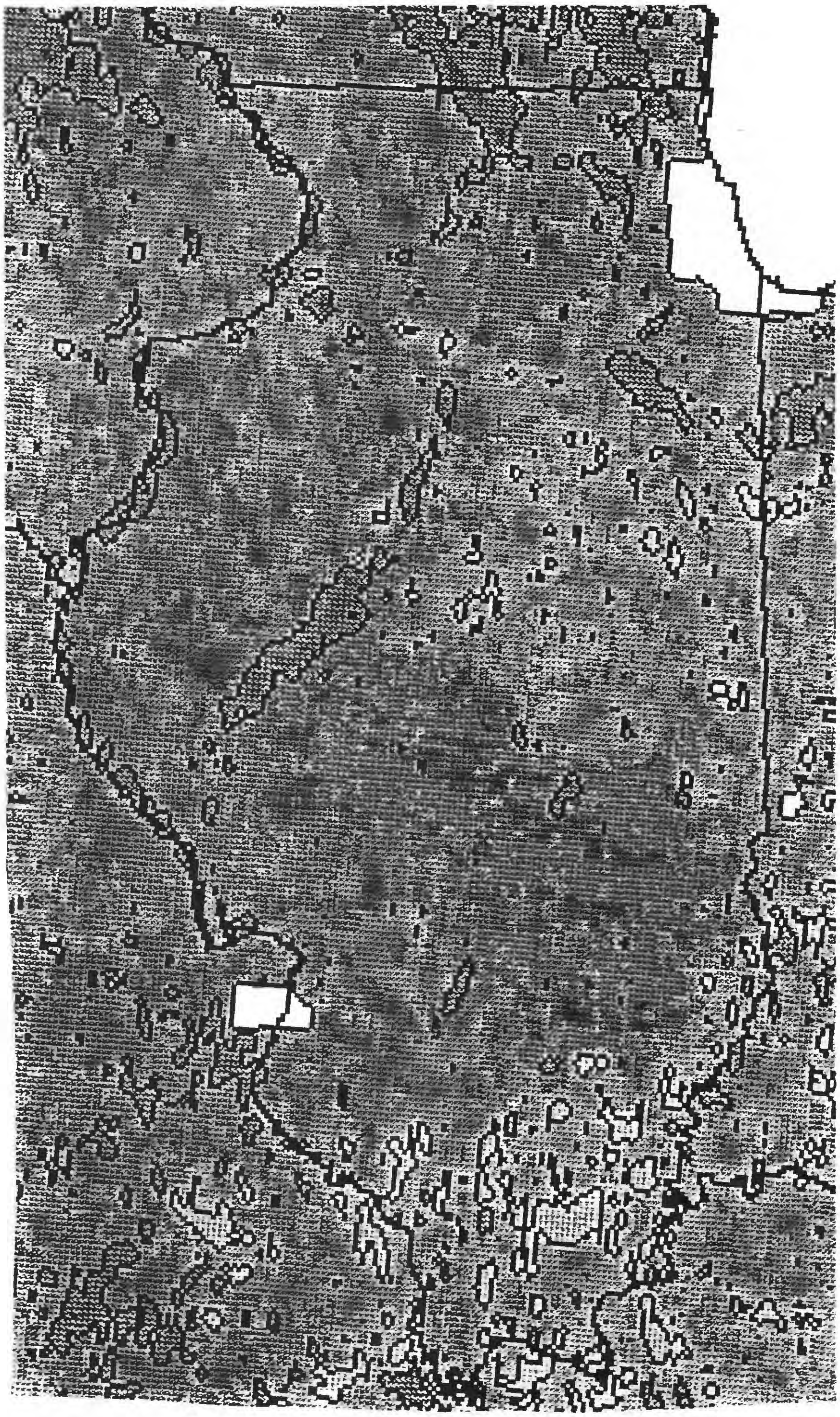


Figure 12. Aerial radiometric map of Illinois (after Duval and others, 1989). Contour lines at 1.5 and 2.5 ppm equivalent uranium (eU). Pixels shaded from 0 to 6.0 ppm eU at 0.5 ppm eU increments; darker pixels have lower eU values; white indicates no data.

In addition, poorly-sorted glacial drift may in many cases have higher permeability than the bedrock from which it is derived. Cracking of clayey soils during dry periods can create sufficient permeability for convective radon transport to occur. This may be an important factor causing elevated radon levels in areas underlain by clay-rich glacial deposits.

Areas underlain by glacial deposits have generally high radon potential, with the exception of windblown sand deposits, such as in part of the Kankakee Plain and major river valleys such as the Illinois and Rock River valleys, and some areas underlain by glacial lake deposits or saturated soils, such as the Chicago Lake Plain and most of the Wheaton Morainal Country (fig. 1). Areas of low soil permeability have generally lower radon potential, a good example of which is the soils developed on Illinoian glacial deposits in the southern one-third of the State (fig. 9), which are deemed to have low to moderate radon potential rather than high, due in part to their low soil permeability. Areas in which black shale constitutes a significant source component to the glacial deposits have high radon potential, but because of the thin subcrop pattern of most of the black shale units underlying Illinois, such areas are expected to be relatively small or localized.

Areas underlain by weathered limestone, such as the Driftless Area in the northwestern corner of the State, or in which carbonate rocks constitute a significant source component to the glacial deposits, have moderate to high radon potential. Although the carbonate rocks themselves are low in uranium and radium, soils and residual deposits developed from these rocks are derived from the dissolution of the calcium carbonate ($CaCO_3$) that makes up the majority of the rock. As the $CaCO_3$ is dissolved away, the soils become relatively enriched in the remaining impurities—predominantly base metals, including uranium. Rinds containing relatively high concentrations of uranium and uranium minerals can be formed on the surfaces of rocks involved with $CaCO_3$ dissolution.

Unglaciated areas in the southern and southwestern parts of Illinois are underlain by sedimentary rocks of Devonian through Pennsylvanian age that have a generally moderate radon potential, except for areas underlain by carbonate rocks or black shales, which have a locally high radon potential. The southern tip of Illinois belonging to the Coastal Plain Province has a low geologic radon potential.

## SUMMARY

For the purposes of this assessment, Illinois is divided into eight geologic radon potential areas (fig. 13) and each assigned Radon Index (RI) and Confidence Index (CI) scores (Table 3). The Radon Index is a semiquantitative measure of radon potential based on geologic, soil, and indoor radon factors, and the Confidence Index is a measure of the relative confidence of the RI assessment based on the quality and quantity of data used to make the predictions (see the Introduction chapter to this regional booklet for more information on the methods and data used).

Area 1 (fig. 13) is the Driftless Area underlain primarily by carbonate rocks. This area has high geologic radon potential (RI=12) with high confidence (CI=10). Area 2 is underlain by Illinoian glacial deposits and loess with generally moderate permeability. This area also includes small areas of Pre-Illinoian glacial deposits and small unglaciated areas along the State's western border (fig. 5). Area 2 has high geologic radon potential (RI=13) with high confidence (CI=10). Area 3 is underlain by Wisconsinan glacial deposits and loess with generally moderate permeability. Local areas underlain by soils with low permeability (fig. 9) may generate moderate radon levels (averaging 2-4 pCi/L). As a whole, Area 3 has generally high geologic radon potential (RI=13) with high confidence (CI=10). Area 4 is underlain by glacial lake deposits and

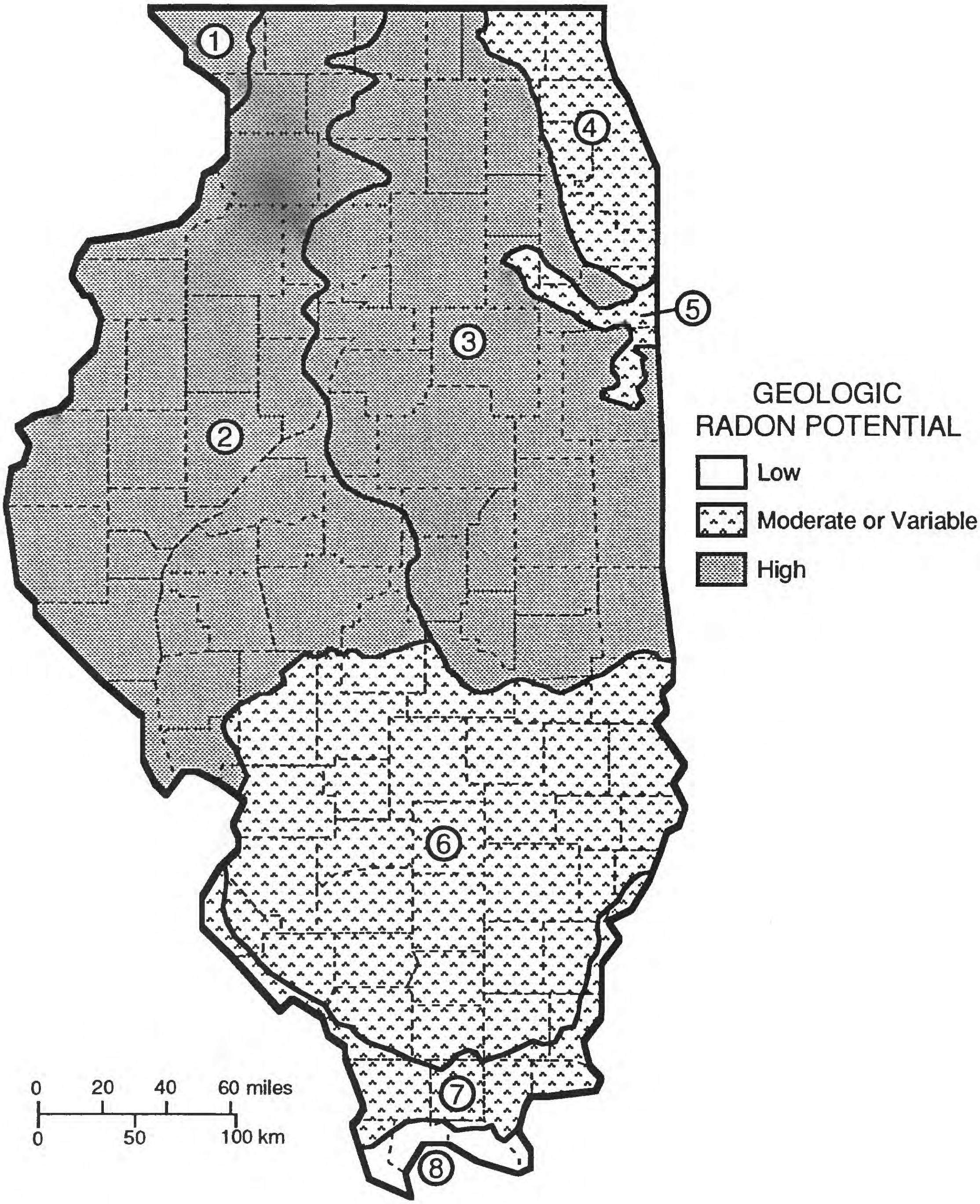



Figure 13. Geologic radon potential areas of Illinois. See Table 3 for Radon Index and Confidence Index rankings of areas.

clay-rich glacial deposits with generally low permeability. Approximately half of this area has no NURE radioactivity data due to restrictions on low-level aircraft flights over the Chicago area. The radioactivity score of 2 points for the area was determined by noting the radioactivity north and south of the Chicago area and assuming that the radioactivity in the Chicago area is similar. The estimate is assigned only one confidence index point due to the lack of data for approximately half of Area 4. This area has moderate geologic radon potential (RI=11) with a moderate confidence index score (CI=8).

Area 5 is underlain by windblown sand deposits with high permeability but low radioactivity because the sand contains mostly quartz with very low concentrations of heavy minerals (including uranium). Areas in which the sand layer is thinner may have moderate to locally high indoor radon levels. Area 5 has moderate geologic radon potential (RI=11) with moderate confidence (CI=9). Homes on windblown sand deposits in Areas 2 and 3 are also likely to have locally low to moderate indoor radon levels. Area 6 is underlain by Illinoian glacial deposits with generally low permeability. The bedrock source material for these deposits contains more sandstone and gray shale, and relatively less black shale and carbonate rock, than in Areas 2 and 3. Areas underlain by glacial lake deposits are likely to have low to moderate indoor radon levels. This area has overall moderate radon potential (RI=9) with moderate confidence (CI=9). Area 7 is unglaciated and is underlain by limestones, sandstones, and shales of Ordovician to Pennsylvanian age (fig. 4). This area has a moderate geologic radon potential (RI=10) with high confidence (CI=10). Area 8 is underlain by alluvium, sand, and loess of the Coastal Plain Province. Area 8 has a low geologic radon potential (RI=8) with high confidence (CI=10). Some areas within Area 8, especially those underlain by thick loess, may have moderate to locally high indoor radon levels.

This is a generalized assessment of the State's geologic radon potential and there is no substitute for having a home tested. The conclusions about radon potential presented in this report cannot be applied to individual homes or building sites. Indoor radon levels, both high and low, can be quite localized, and within any radon potential area there will likely be areas with higher or lower radon potential that assigned to the area as a whole. Any local decisions about radon should not be made without consulting all available local data. 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 3. Radon Index (RI) and Confidence Index (CI) scores for geologic radon potential areas of Illinois. See figure 13 for locations and abbreviations of areas.

| | AREA | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | | 2 | | 3 | | 4 | |
| FACTOR | RI | CI | RI | CI | RI | CI | RI | CI |
| INDOOR RADON | 2 | 3 | 3 | 3 | 3 | 3 | 2 | 3 |
| RADIOACTIVITY | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 |
| GEOLOGY | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 |
| SOIL PERM. | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| ARCHITECTURE | 3 | -- | 3 | -- | 3 | -- | 3 | -- |
| GFE POINTS | 0 | -- | 0 | -- | 0 | -- | 0 | -- |
| TOTAL | 12 | 10 | 13 | 10 | 13 | 10 | 11 | 8 |
| RANKING | HIGH | HIGH | HIGH | HIGH | HIGH | HIGH | MOD | MOD |

| | 5 | | 6 | | 7 | | 8 | |
|---|---|---|---|---|---|---|---|---|
| FACTOR | RI | CI | RI | CI | RI | CI | RI | CI |
| INDOOR RADON | 2 | 3 | 2 | 3 | 2 | 3 | 1 | 3 |
| RADIOACTIVITY | 1 | 2 | 2 | 2 | 2 | 3 | 2 | 3 |
| GEOLOGY | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 2 |
| SOIL PERM. | 3 | 2 | 1 | 2 | 2 | 2 | 2 | 2 |
| ARCHITECTURE | 3 | -- | 2 | -- | 2 | -- | 2 | -- |
| GFE POINTS | 0 | -- | 0 | -- | 0 | -- | 0 | -- |
| TOTAL | 11 | 9 | 9 | 9 | 10 | 10 | 8 | 10 |
| RANKING | MOD | MOD | MOD | MOD | MOD | HIGH | 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

## REFERENCES USED IN THIS REPORT AND GENERAL REFERENCES RELATED TO RADON IN ILLINOIS


Allen, R., and Hamel-Caspary, M., 1991, Radon in Illinois: A status report, *in* Proceedings of the 1991 International Symposium on Radon and Radon Reduction Technology, Volume 4, Symposium Poster Papers: U.S. Environmental Protection Agency report EPA/600/9-91/037D, p. P7-15--P7-33.

Assaf, G., 1971, Comments on "Aircraft measurements of the vertical distribution of radon in the lower atmosphere" by W. E. Bradley and J. E. Pearson: Journal of Geophysical Research, v. 76, p. 2897.

Berg, R.C., and Kempton, J.P., 1988, Stack-unit mapping of geologic materials in Illinois to a depth of 15 meters: Illinois State Geological Survey Circular 542, 23 p., 4 plates.

Berg, R.C., Kempton, J.P., and Cartwright, K., 1984, Potential for contamination of shallow aquifers in Illinois: Illinois State Geological Survey Circular 532, 30 p., 2 plates.

Bradbury, J.C., Ostrom, M.E., and McVicker, L.D., 1955, Preliminary report on uranium in Hardin County, Illinois: Illinois State Geological Survey Circular 200, 21 p.

Cahill, R.A., and Coleman, D.D., 1989, An overview of the significance of radon in natural gas, *in* Proceedings of Conference on Gas Quality and Energy Measurements, sponsored by the Institute of Gas Technology, Rosemont, Illinois, June 12-13, 1989, 19 p.

Cahill, R.A., and Coleman, D.D., 1990, An overview of the significance of radon in natural gas: An update, *in* Proceedings of Conference on Gas Quality and Energy Measurements, sponsored by the Institute of Gas Technology, Chicago, Illinois, July 16-18, 1990, 18 p.

Carmichael, R.S., 1989, Practical Handbook of physical properties of rocks and minerals: Boca Raton, Fla., CRC Press, 741 p.

Duval, J.S., Jones, W.J., Riggle, F.R., and Pitkin, J.A., 1989, Equivalent uranium map of the conterminous United States: U.S. Geological Survey Open-File Report 89-478, 10 p.

Feherenbacher, J.B., Alexander, J.D., Jansen, I.J., Darmody, R.G., Pope, R.A., Flock, M.A., Voss, E.E., Scott, J.W., Andrews, W.F., and Bushue, L.J., 1984, Soils of Illinois: Illinois Agricultural Experiment Station Bulletin 778, 85 p.

Frost, Joyce K., Zierath, D.L., and Shimp, N.F., 1985, Chemical composition and geochemistry of the New Albany Shale Group (Devonian-Mississippian) in Illinois: Illinois State Geological Survey Contract/Grant Report 1985-4, 134 p.

Frye, J.C., Willman, H.B., and Black, R.F., 1965, Outline of glacial geology of Illinois and Wisconsin, *in* Wright, H.E., Jr., and Frye, D.G. (eds.), The Quaternary of the United States: Princeton, NJ, Princeton University Press, p. 29-41.

Ghahremani, D.T., 1987, Radon and hydrocarbon prospecting in basins with shallow black shale deposits: AAPG Bulletin, v. 71, p. 1104.

Gilkeson, R.H., Cartwright, K., Cowart, J.B. and Holtzman, R.B., 1983, Hydrogeologic and geochemical studies of selected natural radioisotopes and barium in groundwater in Illinois: University of Illinois Water Resources Center Research Report 180, p. 93 p.

Gilkeson, R.H., Perry, E.C., Jr., Cowart, J.B. and Holtzman, R.B., 1984, Isotopic studies of the natural sources of radium in groundwater in Illinois: University of Illinois Water Resources Center Research Report 187, 50 p.

Gilkeson, R.H. and Cowart, J.B., 1987, Radium, radon and uranium isotopes in ground water from Cambrian-Ordovician sandstone aquifers in Illinois, *in* B. Graves (ed), Radon, radium, and other radioactivity in ground water: Lewis Publishers, p. 403-422.

Gilkeson, R.H., Cahill, R.A., and Gendron, C.R., 1988, Natural background radiation in the proposed Illinois SSC siting area: Illinois State Geological Survey Environmental Geology Notes 127, 47 p.

Hudson, T.B. and Nelson, R.S., 1989, Analysis of radon concentrations in Pleistocene deposits in Illinois: Transactions of the Illinois State Academy of Science, Suppl., v. 82, p. 49.

Jones, R.L., 1991, Uranium in Illinois surface soils: Soil Science Society of America Journal, v. 55, p. 549-550.

Keefer, D.A., and Berg, R.C., 1990, Potential for aquifer recharge in Illinois: Illinois State Geological Survey map, scale 1:1,000,000.

Lineback, Jerry A., 1979, Quaternary deposits of Illinois: Illinois State Geological Survey , scale 1:500,000.

Lively, Richard, Steck, Daniel, and Brasaemle, Bruce, 1991, A site study of soil characteristics and soil gas radon in Rochester, Minnesota: Minnesota Center for Urban and Regional Affairs report CURA 91-2, 15 p.

Ostrom, M.E., Hopkins, M.E., White, W.A., and McVicker, L.D., 1955, Uranium in Illinois black shales: Illinois State Geological Survey Circular 203, 15 p.

Pearson, J.E. and Jones, G.E., 1965, Emanation of radon 222 from soils and its use as a tracer: Journal of Geophysical Research, v. 70, p. 5279-5290.

Pearson, J.E. and Jones, G.E., 1966, Soil concentrations of "emanating radium-226" and the emanation of radon-222 from soils and plants: Tellus, v. 18, p. 655-662.

Richmond, G.R., and Fullerton, D.S. (eds.), Quaternary Geologic Atlas of the United States: U.S. Geological Survey Miscellaneous Investigations Map I-1420, sheet NK-16, Chicago 4°x6° quadrangle, 1983; sheet NK-15, Des Moines 4°x6° quadrangle, 1991; sheet NJ-16, Louisville 4°x6° quadrangle, 1991; scale 1:1,000,000.

Schumann, R.R., Peake, R.T., Schmidt, K.M., and Owen, D.E., 1991, Correlations of soil-gas and indoor radon with geology in glacially derived soils of the northern Great Plains, *in* Proceedings of the 1990 International Symposium on Radon and Radon Reduction Technology, Volume 2, Symposium Oral Papers: U.S. Environmental Protection Agency report EPA/600/9-91/026b, p. 6-23--6-36.

Striegl, R.G., 1985, Distribution of gases in the unsaturated zone near buried low-level radioactive waste, *in* N.R. Tilford (ed), Site selection, characterization, and design exploration: Proceedings of Association of Engineering Geologists 28th annual meeting; Site selection, characterization, and design exploration; in conjunction with International Symposium on Management of hazardous chemical waste sites, Winston-Salem, NC, Oct. 7-11, 1985, p. 96.

Striegl, R.G., 1988, Distribution of gases in the unsaturated zone at a low-level radioactive-waste disposal site near Sheffield, Illinois: U.S. Geological Survey Water Resources Investigations 88-4025, 69 p.

Willman, H.B., and Frye, J.C., 1970, Pleistocene stratigraphy of Illinois: Illinois State Geological Survey Bulletin 94, 204 p.

Willman, H.B., and others, 1967, Geologic map of Illinois: Illinois State Geological Survey, scale 1:500,000.

Willman, H.B., Atherton, E., Buschbach, T.C., Collinson, C., Frye, J.C., Hopkins, M.E., Lineback, J.A., and Simon, J.A., 1975, Handbook of Illinois stratigraphy: Illinois State Geological Survey Bulletin 95, 251 p.

# PRELIMINARY GEOLOGIC RADON POTENTIAL ASSESSMENT OF INDIANA

*by*
*R. Randall Schumann*
*U.S. Geological Survey*

## INTRODUCTION

Many of the rocks and soils in Indiana have the potential to generate levels of indoor radon exceeding the U.S. Environmental Protection Agency's (EPA) guideline of 4 pCi/L. In a survey of 1,914 homes conducted during the winter of 1987-88 by the Indiana State Board of Health and the EPA, 27 percent of the homes tested had indoor radon levels exceeding this value. The statewide indoor radon average in this survey was 3.7 pCi/L.

This is a generalized assessment of geologic radon potential of rocks, soils, and surficial deposits of Indiana. 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

Indiana lies within the Central Lowland physiographic province, an area of gently rolling landscape and nearly level plains in the Central Stable region of the United States. Indiana may be subdivided into nine main physiographic regions based on altitude, relief, and geomorphic features (fig. 1). The following discussion of the State's physiography is condensed from Schneider (1966).

The Dearborn Upland (fig. 1) is an area of southeasternmost Indiana characterized by dissected uplands about 950 to 1,000 ft (290 to 305 m) in elevation, and smooth, steep slopes leading into valleys 200 to 500 ft (60 to 150 m) deep. The northern boundary of the area is gradational into the Tipton Till Plain, and the area is covered by 50 to 200 ft (15 to 60 m) of Illinoian till. The Muscatatuck Regional Slope lies directly west of the Dearborn Upland. The Laughery Escarpment, at elevations of 875 ft (267 m) near the Ohio River to 1,100 ft (335 m) at its northern edge, forms the eastern boundary of the region. This area is a sloping plain that dips westward from the escarpment and merges gradually with the Scottsburg Lowland to the west (fig. 1). The Scottsburg Lowland is an area of slight relief, broad valleys, and very gentle slopes in south-central Indiana. Elevations in the area range from 600 to 700 ft (183-213 m). The Knobstone Escarpment, Indiana's most prominent physiographic feature, forms the boundary between the Scottsburg Lowland and the Norman Upland to the west.

The Norman Upland is a dissected upland area bordered on the east by the Knobstone Escarpment; to the west it grades into the Mitchell Plain and northward it gradually disappears beneath the Tipton Till Plain. The Norman Upland has relatively high local relief and maturely

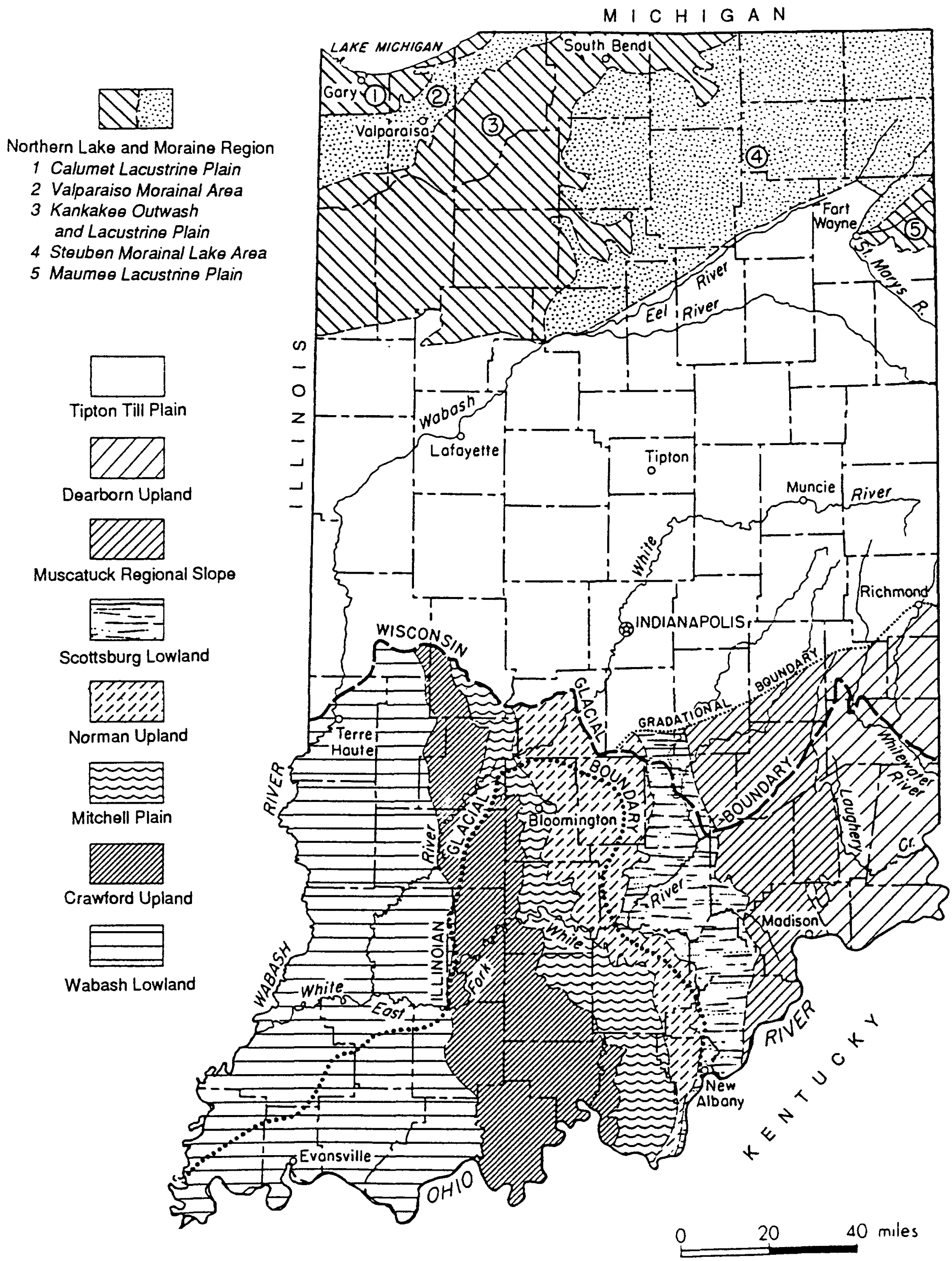



Figure 1. Physiographic regions of Indiana (modified from Wayne, 1956).

dissected topography, as much of the area was not glaciated. The Mitchell Plain (fig. 1) is characterized by karst topography developed on gently westward-dipping limestones. The border between this and the Norman Upland is marked by the onset of solution features including sinkholes, caves, karst valleys, and underground drainage. The best examples of karst features may be found in Washington and Orange Counties (Schneider, 1966). The Chester Escarpment forms the border between the Mitchell Plain and the Crawford Upland, an area of variable and rugged topography including angular and rounded hills, deep narrow valleys, broad shallow valleys, sinkholes, waterfalls, escarpments, caves, and natural bridges. The Wabash Lowland is developed on Pennsylvanian-age shales and sandstones that form more rounded, subdued topography than in the Crawford Upland to the east (fig. 1). The Lowland averages about 500 ft (152 m) in elevation and has low relief, broad, shallow, aggraded valleys, and low hills. Sand dunes may be found east of the larger valleys in the area.

The Tipton Till Plain covers approximately one-third of the State between the Eel River and the Wisconsin glacial boundary (fig. 1). The area is generally flat to gently sloping, with local relief formed by glacial features such as moraines or kames, or where the glacial deposits are draped over bedrock highs. The northern quarter of Indiana is occupied by the Northern Moraine and Lake Region. This area comprises five subdivisions that represent, and are named for, either moraines or glacial lake plains (fig. 1).

Indiana's population is largely rural; most of its counties have less than 50,000 inhabitants (fig. 2). However, several areas of the State have concentrations of population around urban centers, including Marion, Vigo, Vanderburgh, Monroe, Tippecanoe, Madison, Delaware, and Allen Counties, and the area between Gary and Elkhart along the State's northern border (figs. 2, 3). Marion County, with a 1990 population of about 797,000, represents about 15 percent of Indiana's total population.

## GEOLOGY

The discussion of geology is divided into three sections: bedrock geology, glacial geology, and uranium in rocks and soils. "Bedrock" refers to pre-glacial rock units, which are covered by glacial deposits in about two-thirds of the State. A bedrock geologic map (fig. 4) shows rock units that underlie glacial deposits or are exposed at the surface in some areas. The glacial deposits are composed of material derived from underlying bedrock and from rock units to the north and northeast. The discussion of bedrock geology is summarized from Frey and Eckerty (1966), Shaver and others (1986), and Indiana Geological Survey (1990). The section on glacial geology is summarized from Wayne (1963), Wayne and Zumberge (1965), Indiana Geological Survey (1979), and Richmond and Fullerton (1983, 1991). For more detailed discussions and maps of the geology, the reader is encouraged to consult these and other reports.

*Bedrock geology:* Excluding Quaternary glacial deposits, rocks ranging in age from Ordovician to Pennsylvanian are exposed at the surface in Indiana (fig. 4). The bedrock geology of Indiana is largely controlled by its structural setting. The major tectonic features in Indiana are the Michigan Basin in the northern part of the State, the Illinois Basin in the southern and western part, and the Kankakee and Cincinnati Arches, which run from the northwest to the southeast corners of Indiana, separating the two basins.

Ordovician rocks are exposed in the southeastern corner of the State (fig. 4) and are composed of limestone and shale. Silurian strata, including limestone, dolomite, and shale, are exposed directly west of the Ordovician rocks and are coincident with the NW-SE-trending

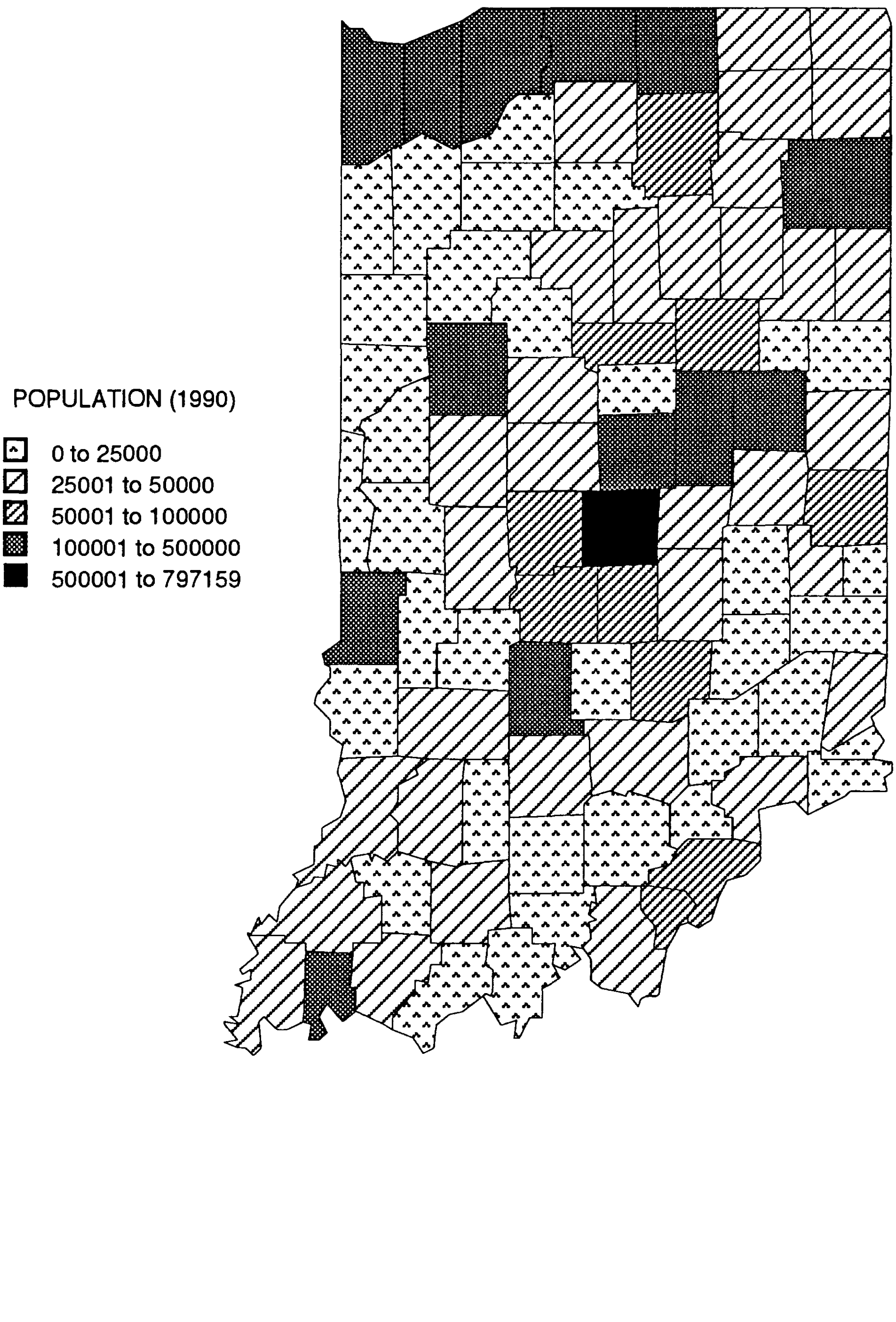



Figure 2. Population of counties in Indiana (1990 U.S. Census data).


Figure 3. Indiana counties.

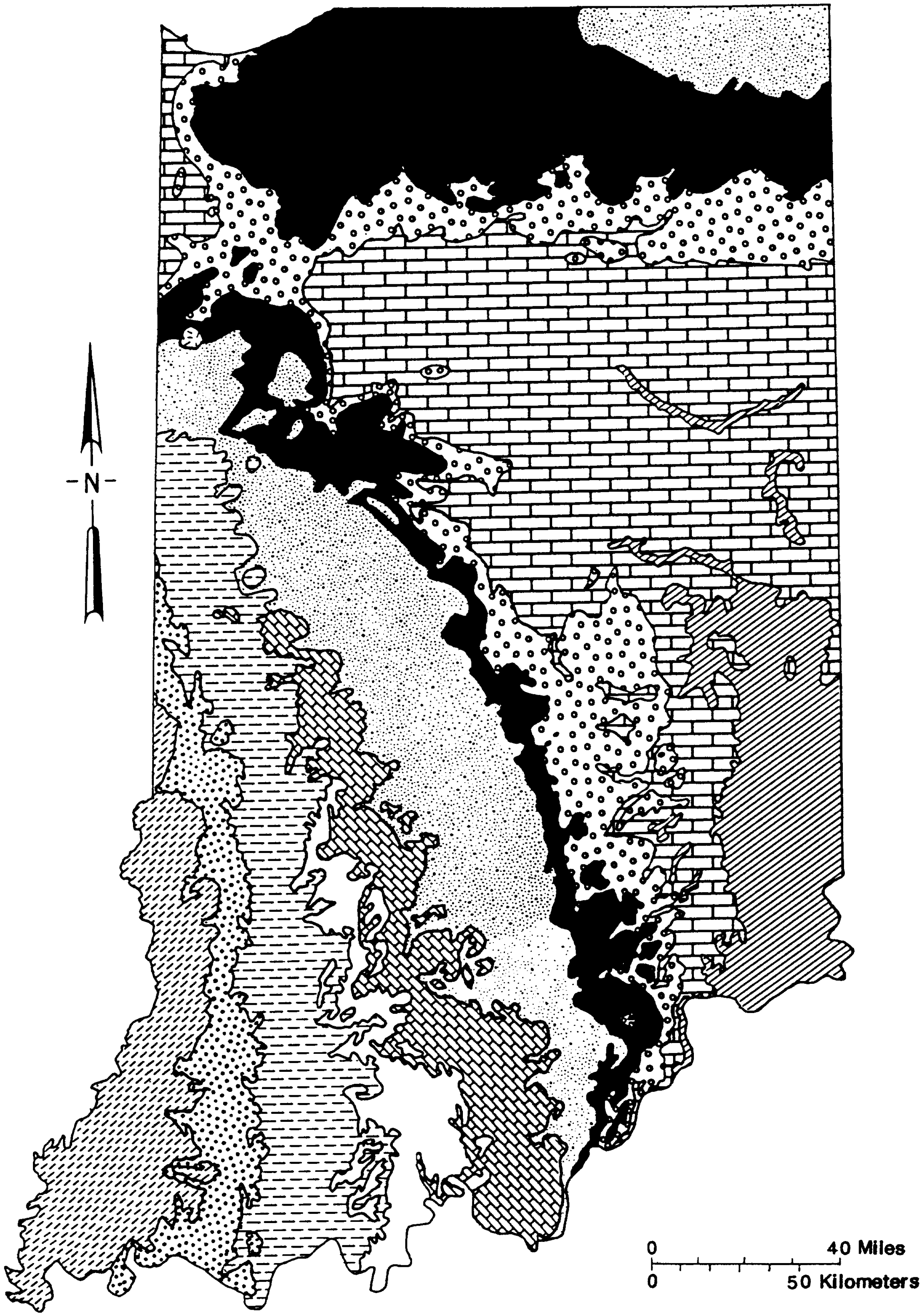



Figure 4. Generalized bedrock geologic map of Indiana (redrawn from Indiana Geological Survey, 1990).

## GENERALIZED BEDROCK GEOLOGIC MAP OF INDIANA

### EXPLANATION

**Pennsylvanian Rocks**

McLeansboro Group - shale and sandstone

Carbondale Group - shale and sandstone; thin beds of limestone,clay, and coal

Raccoon Creek Group - shale and sandstone

**Mississippian Rocks**

Buffalo Wallow, Stephensport, and West Baden Groups - shale, sandstone, and limestone

Blue River and Sanders Groups - limestone

Borden Group and equivalents plus Rockford Limestone - siltstone and shale

**Devonian - Mississippian Rocks**

New Albany Shale and equivalents - black shale

**Devonian Rocks**

Muscatatuck Group - limestone and dolomite

**Silurian Rocks**

Undifferentiated - shale and limestone

**Ordovician Rocks**

Maquoketa Group - shale and limestone

Cincinnati Arch. Middle Devonian rocks include limestone and dolomite; Upper Devonian and Lower Mississippian rocks are dominantly shales. Of particular note are the Devonian Antrim Shale and the Devonian-Mississippian New Albany Shale, both of which contain organic-rich black shales (actually brownish-black in color). The Antrim Shale underlies glacial deposits in an east-west band across the northern part of the State. The New Albany Shale underlies glacial deposits in a northwest-southeast trend from Newton County to the Wisconsinan glacial limit in Bartholomew County and is exposed at the surface south of the Wisconsinan glacial limit and in areas where Illinoian glacial deposits are thin and discontinuous (fig. 4). The Devonian-Mississippian Ellsworth and Sunbury Shales and the Mississippian Coldwater Shale complete the list of Michigan Basin rocks in northern Indiana. These rocks are completely covered by glacial deposits and are significant source components of the till in this area. The bulk of Mississippian rocks consist of limestones and dolomites, with lesser amounts of shale, sandstones, and siltstones. Pennsylvanian rocks are composed of sequences of shale, sandstone, limestone, clay, and coal. Mississippian and Pennsylvanian rocks are exposed in the southwestern and south-central parts of the State and underlie the glacial deposits in west-central Indiana (fig. 4).

*Glacial geology:* About three-quarters of Indiana is covered by glacial deposits from one or more Pleistocene glaciations (fig. 5). Most of the pre-Wisconsinan glacial deposits are Illinoian in age and resulted from at least three separate advances during Illinoian time (Wayne and Zumberge, 1965). Pre-Wisconsinan tills are calcareous loam (approximately equal parts sand, silt, and clay) and clay loam derived from a northeastern source. Source rocks for this drift include carbonate rocks (limestones and dolomites), shales (including the New Albany Shale in southeastern Indiana), sandstones, and siltstones. Rare pebbles of igneous and metamorphic rocks are also found in this unit.

Wisconsinan glacial deposits were deposited by three main glacial lobes—the Lake Michigan lobe, which advanced southward, carving the trough that is now Lake Michigan and continuing southward as far as central Indiana, and the Huron-Erie and Saginaw lobes, which advanced from the northeast across northern Ohio and southern Michigan, respectively. Michigan lobe deposits are clayey near Lake Michigan, sandy and gravelly in an outwash and morainal area in northwestern Indiana, and clayey to loamy in west-central Indiana (fig. 5). Saginaw lobe deposits are loamy and calcareous and are derived primarily from carbonate rocks and shale. The Huron-Erie lobe advanced from the northeast and covered much of northern and central Indiana at its maximum extent. For this discussion the Huron-Erie lobe deposits are divided into two main areas on figure 5. Loamy Huron-Erie lobe deposits cover roughly the middle third of Indiana and are derived from limestone, dolomite, sandstone, siltstone, and shale, with carbonate rocks being the dominant source component of the tills. Clayey Huron-Erie lobe deposits are calcareous clays and silty clays derived primarily from shales in northwestern Ohio and northeastern Indiana, but also include limestone, dolomite, and occasional crystalline rock fragments (Richmond and Fullerton, 1983). Loess (windblown silt derived from glacial or glaciofluvial deposits) covers many of the glacial deposits in discontinuous layers as much as 1 m thick. A large mapped area of loess deposits lies immediately east of the Wabash River in southwestern Indiana (fig. 5).

*Uranium in rocks and soils:* Indiana has no known uranium deposits of commercial value (Blakely, 1958). However, many of the rocks and surficial deposits in the State contain sufficient uranium to generate indoor radon at levels of concern. The average crustal abundance of uranium is about 2.5 ppm, and most non-organic-rich shales contain 1-4 ppm uranium (Carmichael, 1989). Black marine shales, particularly the Devonian-Mississippian New Albany Shale, which contains from 4 to as much as 278 parts per million (ppm) uranium in some areas (Hasenmueller, 1988),

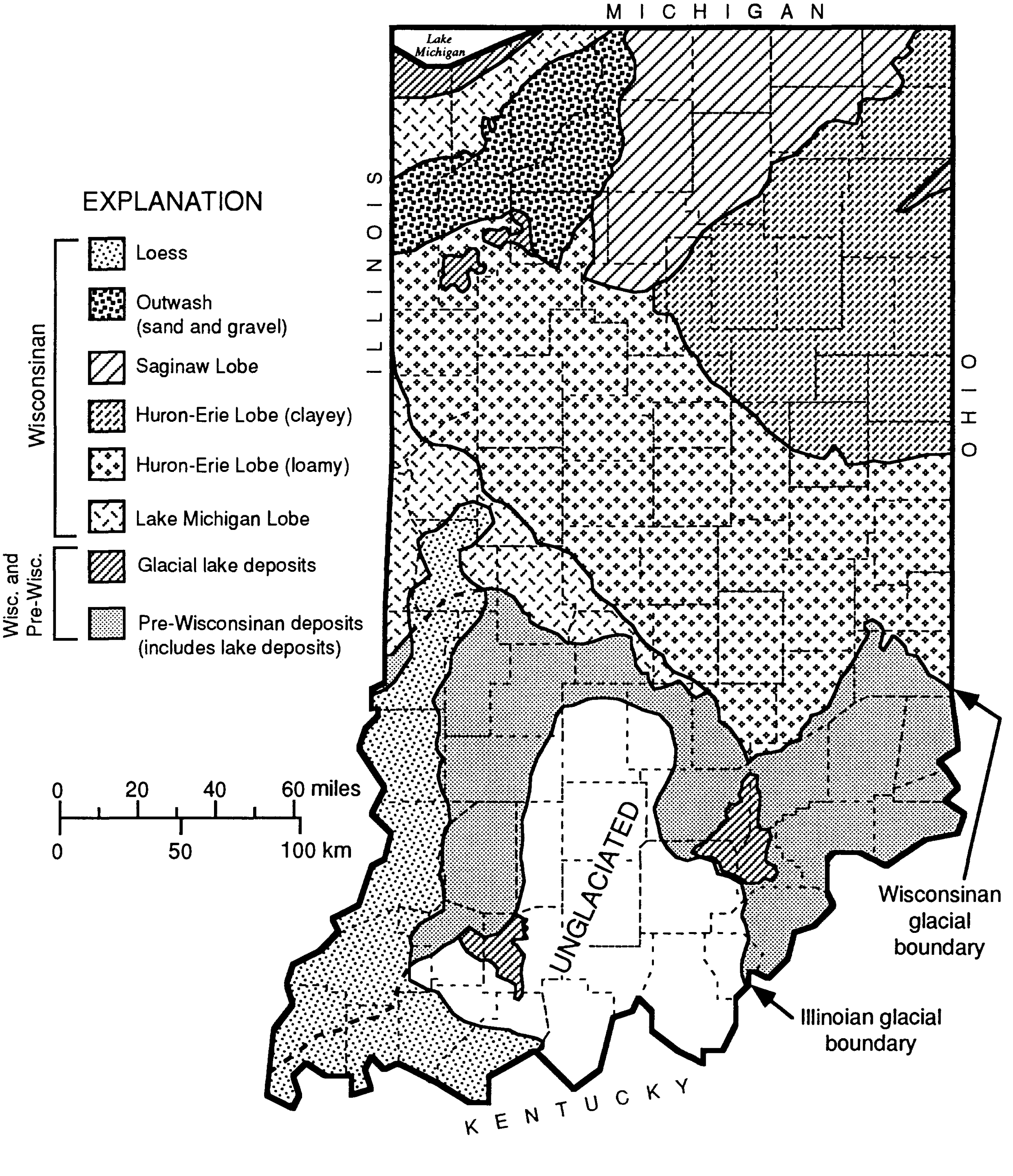



Figure 5. Generalized map of glacial deposits in Indiana (after Richmond and others, 1983; Indiana Geological Survey, 1979; and Wayne, 1963).

and the Devonian Antrim Shale, which is organic-rich in some areas and contains as much as 36 ppm uranium (in samples from southern Michigan), are notable. Thin, organic-rich marine shales of Pennsylvanian age also contain higher-than-average amounts of uranium. Samples of thin Pennsylvanian shale units in southwestern Indiana contain uranium concentrations as high as 289 ppm (Hasenmueller, 1988). The Devonian-Mississippian Ellsworth and Sunbury shales also locally contain black shale units with 6 to 36 ppm uranium or equivalent uranium (measured in samples and wells in southern Michigan). Uranium concentrations in the shales vary between different units and within the same unit in different areas.

Carbonate rocks (limestone, dolomite) may also constitute a source of sufficient uranium to generate elevated indoor radon levels. Although carbonate rocks contain low concentrations of uranium and radium, residual soils developed from these rocks become relatively enriched in the remaining impurities—predominantly base metals, including uranium, as the calcium carbonate is dissolved away during the weathering process. Rinds containing relatively high concentrations of uranium and uranium minerals can form on the surfaces of rocks associated with calcium carbonate dissolution.

## SOILS

Most of the soils in Indiana are Alfisols (fig. 6; Indiana Soil Survey Staff, 1977), gray to brown soils that generally have a subsurface horizon of clay accumulation and are usually moist. These soils have low to moderate and locally high permeability (generally 0.06-6.0 in/hr in U.S. Soil Conservation Service (SCS) percolation tests). Entisols occur in the northwestern part of Indiana (fig. 6). These soils contain no pedogenic horizons, weather easily (U.S. Soil Conservation Service, 1987), and are moderately to highly permeable (0.6 to >20 in/hr in SCS percolation tests). Mollisols are found in west-central and northwestern Indiana. Mollisols are black, organic-rich soils of subhumid climates. These soils are moderately permeable (0.2-2.0 in/hr). Ultisols occur in south-central Indiana (fig. 6). These soils are generally moist, but dry during the warm season, are relatively low in organic matter in the subsurface horizons, have subsurface horizons of clay accumulation, weatherable minerals, or both (U.S. Soil Conservation Service, 1987), and have low to moderate permeability (<0.06 to 6.0 in/hr). A relatively small area of Inceptisols is found in the southeastern corner of the State (fig. 6). Inceptisols have weakly differentiated horizons, and have lost materials through weathering and leaching. There are generally no subsurface accumulations in discrete horizons, but the soils have appreciable free calcium carbonate (U.S. Soil Conservation Service, 1987). These soils have low to moderate permeability.

## INDOOR RADON DATA

Screening indoor radon data from 1,914 homes sampled in the State/EPA Residential Radon Survey conducted in Indiana during the winter of 1987-88 are listed in Table 1 and shown in figure 7. This survey employed short-term (2-7 day) charcoal canister indoor radon tests. The maximum value recorded in the survey was 72 pCi/L in Orange County, and the statewide indoor radon average was 3.7 pCi/L. Twenty-seven percent of the homes tested in this survey had screening indoor radon levels exceeding 4 pCi/L, but only 1.5 percent of the homes tested had levels exceeding 20 pCi/L.

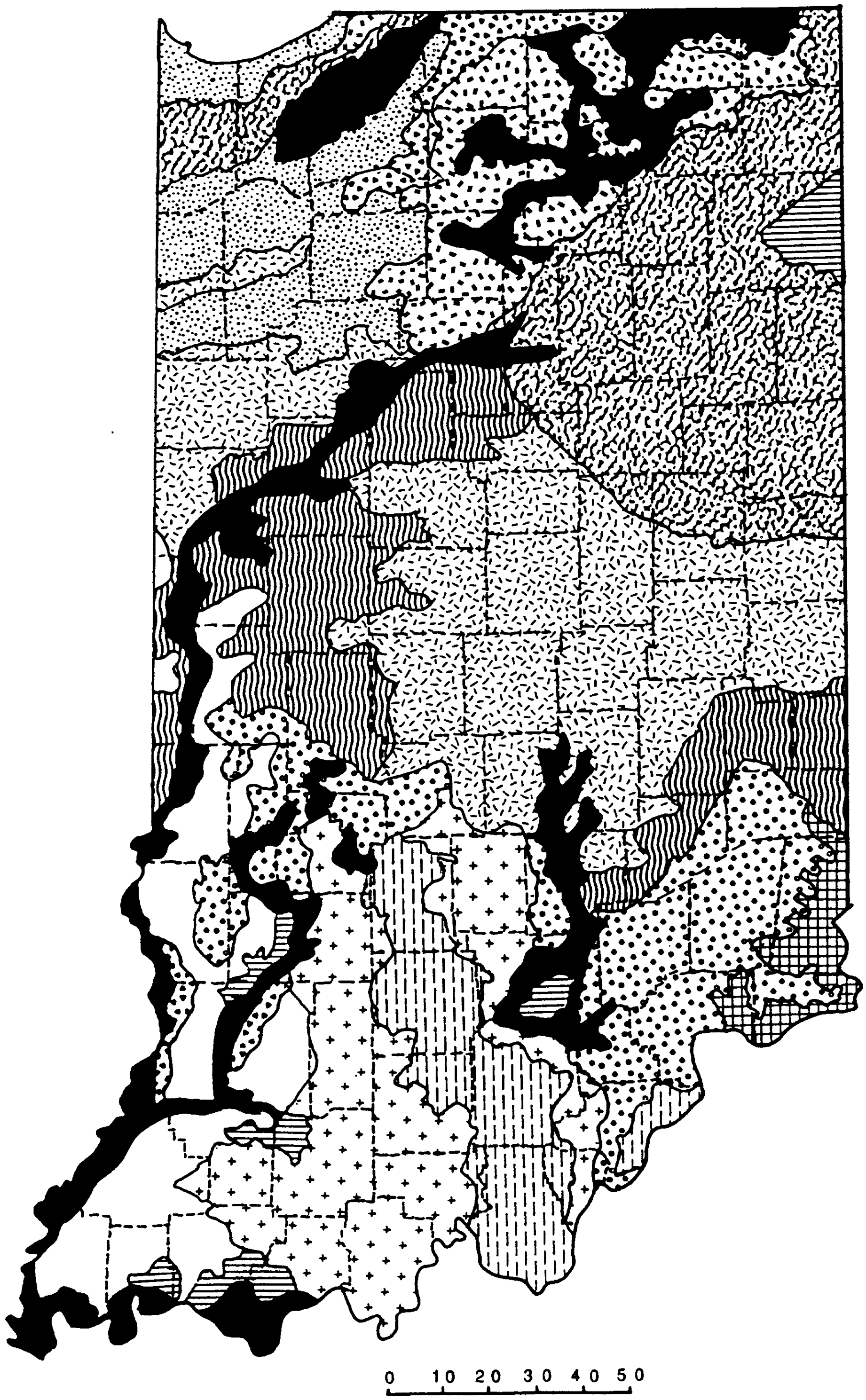



Figure 6. Generalized map showing soil regions of Indiana (after Indiana Soil Survey Staff, 1977, and U.S. Soil Conservation Service county soil survey data).

## GENERALIZED SOIL MAP OF INDIANA
## EXPLANATION

Mollisols and Entisols formed in sandy and loamy lacustrine deposits and eolian sand of Wisconsinan age. *Moderate to high permeability.*

Alfisols formed in silty and clayey Wisconsinan and Illinoian lacustrine deposits. *Moderate permeability.*

Alfisols, Mollisols, and Entisols formed in Holocene alluvial deposits, Wisconsinan outwash and Illinoian outwash.
*Moderate to high permeability.*

Alfisols formed in Wisconsinan eolian sand deposits.
*Moderate to high permeability.*

Alfisols formed in thick Wisconsinan loess deposits.
*Moderate Permeability.*

Alfisols formed in loamy Wisconsinan glacial till.
*Moderate permeability.*

Alfisols formed in clayey Wisconsinan glacial till.
*Moderate permeability.*

Mollisols and Alfisols formed in thin loess over loamy Wisconsinan glacial till. *Moderate permeability.*

Alfisols formed in moderately thick loess over Wisconsinan glacial till.
*Moderate permeability.*

Alfisols formed in moderately thick loess deposits over weathered loamy Illinoian glacial till. *Low to moderate permeability.*

Ultisols and Alfisols formed in discontinuous loess over weathered loamy Illinoian glacial till. *Moderate permeability.*

Ultisols and Alfisols formed in discontinuous loess over weathered Mississippian and Devonian limestone. *Moderate permeability.*

Inceptisols formed in discontinuous loess over weathered Ordovician limestone and shale. *Low to moderate permeability.*

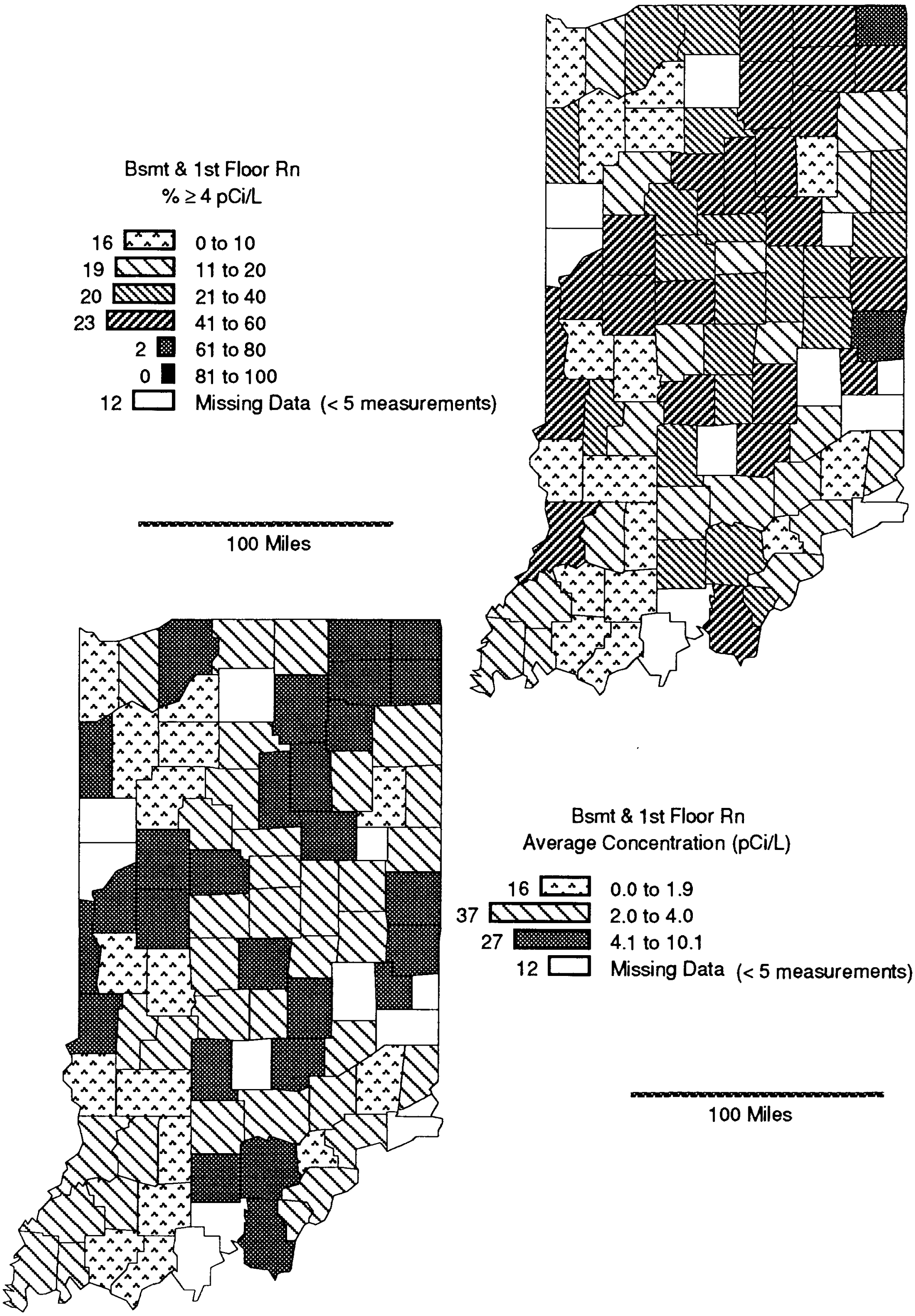



Figure 7. Screening indoor radon data from the EPA/State Residential Radon Survey of Indiana, 1987-88, for counties with 5 or more measurements. Data are from 2-7 day charcoal canister tests. Histograms in map legends show the number of counties in each category. The number of samples in each county (see Table 1) may not be sufficient to statistically characterize the radon levels of the counties, but they do suggest general trends. Unequal category intervals were chosen to provide reference to decision and action levels.

TABLE 1. Screening indoor radon data from the EPA/State Residential Radon Survey of Indiana conducted during 1987-88. Data represent 2-7 day charcoal canister measurements from the lowest level of each home tested.

| COUNTY | NO. OF MEAS. | MEAN | GEOM. MEAN | MEDIAN | STD. DEV. | MAXIMUM | %>4 pCi/L | %>20 pCi/L |
|---|---|---|---|---|---|---|---|---|
| ADAMS | 14 | 3.2 | 2.3 | 2.3 | 2.5 | 7.4 | 36 | 0 |
| ALLEN | 169 | 3.0 | 1.8 | 1.6 | 4.3 | 37.4 | 17 | 1 |
| BARTHOLOMEW | 28 | 5.5 | 3.6 | 4.4 | 4.8 | 18.1 | 57 | 0 |
| BENTON | 2 | 3.4 | 2.7 | 3.4 | 2.8 | 5.3 | 50 | 0 |
| BLACKFORD | 4 | 1.2 | 0.8 | 0.9 | 1.0 | 2.6 | 0 | 0 |
| BOONE | 9 | 4.0 | 3.1 | 4.4 | 2.4 | 6.8 | 56 | 0 |
| BROWN | 3 | 4.4 | 3.6 | 2.3 | 3.6 | 8.5 | 33 | 0 |
| CARROLL | 7 | 2.4 | 1.2 | 1.7 | 2.2 | 5.6 | 29 | 0 |
| CASS | 6 | 3.6 | 2.8 | 4.4 | 2.2 | 6.0 | 50 | 0 |
| CLARK | 92 | 3.0 | 1.8 | 1.7 | 4.1 | 32.3 | 18 | 1 |
| CLAY | 8 | 2.0 | 1.2 | 1.6 | 1.9 | 5.2 | 25 | 0 |
| CLINTON | 7 | 4.1 | 2.3 | 2.8 | 5.1 | 15.3 | 29 | 0 |
| CRAWFORD | 2 | 1.2 | 1.0 | 1.2 | 1.0 | 1.9 | 0 | 0 |
| DAVIESS | 5 | 3.6 | 2.3 | 1.7 | 4.3 | 11.1 | 20 | 0 |
| DE KALB | 21 | 4.6 | 3.7 | 4.5 | 2.9 | 12.1 | 57 | 0 |
| DEARBORN | 6 | 2.5 | 1.8 | 1.5 | 2.9 | 8.4 | 17 | 0 |
| DECATUR | 5 | 3.1 | 2.9 | 2.6 | 1.2 | 4.8 | 20 | 0 |
| DELAWARE | 16 | 3.2 | 2.2 | 2.5 | 2.5 | 7.7 | 25 | 0 |
| DUBOIS | 5 | 1.2 | 1.2 | 1.3 | 0.4 | 1.7 | 0 | 0 |
| ELKHART | 76 | 4.0 | 2.9 | 3.5 | 3.2 | 18.1 | 41 | 0 |
| FAYETTE | 6 | 8.0 | 5.8 | 5.9 | 6.8 | 19.8 | 50 | 0 |
| FLOYD | 32 | 3.0 | 2.1 | 1.8 | 3.0 | 13.3 | 25 | 0 |
| FOUNTAIN | 13 | 10.1 | 4.4 | 3.8 | 11.7 | 33.6 | 46 | 23 |
| FRANKLIN | 4 | 1.0 | 0.8 | 0.8 | 0.7 | 1.9 | 0 | 0 |
| FULTON | 9 | 3.1 | 2.5 | 2.6 | 2.2 | 8.0 | 22 | 0 |
| GIBSON | 16 | 2.6 | 1.8 | 1.9 | 2.5 | 10.9 | 13 | 0 |
| GRANT | 13 | 5.8 | 3.7 | 5.5 | 5.8 | 22.4 | 54 | 8 |
| GREENE | 16 | 1.1 | 0.9 | 1.0 | 0.8 | 2.9 | 0 | 0 |
| HAMILTON | 23 | 3.5 | 2.3 | 2.7 | 3.7 | 17.0 | 26 | 0 |
| HANCOCK | 8 | 3.5 | 2.1 | 1.6 | 4.9 | 15.5 | 13 | 0 |
| HARRISON | 19 | 6.2 | 3.1 | 3.0 | 7.7 | 28.8 | 42 | 11 |
| HENDRICKS | 22 | 2.0 | 1.3 | 1.0 | 1.8 | 6.4 | 14 | 0 |
| HENRY | 11 | 3.5 | 2.1 | 2.7 | 3.7 | 13.3 | 27 | 0 |
| HOWARD | 22 | 3.4 | 2.3 | 2.6 | 2.8 | 9.7 | 32 | 0 |
| HUNTINGTON | 13 | 2.9 | 2.4 | 2.8 | 1.8 | 7.8 | 8 | 0 |
| JACKSON | 7 | 2.0 | 1.0 | 1.0 | 2.0 | 5.9 | 14 | 0 |
| JASPER | 11 | 1.5 | 1.1 | 1.2 | 1.1 | 3.4 | 0 | 0 |
| JAY | 5 | 3.4 | 2.2 | 2.6 | 3.2 | 8.4 | 40 | 0 |
| JEFFERSON | 16 | 2.1 | 1.3 | 1.2 | 2.3 | 7.7 | 19 | 0 |
| JENNINGS | 19 | 2.4 | 1.4 | 1.8 | 2.6 | 10.4 | 11 | 0 |
| JOHNSON | 34 | 2.7 | 1.7 | 1.8 | 2.3 | 8.7 | 29 | 0 |

TABLE 1 (continued). Screening indoor radon data for Indiana.

| COUNTY | NO. OF MEAS. | MEAN | GEOM. MEAN | MEDIAN | STD. DEV. | MAXIMUM | %>4 pCi/L | %>20 pCi/L |
|---|---|---|---|---|---|---|---|---|
| KNOX | 9 | 3.4 | 2.2 | 2.2 | 2.9 | 9.0 | 44 | 0 |
| KOSCIUSKO | 30 | 5.9 | 3.8 | 4.5 | 6.3 | 28.7 | 60 | 3 |
| LA PORTE | 66 | 4.7 | 2.2 | 2.1 | 5.8 | 23.0 | 32 | 3 |
| LAGRANGE | 9 | 8.9 | 5.2 | 7.5 | 8.7 | 27.6 | 56 | 11 |
| LAKE | 125 | 1.3 | 0.9 | 1.0 | 1.0 | 5.2 | 2 | 0 |
| LAWRENCE | 28 | 3.0 | 1.8 | 1.7 | 4.2 | 21.5 | 18 | 4 |
| MADISON | 27 | 3.6 | 2.2 | 2.5 | 4.0 | 19.6 | 37 | 0 |
| MARION | 115 | 4.9 | 2.8 | 3.2 | 7.0 | 60.3 | 37 | 3 |
| MARSHALL | 3 | 0.9 | 0.9 | 0.9 | 0.5 | 1.4 | 0 | 0 |
| MARTIN | 5 | 1.9 | 1.6 | 1.2 | 1.3 | 3.9 | 0 | 0 |
| MIAMI | 28 | 6.5 | 3.7 | 4.7 | 6.8 | 28.3 | 54 | 4 |
| MONROE | 30 | 4.6 | 2.5 | 3.0 | 7.7 | 41.5 | 30 | 3 |
| MONTGOMERY | 21 | 5.7 | 3.8 | 4.1 | 4.8 | 16.2 | 52 | 0 |
| MORGAN | 7 | 3.8 | 2.2 | 3.2 | 3.2 | 9.4 | 43 | 0 |
| NEWTON | 12 | 4.2 | 2.5 | 2.6 | 4.3 | 13.8 | 33 | 0 |
| NOBLE | 20 | 5.3 | 2.7 | 3.8 | 5.2 | 18.2 | 50 | 0 |
| OHIO | 4 | 2.3 | 2.0 | 2.3 | 1.2 | 3.6 | 0 | 0 |
| ORANGE | 11 | 9.2 | 2.6 | 3.2 | 20.9 | 71.8 | 36 | 9 |
| OWEN | 5 | 2.0 | 0.7 | 1.9 | 2.2 | 5.6 | 20 | 0 |
| PARKE | 7 | 1.9 | 1.7 | 1.6 | 1.0 | 4.0 | 0 | 0 |
| PERRY | 3 | 2.0 | 1.7 | 2.3 | 1.2 | 3.1 | 0 | 0 |
| PIKE | 8 | 2.0 | 1.3 | 2.0 | 1.3 | 3.8 | 0 | 0 |
| PORTER | 84 | 2.8 | 1.7 | 1.8 | 3.2 | 15.5 | 19 | 0 |
| POSEY | 6 | 2.9 | 2.3 | 2.6 | 1.8 | 5.8 | 17 | 0 |
| PULASKI | 5 | 1.5 | 1.2 | 1.1 | 1.1 | 3.3 | 0 | 0 |
| PUTNAM | 6 | 1.7 | 1.0 | 1.4 | 1.5 | 4.0 | 0 | 0 |
| RANDOLPH | 9 | 4.1 | 2.2 | 4.1 | 3.0 | 7.3 | 56 | 0 |
| RIPLEY | 6 | 1.3 | 1.1 | 1.2 | 0.7 | 2.2 | 0 | 0 |
| RUSH | 1 | 0.6 | 0.6 | 0.6 | 0.0 | 0.6 | 0 | 0 |
| SCOTT | 21 | 1.8 | 0.9 | 0.9 | 2.7 | 12.2 | 10 | 0 |
| SHELBY | 7 | 5.1 | 3.3 | 2.3 | 4.8 | 13.7 | 43 | 0 |
| SPENCER | 11 | 1.9 | 1.6 | 1.5 | 1.3 | 5.2 | 9 | 0 |
| ST. JOSEPH | 114 | 3.7 | 2.5 | 2.5 | 4.0 | 25.7 | 26 | 2 |
| STARKE | 8 | 1.3 | 1.1 | 1.2 | 0.9 | 3.3 | 0 | 0 |
| STEUBEN | 13 | 5.2 | 4.3 | 5.0 | 2.9 | 10.8 | 69 | 0 |
| SULLIVAN | 12 | 1.3 | 0.8 | 0.7 | 1.4 | 4.8 | 8 | 0 |
| SWITZERLAND | 2 | 1.9 | 1.8 | 1.9 | 0.4 | 2.1 | 0 | 0 |
| TIPPECANOE | 39 | 7.1 | 3.7 | 3.4 | 9.1 | 45.7 | 49 | 5 |
| TIPTON | 5 | 3.0 | 1.4 | 1.3 | 4.6 | 11.1 | 20 | 0 |
| VANDERBURGH | 32 | 2.5 | 1.5 | 1.7 | 2.3 | 9.9 | 19 | 0 |
| VERMILLION | 8 | 7.9 | 2.6 | 3.7 | 13.5 | 40.4 | 50 | 13 |
| VIGO | 34 | 4.8 | 3.0 | 3.3 | 4.7 | 20.2 | 44 | 3 |
| WABASH | 15 | 5.3 | 3.8 | 4.7 | 3.7 | 11.0 | 60 | 0 |

TABLE 1 (continued). Screening indoor radon data for Indiana.

| COUNTY | NO. OF MEAS. | MEAN | GEOM. MEAN | MEDIAN | STD. DEV. | MAXIMUM | %>4 pCi/L | %>20 pCi/L |
|---|---|---|---|---|---|---|---|---|
| WARREN | 4 | 6.6 | 3.0 | 2.5 | 9.5 | 20.7 | 25 | 25 |
| WARRICK | 21 | 1.5 | 0.9 | 1.0 | 1.6 | 7.5 | 5 | 0 |
| WASHINGTON | 10 | 4.6 | 2.9 | 3.1 | 4.6 | 15.4 | 30 | 0 |
| WAYNE | 18 | 8.8 | 5.5 | 5.1 | 10.3 | 44.4 | 67 | 6 |
| WELLS | 7 | 1.9 | 1.3 | 1.2 | 1.7 | 5.2 | 14 | 0 |
| WHITE | 16 | 1.7 | 1.1 | 1.3 | 1.7 | 6.2 | 13 | 0 |
| WHITLEY | 23 | 4.9 | 3.0 | 2.9 | 4.6 | 16.7 | 43 | 0 |

The following counties had screening indoor radon averages of 4 pCi/L or greater in the State/EPA survey: Bartholomew*, Boone*, Brown, Clinton, De Kalb*, Elkhart, Fayette, Fountain, Grant*, Harrison, Kosciusko*, Lagrange*, La Porte, Marion, Miami*, Monroe, Montgomery*, Newton, Noble, Orange, Randolph*, Shelby, Steuben*, Tippecanoe, Vermillion, Vigo, Wabash*, Warren, Washington, Wayne*, and Whitley (* indicates that more than 50 percent of the homes tested in the county had basement or first-floor radon levels greater than 4 pCi/L) (fig. 7; Table 1).

## GEOLOGIC RADON POTENTIAL

A comparison of bedrock geology (fig. 4), glacial geology, (fig. 5) and soils (fig. 6) with indoor radon (fig. 7) and aeroradioactivity (fig. 8) data allows delineation of rock and soil units with identifiable radon potential. This assessment differs somewhat from that of Hasenmueller (1988) in that a different ranking scheme is used and the areas delineated in this report are more generalized. The reader is urged to consult Hasenmueller (1988) for additional information.

In general, elevated indoor radon levels (defined as ≥ 4 pCi/L for purposes of this report) in Indiana are associated with black shales and carbonate rocks (limestone and dolostone), and with glacial deposits derived from these rocks. Black shales are concentrators of uranium and are known to cause indoor radon problems in a number of areas in the United States. Uranium is concentrated with organic matter in the shales or in phosphate layers within the shales (Coveney and others, 1988). As discussed in the uranium section of this report, the soils developed from carbonate rocks are composed of the residue, including heavy minerals and metals such as uranium, that remains after dissolution of the calcium carbonate. The development of karst topography, characterized by solution cavities, sinkholes, and caves, in carbonate rocks, increases the overall permeability of the rocks in these areas and generally increases the radon potential of these rocks.

Areas covered by clayey Huron-Erie lobe deposits (fig. 5) have high radon potential. A significant proportion of the source material for these deposits is uranium-bearing black shale including the Ohio Shale transported from northwestern Ohio, and locally, the Antrim Shale. The northern part of this area has a higher proportion of black shale, a higher radiometric signature, (fig. 8; Gooding, 1973), and slightly higher average indoor radon levels than the southern part. Higher radon levels may be associated with end moraines versus ground moraine, but a definitive determination cannot be made at the scale of this assessment. Loamy Huron-Erie lobe deposits (fig. 5) containing limestone as their primary source component also have overall high radon potential, though indoor radon averages are somewhat lower than in areas with more shale-rich glacial deposits. Part of the area is underlain by the New Albany Shale (fig. 4), and where the glacial deposits contain black shale as a significant source component, radon levels are likely to be higher. Locally elevated radon levels in White, Carroll, and Tippecanoe counties may be due to the influence of the New Albany Shale (Hasenmueller, 1988).

Areas covered by glacial lake deposits in the vicinity of Lake Michigan have variable radon potential depending on the texture, moisture content, and composition of the deposits. The area has generally low surface radioactivity (fig. 8). Areas of dune sands or wetlands have low radon potential; areas of till or lake deposits derived from carbonate rocks or black shale have moderate to high radon potential. In light of the variable nature of most of the significant factors, the area is assigned an overall moderate radon potential.

Figure 8. Aerial radiometric map of Indiana (after Duval and others, 1989). Contour lines at 1.5 and 2.5 ppm equivalent uranium (eU). Pixels shaded from 0 to 6.0 ppm eU at 0.5 ppm eU increments; darker pixels have lower eU values; white indicates no data.

Immediately to the south of the lake deposits is an area of morainal till of the Lake Michigan lobe and outwash (fig. 5). These deposits are generally coarse grained (sand and gravel), but locally they may contain significant clay derived from the underlying shale units (fig. 4). Areas of dune sand have low radon potential; most of the rest of the area has moderate radon potential. Elevated indoor radon levels in Newton County are likely associated with the New Albany Shale, especially in areas where the surficial deposits are thin (Hasenmueller, 1988). Overall, this map unit has moderate radon potential.

Deposits of the Saginaw lobe (fig. 5) contain carbonate rocks from southern Michigan and shales from northern Indiana, some of which are organic-rich, as primary source components. Igneous and metamorphic rocks of the Canadian Shield comprise the larger cobbles and boulders found in the till. The surface radioactivity of this unit is low (fig. 8), but in light of the geology and indoor radon data, areas underlain by this unit are considered to have high radon potential overall.

Loess deposits in southwestern Indiana (fig. 5) generate low to moderate indoor radon levels (fig. 7). Most of southwestern Indiana is underlain by Pennsylvanian shale, sandstone, thin limestone, and relatively thin pre-Wisconsinan glacial deposits (mostly less than 50 ft (15 m) thick) with low to moderate radon potential. Scattered radiometric anomalies in this area (fig. 8) may be associated with localized exposures of Middle Pennsylvanian black shale (Hasenmueller, 1988). Mississippian limestones and dolostones in the unglaciated region (figs. 4, 5) have moderate to locally high radon potential. A line of aeroradiometric anomalies (fig. 8) and elevated indoor radon averages in Harrison, Orange, and Washington counties (fig. 7) appears to be associated with terra rosa soils formed on karsted limestones of the Mississippian Blue River Group (fig. 4) in this area (Hasenmueller, 1988). Locally elevated indoor radon levels are likely to occur in this area. The Devonian-Mississippian New Albany Shale is likely associated with high radon levels in Clark, Scott, Jennings, and Bartholomew counties (fig. 7) as well as in counties north of the Wisconsinan glacial limit (fig. 5) in which the New Albany Shale makes up a significant component of the source rock for the till. A line of radiometric anomalies follows the outcrop of the New Albany Shale from the Indiana-Kentucky state line to the Wisconsinan glacial limit (fig. 8). Rocks in southeastern Indiana include Devonian and Silurian carbonate rocks and shale (fig. 4) with moderate radon potential and Ordovician shale and limestone with generally low to moderate radon potential.

## SUMMARY

For the purposes of this assessment, Indiana is divided into nine geologic radon potential areas (fig. 9) and each assigned Radon Index (RI) and Confidence Index (CI) scores (Table 2). The Radon Index is a semiquantitative measure of radon potential based on geologic, soil, and indoor radon factors, and the Confidence Index is a measure of the relative confidence of the RI assessment based on the quality and quantity of data used to make the predictions. See the introduction chapter to this regional booklet for more information on the methods and data used.

Area 1 is underlain primarily by silty to clayey glacial lake deposits and sand dunes adjacent to Lake Michigan. This area has moderate geologic radon potential (RI=11) with moderate confidence (CI=9). Area 2 has an overall moderate geologic radon potential (RI=10) with moderate confidence (CI=9). Moraine deposits in the northern part of the area are associated with moderate indoor radon levels, whereas outwash and dune sand in the southern part of Area 2 are generally associated with low radon levels. Homes underlain by New Albany Shale in Newton

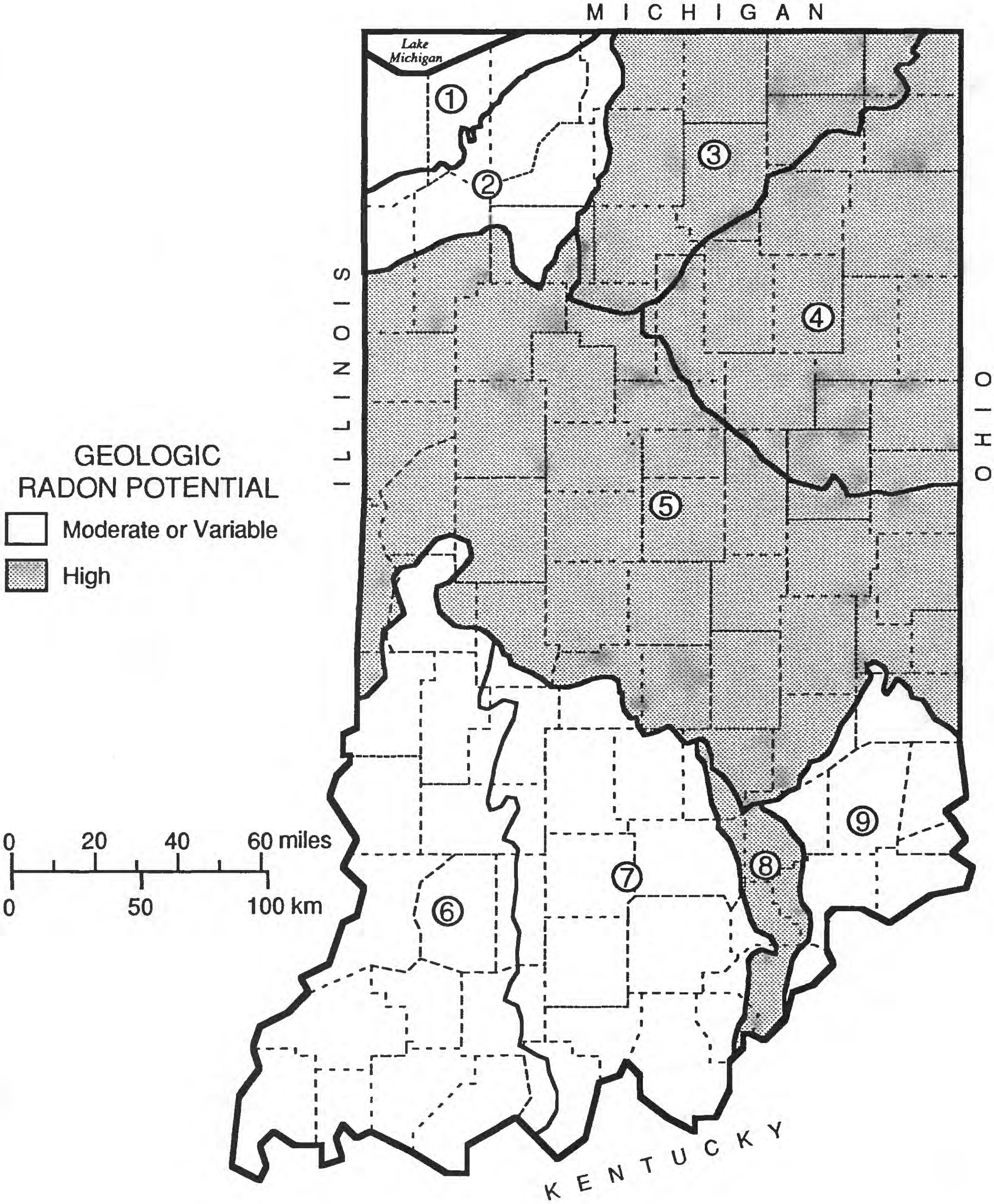



Figure 9. Geologic radon potential areas of Indiana. See Table 2 for area rankings and text for discussion of areas.

County are likely to have locally high indoor radon levels. Area 3 is underlain by clayey and loamy deposits of the Saginaw lobe. Carbonates and shales, some of which are locally organic-rich (such as the Antrim Shale) are primary source rocks. This area has high geologic radon potential (RI=12) with moderate confidence (CI=9). Area 4 delineates clayey glacial deposits of the Huron-Erie lobe. Organic-rich shale and carbonate rocks are primary source materials for the till, with more shale in the northern part of the area than in the southern part. Area 4 has high geologic radon potential (RI=13) with moderate confidence (CI=9). Elevated radon levels can be expected throughout this area, but somewhat higher levels may be associated with glacial deposits with higher shale contents. Loamy Huron-Erie lobe deposits cover most of Area 5; Lake Michigan lobe deposits are present in the southwest corner of the area. Carbonate rocks and shale are primary source rocks for the tills. Area 5 has high geologic radon potential (RI=12) with moderate confidence (CI=9). Areas underlain by and immediately west of the New Albany Shale subcrop area have higher average indoor radon levels, probably due to the higher proportion of shale in the tills.

Area 6 includes the southwestern part of Indiana south of the Wisconsinan glacial limit. This area is covered by loess, thin pre-Wisconsinan glacial deposits, and Pennsylvanian shale, sandstone, and carbonate bedrock. Areas underlain by loess have moderate geologic radon potential. Homes built on the Pennsylvanian Raccoon Creek Group (fig. 4) appear to have generally low radon levels (fig. 7). Overall, Area 6 has moderate geologic radon potential (RI=10) with high confidence (CI=10). Unglaciated areas underlain by karsted Mississippian carbonate rocks covered by terra rosa soils in south-central Indiana (Area 7) have moderate to locally high geologic radon potential. Areas where the Mississippian Blue River Group is present have high average indoor radon levels. Area 7 has moderate to locally high geologic radon potential (RI=11) with high confidence (CI=10).

Area 8 outlines the outcrop area of the New Albany Shale south of the Wisconsinan glacial limit. This area has high geologic radon potential (RI=13) with high confidence (CI=10). Area 9 is characterized by Ordovician through Devonian limestone, dolostone, and gray shale, and pre-Wisconsinan glacial deposits derived from these rocks. The area has moderate geologic radon potential (RI=10) with high confidence (CI=10). Homes built on carbonate rocks in this area are slightly more likely to have elevated indoor radon levels than homes built on shale.

This is a generalized assessment of the State's geologic radon potential and there is no substitute for having a home tested. The conclusions about radon potential presented in this report cannot be applied to individual homes or building sites. Indoor radon levels, both high and low, can be quite localized, and within any radon potential area there will likely be areas with higher or lower radon potential that assigned to the area as a whole. Any local decisions about radon should not be made without consulting all available local data. 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 2. Radon Index (RI) and Confidence Index (CI) scores for geologic radon potential areas of Indiana. See figure 9 for locations of numbered areas.

| | AREA | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | | 2 | | 3 | | 4 | |
| FACTOR | RI | CI | RI | CI | RI | CI | RI | CI |
| INDOOR RADON | 2 | 3 | 2 | 3 | 3 | 3 | 2 | 3 |
| RADIOACTIVITY | 2 | 2 | 1 | 2 | 1 | 2 | 3 | 2 |
| GEOLOGY | 2 | 2 | 2 | 2 | 3 | 2 | 3 | 2 |
| SOIL PERM. | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| ARCHITECTURE | 3 | -- | 3 | -- | 3 | -- | 3 | -- |
| GFE POINTS | 0 | -- | 0 | -- | 0 | -- | 0 | -- |
| TOTAL | 11 | 9 | 10 | 9 | 12 | 9 | 13 | 9 |
| RANKING | MOD | MOD | MOD | MOD | HIGH | MOD | HIGH | MOD |

| | 5 | | 6 | | 7 | | 8 | | 9 | |
|---|---|---|---|---|---|---|---|---|---|---|
| FACTOR | RI | CI | RI | CI | RI | CI | RI | CI | RI | CI |
| INDOOR RADON | 2 | 3 | 2 | 3 | 3 | 3 | 2 | 3 | 2 | 3 |
| RADIOACTIVITY | 2 | 2 | 2 | 3 | 2 | 3 | 3 | 3 | 2 | 3 |
| GEOLOGY | 3 | 2 | 2 | 2 | 2 | 2 | 3 | 2 | 2 | 2 |
| SOIL PERM. | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| ARCHITECTURE | 3 | -- | 2 | -- | 2 | -- | 2 | -- | 2 | -- |
| GFE POINTS | 0 | -- | 0 | -- | 0 | -- | 0 | -- | 0 | -- |
| TOTAL | 12 | 9 | 10 | 10 | 11 | 10 | 12 | 10 | 10 | 10 |
| RANKING | HIGH | MOD | MOD | HIGH | MOD | HIGH | HIGH | HIGH | MOD | HIGH |

RADON INDEX SCORING:

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

Possible range of points = 3 to 17

CONFIDENCE INDEX SCORING:

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

Possible range of points = 4 to 12

## REFERENCES CITED IN THIS REPORT AND GENERAL REFERENCES RELAVENT TO RADON IN INDIANA


Blakely, R.F., 1958, Indiana's radioactive rocks: Outdoor Indiana, v.2, p. 19-21.

Bork, K.B., 1966, Geomorphology and glacial geology of Indiana, *in* Frey, R.W., and Lane, M.A., eds, A survey of Indiana geology, with road logs for two field trips: Bloomington, Indiana, Rho Chapter, Sigma Gamma Epsilon, Indiana University Department of Geology, p. 65-74.

Carmichael, R.S., 1989, Practical Handbook of physical properties of rocks and minerals: Boca Raton, Fla., CRC Press, 741 p.

Coveney, R.M., Jr., Hilpman, P.L., Allen, A.V., and Glascock, M.D., 1988, Radionuclides in Pennsylvanian black shales of the midwestern United States, *in* Marikos, M.A., and Hansman, R.H., eds, Geologic causes of natural radionuclide anomalies: Missouri Division of Geology and Land Survey Special Publication No. 4, p. 25-42.

Duval, J.S., Jones, W.J., Riggle, F.R., and Pitkin, J.A., 1989, Equivalent uranium map of the conterminous United States: U.S. Geological Survey Open-File Report 89-478, 10 p.

Frey, R.W., and Eckerty, D.G., 1966, Descriptions of stratigraphic units in Indiana, *in* Frey, R.W., and Lane, M.A., eds, A survey of Indiana geology, with road logs for two field trips: Bloomington, Indiana, Rho Chapter, Sigma Gamma Epsilon, Indiana University Department of Geology, p. 22-38.

Gooding, A.M., 1973, Characteristics of Late Wisconsinan tills in eastern Indiana: Indiana Geological Survey Bulletin 49, 28 p.

Hasenmueller, Nancy R., 1988, Preliminary geologic characterization of Indiana for indoor-radon survey: Indiana Geological Survey Report of Progress 32, 7 p.

Indiana Geological Survey, 1979, Map of Indiana showing unconsolidated deposits: Indiana Geological Survey Miscellaneous Map 26, scale 1 inch=approx. 28 miles.

Indiana Geological Survey, 1990, Map of Indiana showing bedrock geology: Indiana Geological Survey Miscellaneous Map 50, scale 1 inch=approx. 28 miles.

Indiana Soil Survey Staff, 1977, Map of soil associations of Indiana: Purdue University Cooperative Extension Service, map AY-209, scale 1:500,000.

Richmond, G.R., and Fullerton, D.S. (eds.), Quaternary Geologic Atlas of the United States: U.S. Geological Survey Miscellaneous Investigations Map I-1420, sheet NK-16, Chicago 4°x6° quadrangle, 1983; sheet NJ-16, Louisville 4°x6° quadrangle, 1991; scale 1:1,000,000.

Samuelson, A.C., Hammer, J., Ober, D., Govaer, D., Dewus, Michael, Koltenbah, B., Godish, T. and Bennett, A., 1989, Air and water radon investigations in glaciated regions of Indiana: Geological Society of America, Abstracts with Programs, v. 21, no. 4, p. 46.

Schneider, A.F., 1966, Physiography, *in* Lindsey, A.A. (ed.), Natural features of Indiana: Indiana Sesquitennial Volume, 1816-1966, Indiana Academy of Science, p. 40-56.

Shaver, R.B., Ault, C.H., Burger, A. M., Carr, D.D., Droste, J.B., Eggert, D.L., Gray, H.H., Harper, D., Hasenmueller, N. R., Hasenmueller, W.A., Horowitz, A.S., Hutchison, H.C., Keith, B.D., Keller, S.J., Patton, J.B., Rexroad, C.B., and Wier, C.E., 1986, Compendium of Paleozoic rock-unit stratigraphy in Indiana—a revision: Indiana Geological Survey Bulletin 59, 203 p.

Wayne, W.J., 1956, Thickness of drift and bedrock physiography of Indiana north of the Wisconsin glacial boundary: Indiana Geological Survey Report of Progress 7, 70 p.

Wayne, W.J., 1963, Pleistocene formations in Indiana: Indiana Geological Survey Bulletin 25, 85 p.

Wayne, W.J., and Zumberge, J.H., 1965, Pleistocene geology of Indiana and Michigan, *in* Wright, H.E., Jr., and Frey, D.G. (eds.), The Quaternary of the United States: Princeton, NJ, Princeton University Press, p. 63-84.

U.S. Soil Conservation Service, 1987, Soils: U.S. Geological Survey National Atlas sheet 38077-BE-NA-07M-00, scale 1:7,500,000.

PRELIMINARY GEOLOGIC RADON POTENTIAL ASSESSMENT OF MICHIGAN

*by*
*R. Randall Schumann*
*U.S. Geological Survey*

## INTRODUCTION

In a survey of 1989 homes conducted during the winters of 1986-88 by the Michigan Department of Public Health and the U.S. Environmental Protection Agency (EPA), 14 percent of the homes had indoor radon levels exceeding the EPA's guideline of 4 pCi/L. This chapter describes the geology and other aspects of Michigan in terms of their potential to generate radon.

This is a generalized assessment of geologic radon potential of rocks, soils, and surficial deposits of Michigan. 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

Michigan's geography is unique in that the State is divided into two parts, an Upper, or Northern, Peninsula and a Lower, or Southern, Peninsula, separated by Lake Michigan. Most of Michigan lies in the Central Lowlands province of the north-central United States. The western part of the Upper Peninsula is part of the Superior Upland province, which is formed on the crystalline core of the continent known as the North American Shield (or Canadian Shield). The State can be further subdivided into six main physiographic regions (fig. 1). Politically, Michigan is divided into 83 counties (fig. 2).

The Hilly Moraines region covers most of the southern half of the Lower Peninsula (fig. 1). It is characterized by a series of narrow glacial moraines spaced from 10 to 25 miles (16 to 40 km) apart and separated by outwash or till plains (Sommers and others, 1984). Overall, the area is gently rolling to hilly and contains many lakes and poorly drained areas. This area is the most densely populated part of the State (fig. 3). Most of the northern half of the Lower Peninsula is the region known as the High Plains and Moraines. In this region, sandy areas are more common, the moraines are more massive, and the elevation is generally higher than in the Hilly Moraines region to the south (Sommers and others, 1984). The area bordering Lake Michigan along the western edge of the Lower Peninsula is characterized by beaches and dunes that vary from low and tree-covered to high and bare-sand covered. Many of the sand dunes are accumulated on glacial moraines.

An area called Eastern Lowlands is found on each of Michigan's two peninsulas. In the Lower Peninsula, the Eastern Lowlands is an area of very flat topography along the eastern edge of the peninsula and encompasses a relatively large area surrounding Saginaw Bay. This area was

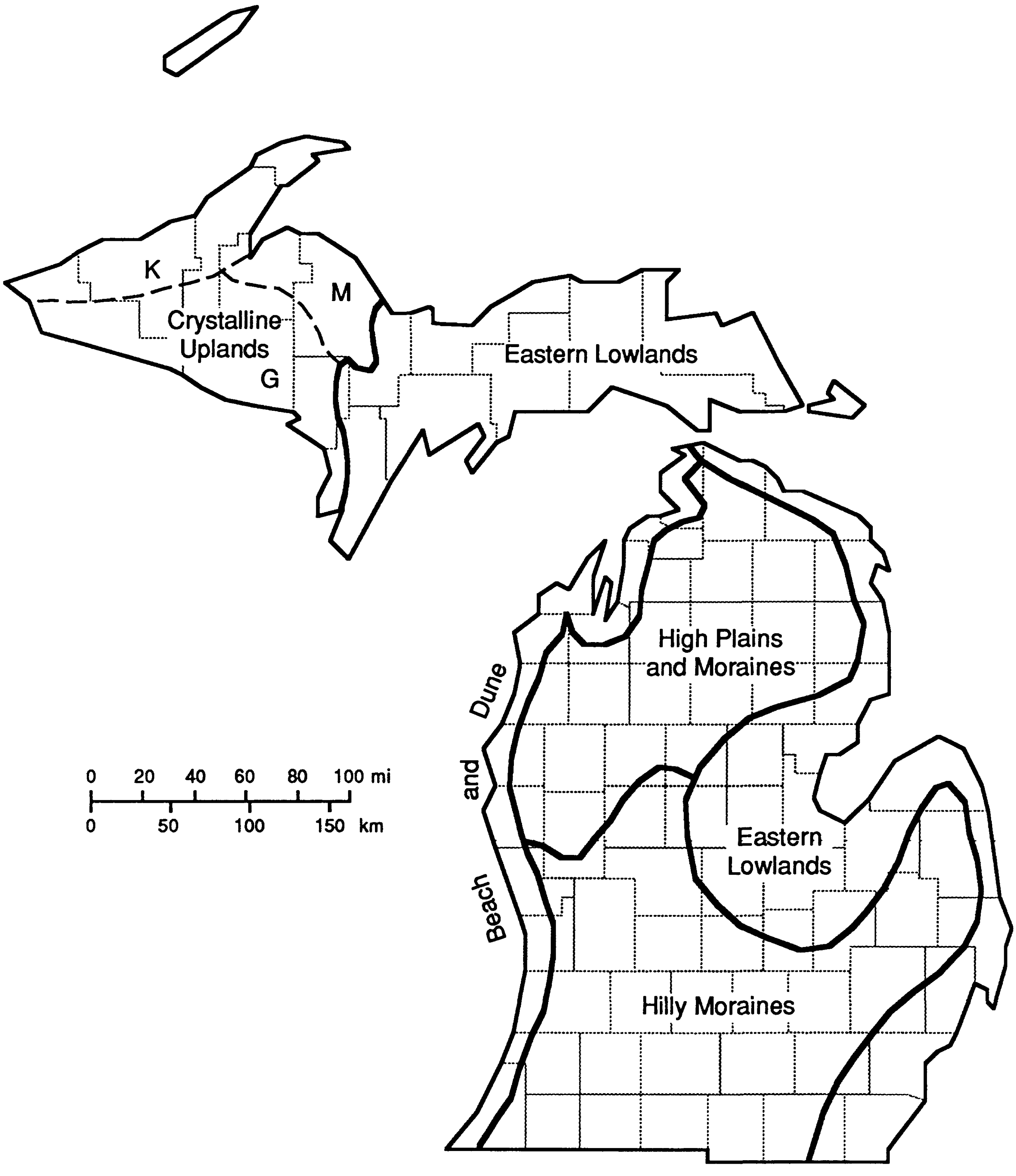



Figure 1. Physiographic regions of Michigan. K, Keweenaw Peninsula; M, Marquette Highland; G, Gogebic Upland. After Sommers and others (1984).


Figure 2. Michigan counties.

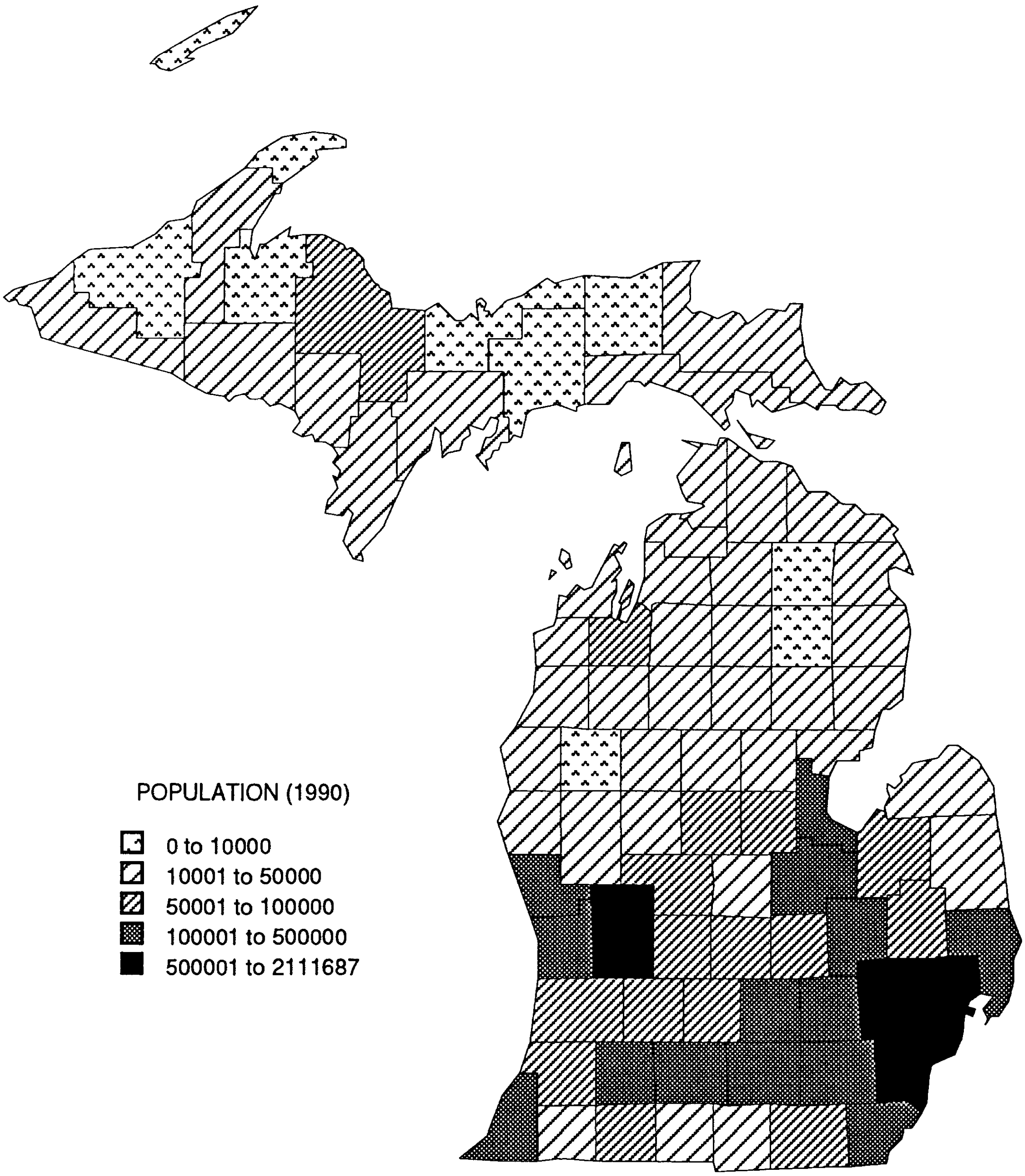



Figure 3. Population of counties in Michigan (1990 U.S. Census data).

glacial lake floor that was exposed after the ice retreated and the land rose, or rebounded. Much of the area is underlain by poorly drained soils formed from silt- and clay-rich lake deposits. The most significant cultural feature of this region is the Detroit metropolitan area in the southeastern part of the State. The eastern half of the Upper Peninsula is also called Eastern Lowlands, and is also covered by a veneer of glacial lake deposits, though the deposits are generally thinner than in the Lower Peninsula and bedrock is exposed at the surface in some places (Sommers and others, 1984). Much of this area is covered by forests, lakes, ponds, and wetlands. The Mackinac Bridge, built in 1957, spans from St. Ignace on the Northern Peninsula to Mackinaw City on the Southern Peninsula, connecting the two parts of the State.

The western part of the Upper Peninsula is called the Crystalline Uplands and consists of glacially-sculpted bedrock mountains and hills and glacial landforms such as moraines and till plains. The highest point in the State, Mount Arvon, at 1979 feet (603 m), is located in this area just east of the southern tip of Keweenaw Bay. Subdivisions of the Crystalline Uplands area include the Gogebic Iron Range, Marquette Highland, and the Keweenaw Peninsula (fig. 1).

## GEOLOGY

The discussion of geology is divided into three sections: bedrock geology, glacial geology, and a discussion of uranium in rocks and soils. "Bedrock" refers to pre-glacial rock units, which are covered by glacial deposits in most parts of the State. A bedrock geologic map (fig. 4) shows rock units that underlie glacial deposits or are exposed at the surface in some areas. The glacial deposits are composed of material derived from underlying bedrock and from rock units to the north and northeast. For more detailed discussions and maps of the geology, the reader is encouraged to consult Dorr and Eschman (1970), Martin (1936a, 1936b, 1955, 1957), Richmond and Fullerton (1983, 1984, 1991), and other reports.

*Bedrock geology:* Michigan's bedrock geology is characterized by two distinct terranes: the Michigan Basin, a sedimentary sequence covering all of the Lower Peninsula and the eastern half of the Upper Peninsula, and the Canadian Shield (also called the North American Shield), an area of mostly Precambrian igneous and metamorphic rocks in the western part of the Upper Peninsula. The Michigan Basin covers the entire Lower Peninsula, the eastern part of the Upper Peninsula, and parts of Wisconsin, Illinois, Indiana, Ohio, Ontario, and much of the Great Lakes. The basin center lies near the center of the Lower Peninsula. The rocks directly underlying the glacial deposits in the Michigan Basin include marine limestone, dolomite, sandstone, and shale, and some continental sandstone, ranging in age from Cambrian to Jurassic (fig. 4). Carbonate rocks of Silurian and Devonian age and evaporites, including gypsum, anhydrite, and halite, form karst and other solution features in the northern part of the Lower Peninsula and the adjacent part of the Upper Peninsula, and in Monroe and Lenawee Counties in the southeastern part of the State (Western Michigan University, 1981).

The western part of the Upper Peninsula is underlain mostly by rocks of the Canadian Shield, including granite, gneiss, basalt, quartzite, marble, slate, and schist of Precambrian age. Precambrian iron-formation is found in Gogebic, Iron, Baraga, Marquette, and Dickinson Counties. The Keweenaw Peninsula is underlain by Precambrian and Cambrian sandstone and conglomerate separated by a ridge of Precambrian basalt (fig. 4).

*Glacial geology:* Glacial deposits of late Wisconsinan age cover nearly all of Michigan. Ice moved from the northwest, north, and northeast in four major lobes and several large sublobes (fig. 5). The arrows shown in figure 5 show general directions of ice movement during the last

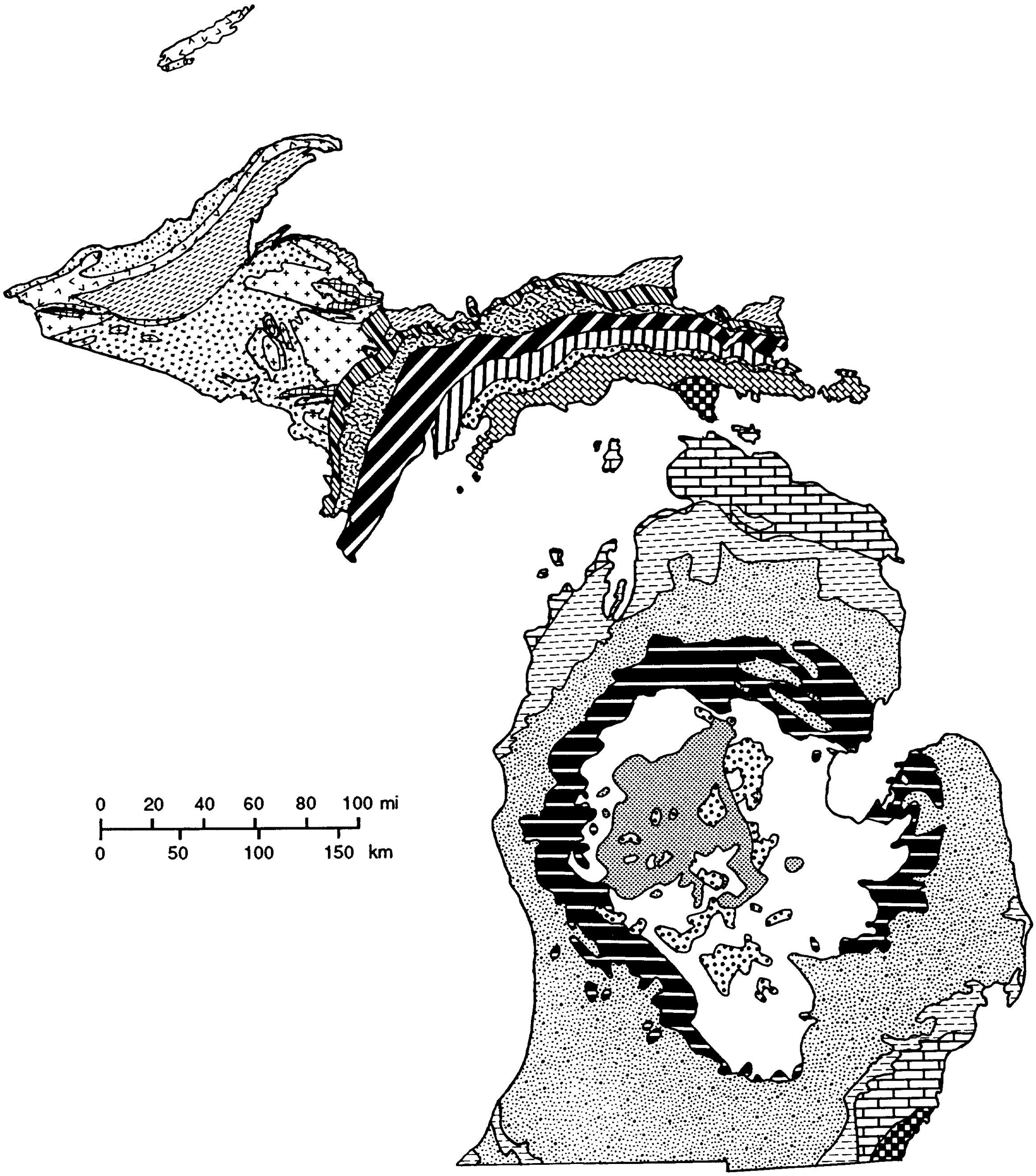
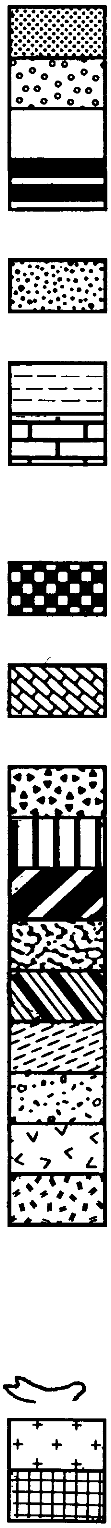



Figure 4. Generalized bedrock geologic map of Michigan (redrawn from King and Beikman, 1974).

GENERALIZED BEDROCK GEOLOGIC MAP OF MICHIGAN
EXPLANATION OF MAP UNITS
(after Martin, 1936; King and Beikman, 1974; Western Michigan University, 1981).



*Jurassic* "Red beds" (continental sedimentary rocks)

*Pennsylvanian* Grand River Fm. (marine sandstones with some shale)

*Pennsylvanian* Saginaw Fm. (limestone with thin beds of sandstone, shale, coal)

*Mississippian* Bayport Limestone (limestone and chert); Michigan Fm. (shale, sandstone, gypsum, limestone, dolomite)

*Mississippian* Marshall Sandstone; Coldwater Shale; Sunbury Shale; Berea Sandstone; Bedford Shale; Ellsworth Shale

*Devonian* Antrim Shale

*Devonian* Traverse Group (limestone and shale); Rogers City Limestone; Dundee Limestone; Detroit River Group (dolomite and sandstone); Sylvania Sandstone; Bois Blanc Fm. (limestone, dolomite, chert); Macinac Breccia (limestone, limestone breccia)

*Silurian* Bass Islands Group (dolomite and shale); St. Ignace Dolomite (Northern Peninsula); Point Aux Chenes Shale (Northern Peninsula)

*Silurian* Engadine Dolomite; Manistique Group (dolomite and limestone); Burnt Bluff Group (limestone and dolomite)

*Silurian* Cataract Group (limestone and shale)

*Ordovician* Richmond Group (limestone and shale); Collingwood Fm. (shale)

*Ordovician* Trenton Group (limestone); Black River Group (limestone and dolomite)

*Ordovician* St. Peter Sandstone; Hermansville Fm. (dolomitic sandstone, dolomite)

*Cambrian* Munising Fm. (sandstone); Mt. Simon Sandstone

*Precambrian Z* Jacobsville Sandstone

*Precambrian Y* Freda Sandstone; Nonesuch Shale; Copper Harbor Conglomerate

*Precambrian Y* Porcupine Mountain Fm.; Bergland Hills Rhyolite; Portage Lake Lava

*Precambrian X* Killarney Granite (Presque Isle Granite); Michigamme Slate; Tyler Slate; Clarksburg Fm. (mafic volcanic rocks); Siamo Fm. (slate, quartzite, schist); Ajibik Fm. (quartzite, schist, granite gneiss, granite); Palms Fm. (slate); Wewe, Kona, Mesnard, Goodrich, and Sunday Fms. (slate, quartzite, graywacke, dolomite, marble, conglomerate)

*Precambrian X* Iron Formation

*Precambrian W* Granite and granite gneiss

*Precambrian W* Metamorphosed volcanics and sediments, greenstone

Figure 4 (continued)

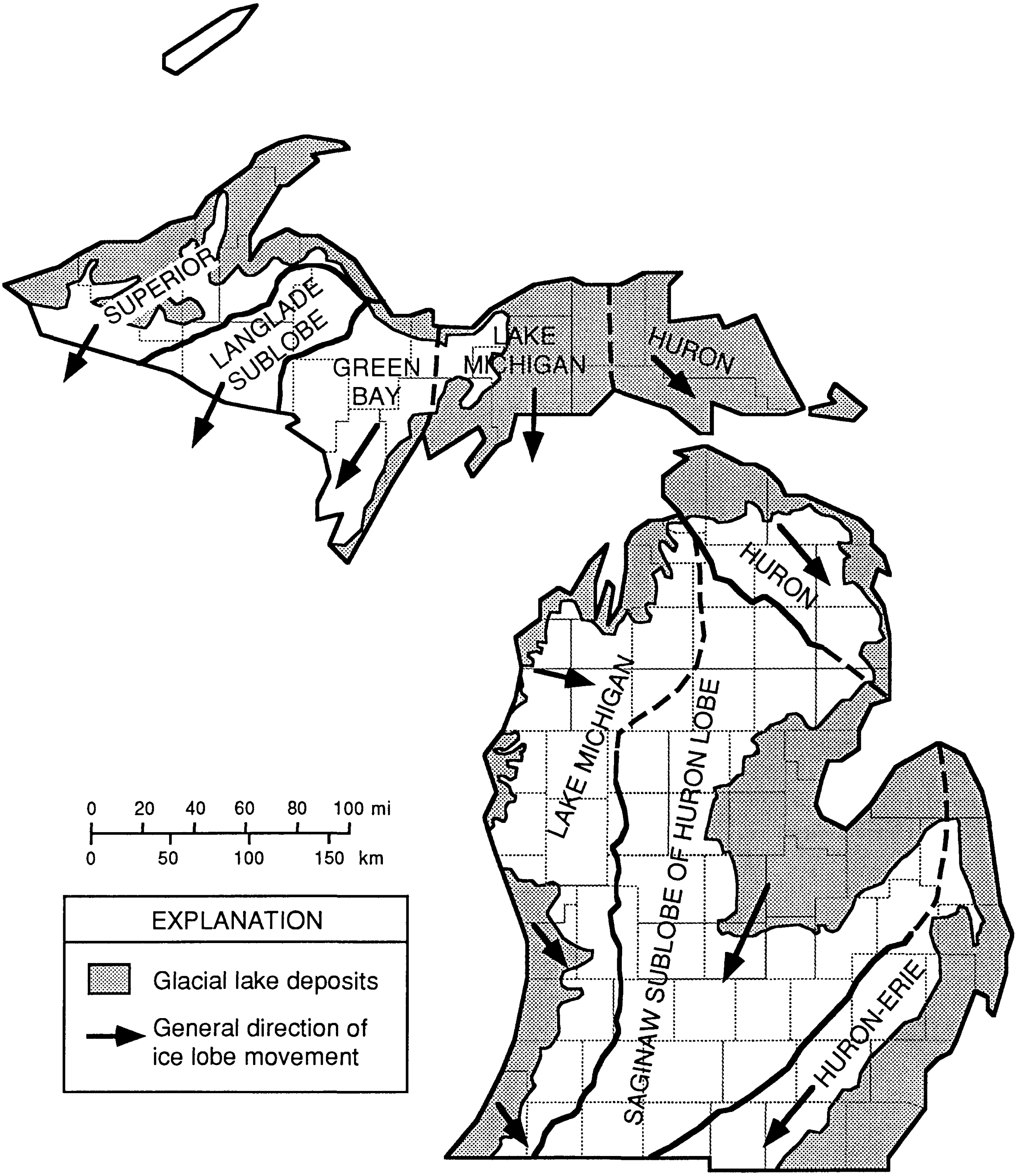



Figure 5. Map showing names and locations of Wisconsinan glacial lobes, general directions of ice movement, and glacial lake deposits of Michigan. Lobe boundaries are dashed where uncertain. After Martin (1955, 1957) and Richmond and Fullerton (1983, 1984, 1991).

advance of each lobe. The Huron lobe advanced from the northwest across the eastern part of the Upper Peninsula, across the northern part of the Lower Peninsula, and combined with the Erie lobe in the southeastern part of the State. The latest advance of the Huron lobe deposited red, clay-rich till from Lake Superior which contrasts with underlying gray to brown sandy till from an earlier advance in which the Huron lobe entered the area from the northeast (Wayne and Zumberge, 1965). The Saginaw sublobe branched from the main part of the Huron lobe and moved in a southwest direction, carving Saginaw Bay (fig. 5). The southern part of the area covered by Saginaw sublobe deposits, in particular, contains many arcuate moraines left by the retreating ice mass. Huron lobe tills (including the Saginaw sublobe) are sandy to gravelly and calcareous, containing pebbles and cobbles of limestone, dolomite, and some sandstone and shale, with boulders of igneous and metamorphic rocks and quartzite (Wayne and Zumberge, 1965; Richmond and Fullerton, 1983, 1984, 1991). Tills of the Erie and Lake Michigan lobes are derived from similar source rocks but are more silty and clayey in texture (Wayne and Zumberge, 1965).

The Superior lobe, including the Langlade sublobe, and the Green Bay lobe advanced from the north and northeast across the western part of the Upper Peninsula (fig. 5), depositing sandy tills. Green Bay lobe tills are derived from sandstone, limestone, and dolomite, with cobbles and boulders of igneous and metamorphic rocks. Superior and Langlade tills contain clasts of granite, metavolcanic rocks, and sandstone (Richmond and Fullerton, 1983, 1984, 1991). Areas underlain by significant glacial lake deposits are shaded in figure 5. Glacial lake deposits are typically clays or silty clays with low permeability; areas underlain by these deposits are commonly poorly drained and may contain numerous lakes and wetlands.

*Uranium geology:* Most uranium occurrences in Michigan occur in Precambrian rocks in the Northern Peninsula (fig. 6). Uranium is associated with mineralized shear and fracture zones in Precambrian metasedimentary rocks, diabase dikes, and felsites. Granitic gneisses contain uranium minerals in the granite; in faults, fractures, and shears; and in uranium-bearing pegmatite dikes. Uranium in metasedimentary rocks occurs mainly in black slates and in iron-formation near stratigraphic contacts with black slates. Uranium occurrences are also associated with spoil from iron mines in a number of localities (Johnson, 1976). Uranium occurrences in Precambrian rocks discussed by Johnson (1976) but not shown on figure 6 include a basal conglomerate in the Proterozoic-age Ajibik Quartzite, near Negaunee, containing as much as 12.4 ppm equivalent uranium (eU) and the Proterozoic Mesnard Quartzite in the Palmer area, with 10.7 ppm eU. Uranium contents of 10–62 ppm were measured in 10 outcrop and glacial boulder samples of the basal conglomerate of the Proterozoic Goodrich Quartzite in the Palmer area (Parker, 1981). The uranium, as well as high thorium and rare earth element concentrations, appear to be associated with a detrital monazite-rich zone in the Goodrich Quartzite that has an outcrop area of about 4 $mi^2$ (Parker, 1981). The Keweenawan (Middle Proterozoic) Nonesuch Shale was found to contain 10–30 ppm eU in the White Pine Mine in Ontonagon County (Johnson, 1976).

In the Southern Peninsula, the Devonian Bell Shale, Devonian and Mississippian Antrim Shale, and Mississippian Sunbury and Ellsworth Shales contain organic rich (black shale) layers with higher-than-average amounts of uranium (according to Carmichael (1989), the average crustal abundance of uranium is 2.5 ppm). These shales underlie and constitute source rock for glacial deposits in the northern, southeastern, and southwestern parts of the Southern Peninsula, and are locally exposed at the surface in the northern part of the Southern Peninsula. Samples of Antrim Shale in Charlevoix and St. Clair Counties contained from 6 to 36 ppm uranium, and subsurface gamma-ray logs from a number of wells suggest that these uranium contents may be typical of the Antrim Shale across the State. The Ellsworth Shale has radioactivity levels in the 6 to 10 ppm eU

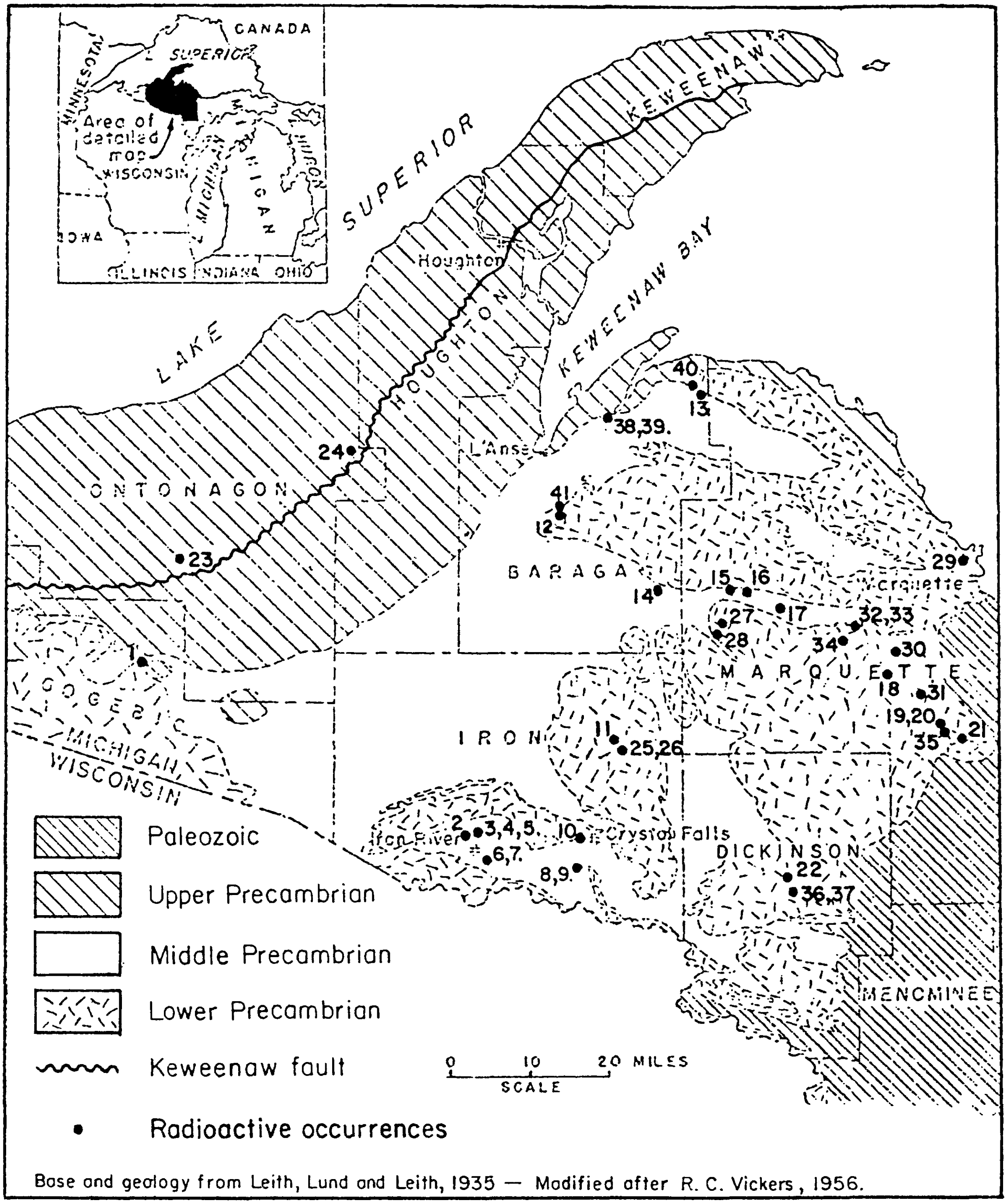



Figure 6. Radioactive occurrences in northern Michigan (from Johnson, 1976).

Figure 6 (continued). Radioactive occurrences in northern Michigan. Data from Johnson (1976). NO., map number; U, highest reported uranium content for each occurrence; --, no data.

| NO. | NAME | COUNTY | HOST ROCK | U |
|---|---|---|---|---|
| 1. | Erikson Prospect | Gogebic | granite in Presque Isle Gneiss | 40 ppm |
| 2. | Cardiff Mine | Iron | iron formation (?) | 410 ppm |
| 3. | Wauseca Mine | Iron | iron formation (?) | 150 ppm |
| 4. | James Mine | Iron | iron formation (?) | 200 ppm |
| 5. | Sherwood Mine | Iron | pitchblende, oxidized iron formation | 0.513% |
| 6. | Zimmerman Mine | Iron | iron formation (?) | 140 ppm |
| 7. | Buck Mine | Iron | pitchblende, slate, iron formation | -- |
| 8. | Book Mine | Iron | iron formation (?) | 100 ppm |
| 9. | S. Mastadon Mine | Iron | iron formation (?) | 100 ppm |
| 10. | Tobin Mine | Iron | iron formation (?) | 140 ppm |
| 11. | Anderson-Wiggins Prospect | Iron | granite in Margeson Creek Gneiss | 20 ppm |
| 12. | Graphite Quarry | Baraga | metadiabase dike in Michigamme Slate | 0.1% |
| 12. | Graphite Quarry | Baraga | Michigamme Slate | 40 ppm |
| 13. | Huron River | Baraga | shears in Michigamme Slate | -- |
| 14. | Portland Mine | Baraga | iron formation | 170 ppm |
| 15. | Taxpayer Sample | Marquette | -- | -- |
| 16. | M & G Mine | Marquette | oxidized iron formation | 350 ppm |
| 16. | M & G Mine | Marquette | unoxidized iron formation | 20 ppm |
| 16. | M & G Mine | Marquette | black slate | 50 ppm |
| 17. | Float | Marquette | ferruginous slate | 0.3% |
| 18. | Greens Creek slate trench | Marquette | slate and quartzite in Compeau Creek Gneiss | 0.87% |
| 19. | Princeton Mine | Marquette | iron formation | 0.1% |
| 20. | Stephenson Mine | Marquette | iron formation | 120 ppm |
| 21. | Francis Mine | Marquette | pitchblende, iron formation | 0.12% |
| 22. | Isham Prospect | Dickinson | fracture zones in granite, granite | 0.11% |
| 23. | Bergland Prospect | Ontonagon | altered felsite | -- |
| 24. | Indiana Copper Mine | Ontonagon | felsite | 200 ppm |
| 25. | Lavato's Occurrences | Iron | Margeson Creek Gneiss (shear zone) | 418 ppm |
| 26. | Float | Iron | Margeson Creek Gneiss | -- |
| 27. | Sargent Prospect | Marquette | Bell Creek (granite) Gneiss | 30 ppm |
| 28. | Republic Migmatite | Marquette | leucocratic part of migmatite | 14.7 ppm |
| 29. | Syenite dike | Marquette | syenite dike in granite | 18 ppm |
| 30. | Voelker Prospect | Marquette | granite gneiss (shear zone) | -- |
| 31. | Greens Creek granite prospect | Marquette | pegmatite in granite | -- |
| 32. | Goodrich Conglomerate | Marquette | base of Goodrich Quartzite | -- |
| 33. | Goodrich boulder | Marquette | Goodrich Quartzite | -- |
| 34. | Goodrich float | Marquette | Goodrich Quartzite | -- |
| 35. | Smith Mine | Marquette | iron formation | 180 ppm |
| 36. | Leitch and Isham sec. 13 | Dickinson | boitite schist in granite gneiss | 300 ppm |
| 37. | Leitch and Isham sec. 12 | Dickinson | shear zone in granite | 200 ppm |
| 38. | Joe Forsythe Prospect | Baraga | iron formation | -- |
| 39. | Haggett Dike | Baraga | diabase dike in granite gneiss | -- |
| 40. | Big Eric's Crossing | Baraga | Lower Precambrian granite | -- |
| 41. | Taylor Mine | Baraga | brecciated slate in Baraga Group (?) | -- |

range in subsurface well logs, and the Sunbury Shale has values similar to that of the Antrim Shale (J.K. Otton, unpublished report, 1986).

## SOILS

Most of the soils in Michigan are either Spodosols, Alfisols, or Inceptosols (U.S. Department of Agriculture, 1987). Most of the Upper Peninsula and the northern half of the Lower Peninsula are covered by Haplorthods, a type of Spodosol, and by smaller areas of Psammaquents (a permanently or seasonally wet type of Entisol), Eutroboralfs, and Glossoboralfs (generally wet Alfisols). A relatively large area surrounding Saginaw Bay and the "thumb" area is covered by Haplaquepts, seasonally wet Inceptosols. The southern half of the Lower Peninsula is covered by Hapludalfs, a moist to seasonally dry form of Alfisol (U.S. Department of Agriculture, 1987). Soils in Michigan are generally moist to wet and contain subsurface accumulations of iron and aluminum oxides or clay. Many of the soils contain significant accumulations of organic matter in the upper horizons (Whiteside and others, 1968).

A generalized soil permeability map (fig. 7) suggests that much of the northern part of the Lower Peninsula is covered by soils with high permeability. However, it is important to point out that the "permeability" values given in the SCS soil surveys are actually water percolation rates. These values correspond fairly well to actual permeability to water moving through the soil. Permeability to gas flow is similar to that for water except that it is also dependent on soil moisture; water in the soil pores may partially or completely obstruct gas flow in otherwise "highly permeable" soils, giving these soils a low gas permeability when the soils are wet. Because many of the soils in Michigan are moist to wet at least seasonally, particularly in the northern part of the State and around Saginaw Bay, their gas permeability is usually lower than that indicated by the water permeability.

## INDOOR RADON DATA

Indoor radon data from 1989 homes tested in the State/EPA Residential Radon Survey conducted in Michigan during the winters of 1986-88 are listed in Table 1 and shown in figure 8. Data are shown in figure 8 only for those counties with 5 or more data values. The maximum value recorded in the survey was 162 pCi/L in Republic Township, southwestern Marquette County. The statewide average radon value in this survey was 2.4 pCi/L, and 14 percent of the homes tested had screening indoor radon levels exceeding 4 pCi/L. In this discussion, "elevated" refers to screening indoor radon levels greater than 4.0 pCi/L.

Counties with average screening indoor radon levels greater than 4.0 pCi/L include Hillsdale, Kalamazoo, Lenawee, and Washtenaw (fig. 8). More than 50 percent of the homes tested in Hillsdale and Lenawee Counties had indoor radon levels greater than 4 pCi/L (fig. 8, Table 1). The highest county screening radon average is 8.2 pCi/L in Lenawee County. Most areas of Michigan have characteristically low (<2 pCi/L) to moderate (2-4 pCi/L) average indoor radon values. Areas with significant numbers of elevated indoor radon values are the South-Central part of the Lower Peninsula, the northern part of the Lower Peninsula (from Antrim to Alpena County and north), and the Gogebic Iron Range and Marquette Highland (fig. 8).

As part of EPA's cooperative State Indoor Radon Grant program, screening indoor radon tests were conducted by the Michigan Department of Public Health in about 230 of the 350 homes in Republic Township, southwestern Marquette County, where the highest indoor radon level in

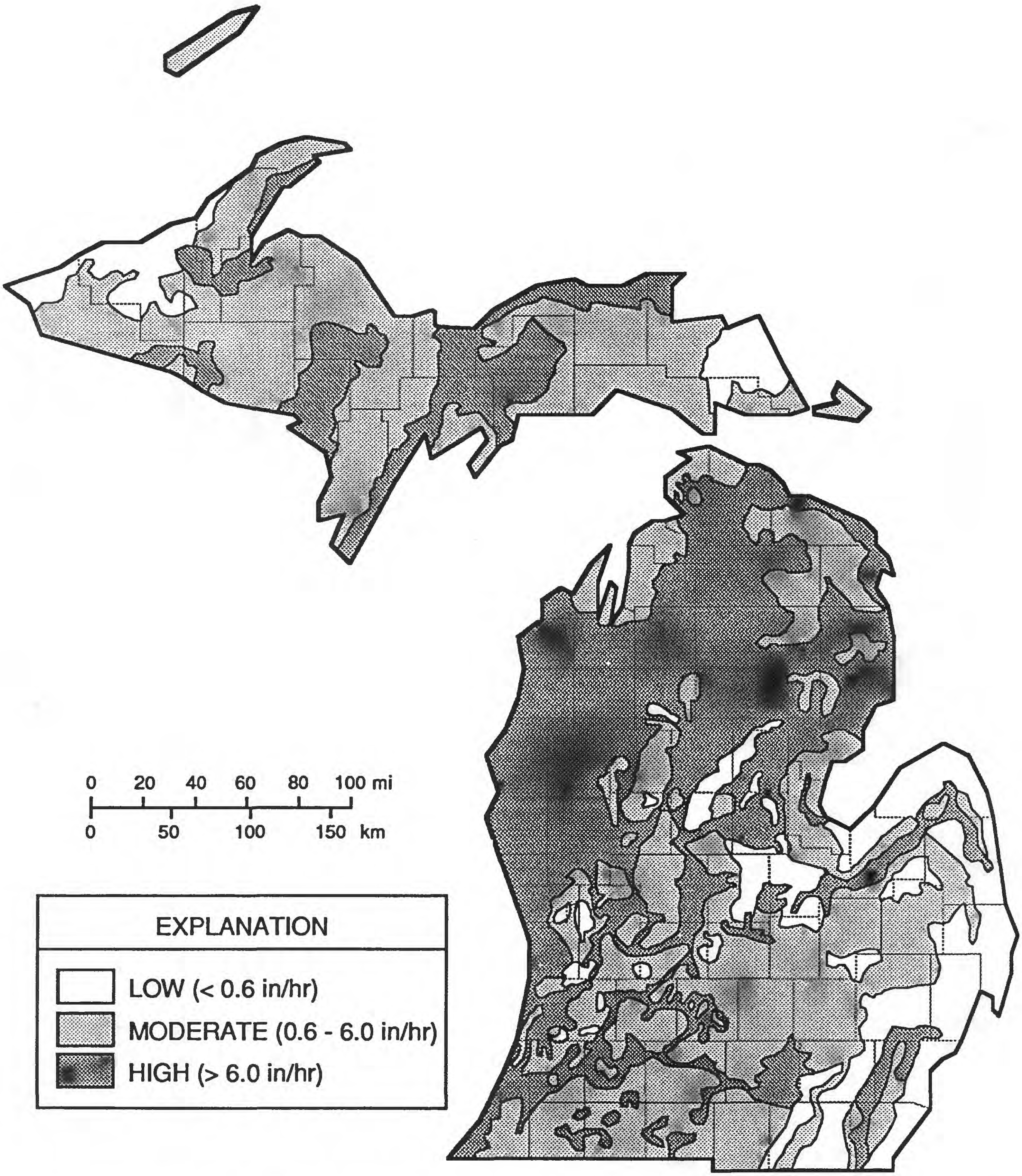
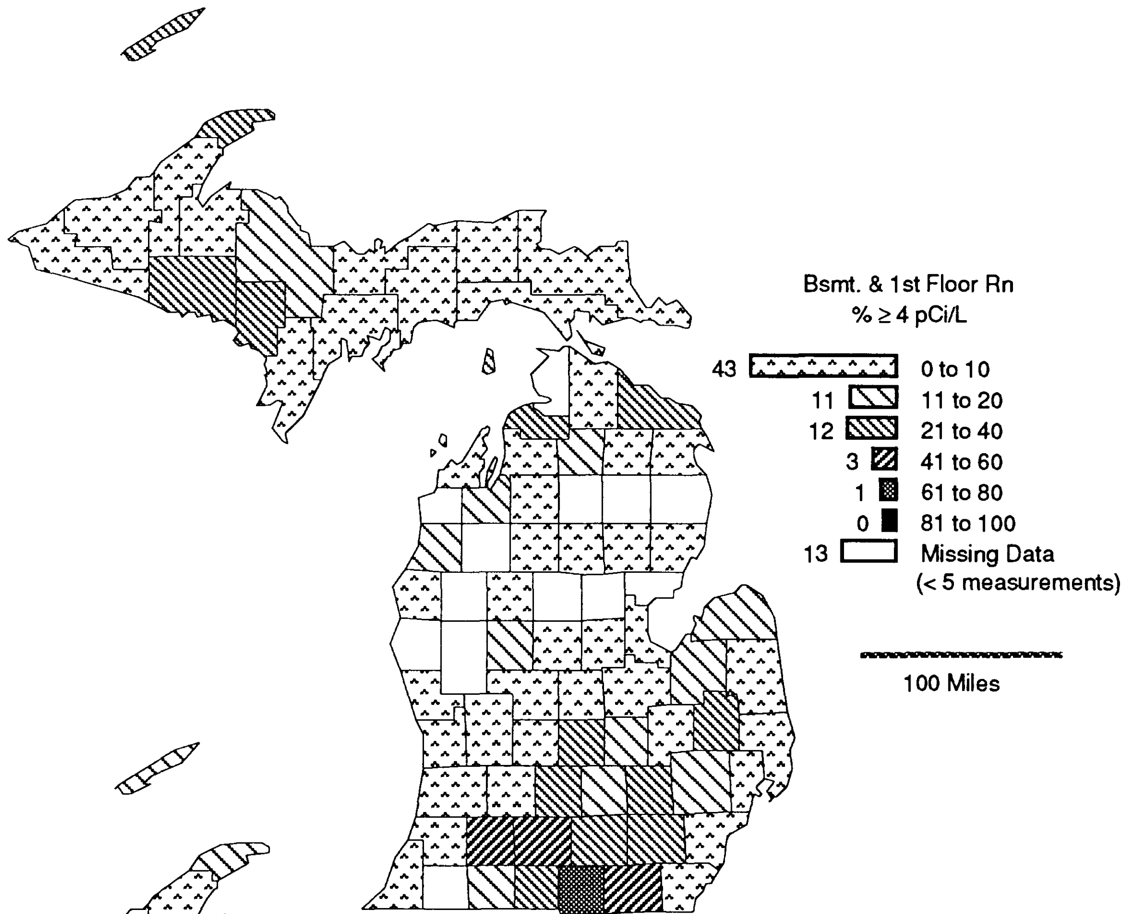



Figure 7. Generalized soil permeability map of Michigan. Boundaries are approximate. Compiled by Kevin M. Schmidt, U.S. Geological Survey, from Martin (1955, 1957) and SCS soil survey data.



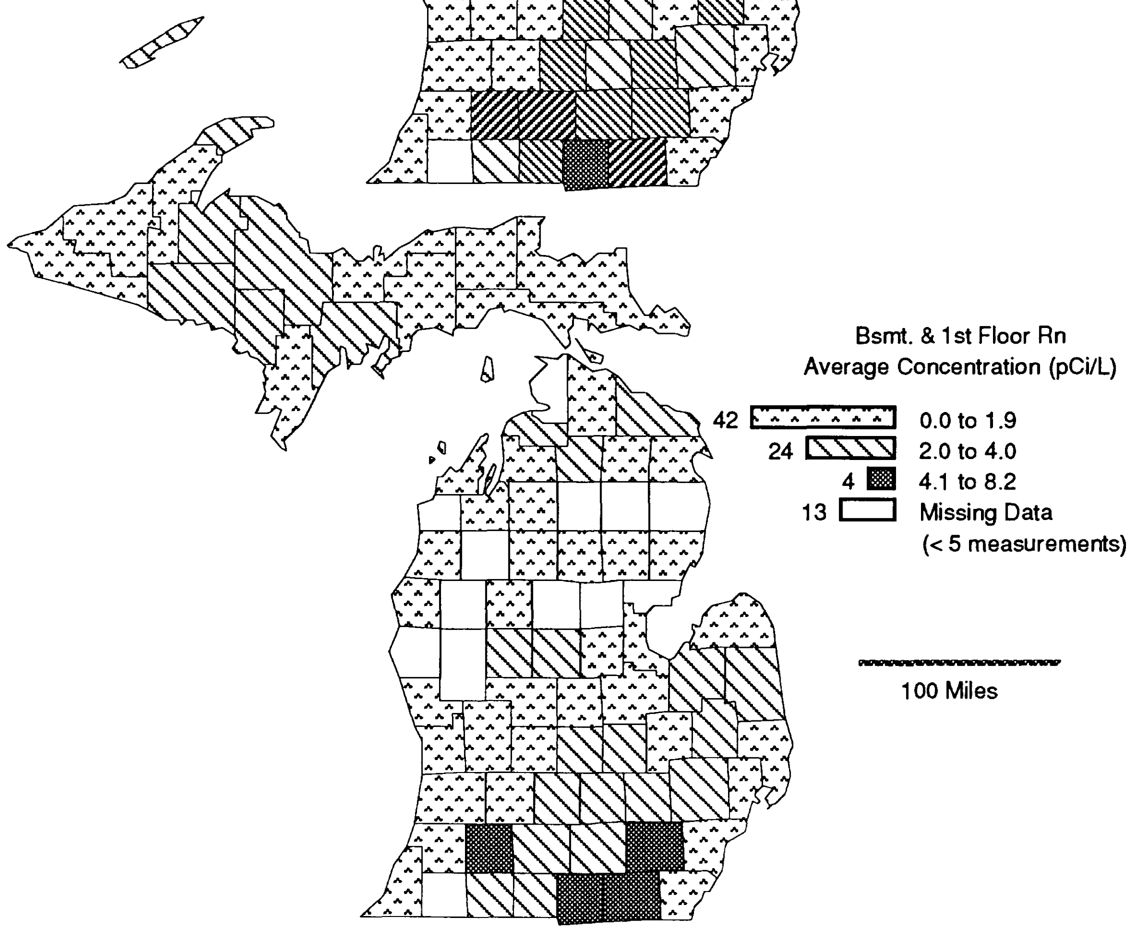




Figure 8. Screening indoor radon data from the EPA/State Residential radon Survey of Michigan, 1986-88, for counties with 5 or more measurements. Data are from 2-7 day charcoal canister tests. Histograms in map legends show the number of counties in each category. The number of samples in each county (see Table 1) may not be sufficient to statistically characterize the radon levels of the counties, but they do suggest general trends. Unequal category intervals were chosen to provide reference to decision and action levels.

TABLE 1. Screening indoor radon data from the EPA/State Residential Radon Survey of Michigan conducted during 1986-88. Data represent 2-7 day charcoal canister measurements from the lowest level of each home tested.

| COUNTY | NO. OF MEAS. | MEAN | GEOM. MEAN | MEDIAN | STD. DEV. | MAXIMUM | %>4 pCi/L | %>20 pCi/L |
|---|---|---|---|---|---|---|---|---|
| ALCONA | 4 | 0.6 | 0.4 | 0.4 | 0.5 | 1.3 | 0 | 0 |
| ALGER | 11 | 1.1 | 0.8 | 0.6 | 1.0 | 3.3 | 0 | 0 |
| ALLEGAN | 8 | 1.3 | 1.1 | 1.4 | 0.6 | 2.1 | 0 | 0 |
| ALPENA | 18 | 0.8 | 0.7 | 0.7 | 0.5 | 1.9 | 0 | 0 |
| ANTRIM | 8 | 1.1 | 0.7 | 1.0 | 1.0 | 2.5 | 0 | 0 |
| ARENAC | 3 | 0.7 | 0.7 | 0.7 | 0.1 | 0.7 | 0 | 0 |
| BARAGA | 22 | 2.4 | 1.1 | 1.0 | 6.0 | 29.1 | 5 | 5 |
| BARRY | 14 | 1.5 | 1.0 | 1.4 | 1.1 | 3.1 | 0 | 0 |
| BAY | 18 | 1.2 | 0.9 | 0.9 | 1.0 | 3.5 | 0 | 0 |
| BENZIE | 3 | 0.9 | 0.8 | 0.9 | 0.4 | 1.3 | 0 | 0 |
| BERRIEN | 44 | 1.8 | 1.3 | 1.4 | 1.6 | 8.2 | 9 | 0 |
| BRANCH | 9 | 3.7 | 2.1 | 2.4 | 4.5 | 14.9 | 22 | 0 |
| CALHOUN | 31 | 3.8 | 2.9 | 2.8 | 3.0 | 14.9 | 45 | 0 |
| CHARLEVOIX | 12 | 2.5 | 1.9 | 1.7 | 1.7 | 4.7 | 33 | 0 |
| CHEBOYGAN | 14 | 1.0 | 0.5 | 0.7 | 1.3 | 5.1 | 7 | 0 |
| CHIPPEWA | 8 | 1.0 | 0.8 | 0.9 | 0.6 | 2.1 | 0 | 0 |
| CLARE | 3 | 1.1 | 1.0 | 1.3 | 0.7 | 1.7 | 0 | 0 |
| CLINTON | 18 | 3.8 | 2.4 | 3.2 | 3.2 | 11.9 | 33 | 0 |
| CRAWFORD | 1 | 0.3 | 0.3 | 0.3 | 0.0 | 0.3 | 0 | 0 |
| DELTA | 41 | 2.0 | 1.2 | 1.1 | 3.1 | 16.8 | 7 | 0 |
| DICKINSON | 77 | 3.7 | 2.5 | 2.3 | 4.0 | 23.9 | 29 | 1 |
| EATON | 21 | 3.4 | 2.4 | 2.4 | 3.2 | 13.8 | 29 | 0 |
| EMMET | 4 | 1.2 | 0.6 | 0.8 | 1.3 | 2.9 | 0 | 0 |
| GENESEE | 42 | 1.8 | 1.3 | 1.5 | 1.4 | 6.3 | 7 | 0 |
| GLADWIN | 4 | 1.4 | 1.0 | 1.5 | 1.0 | 2.3 | 0 | 0 |
| GOGEBIC | 11 | 1.0 | 0.7 | 0.5 | 0.9 | 3.1 | 0 | 0 |
| GRAND TRAVERSE | 21 | 1.9 | 1.4 | 1.1 | 1.5 | 5.1 | 14 | 0 |
| GRATIOT | 7 | 1.3 | 1.2 | 1.1 | 0.6 | 2.3 | 0 | 0 |
| HILLSDALE | 12 | 6.7 | 4.3 | 4.9 | 8.5 | 32.8 | 67 | 8 |
| HOUGHTON | 18 | 1.8 | 0.7 | 0.8 | 4.1 | 18.1 | 6 | 0 |
| HURON | 15 | 1.5 | 0.9 | 0.7 | 1.5 | 4.7 | 13 | 0 |
| INGHAM | 42 | 3.3 | 2.4 | 2.2 | 4.1 | 26.2 | 17 | 2 |
| IONIA | 10 | 1.7 | 1.2 | 1.6 | 1.2 | 3.6 | 0 | 0 |
| IOSCO | 9 | 0.5 | 0.4 | 0.5 | 0.3 | 1.1 | 0 | 0 |
| IRON | 38 | 3.8 | 2.3 | 2.0 | 4.3 | 14.4 | 24 | 0 |
| ISABELLA | 12 | 2.1 | 1.5 | 1.5 | 2.4 | 9.4 | 8 | 0 |
| JACKSON | 23 | 3.9 | 3.3 | 3.1 | 2.4 | 9.6 | 35 | 0 |
| KALAMAZOO | 55 | 4.5 | 3.2 | 3.5 | 3.7 | 18.1 | 44 | 0 |
| KALKASKA | 5 | 1.0 | 0.6 | 1.1 | 0.9 | 2.3 | 0 | 0 |
| KENT | 73 | 1.8 | 1.4 | 1.5 | 1.5 | 8.3 | 7 | 0 |
| KEWEENAW | 6 | 2.1 | 1.4 | 1.0 | 2.1 | 5.1 | 33 | 0 |

TABLE 1 (continued). Screening indoor radon data for Michigan.

| COUNTY | NO. OF MEAS. | MEAN | GEOM. MEAN | MEDIAN | STD. DEV. | MAXIMUM | %>4 pCi/L | %>20 pCi/L |
|---|---|---|---|---|---|---|---|---|
| LAPEER | 13 | 2.7 | 1.9 | 1.4 | 2.8 | 10.3 | 23 | 0 |
| LEELANAU | 6 | 1.6 | 1.3 | 1.5 | 1.0 | 2.7 | 0 | 0 |
| LENAWEE | 37 | 8.2 | 4.5 | 5.0 | 11.7 | 69.7 | 51 | 5 |
| LIVINGSTON | 21 | 3.3 | 2.0 | 2.4 | 3.1 | 13.0 | 33 | 0 |
| LUCE | 7 | 1.0 | 0.8 | 0.7 | 0.9 | 2.7 | 0 | 0 |
| MACKINAC | 6 | 0.8 | 0.5 | 0.6 | 0.9 | 2.4 | 0 | 0 |
| MACOMB | 92 | 1.2 | 0.9 | 1.0 | 0.9 | 5.8 | 2 | 0 |
| MANISTEE | 6 | 1.7 | 1.2 | 1.0 | 1.9 | 5.5 | 17 | 0 |
| MARQUETTE | 139 | 3.4 | 1.5 | 1.5 | 13.9 | 162.1 | 12 | 1 |
| MASON | 6 | 1.3 | 0.9 | 0.7 | 1.2 | 3.2 | 0 | 0 |
| MECOSTA | 5 | 2.2 | 1.8 | 1.6 | 1.8 | 5.2 | 20 | 0 |
| MENOMINEE | 22 | 1.5 | 1.1 | 1.1 | 1.3 | 5.3 | 5 | 0 |
| MIDLAND | 16 | 0.7 | 0.5 | 0.5 | 0.5 | 1.6 | 0 | 0 |
| MISSAUKEE | 7 | 1.9 | 1.7 | 1.9 | 0.9 | 3.1 | 0 | 0 |
| MONROE | 20 | 1.8 | 1.3 | 2.0 | 1.1 | 3.9 | 0 | 0 |
| MONTCALM | 10 | 1.6 | 1.4 | 1.5 | 0.8 | 2.9 | 0 | 0 |
| MONTMORENCY | 8 | 1.5 | 1.2 | 1.2 | 1.1 | 4.0 | 0 | 0 |
| MUSKEGON | 34 | 1.1 | 0.9 | 1.0 | 0.7 | 3.5 | 0 | 0 |
| OAKLAND | 158 | 2.5 | 1.5 | 1.3 | 3.4 | 29.5 | 16 | 1 |
| OGEMAW | 7 | 1.1 | 0.9 | 0.9 | 0.9 | 3.1 | 0 | 0 |
| ONTONAGON | 24 | 0.9 | 0.7 | 0.7 | 0.5 | 2.0 | 0 | 0 |
| OSCEOLA | 9 | 1.2 | 1.0 | 1.0 | 0.8 | 2.5 | 0 | 0 |
| OSCODA | 4 | 0.9 | 0.7 | 0.8 | 0.7 | 1.9 | 0 | 0 |
| OTSEGO | 15 | 2.3 | 1.5 | 1.9 | 1.8 | 6.3 | 13 | 0 |
| OTTAWA | 36 | 1.8 | 1.2 | 1.1 | 1.9 | 9.8 | 8 | 0 |
| PRESQUE ISLE | 12 | 3.0 | 1.8 | 1.7 | 3.3 | 11.9 | 33 | 0 |
| ROSCOMMON | 9 | 0.9 | 0.7 | 0.7 | 0.8 | 2.9 | 0 | 0 |
| SAGINAW | 41 | 1.4 | 1.0 | 1.1 | 1.2 | 5.8 | 5 | 0 |
| SANILAC | 21 | 2.1 | 1.3 | 1.4 | 3.1 | 14.9 | 10 | 0 |
| SCHOOLCRAFT | 8 | 0.6 | 0.5 | 0.5 | 0.5 | 1.4 | 0 | 0 |
| SHIAWASSEE | 18 | 2.7 | 2.1 | 1.9 | 2.1 | 9.5 | 11 | 0 |
| ST. CLAIR | 60 | 1.1 | 0.7 | 0.9 | 1.1 | 7.2 | 2 | 0 |
| ST. JOSEPH | 13 | 2.7 | 2.3 | 2.3 | 2.0 | 8.5 | 15 | 0 |
| TUSCOLA | 17 | 2.0 | 1.6 | 1.7 | 1.4 | 5.2 | 12 | 0 |
| VAN BUREN | 15 | 0.7 | 0.5 | 0.5 | 0.5 | 1.7 | 0 | 0 |
| WASHTENAW | 93 | 4.8 | 2.8 | 3.3 | 6.7 | 47.7 | 37 | 3 |
| WAYNE | 177 | 1.3 | 1.1 | 1.0 | 1.2 | 10.5 | 3 | 0 |
| WEXFORD | 2 | 1.4 | 1.4 | 1.4 | 0.0 | 1.4 | 0 | 0 |

the State/EPA survey was measured. Of the 230 homes tested, 84 percent had screening indoor radon levels exceeding 4 pCi/L and nearly 20 percent of the homes had screening levels greater than 20 pCi/L. About 5 percent of the homes tested had screening indoor radon levels exceeding 100 pCi/L. The highest indoor radon level of those tested was 389 pCi/L in the basement of a home in the Republic area (R. DeHaan, personal communication, 1992).

## GEOLOGIC RADON POTENTIAL

A map of equivalent uranium (eU) concentrations in surficial deposits (fig. 9) derived from National Uranium Resource Evaluation (NURE) aeroradiometric data (Duval and others, 1989) suggests that most of Michigan is covered by soils and surficial deposits with low surface radioactivity. Only one area of the State has a radiometric signature exceeding 2.0 parts per million (ppm) eU. This area extends from central Sanilac to eastern Hillsdale County along the southeastern border of the State (fig. 9). This eastern part of this area appears to coincide with the pattern of bedrock exposure of the Antrim Shale or with glacial deposits derived from it. The western part of the area, comprising southern Hillsdale, central Lenawee, and southern Washtenaw Counties, is east of the Antrim Shale outcrop area and also has an eU signature in the 2-3 ppm range (fig. 9). This area of higher radioactivity may be associated with glacial deposits containing transported Antrim Shale fragments and(or) Coldwater Shale fragments.

The eU pattern across the State is generally consistent with the geology, although the radiometric signature of the State as a whole appears lower than expected given the known higher uranium concentrations in the bedrock sources of the glacial deposits in several areas, and compared with the radiometric signature of non-glaciated areas on a national scale (see Duval and others, 1989). Recent studies (for example, Lively and others, 1991; Schumann and others, 1991) suggest that some of the radium in the near-surface horizons of glacially-derived soils may have been leached and transported downward in the soil profile, giving a low surface radiometric signature while generating significant radon at depth (1-2 m or greater) to produce elevated indoor radon levels in some areas. Glacial crushing and grinding of the rocks exposes more radionuclides at grain surfaces, enhancing radionuclide mobility and radon emanation. In addition, glacial drift may in many cases have higher permeability than the bedrock from which it is derived.

Elevated indoor radon levels in Iron, Dickinson, and Marquette Counties are probably associated with igneous and metamorphic bedrock exposed at the surface or under shallow glacial drift on this area, particularly granitic intrusive rocks in the Marquette and Gogebic Ranges. Localized elevated radon levels may occur in homes underlain by mineralized shear and fracture zones in Precambrian metasedimentary rocks, diabase dikes, felsites, in black slates, and in iron-formation near stratigraphic contacts with black slates (see the uranium geology section earlier in this report). Some elevated indoor radon levels in the Republic area, southwestern Marquette County, may be associated with a northwest-trending, mylonitized (and possibly mineralized) shear zone. Fault and shear zones are commonly areas of locally elevated radon because these zones typically have higher permeability than the surrounding rocks, because they are preferred zones of uranium mineralization, and because they are pathways for potentially uranium-, radium-, and(or) radon-bearing fluids and gases to migrate (Gundersen, 1991). Rock types in the area that are likely to cause a radon problem include black slate of the Michigamme Formation, the Ajibik Quartzite, granitic gneiss of the southern Marquette Complex, and iron-formation. The high radon levels in the Republic area are likely due to proximity to the shear zone, contact with one or more

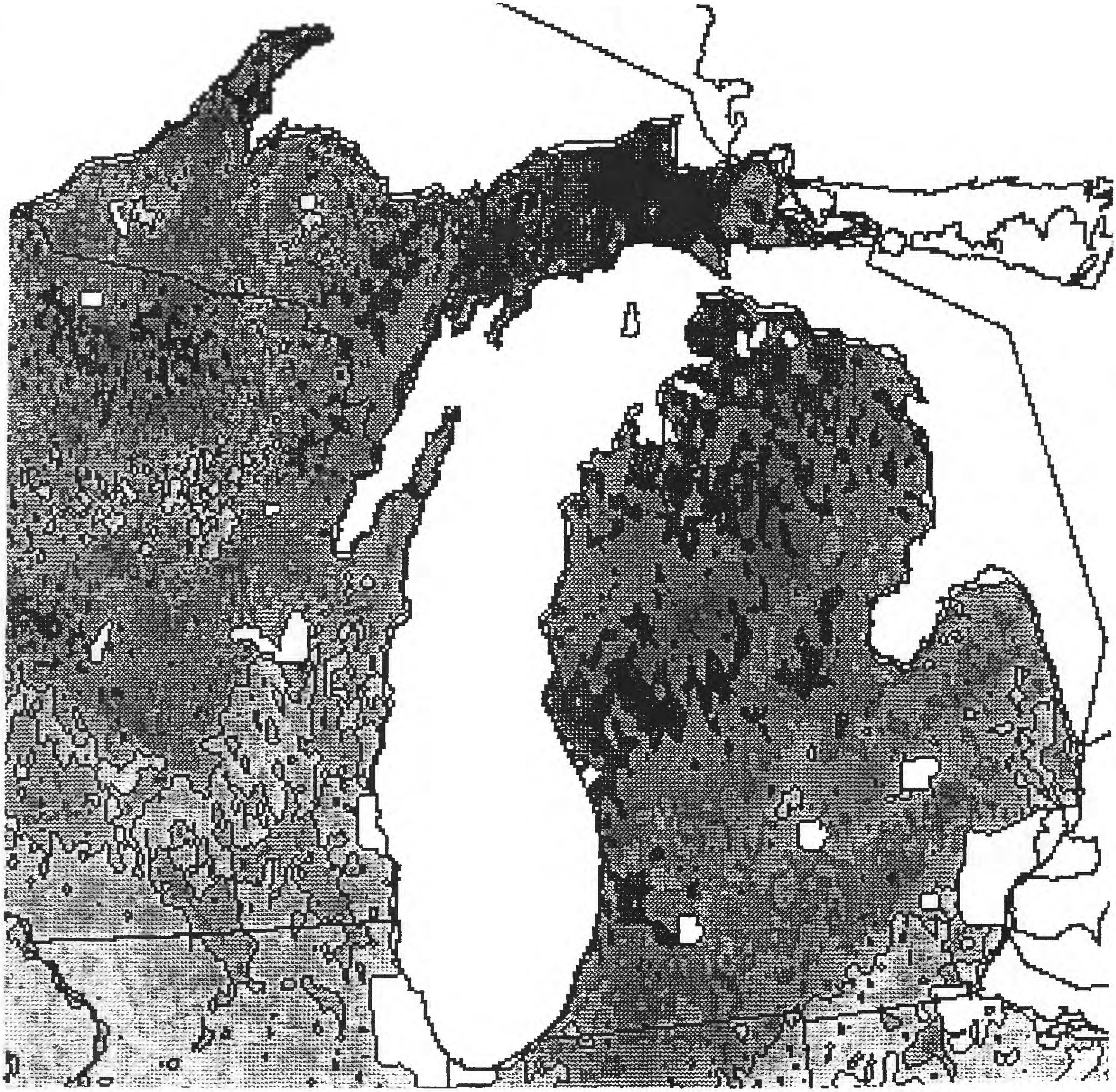


Figure 9. Aerial radiometric map of Michigan (after Duval and others, 1989). Contour lines at 1.5 and 2.5 ppm equivalent uranium (eU). Pixels shaded from 0 to 6.0 ppm eU at 0.5 ppm eU increments; darker pixels have lower eU values; white indicates no data.

of the rock types lised above, use of iron mine tailings as fill in housing construction, or a combination of these factors.

Sedimentary rocks, primarily Ordovician carbonate rocks, in Menominee, eastern Marquette, and Alger Counties, form the northwestern edge of the Michigan Basin and have moderate radon potential. Precambrian and Cambrian sandstones in this area likely generate lower radon levels than adjacent carbonate rocks.

The northern part of the Lower Peninsula that is underlain by the Antrim black shale and by glacial deposits derived from the Antrim Shale has the potential to produce elevated indoor radon levels. This area includes parts of Manistee, Benzie, Leelanau, Grand Traverse, Antrim, Ostego, Charlevoix, Cheboygan, Montmorency, and Alpena Counties. Elevated indoor radon levels in Presque Isle County may be associated with karst or other solution features in the limestone bedrock or with glacial deposits and soils derived from the carbonate rocks.

The Antrim Shale, and glacial deposits derived from it, also underlie an area in the southeastern part of the Lower Peninsula from Lenawee to St. Clair County (fig. 4). The Antrim or Coldwater shales, or glacial deposits containing either or both of these shales as a significant source component, appear to be the cause of elevated indoor radon levels in Lenawee, Washtenaw, and Oakland Counties. Wayne, Macomb, and St. Clair Counties are covered by glacial lake deposits with relatively low permeability and poor drainage characteristics, and thus do not appear to have the potential for significant indoor radon problems, although localized elevated levels are more likely to be found in the western and northern suburbs of Detroit than in other parts of these counties.

A significant number of the homes sampled in the south-central part of the Lower Peninsula also had elevated screening indoor radon levels. This area includes parts or all of the following counties: Branch, Hillsdale, Lenawee, Kalamazoo, Calhoun, Jackson, Washtenaw, Eaton, Ingham, Livingston, and Clinton. The elevated radon levels in this area are probably due to several geologic factors or combinations of factors. The area is underlain primarily by glacial deposits derived from sandstone, limestone, and shale, but may also contain some black shale fragments from sources to the east (Antrim Shale). Though they have lower uranium contents than the Antrim Shale, "gray shales" such as the Coldwater and Ellsworth shales contain sufficient uranium to generate elevated radon levels in many areas. Southern Michigan also has a higher concentration of moraines than other parts of the State, and the soils may be relatively drier, and thus more permeable to gas, on these topographically higher areas than in low-lying areas. Kalamazoo and St. Joseph Counties contain relatively large amounts of highly permeable glacial outwash.

Some elevated radon levels in southern Michigan may be related to geologic structural features, such as faults or fracture systems. The Howell anticline, a structural feature that is likely associated with faults or fracture zones, underlies parts of Livingston, Shiawassee, and Clinton Counties and may be a source for high radon in those areas. Faults associated with an oilfield in Hillsdale county may be a source for elevated radon there. More detailed studies would be needed to definitively identify the source(s) of elevated radon in southern Michigan; nevertheless, the area has a moderate to high radon potential overall.

The remainder of the State has a generally low radon potential (although very localized elevated indoor radon levels could be found almost anywhere in Michigan). Low radon potential is generally associated with rocks and soils with low radium content, low soil permeability, wet soils, or some combination of these factors.

## SUMMARY

Discrete areas of Michigan were delineated based on the data discussed in the preceding sections and designated geologic radon potential areas (fig. 10). For each area, a Radon Index (RI) and Confidence Index (CI) were determined (Table 2). For additional information on the methods and data used to derive the RI and CI, refer to the introduction chapter of this booklet.

Area labelled GLA are underlain primarily by glacial lake deposits which typically have low soil permeability and poor drainage characteristics. In Michigan the source rocks for these lake deposits do not contain significant amounts of radioactive minerals. Areas labelled GLA have a low radon potential (RI=7) with a moderate confidence (CI=9) assigned to this ranking. Area LML, Lake Michigan lobe deposits, is underlain by sandy to clayey glacial deposits and some glacial lake deposits. This area has a low radon potential (RI=8) with moderate confidence (CI=9). Area SMB, the south-central part of the Michigan Basin, is underlain by sandy and silty glacial deposits derived from sandstones, gray shales, limestones, and dolomites. This area has a moderate radon potential (RI=10) with a moderate confidence index (CI=9). Area NMB, the north-central part of the Michigan Basin, is geologically similar to area SMB. Soils in this area have higher water permeability but are also generally wetter than those to the south, which may account for their low radon potential (RI=8). There is moderate confidence (CI=8) associated with this ranking. An area of Paleozoic-age carbonate rocks and sandstones at the outer edge of the Michigan Basin has been designated OMB. Carbonate (limestone and dolomite) bedrock and glacial deposits derived from carbonate rocks have moderate radon potential, whereas areas underlain by sandstones have generally lower radon potential, although locally moderate or high indoor radon levels are possible anywhere in the area. This area is assigned an overall moderate (RI=10) radon potential with moderate confidence (CI=9).

Area AS, underlain by the Antrim black shale, has a moderate radon potential (RI=10) and a moderate associated confidence index (CI=9). Homes in this area may have indoor radon levels ranging from less than 1 to more than 4 pCi/L depending on their individual settings and construction characteristics. Area SAS is also underlain in part by the Antrim Shale, but is covered by glacial lake deposits. This area has moderate radon potential (RI=9) and confidence (CI=9).

Area SLM (Saginaw lobe moraine area) contains counties with high and moderate indoor radon averages. There are several possible explanations, depending on specific location, for the elevated radon values in this area (see the preceding geologic radon potential section). This area is assigned a high radon potential (RI=12) with moderate confidence (CI=9). Area MKG includes the Marquette Highland, Keweenaw Peninsula, and Gogebic Range in the Northern Peninsula. Locally elevated radon levels occur in areas underlain by granites, in the vicinity of iron-formation, and near fault and shear zones. Overall, the area has a moderate geologic radon potential (RI=11) with moderate confidence in the assessment (CI=9).

This is a generalized assessment of the State's geologic radon potential and there is no substitute for having a home tested. The conclusions about radon potential presented in this report cannot be applied to individual homes or building sites. Indoor radon levels, both high and low, can be quite localized, and within any radon potential area there will likely be areas with higher or lower radon potential that assigned to the area as a whole. Any local decisions about radon should not be made without consulting all available local data. 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 2. Radon Index (RI) and Confidence Index (CI) scores for geologic radon potential areas of Michigan. See figure 10 for locations and abbreviations of areas.

| | AREA | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | GLA | | LML | | SMB | | NMB | |
| FACTOR | RI | CI | RI | CI | RI | CI | RI | CI |
| INDOOR RADON | 1 | 3 | 1 | 3 | 2 | 3 | 1 | 2 |
| RADIOACTIVITY | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| GEOLOGY | 1 | 2 | 1 | 2 | 2 | 2 | 2 | 2 |
| SOIL PERM. | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| ARCHITECTURE | 3 | -- | 3 | -- | 3 | -- | 2 | -- |
| GFE POINTS | 0 | -- | 0 | -- | 0 | -- | 0 | -- |
| TOTAL | 7 | 9 | 8 | 9 | 10 | 9 | 8 | 8 |
| RANKING | LOW | MOD | LOW | MOD | MOD | MOD | LOW | MOD |

| | AS | | SAS | | SLM | | MKG | | OMB | |
|---|---|---|---|---|---|---|---|---|---|---|
| FACTOR | RI | CI | RI | CI | RI | CI | RI | CI | RI | CI |
| INDOOR RADON | 2 | 3 | 1 | 3 | 3 | 3 | 2 | 3 | 2 | 3 |
| RADIOACTIVITY | 1 | 2 | 2 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| GEOLOGY | 3 | 2 | 2 | 2 | 3 | 2 | 3 | 2 | 2 | 2 |
| SOIL PERM. | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| ARCHITECTURE | 2 | -- | 3 | -- | 3 | -- | 3 | -- | 3 | -- |
| GFE POINTS | 0 | -- | 0 | -- | 0 | -- | 0 | -- | 0 | -- |
| TOTAL | 10 | 9 | 9 | 9 | 12 | 9 | 11 | 9 | 10 | 9 |
| RANKING | MOD | MOD | MOD | MOD | HIGH | MOD | MOD | MOD | MOD | 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

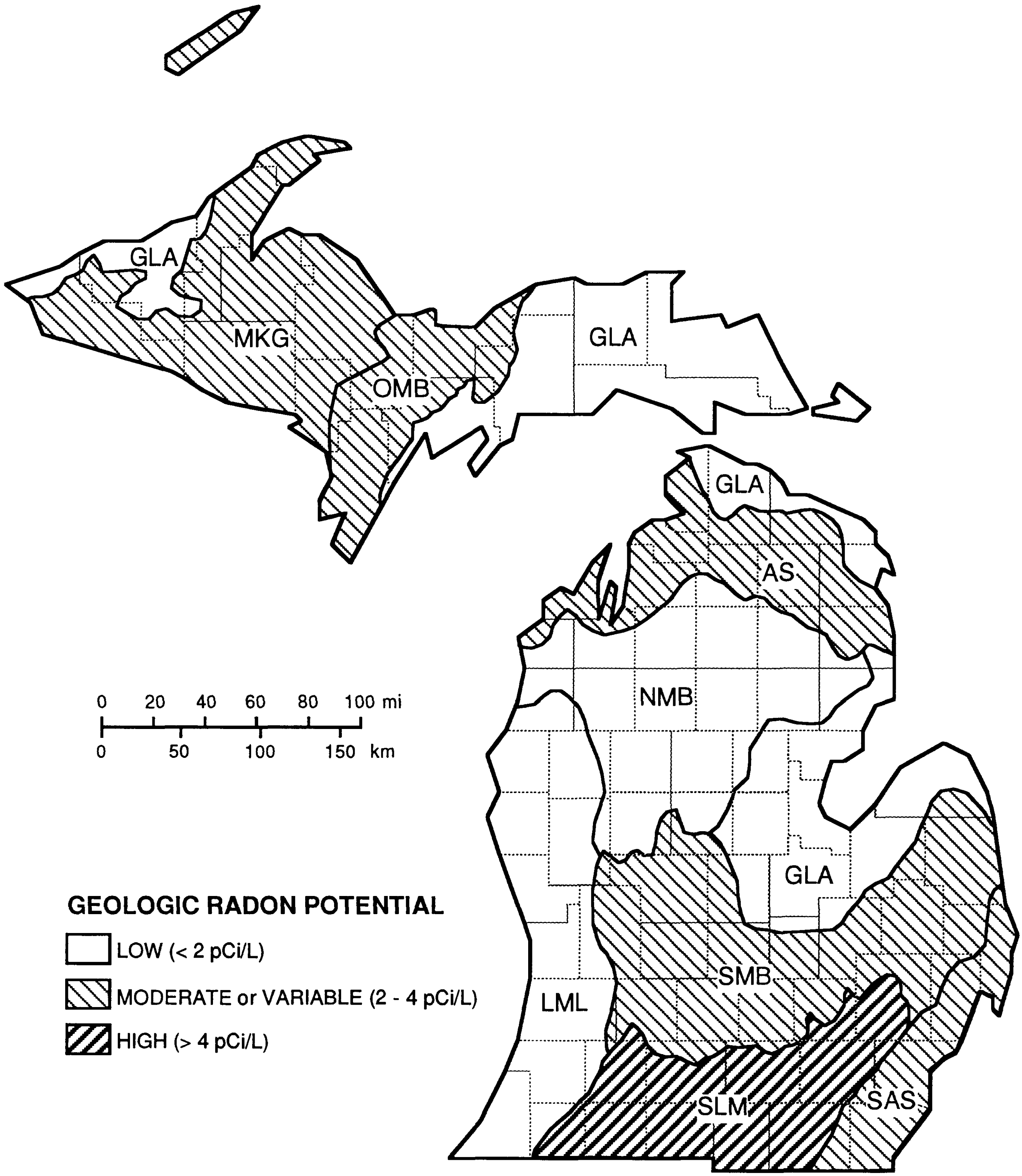



Figure 10. Geologic radon potential areas of Michigan. Radon levels in parentheses indicate expected average screening indoor radon levels for all homes, taken as a group, in the indicated geologic radon potential area. Refer to text for discussion of areas.

REFERENCES CITED IN THIS REPORT
AND GENERAL REFERENCES RELAVENT TO RADON IN MICHIGAN


Carmichael, R.S., 1989, Practical Handbook of physical properties of rocks and minerals: Boca Raton, Fla., CRC Press, 741 p.

Dorr, J.A., Jr., and Eschman, D.F., 1970, Geology of Michigan: Ann Arbor, Mich., The University of Michigan Press, 476 p.

Duval, J.S., Jones, W.J., Riggle, F.R., and Pitkin, J.A., 1989, Equivalent uranium map of the conterminous United States: U.S. Geological Survey Open-File Report 89-478, 10 p.

Ghahremani, D.T., 1987 , Radon and hydrocarbon prospecting in basins with shallow black shale deposits: AAPG Bulletin, v. 71, p. 1104.

Grace, J.D., 1985, Radon emanations from basement floors: Geological Society of America, Abstracts with Programs, v. 17, no. 5, p. 290.

Grace, J.D., 1986, Variations in radon soil gas geochemistry in Southwest Michigan: Geological Society of America, Abstracts with Programs, v. 18, no. 4, p. 290.

Grace, J.D., 1988, Variation in radon activity from cement basement floors, *in* Proceedings of V.M. Goldschmidt Conference, Baltimore, MD, May 11-13, 1988, p. 44.

Gundersen, L.C.S., 1991, Radon in sheared metamorphic and igneous rocks, *in* Gundersen, L.C.S., and Wanty, R.B. (eds), Field studies of radon in rocks, soils, and water: U.S. Geological Survey Bulletin 1971, p. 39-50.

Horrocks, R., 1979, The use of radon for oil and gas exploration, *in* Hydrocarbon potential, the Michigan Basin; the way ahead: Proceedings of the Michigan Basin Geological Society Annual Field Conference, Lansing, Mich., May 17-18, 1979, p. 20.

Johnson, Carol, 1976, Modes of occurrence of uranium and thorium in the Precambrian rocks of the Upper Peninsula of Michigan, *in* Kalliokoski, J., Uranium and thorium occurrences in Precambrian rocks, Upper Peninsula of Michigan and northern Wisconsin, with thoughts on other possible settings: Report prepared for the U.S. Energy Research and Development Administration, Grand Junction , CO, GJBX 48(76), p. 13-159.

King, P.B., and Beikman, Helen M., 1974, Geologic Map of the United States: U.S. Geological Survey, scale 1:2,500,000.

Lively, Richard, Steck, Daniel, and Brasaemle, Bruce, 1991, A site study of soil characteristics and soil gas radon in Rochester, Minnesota: Center for Urban and Regional Affairs report CURA 91-2, 15 p.

Martin, Helen M., 1936a, The centennial geologic map of the Northern Peninsula of Michigan: Michigan Department of Conservation, Geological Survey Division Publication 39, scale 1:500,000.

Martin, Helen M., 1936b, The centennial geologic map of the Southern Peninsula of Michigan: Michigan Department of Conservation, Geological Survey Division Publication 39, scale 1:500,000.

Martin, Helen M., 1955, Map of the surface formations of the Southern Peninsula of Michigan: Michigan Department of Conservation, Geological Survey Division Publication 49, scale 1:500,000.

Martin, Helen M., 1957, Map of the surface formations of the Northern Peninsula of Michigan: Michigan Department of Conservation, Geological Survey Division Publication 49, scale 1:500,000.

Michigan Department of Public Health, 1988, Indoor radon in Michigan, Report to the Governor: Michigan Department of Public Health report RH-947, 116 p.

Moed, B.A., Prichard, H.M., Gesell, T.F. and Adams, J.A.S., 1977, Potential radiometric impact of technologically mobilized radon-222 and its progeny: Geological Society of America, Abstracts with Programs, v. 9, no. 7, p. 1097-1098.

Parker, B.K., 1981, Rare earth and related elements in the Goodrich Quartzite, Marquette County, Michigan: Michigan Department of Natural Resources, Geological Survey Division report, 21 p.

Paull, R.K., and Paull, R.A., 1977, Geology of Wisconsin and upper Michigan including parts of adjacent states: Dubuque, Iowa, Kendall/Hunt Publishing Company, 232 p.

Richmond, G.R., and Fullerton, D.S. (eds.), Quaternary Geologic Atlas of the United States: U.S. Geological Survey Miscellaneous Investigations Map I-1420, sheet NL-15, Minneapolis 4°x6° quadrangle, 1983; sheet NL-16, Lake Superior 4°x6° quadrangle, 1984; sheet NK-15, Des Moines 4°x6° quadrangle, 1991; sheet NK-16, Chicago 4°x6° quadrangle, 1983; scale 1:1,000,000.

Schumann, R.R., Peake, R.T., Schmidt, K.M., and Owen, D.E., 1991, Correlations of soil-gas and indoor radon with geology in glacially derived soils of the northern Great Plains, *in* Proceedings of the 1990 International Symposium on Radon and Radon Reduction Technology, Volume 2, Symposium Oral Papers: U.S. Environmental Protection Agency report EPA/600/9-91/026b, p. 6-23--6-36.

Sims, P.K., 1976, Precambrian tectonics and mineral deposits, Lake Superior region: Economic Geology, v. 71, p. 1092-1127.

Sims, P.K., 1992, Geologic map of Precambrian rocks, southern Lake Superior region, Wisconsin and northern Michigan: U.S. Geological Survey Miscellaneous Investigations Map I-2185, scale 1:500,000.

Sommers, L.M., Darden, J.T., Harman, J.R., and Sommers, L.K., 1984, Michigan: A geography: Boulder, Colo., Westview Press, 254 p.

Steck, D.J., 1987 , Geological variation of radon sources and indoor radon concentrations along the southwestern edge of the Canadian Shield: Health Physics, v. 52, p. S40.

Steck, D.J., 1988, Geological variation of radon sources and indoor radon along the southwestern edge of the Canadian Shield, *in* M.A. Marikos and R.H. Hansman (eds), Geologic causes of natural radionuclide anomalies: Proceedings of the GEORAD Conference, St. Louis, MO, Missouri Department of Natural Resources Special Publication 4, p. 17-23.

U.S. Department of Agriculture (Soil Conservation Service), 1987, Soils: U.S. Geological Survey National Atlas sheet 38077-BE-NA-07M-00, scale 1:7,500,000.

Wayne, W.J., and Zumberge, J.H., 1965, Pleistocene geology of Indiana and Michigan, *in* Wright, H.E., Jr., and Frey, D.G. (eds.), The Quaternary of the United States: Princeton, NJ, Princeton University Press, p. 63-84.

Western Michigan University, 1981, Hydrogeologic atlas of Michigan: Kalamazoo, Michigan, Western Michigan University, 35 plates, scale 1:500,000.

Whiteside, E.P., Schneider, I.F., and Cook, R.L., 1968, Soils of Michigan: Agricultural Experiment Station, Michigan State University, Extension Bulletin E-630, 52 p.

PRELIMINARY GEOLOGIC RADON POTENTIAL ASSESSMENT OF MINNESOTA

*by*
*R. Randall Schumann and Kevin M. Schmidt*
*U.S. Geological Survey*

## INTRODUCTION

Many of the rocks and soils in Minnesota have the potential to generate levels of indoor radon exceeding the U.S. Environmental Protection Agency's (EPA) guideline of 4 pCi/L. In a survey of 919 homes conducted during the winter of 1987-88 by the Minnesota Department of Health and the EPA, 44 percent of the homes had indoor radon levels exceeding this value.

This is a generalized assessment of geologic radon potential of rocks, soils, and surficial deposits of Minnesota. 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

Minnesota's landscape is diverse and is influenced in most of the State by the action of glaciers. A map of physiographic provinces (fig. 1) shows several distinct areas characterized by different landscape features. The following discussion is summarized in large part from Wright (1972a). The Superior Upland is an area primarily of glacial erosion, where exposed bedrock has been eroded by glaciers, producing linear patterns of lakes and ridges. The North Shore Highland, in the eastern part of the Superior Upland, is a ridge formed by resistant lava flows that follows the shore of Lake Superior. Prominent features in the southern and western parts of the Superior Upland are the Toimi drumlin area, characterized by elongate mounds of glacial drift (drumlins), and the Giants Range, a ridge of granite flanking the Mesabi Iron Range on the north from Hibbing to Babbitt. The Giants Range rises about 60-120 m above the surrounding landscape. The Mesabi Range is easily recognized by the many large open-pit iron mines and piles of mine tailings in the area. Many of the mine pits are now occupied by lakes.

The Western Lake Section of the Central Lowlands province (fig. 1) is characterized by glacial landscape features including various types of glacial hills and ridges, including moraines, drumlins, eskers, and kames; and depressions, most of which are filled with lakes or wetlands. The northwestern part of this area is occupied by a pitted outwash plain in the Bemidji area. The major glacial features in the Western Lake Section are the Alexandria moraine complex, a 15-30 km-wide belt of north-south trending ridges along the western margin of the Western Lake Section that reach 500 m (1,700 feet) above sea level in the Leaf Hills (Wright, 1972a), and the western part of the St. Croix moraine, a 10 km-wide ridge extending for about 160 km from St. Cloud north to Walker.

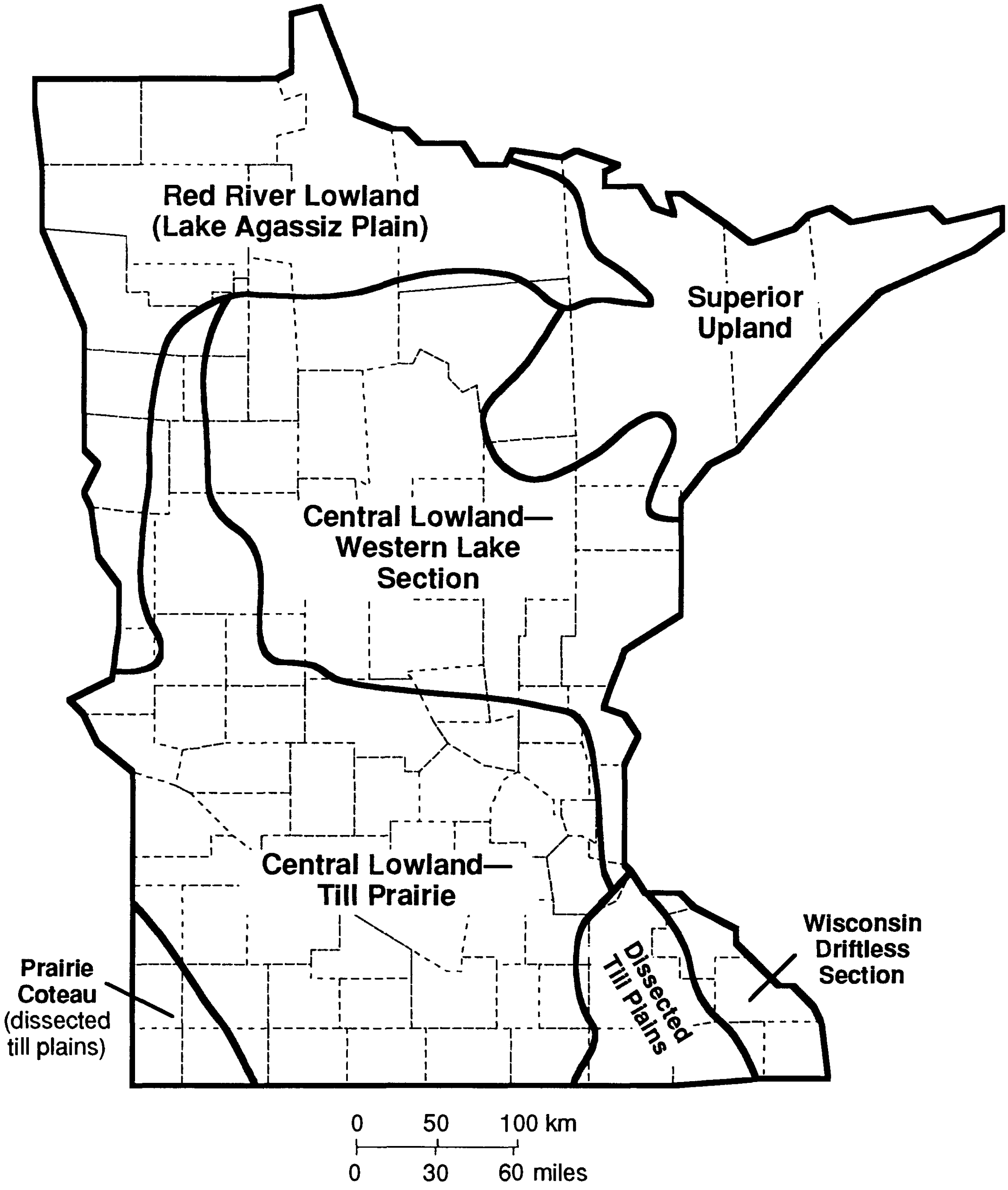



Figure 1. Generalized physiographic regions of Minnesota (after Belthuis, 1966, and Schwartz and Thiel, 1963).

The Till Prairie (or till plain) Section of the Central Lowlands province occupies most of the southern half of the State. This area is relatively flat and featureless, except where it is dissected by rivers and streams, largest of which is the Minnesota River. Linear ridges and chains of lakes are common features and the lakes may owe their origin to buried preglacial valleys (Wright, 1972a). Along the southern border of Minnesota the Till Prairie lies between dissected, till-mantled uplands. The eastern part consists of the dissected till plains and Wisconsin driftless area (fig. 1), which is partially covered by loess (windblown silt). In the southwestern corner of Minnesota lies the Coteau des Prairies, or Prairie Coteau, an upland area between the Minnesota River lowland and the James River basin (in South Dakota). The eastern escarpment of the Prairie Coteau is straight and steep, and probably represents a bedrock highland that existed in preglacial time. The Coteau des Prairies is also covered by loess deposits.

The Red River Lowland, in the northwestern part of the State, is a relatively flat-lying lowland that was once part of the Lake Agassiz Basin, one of the largest Wisconsinan glacial lakes in North America. The flatness and the lake clays have made this area very poorly drained, and, as a result, much of the northeastern part of this area is occupied by wetlands.

A significant portion of Minnesota's population is clustered around urban centers such as the Twin Cities and Duluth (fig. 2). Major land uses in the State include agriculture and manufacturing in the southern part of the State and logging, mining, and tourism in the north. Minnesota is divided into 87 counties (fig. 3).

## GEOLOGY

The discussion of geology is divided into three sections: bedrock geology, glacial geology, and uranium geology. "Bedrock" refers to pre-glacial rock units, which are covered by unconsolidated, Pleistocene glacial deposits in most parts of the State. Generalized bedrock geologic maps (figs. 4 and 5) show the types and distribution of rocks that underlie glacial deposits or are exposed at the surface in some areas. The glacial deposits are composed of material derived from underlying bedrock and from rock units to the north, northwest, and northeast. The discussion of bedrock geology is summarized from Ojakangas and Matsch (1982), Sims (1970), and Sims and Morey (1972). The section on glacial geology is summarized from Wright and Ruhe (1965), Wright (1972b), and Hobbs and Goebel (1982). For more detailed discussions and maps of the geology, the reader is encouraged to consult these and other reports.

*Bedrock geology:* Northeastern Minnesota has more exposures of bedrock at the surface than any other part of the State (fig. 6). Erosion has exposed Middle Proterozoic volcanic and igneous intrusive rocks including basalt, felsite, and rhyolite along the shore of Lake Superior. Intrusive into these are rocks of the Middle Proterozoic Duluth Complex, composed primarily of gabbro and anorthosite (fig. 4). The area covering most of northern Minnesota labelled "crystalline rocks" on figure 4 is underlain by Precambrian rocks of the Canadian Shield, the core of the North American continent. They comprise mainly metamorphic (metasedimentary and metavolcanic) rocks and granites of Archean age, including the Giants Range and Vermilion Granites. Because many of the volcanic rocks have undergone "greenschist-facies" metamorphism, the metavolcanic complexes in this area are commonly referred to as "greenstone belts". The northwestern corner of the State is underlain by Ordovician carbonates (limestone and dolomite) and Jurassic redbeds.

Iron-formation rocks (thick black lines in figures 4 and 5) include the Biwabik Iron Formation in the Mesabi Range, the Gunflint Iron Formation in the Gunflint Range, and the Trommald Iron Formation in the Cuyuna Range. The iron-bearing rocks range from silicate-rich to

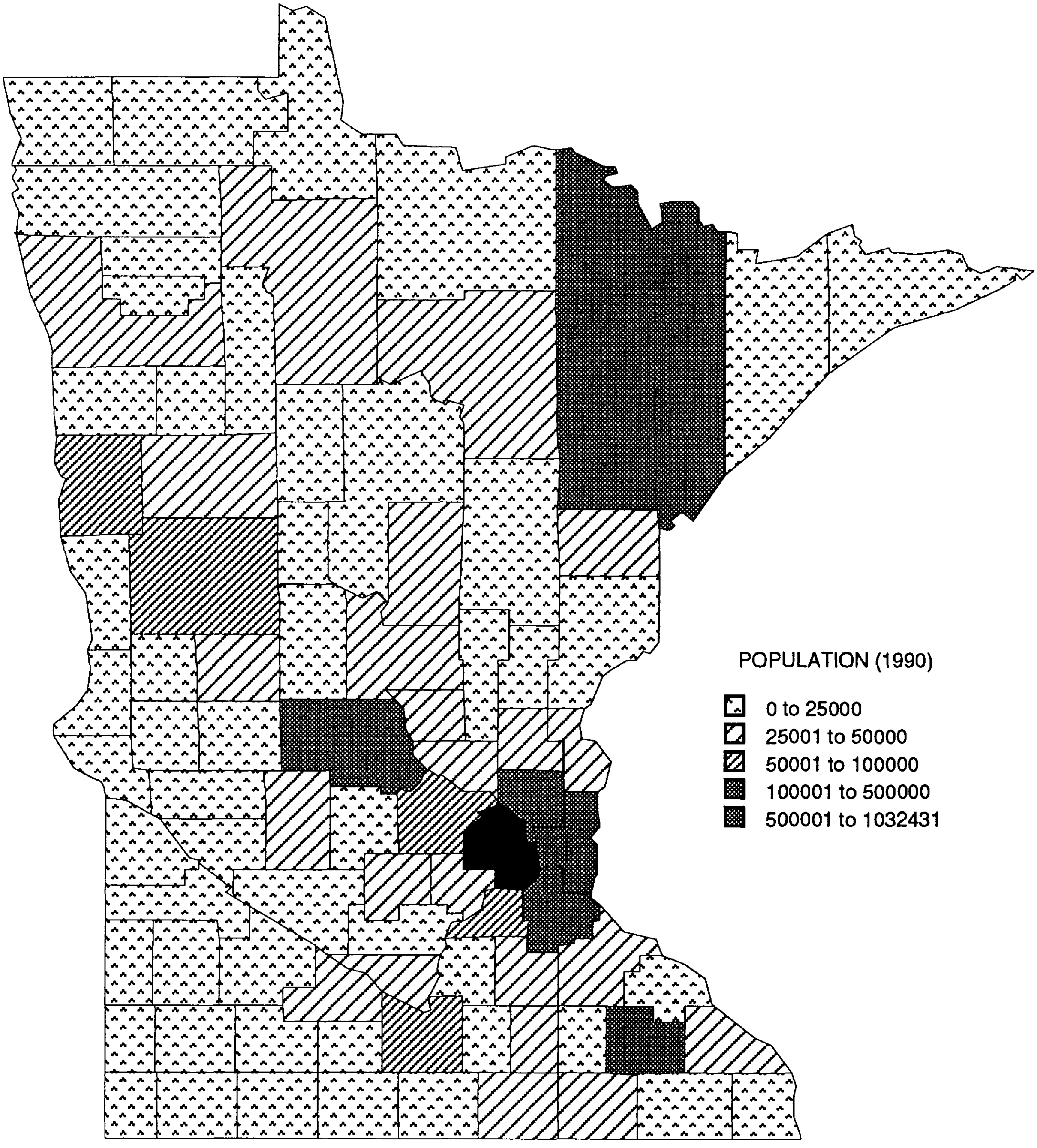



Figure 2. Population of counties in Minnesota (1990 U.S. Census data).


Figure 3. Minnesota counties.

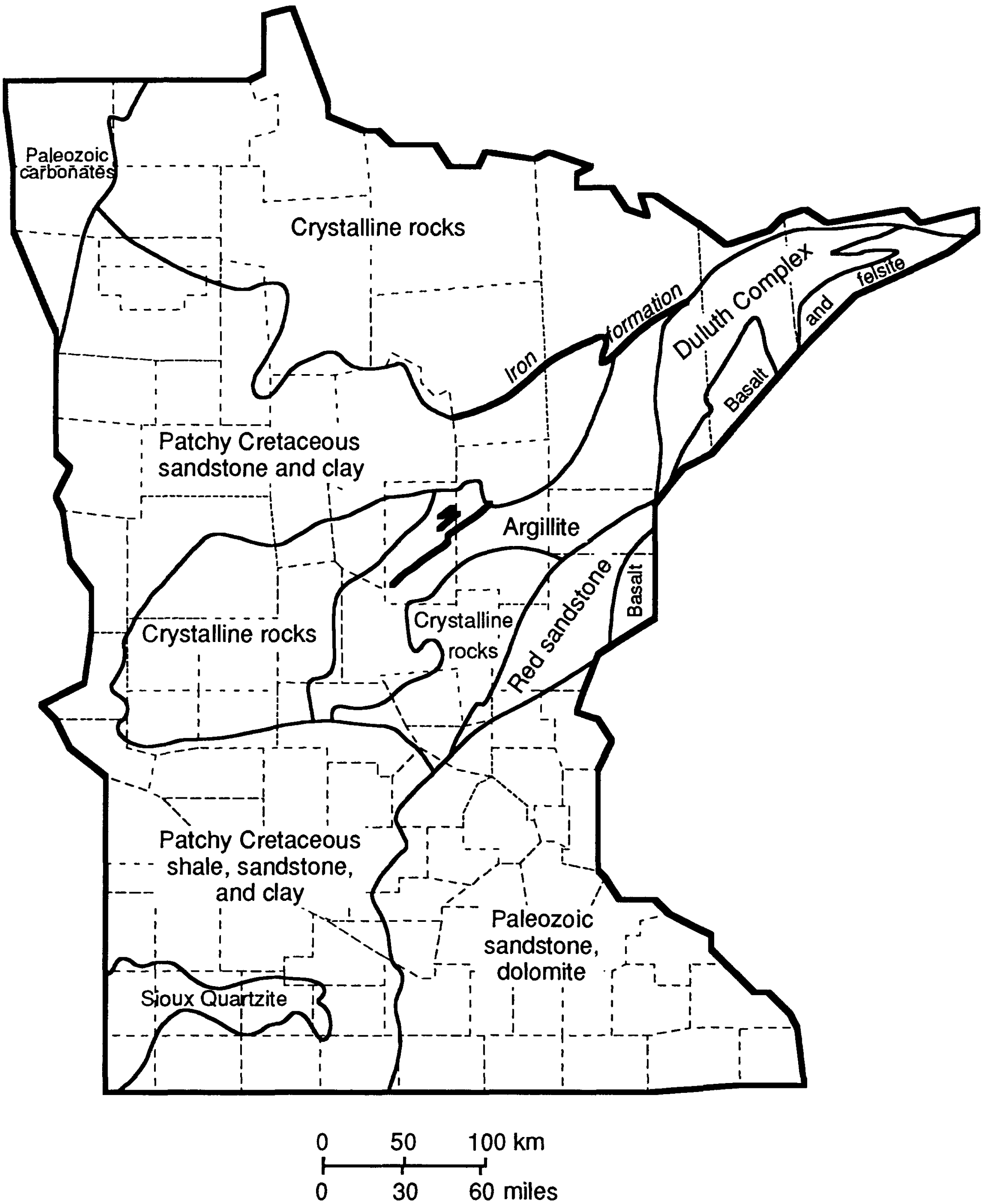



Figure 4. Generalized bedrock geologic map of Minnesota (after Wright, 1972b).

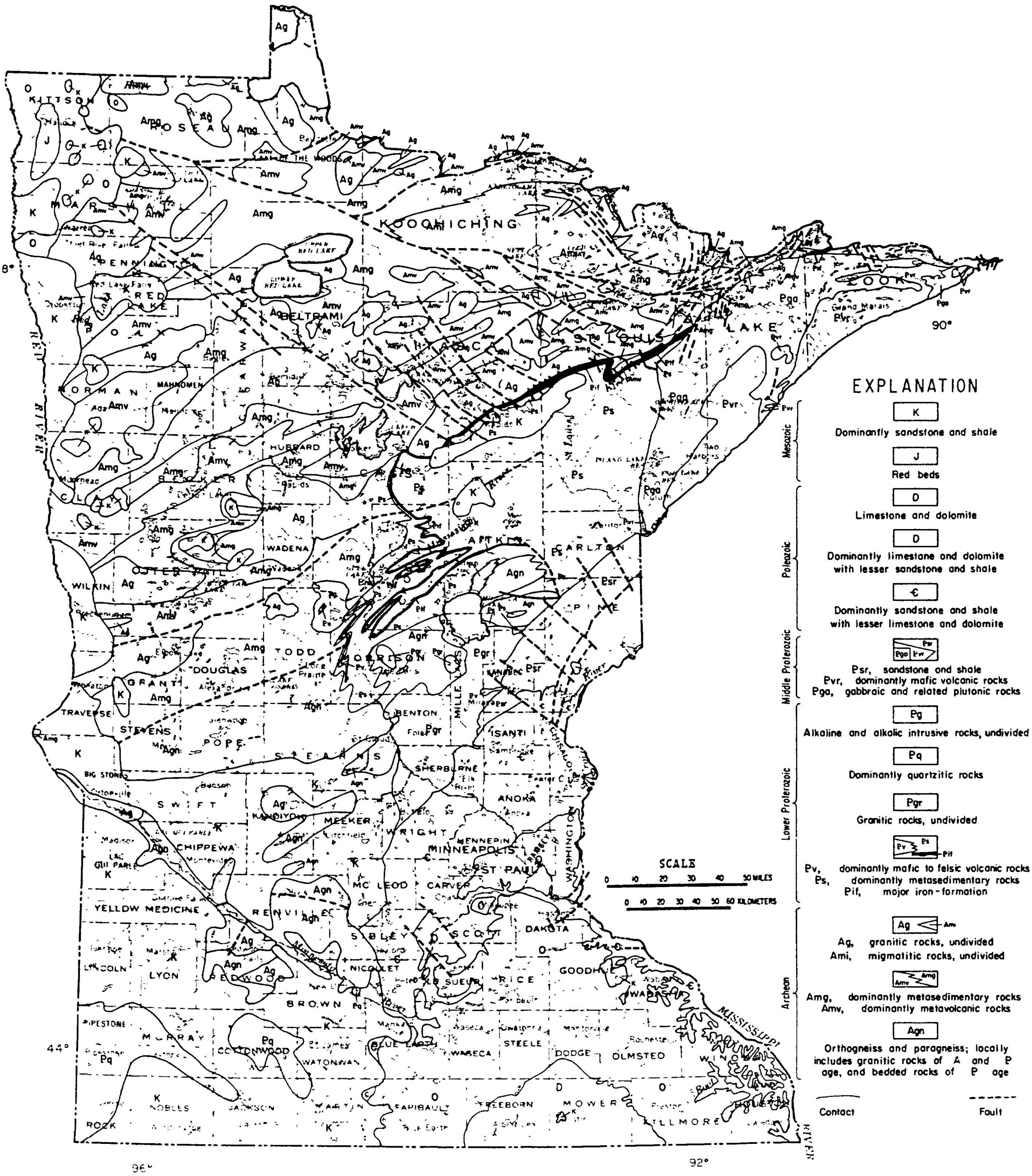



Figure 5. Generalized bedrock geologic map of Minnesota (modified from Morey, 1981).

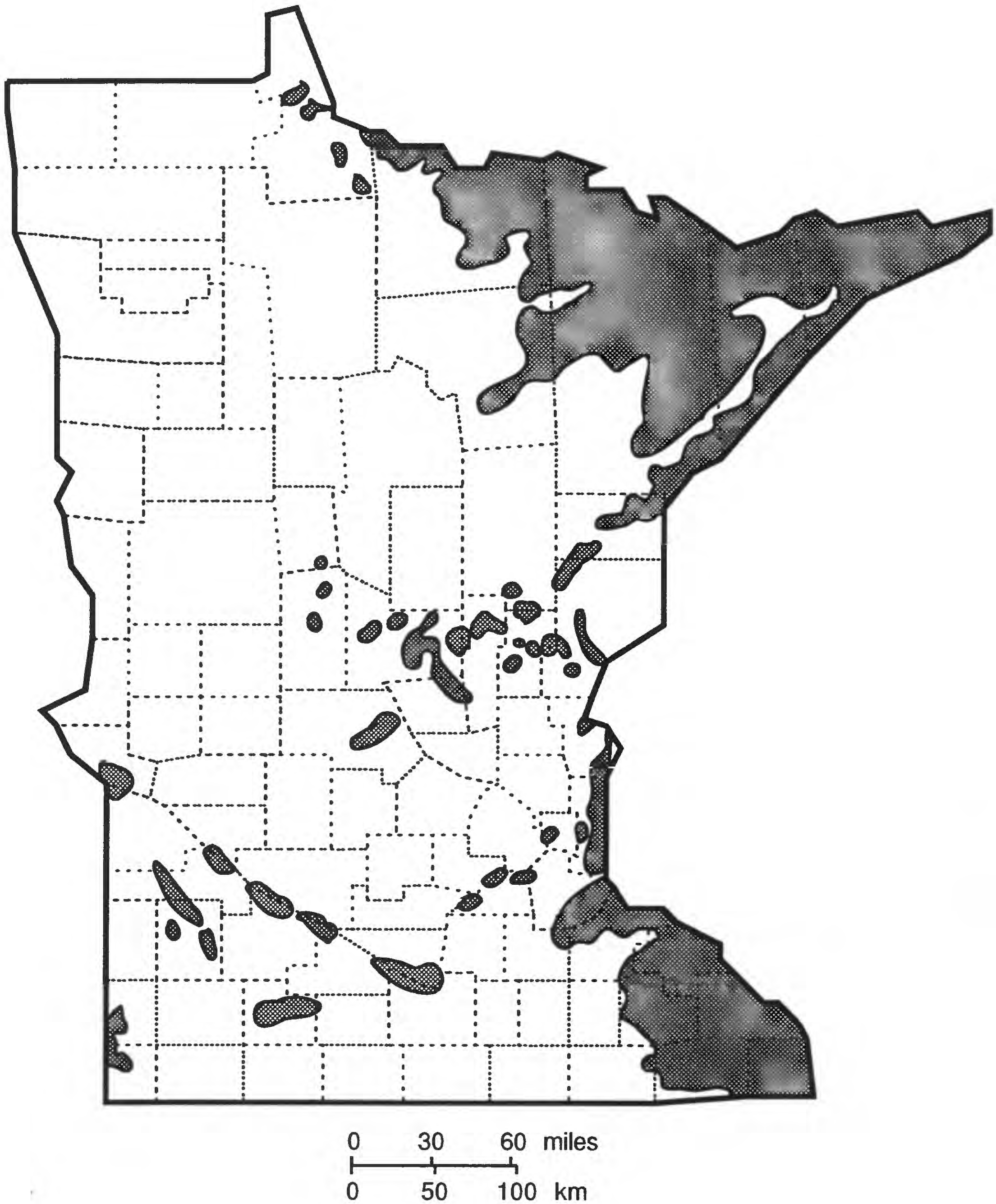



Figure 6. Map showing areas (shaded) in which bedrock is at the surface or covered by less than 15 m of glacial drift (after Morey, 1982).

carbonate rich and they are mineralogically complex. The term "taconite" is sometimes used to describe iron-formation that contains economic quantities of magnetite. To the southeast of the Mesabi Iron Range is an area of argillite, or weakly metamorphosed claystone or shale. One of the major rock units in this area is the Early Proterozoic Thomson Formation, which consists mainly of intermixed graywacke, siltstone, and shale, and increases in degree of metamorphism to the southwest (Keighin and others, 1972).

The area of crystalline rocks to the south of the argillite area in figure 4 consists of Early Proterozoic rocks of granitic composition (diorite, granodiorite, and quartz monzonite) and the Archean-age McGrath Gneiss (Keighin and others, 1972; Sims, 1970). To the east of these rocks are red-colored sandstone and interbedded shale of the Middle Proterozoic Hinckley and Fond du lac Formations (Sims, 1970), and volcanic rocks, mostly basalt, along the Minnesota-Wisconsin border just south of Lake Superior (figs. 4, 5). The area of crystalline rocks in west-central Minnesota (fig. 4) consists of metamorphic and igneous rocks, including mafic (containing dark-colored minerals such as hornblende) gneisses; mafic lavas and other metavolcanic rocks; metasedimentary rocks such as graywacke, slate, metaconglomerate, and quartzite; and felsic granites and gneisses (Sims, 1970).

Most of the western and some of the northern part of Minnesota is underlain by Cretaceous marine and nonmarine shale, sandstone, and minor limestone that overlie crystalline rocks. In northern Minnesota these rocks are called the Coleraine Formation, and in northwestern and southwestern Minnesota they are called the Split Rock Creek Formation, and are equivalent to the Dakota, Graneros, Greenhorn, Carlisle, Niobrara, and Pierre Formations (Setterholm, 1990). Small, localized outcrops of Cretaceous sandstone and shale also occur in the vicinity of Austin, and in eastern Goodhue and western Wabasha Counties in southeastern Minnesota (fig. 5).

In southwestern Minnesota the Cretaceous rocks form a discontinuous cover over older metamorphic and igneous rocks. One of these, the Early Proterozoic Sioux Quartzite, covers an area from the southwestern corner of the State eastward to the Minnesota River (fig. 4). The quartzite typically consists of red or pink, tightly silica-cemented, medium-grained quartz sand containing occasional beds of conglomerate and mudstone (Southwick and others, 1986).

The southeastern quarter of Minnesota is underlain by more than 300 m of carbonates, primarily limestone and dolomite; sandstone; and shale, ranging from Cambrian to Devonian in age. Approximately 75 percent of the area shown as "Paleozoic sandstone and dolomite" in figure 4 is underlain by carbonate rocks. These rocks are the primary ground-water aquifers for much of southeastern Minnesota (Lively and Southwick, 1981).

*Glacial geology:* Pleistocene-age glacial drift covers most of Minnesota. The drift ranges in thickness from zero in the northeastern and southeastern parts of the State (fig. 6) to as much as 150 m in the northwestern part (Ojakangas and Matsch, 1982). Glacial drift exposed at the surface , most of which was deposited during the Wisconsinan glacial period, has been divided into deposits of four major ice lobes that advanced at different times and moved in different directions, from areas with different source lithologies (fig. 7). Each lobe experienced multiple phases of ice advance, some of which overlapped with other lobes in time and space. In order of roughly decreasing age, the major lobes are the Wadena, Rainy, Superior, and Des Moines. Wadena lobe deposits are pre-late Wisconsinan in age, those of the other three lobes are of late Wisconsinan age.

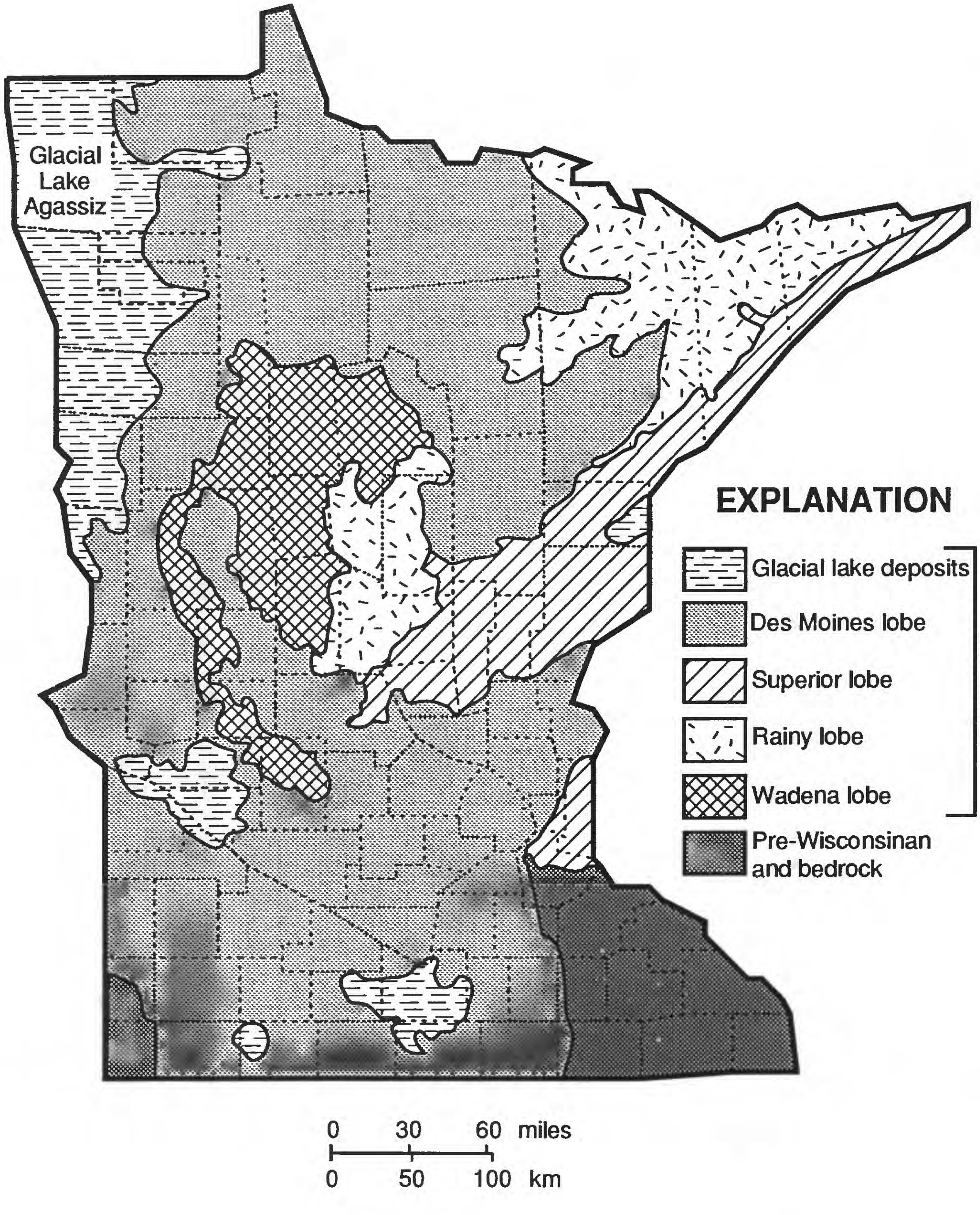



Figure 7. Generalized map showing glacial deposits in Minnesota (after Hobbs and Goebel, 1982).

Drift of the Wadena lobe is exposed mainly in central Minnesota (fig. 7). The Wadena lobe advanced southward from the north and northwest. Wadena drift is dominantly gray to buff-colored, sandy, calcareous till derived from carbonate rocks of southern Manitoba and northwestern Minnesota.

The Rainy lobe moved from northeast to southwest. Rainy lobe drift covers parts of northeastern and central Minnesota and varies in both color and constituent lithology. In the northeast the drift is derived primarily from gabbro and basalt, giving it a gray color. Further west the drift is light gray to light brown, reflecting a dominantly granite source. In central Minnesota, Rainy lobe drift is derived mostly from metamorphic rocks and has a brown color resulting from oxidation of the metamorphic rock fragments.

The Superior lobe advanced from northeast to southwest in the eastern part of the State, roughly parallel to the Rainy lobe. It deposited sandy red till containing sandstone and slate pebbles with little or no carbonate or shale.

Drift of the Des Moines lobe was primarily derived from Upper Cretaceous shales of southern Manitoba, eastern North Dakota, and western Minnesota. Sublobes of the Des Moines lobe moved eastward across northern Minnesota (the St. Louis sublobe) and southward to central Iowa (main part of the Des Moines lobe). Till derived from the Des Moines lobe is generally gray to buff, calcareous, and silty to clayey. Silty and clayey lacustrine deposits of Lake Agassiz cover much of the Red River Valley in the northwestern part of the State (fig. 7). Pre-Wisconsinan glacial deposits and Wisconsinan loess (included in the area labelled "Pre-Wisconsin") cover parts of the southwestern and southeastern parts of the State (fig. 7).

*Uranium geology:* Many areas in Minnesota are covered by rocks or sediments that contain enough uranium (here defined as > 2.5 ppm U) to generate radon at levels of concern. Rocks of the greenstone-granite terrane in northern Minnesota, labelled Ag, Amg, and Amv (fig. 5), generally have low uranium contents, due in large part to their mafic compositions. Some of the granite plutons in this area may have locally higher amounts of uranium. For example, some migmatitic parts of the Vermilion Granitic Complex contain up to 9 ppm U, probably due to melting and mixing with older metasedimentary rocks (Morey, 1981). Rocks in northeastern Minnesota labelled Pvr, Pga, and Psr in figure 5, which include the Duluth Complex, are generally low in uranium. The Thomson Formation in east-central Minnesota may contain uranium in northwest-trending fracture zones and along the contact between the Thomson and Fond du Lac Formations in Carlton and Pine Counties (fig. 5). Radioactivity anomalies in ground water derived from the Hinckley Sandstone suggest that it may contain uranium accumulation zones in the vicinity of Mora (Morey, 1981). Metasedimentary rocks in northeastern Minnesota, labelled Ps in figure 5, are generally low in uranium. The basal part of the Mille Lacs Group in northwestern Pine County and Morrison County and phosphate-rich beds in the Thomson Formation may contain locally elevated uranium concentrations.

Rocks of central Minnesota and the Minnesota River valley include gneisses labelled Amg and Agn in figure 5. These rocks contain 1-10 ppm uranium, with higher concentrations (5-12 ppm) occurring in granitic pegmatites that traverse the gneisses (Morey, 1981). In northwestern Pine County near Denham, anomalously high concentrations of uranium and radon occur in several water wells (Morey and Lively, 1980; Lively and Southwick, 1981). The Sacred Heart Granite in Redwood, Renville, and Yellow Medicine Counties contains 10-20 ppm U, and the St. Cloud Granite contains an average of about 5 ppm U but locally contains as much as 12 ppm U (Morey, 1981).

Upper Cretaceous sedimentary rocks in southeastern Minnesota and along the Red River Valley are labelled K in figure 5. These rocks contain a few (3-10?) ppm U on average, but locally as much as 20 ppm has been found in Cretaceous shale in the Red River Valley (Morey, 1981). In general, tills derived from Cretaceous shale in the southern and western parts of the State contain more uranium than tills derived from metamorphic and other crystalline rocks in other parts of the State. Water from some wells sourced in the Sioux Quartzite, labelled Pq in southwestern Minnesota (fig. 5), contains anomalously high concentrations of uranium and radon, suggesting localized uranium enrichment, possibly along the unconformity at the base of the Sioux Quartzite (Morey, 1981).

Cambrian (C), Devonian (D), and Ordovician (O) limestone, dolomite, and sandstone in southeastern Minnesota (fig. 5) are generally low in uranium, but these rocks contain small amounts of uranium-bearing heavy minerals that may be locally concentrated as the carbonate matrix dissolves away during weathering or development of solution features. Carbonate bedrock containing fractures or solution features, and soils developed on carbonate rocks, may generate sufficient radon to be of concern in some areas.

## SOILS

Soils in Minnesota belong primarily to the great soil groups Alfisols, Entisols, and Histosols in northeastern and east-central Minnesota, and Mollisols in western and southern Minnesota (U.S. Department of Agriculture, Soil Conservation Service, 1987). Figure 8 is a generalized map of soil types. A generalized soil permeability map (fig. 9) was compiled by the authors using Soil Conservation Service (SCS) soil surveys and a hydrogeologic map of the State (Kanivetsky, 1979). The soil permeabilities listed are for water, but gas permeability is generally similar to permeability to water if the soils are not excessively wet.

About half of the State is underlain by soils of moderate permeability (defined here as between 0.6 and 6.0 in/hr in percolation tests) (fig. 9). Low permeability (< 0.6 in/hr) soils are mainly those developed from glacial lake deposits in northern and western Minnesota. Soils developed on till of the Des Moines glacial lobe are low to moderate in permeability where the till is mainly derived from shale. Cracking of clayey glacial soils during dry periods can significantly enhance permeability to gases.

Much of the area shown in the moderate or high soil permeability category in northern Minnesota is wetland with seasonally or continuously saturated soils, so the permeability to soil gas in this area is low. High permeability (> 6.0 in.hr) soils occur mainly in central Minnesota but are scattered across the State (fig. 9). These soils are mainly derived from outwash of sandy tills, particularly those of the Rainy and Wadena lobes.

## INDOOR RADON DATA

Screening indoor radon data from 919 homes tested in the State/EPA Residential Radon Survey of Minnesota conducted during the winter of 1987-88 are listed in Table 1 and shown in figure 10. These data represent short-term (2-7 day) screening indoor radon measurements using charcoal canisters. The sampling distribution was biased toward population centers, and some less-populated areas of the State are represented by inadequate or no samples. Only eight counties had more than 20 homes tested and only four counties had more than 50 homes tested (Table 1). Data are only shown in Figure 10 for counties in which more than 5 homes were tested. Although the data are insufficient to represent indoor radon levels across Minnesota at a statistically

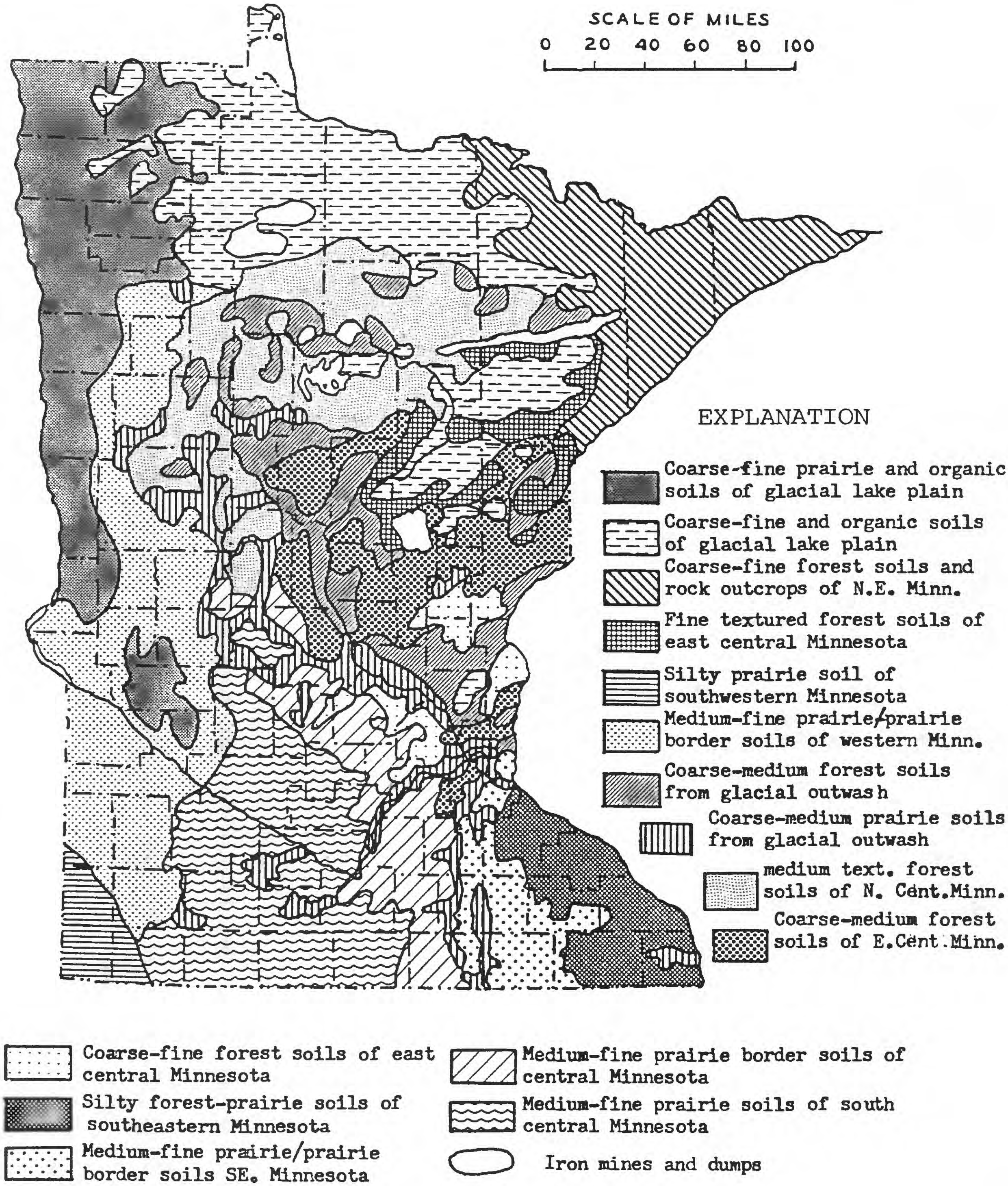



Figure 8. Generalized map of soil associations in Minnesota (modified from Belthuis, 1966).

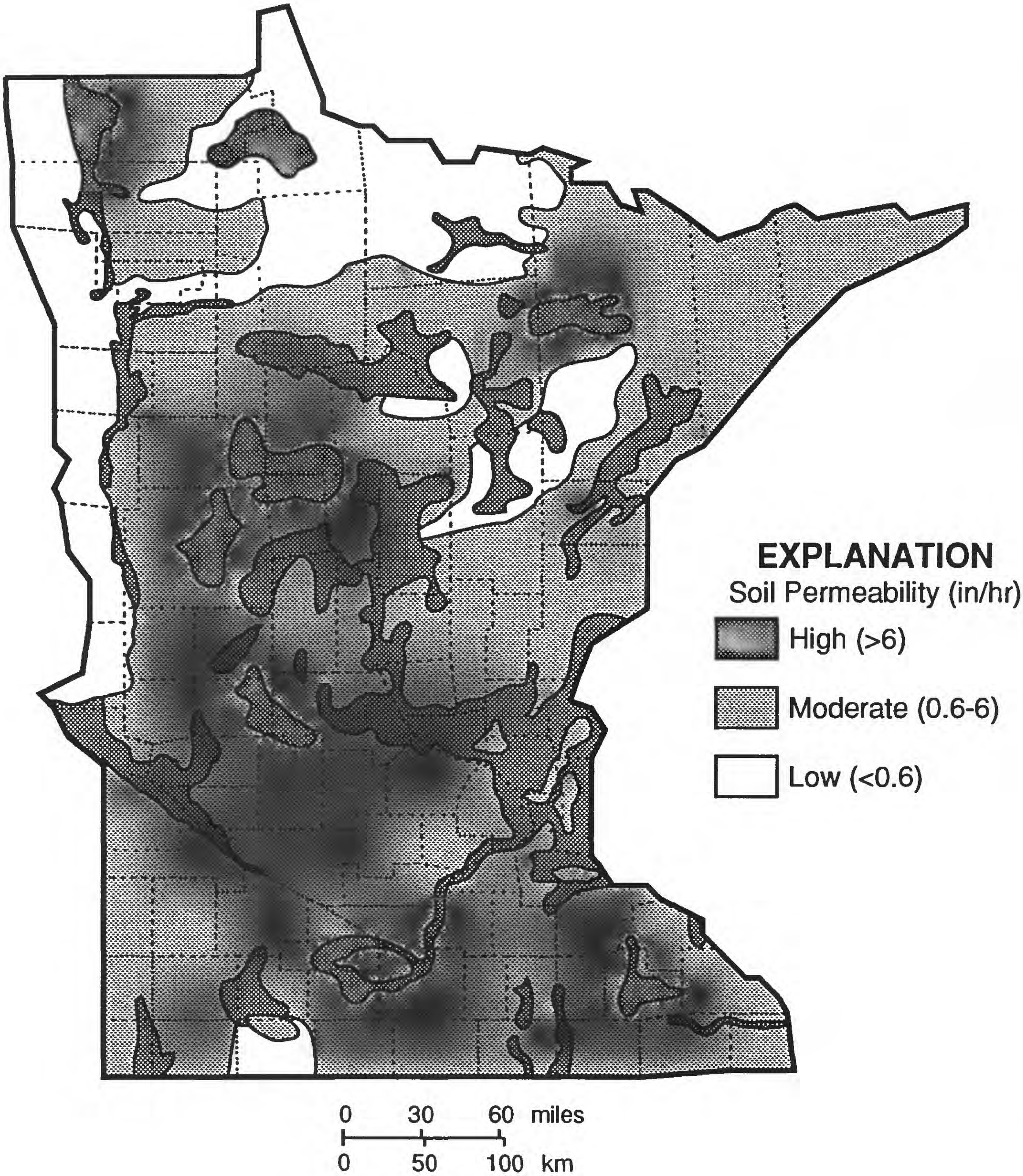
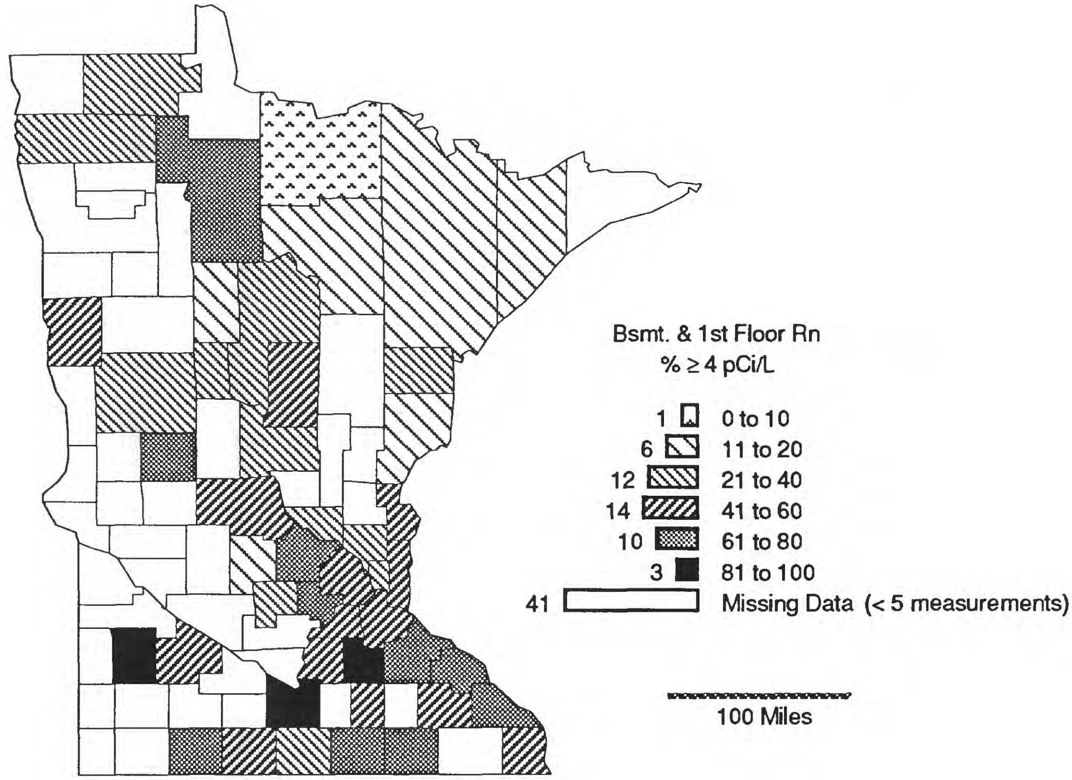



Figure 9. Generalized soil permeability map of Minnesota, compiled by the authors from data in Kanivetsky (1979) and SCS county soil surveys.



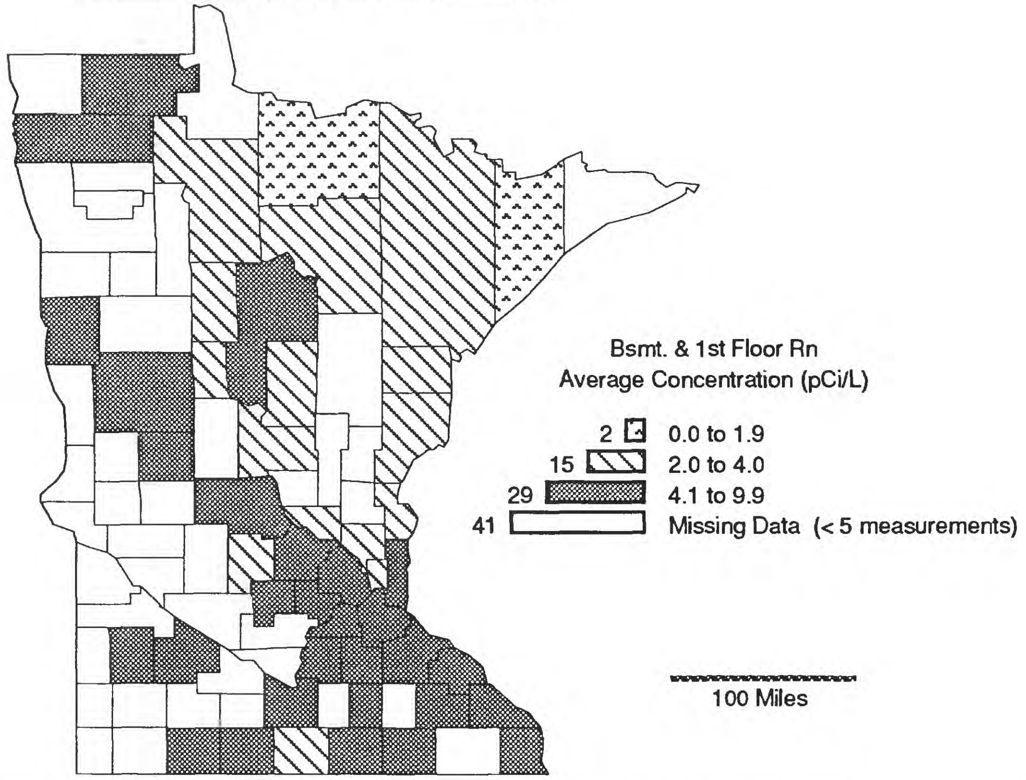




Figure 10. Screening indoor radon data from the EPA/State Residential Radon Survey of Minnesota, 1987-88, for counties with 5 or more measurements. Data are from 2-7 day charcoal canister tests. Histograms in map legends show the number of counties in each category. The number of samples in each county (see Table 1) may not be sufficient to statistically characterize the radon levels of the counties, but they do suggest general trends. Unequal category intervals were chosen to provide reference to decision and action levels.

TABLE 1. Screening indoor radon data from the EPA/State Residential Radon Survey of Minnesota conducted during 1987-88. Data represent 2-7 day charcoal canister measurements from the lowest level of each home tested.

| COUNTY | NO. OF MEAS. | MEAN | GEOM. MEAN | MEDIAN | STD. DEV. | MAXIMUM | %>4 pCi/L | %>20 pCi/L |
|---|---|---|---|---|---|---|---|---|
| AITKIN | 4 | 2.1 | 1.9 | 2.2 | 0.8 | 2.9 | 0 | 0 |
| ANOKA | 52 | 3.0 | 2.3 | 2.3 | 2.0 | 8.1 | 27 | 0 |
| BECKER | 3 | 3.3 | 2.9 | 4.3 | 1.9 | 4.5 | 67 | 0 |
| BELTRAMI | 7 | 4.0 | 3.1 | 4.6 | 2.1 | 6.3 | 71 | 0 |
| BENTON | 4 | 3.8 | 3.5 | 2.9 | 1.9 | 6.6 | 25 | 0 |
| BIG STONE | 3 | 4.9 | 4.5 | 5.0 | 2.3 | 7.2 | 67 | 0 |
| BLUE EARTH | 14 | 7.7 | 6.7 | 6.9 | 3.7 | 14.3 | 86 | 0 |
| BROWN | 4 | 5.8 | 5.1 | 5.4 | 3.3 | 10.1 | 50 | 0 |
| CARLTON | 10 | 3.0 | 2.5 | 2.8 | 1.6 | 5.6 | 30 | 0 |
| CARVER | 6 | 7.3 | 3.0 | 7.2 | 6.1 | 14.7 | 67 | 0 |
| CASS | 5 | 4.5 | 4.1 | 4.0 | 2.0 | 7.4 | 40 | 0 |
| CHIPPEWA | 4 | 7.1 | 5.6 | 8.6 | 3.9 | 10.0 | 75 | 0 |
| CHISAGO | 6 | 3.7 | 2.8 | 3.3 | 2.7 | 8.1 | 50 | 0 |
| CLAY | 14 | 8.9 | 5.9 | 7.9 | 7.5 | 26.6 | 57 | 7 |
| CLEARWATER | 4 | 3.1 | 2.7 | 3.4 | 1.6 | 4.8 | 25 | 0 |
| COOK | 2 | 2.1 | 1.9 | 2.1 | 0.9 | 2.7 | 0 | 0 |
| COTTONWOOD | 4 | 5.1 | 1.8 | 4.7 | 4.9 | 11.1 | 50 | 0 |
| CROW WING | 12 | 3.1 | 2.6 | 2.7 | 1.9 | 6.7 | 42 | 0 |
| DAKOTA | 63 | 4.7 | 3.6 | 4.3 | 3.6 | 21.2 | 52 | 2 |
| DODGE | 3 | 6.1 | 6.1 | 5.7 | 1.0 | 7.2 | 100 | 0 |
| DOUGLAS | 9 | 5.5 | 5.2 | 5.5 | 1.7 | 7.8 | 78 | 0 |
| FARIBAULT | 6 | 2.8 | 1.7 | 2.9 | 1.9 | 5.2 | 33 | 0 |
| FILLMORE | 2 | 2.9 | 2.8 | 2.9 | 0.5 | 3.2 | 0 | 0 |
| FREEBORN | 9 | 9.5 | 7.0 | 6.3 | 9.3 | 32.6 | 78 | 11 |
| GOODHUE | 14 | 8.8 | 6.3 | 5.3 | 10.5 | 43.5 | 71 | 7 |
| HENNEPIN | 105 | 4.6 | 3.6 | 3.9 | 3.5 | 23.6 | 45 | 1 |
| HOUSTON | 6 | 5.3 | 4.6 | 4.2 | 2.8 | 9.0 | 50 | 0 |
| HUBBARD | 5 | 2.7 | 2.2 | 2.8 | 1.6 | 4.6 | 20 | 0 |
| ISANTI | 3 | 2.9 | 2.9 | 3.0 | 0.7 | 3.6 | 0 | 0 |
| ITASCA | 11 | 3.0 | 2.5 | 2.5 | 2.3 | 9.4 | 18 | 0 |
| JACKSON | 5 | 8.9 | 7.5 | 8.4 | 5.2 | 15.3 | 80 | 0 |
| KANABEC | 4 | 4.0 | 3.4 | 3.2 | 2.7 | 7.9 | 25 | 0 |
| KANDIYOHI | 4 | 8.6 | 7.9 | 9.0 | 3.9 | 12.3 | 100 | 0 |
| KITTSON | 3 | 4.1 | 3.0 | 4.5 | 3.0 | 6.9 | 67 | 0 |
| KOOCHICHING | 7 | 1.6 | 1.5 | 1.4 | 0.6 | 2.8 | 0 | 0 |
| LAC QUI PARLE | 2 | 13.7 | 13.4 | 13.7 | 3.3 | 16.0 | 100 | 0 |
| LAKE | 9 | 1.9 | 1.4 | 1.3 | 2.1 | 7.1 | 11 | 0 |
| LAKE OF THE WOODS | 4 | 5.2 | 4.5 | 3.8 | 3.4 | 10.1 | 50 | 0 |
| LE SUEUR | 5 | 5.7 | 5.0 | 4.2 | 3.8 | 12.5 | 60 | 0 |
| LINCOLN | 4 | 9.9 | 8.5 | 9.3 | 5.9 | 17.5 | 75 | 0 |
| LYON | 8 | 6.9 | 6.5 | 6.2 | 2.5 | 12.0 | 100 | 0 |

TABLE 1 (continued). Screening indoor radon data for Minnesota.

| COUNTY | NO. OF MEAS. | MEAN | GEOM. MEAN | MEDIAN | STD. DEV. | MAXIMUM | %>4 pCi/L | %>20 pCi/L |
|---|---|---|---|---|---|---|---|---|
| MAHNOMEN | 1 | 3.9 | 3.9 | 3.9 | 0.0 | 3.9 | 0 | 0 |
| MARSHALL | 9 | 9.9 | 3.3 | 1.5 | 16.2 | 48.2 | 33 | 22 |
| MARTIN | 7 | 4.3 | 2.6 | 4.1 | 3.6 | 9.2 | 57 | 0 |
| MCLEOD | 13 | 5.8 | 2.8 | 2.8 | 7.0 | 25.4 | 38 | 8 |
| MEEKER | 5 | 3.7 | 3.4 | 3.2 | 2.1 | 7.2 | 20 | 0 |
| MILLE LACS | 2 | 3.1 | 1.7 | 3.1 | 3.7 | 5.7 | 50 | 0 |
| MORRISON | 9 | 3.1 | 2.9 | 3.0 | 1.1 | 4.9 | 22 | 0 |
| MOWER | 13 | 7.1 | 4.9 | 6.4 | 6.2 | 24.0 | 62 | 8 |
| MURRAY | 1 | 12.1 | 12.1 | 12.1 | 0.0 | 12.1 | 100 | 0 |
| NICOLLET | 4 | 9.7 | 8.7 | 9.5 | 4.8 | 15.7 | 100 | 0 |
| NOBLES | 3 | 7.1 | 6.9 | 6.2 | 2.3 | 9.7 | 100 | 0 |
| NORMAN | 3 | 3.8 | 2.7 | 1.6 | 3.8 | 8.1 | 33 | 0 |
| OLMSTED | 23 | 4.3 | 3.4 | 3.2 | 3.0 | 11.2 | 43 | 0 |
| OTTER TAIL | 8 | 5.2 | 3.8 | 3.5 | 4.5 | 12.6 | 38 | 0 |
| PENNINGTON | 3 | 3.3 | 1.9 | 3.7 | 2.8 | 5.8 | 33 | 0 |
| PINE | 6 | 2.1 | 1.9 | 1.7 | 1.1 | 4.1 | 17 | 0 |
| PIPESTONE | 4 | 6.9 | 5.4 | 6.9 | 4.7 | 12.1 | 75 | 0 |
| POLK | 4 | 5.1 | 3.9 | 4.7 | 3.8 | 9.6 | 50 | 0 |
| POPE | 2 | 3.6 | 3.6 | 3.6 | 0.3 | 3.8 | 0 | 0 |
| RAMSEY | 32 | 3.6 | 3.0 | 3.3 | 2.3 | 10.1 | 31 | 0 |
| REDWOOD | 5 | 8.5 | 6.3 | 7.4 | 7.3 | 20.7 | 60 | 20 |
| RENVILLE | 3 | 4.6 | 4.2 | 5.8 | 2.2 | 6.0 | 67 | 0 |
| RICE | 11 | 6.9 | 5.9 | 5.6 | 4.6 | 19.0 | 82 | 0 |
| ROCK | 2 | 5.0 | 3.7 | 5.0 | 4.8 | 8.4 | 50 | 0 |
| ROSEAU | 14 | 4.3 | 3.5 | 3.6 | 3.1 | 11.4 | 36 | 0 |
| SCOTT | 13 | 7.5 | 4.9 | 4.3 | 7.5 | 25.2 | 54 | 8 |
| SHERBURNE | 8 | 3.2 | 3.0 | 3.0 | 1.2 | 5.1 | 25 | 0 |
| SIBLEY | 4 | 3.8 | 3.5 | 4.4 | 1.6 | 5.0 | 50 | 0 |
| ST. LOUIS | 116 | 3.1 | 2.2 | 2.0 | 3.7 | 32.2 | 18 | 1 |
| STEARNS | 25 | 4.9 | 4.0 | 5.0 | 3.2 | 14.5 | 52 | 0 |
| STEELE | 10 | 5.6 | 4.9 | 4.8 | 2.9 | 10.6 | 60 | 0 |
| STEVENS | 2 | 6.3 | 6.0 | 6.3 | 2.5 | 8.0 | 100 | 0 |
| SWIFT | 4 | 2.9 | 2.7 | 2.7 | 1.4 | 4.8 | 25 | 0 |
| TODD | 3 | 5.0 | 4.4 | 6.0 | 2.5 | 6.8 | 67 | 0 |
| TRAVERSE | 4 | 8.2 | 6.2 | 5.4 | 7.6 | 19.3 | 50 | 0 |
| WABASHA | 7 | 6.9 | 5.6 | 8.4 | 3.7 | 11.5 | 71 | 0 |
| WADENA | 5 | 3.3 | 2.7 | 3.2 | 1.7 | 4.8 | 40 | 0 |
| WASECA | 4 | 3.1 | 1.5 | 1.3 | 4.2 | 9.3 | 25 | 0 |
| WASHINGTON | 46 | 4.7 | 3.5 | 3.8 | 4.0 | 20.4 | 46 | 2 |
| WATONWAN | 3 | 9.9 | 9.3 | 10.2 | 4.1 | 13.8 | 100 | 0 |
| WILKIN | 1 | 9.3 | 9.3 | 9.3 | 0.0 | 9.3 | 100 | 0 |
| WINONA | 13 | 6.1 | 4.3 | 4.7 | 4.1 | 11.8 | 69 | 0 |
| WRIGHT | 13 | 5.8 | 4.9 | 5.1 | 3.7 | 15.9 | 69 | 0 |
| YELLOW MEDICINE | 2 | 3.3 | 3.3 | 3.3 | 0.6 | 3.7 | 0 | 0 |

significant level, and any interpretations based on these data should not be considered definitive, they do indicate trends related to geology, soils, and other factors.

Overall, 44 percent of the homes in this screening survey had indoor radon levels that exceeded 4 pCi/L. The maximum level recorded in this survey was 48.2 pCi/L in Marshall County. With the exception of Faribault and Meeker Counties, average indoor radon concentrations are consistently greater than 4 pCi/L in all counties with 5 measurements or more south of a northwest-southeast trending line from Clay County to Dakota and Washington Counties (fig. 10). Cass, Marshall, and Roseau Counties also have average indoor radon levels greater than 4 pCi/L (fig. 10). The same general trend is seen in the percentage of homes tested in each county that had indoor radon levels greater than 4 pCi/L (fig. 10). Note that although Fairbault County had an average indoor radon level of 2.7 pCi/L, 33 percent of the homes measured in the county had levels exceeding 4 pCi/L (fig. 10; Table 1). The central part of the State has generally moderate (2-4 pCi/L) average radon levels, though some counties have low (<2 pCi/L) and high (>4 pCi/L) average indoor radon levels (fig. 10).

In general, northeastern Minnesota is characterized by low to moderate indoor radon levels. Most of the counties in the northeastern part of the State have average indoor radon levels less than 3 pCi/L, with the exception of St. Louis County (3.1 pCi/L). Data from counties in the Red River Valley and other areas underlain by deposits of glacial Lake Agassiz are scarce, but this area may have generally high indoor radon levels as indicated by data from Clay, Marshall, and Roseau Counties, which each have average indoor radon levels exceeding 4 pCi/L (fig. 10).

## GEOLOGIC RADON POTENTIAL

An aerial radiometric map of Minnesota (fig. 11) corresponds fairly well with patterns of surficial units. The highest values of equivalent uranium (eU) are associated with Lake Agassiz sediments in the Red River Valley along the Minnesota-North Dakota state line, with loess and areas of thin glacial cover or exposed bedrock in the southeast and southwest corners of the State, and with some Des Moines lobe deposits in southwestern Minnesota (figs. 7, 11). Low eU values are associated with glacial deposits derived from metavolcanic and metasedimentary rocks in the northeast and north-central parts of the State. Some of the lowest eU values (near zero ppm eU) are associated with wetlands in northern Minnesota, particularly in the Red Lake-Lake of the Woods area (fig. 11). The eU pattern is consistent with the surficial geology within the State, although the radiometric signature of the State as a whole appears lower than expected compared to indoor and soil-gas radon, and compared with the radiometric signature of non-glaciated areas on a national scale (see Duval and others, 1989). Recent studies (for example, Lively and others, 1991; Schumann and others, 1991) suggest that radium in some near-surface soil horizons may have been leached and transported downward in the soil profile, giving lower surface radiometric signatures while generating significant radon at depth (1-2 m? or greater), as indicated by measured soil-gas radon concentrations, to produce elevated indoor radon levels. In general, soils can develop more rapidly on glacial deposits than on bedrock, because crushing and grinding of the rocks by glaciers can enhance soil weathering processes (Jenny, 1935). Glacial crushing reduces the grain size of rock fragments, enhancing radon emanation by increasing the surface area-to-volume ratio of the grains, and enhances radionuclide mobility by exposing uranium on grain surfaces where it can be more readily leached by oxidizing ground water. In addition, some poorly-sorted glacial drift may have higher permeability than the bedrock from which it is derived, allowing enhanced radon migration through the soil. Cracking of clayey glacial soils during dry

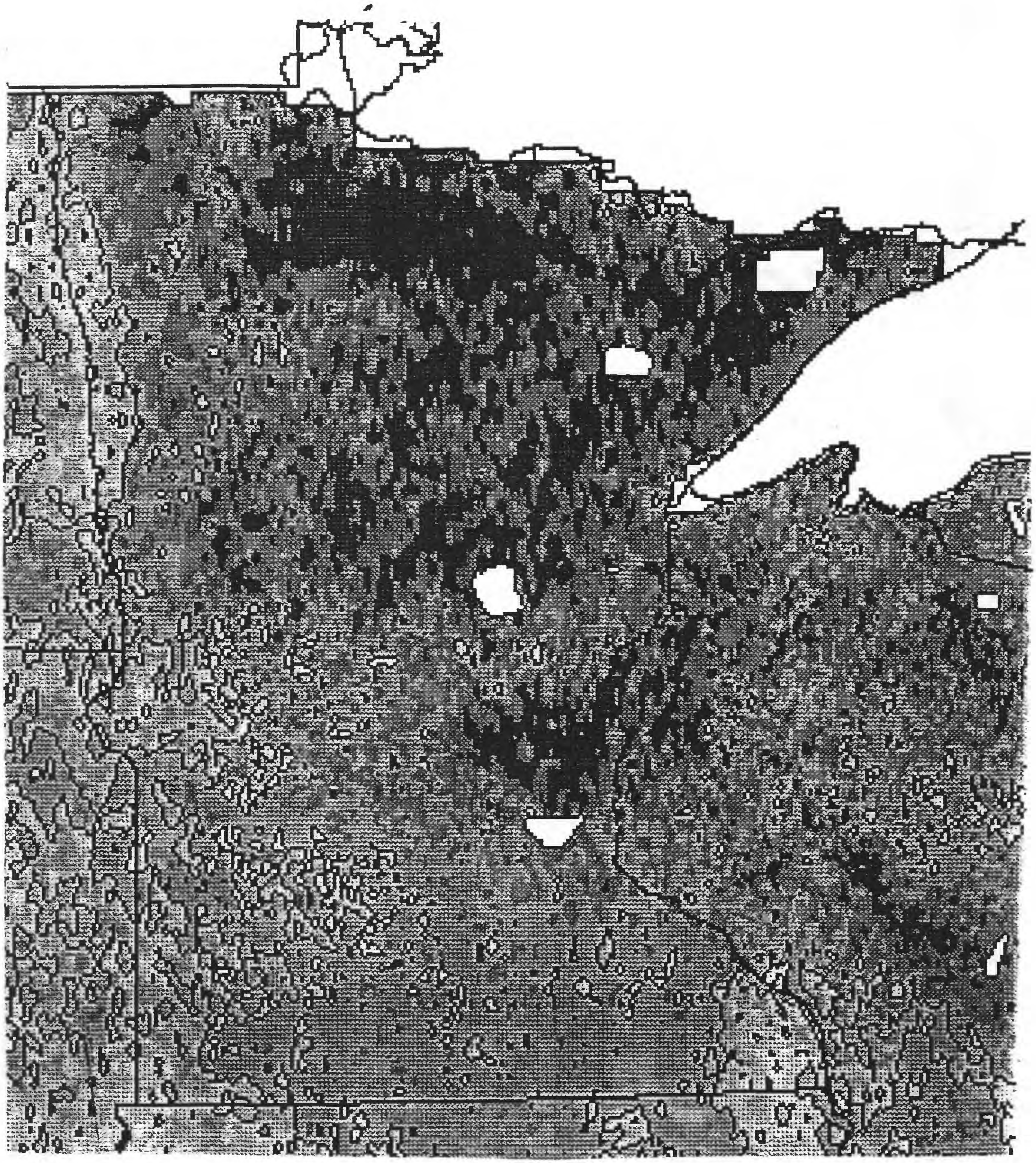


Figure 11. Aerial radiometric map of Minnesota (after Duval and others, 1989). Contour lines at 1.5 and 2.5 ppm equivalent uranium (eU). Pixels shaded from 0 to 6.0 ppm eU at 0.5 ppm eU increments; darker pixels have lower eU values; white indicates no data.

periods can create secondary permeability and allow convective radon transport to occur. This could be an important factor associated with elevated radon levels in areas of clay-rich glacial deposits.

Glacial lake deposits are likely to generate elevated indoor radon levels. Clays and silts of Lake Agassiz, in the Red River Valley, are known to generate elevated radon in homes and in soil gas in Manitoba (Grasty, 1989) and North Dakota (Schumann and others, 1991). Clay-rich glacial deposits of the Des Moines lobe have a high radon potential where they contain fragments of Cretaceous shale as major constituents. Des Moines lobe deposits cover most of southern Minnesota, although the shale content decreases eastward. Areas underlain by deposits of the St. Louis sublobe of the Des Moines lobe in north-central Minnesota, tills of the Superior and Rainy lobes in northeastern Minnesota, and by mafic crystalline bedrock in northern Minnesota have moderate radon potential because of the overall lower uranium content of the mafic source rocks. Deposits derived from felsic source rocks may have locally higher U contents. In either case, however, the sandy tills derived from these rocks have higher permeability than the clayey glacial deposits in western and southern Minnesota (suggested by limited measurements of soil-gas radon and soil permeability by Schumann and others, 1991), allowing building foundations to draw on a relatively large soil source volume, producing moderately elevated (generally 2-10 pCi/L) indoor radon levels (fig. 10).

Areas underlain by Wadena lobe deposits in the central part of the State have high geologic radon potential. These deposits are derived from carbonate rocks, shale, sandstone, and granitic rocks and have low to locally elevated uranium contents and moderate to high soil permeability. The higher radon potential of Wadena lobe deposits compared to other glacial deposits in northeastern Minnesota may be due to a slightly different bedrock source for the Wadena lobe deposits or to mixing with Des Moines lobe deposits. Areas of limestone bedrock, thin glacial cover, pre-Wisconsinan glacial deposits, and Wisconsinan loess in the southeast and southwest corners of Minnesota also have high radon potential. These areas are underlain by Sioux Quartzite in the southwest and Ordovician carbonates in the southeast, both of which may contain localized concentrations of uranium (see the uranium section of this chapter).

Elevated radon in ground water may be a source of indoor radon for some homes obtaining their water from domestic wells. The Minnesota Geological Survey tested radon concentrations in 1,975 private water wells from seven areas in the State in which geologic factors were thought to be favorable for uranium accumulation (Lively and Southwick, 1981). Of these samples, about 90 percent contained less than 2000 pCi/L radon, about 10 percent contained 2000-10,000 pCi/L, and about one percent exceeded 10,000 pCi/L. The highest radon level of the wells tested in the study was 26,000 pCi/L in east-central Minnesota (Lively and Southwick, 1981). In general, most of the water samples with elevated radon levels were obtained from wells finished in bedrock in east-central Minnesota (primarily in Carlton, Pine, Aitkin, and Kanabec Counties). About 100 of the wells tested in this area (11 percent) had radon levels in excess of 2000 pCi/L, and of these, more than 90 percent were finished in bedrock. Seventeen percent of the wells tested in the Sanborn-Jeffers test area, in Brown and Cottonwood Counties, also had radon levels greater than 2000 pCi/L (Lively and Southwick, 1981). In the remaining 5 test areas, fewer than 5 percent of the wells within in each area had radon concentrations exceeding 2000 pCi/L.

SUMMARY

For this assessment, Minnesota was divided into six geologic radon potential areas (fig. 12) and each area assigned Radon Index (RI) and Confidence Index (CI) rankings (Table 2). Area GLA (Glacial Lake Agassiz) has a high radon potential (RI=15) with high confidence (CI=10). Area WL (deposits of the Wadena lobe in central Minnesota) has a high (RI=14) radon potential with high confidence (CI=10). Area DML (deposits of the Des Moines lobe in southern Minnesota, which also includes some Wadena lobe and glacial lake deposits) has a high radon potential (RI=14) with high confidence (CI=10). Two Geologic Field Evidence (GFE) points were added to the scores for areas GLA, WL, and DML in light of reports of field studies showing that significant levels of soil-gas radon are generated in these areas (Lively and others, 1991; Schumann and others, 1991). Area PW (pre-Wisconsinan glacial deposits, which also includes outcrops of Sioux Quartzite in southwestern Minnesota, Ordovician carbonate bedrock in the southeastern part of the State, and loess in both areas) has a high radon potential (RI=12) and a moderate confidence index (CI=9). Area GDV (glacial deposits derived primarily from volcanic rocks) is underlain by metavolcanic bedrock and deposits of the Superior and Rainy lobes in northeastern Minnesota, and by a relatively small area of Des Moines lobe deposits (mainly deposits of the Grantsburg sublobe) in east-central Minnesota (compare figures 12 and 7) which appear to have properties similar to surrounding Superior lobe deposits. Area GDV has a moderate radon potential (RI=10) with moderate confidence (CI=9). Area SLS (deposits of the St. Louis sublobe in northern Minnesota) has a moderate radon potential (RI=10) with a moderate confidence index (CI=7). The confidence index rating of 1 for the indoor radon data is due to the scarcity of indoor radon data in this area.

This is a generalized assessment of the State's geologic radon potential and there is no substitute for having a home tested. The conclusions about radon potential presented in this report cannot be applied to individual homes or building sites. Indoor radon levels, both high and low, can be quite localized, and within any radon potential area there will likely be areas with higher or lower radon potential that assigned to the area as a whole. Any local decisions about radon should not be made without consulting all available local data. 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 2. Radon Index (RI) and Confidence Index (CI) scores for geologic radon potential areas of Minnesota. See figure 12 for locations and abbreviations of areas.

AREA

| | GLA | | WL | | DML | |
|---|---|---|---|---|---|---|
| FACTOR | RI | CI | RI | CI | RI | CI |
| INDOOR RADON | 3 | 3 | 3 | 3 | 3 | 3 |
| RADIOACTIVITY | 3 | 2 | 1 | 2 | 1 | 2 |
| GEOLOGY | 3 | 3 | 3 | 3 | 3 | 3 |
| SOIL PERM. | 1 | 2 | 2 | 2 | 2 | 2 |
| ARCHITECTURE | 3 | -- | 3 | -- | 3 | -- |
| GFE POINTS | +2 | -- | +2 | -- | +2 | -- |
| TOTAL | 15 | 10 | 14 | 10 | 14 | 10 |
| RANKING | HIGH | HIGH | HIGH | HIGH | HIGH | HIGH |

| | PW | | GDV | | SLS | |
|---|---|---|---|---|---|---|
| FACTOR | RI | CI | RI | CI | RI | CI |
| INDOOR RADON | 3 | 3 | 2 | 3 | 2 | 1 |
| RADIOACTIVITY | 2 | 2 | 1 | 2 | 1 | 2 |
| GEOLOGY | 2 | 2 | 2 | 2 | 2 | 2 |
| SOIL PERM. | 2 | 2 | 2 | 2 | 2 | 2 |
| ARCHITECTURE | 3 | -- | 3 | -- | 3 | -- |
| GFE POINTS | 0 | -- | 0 | -- | 0 | -- |
| TOTAL | 12 | 9 | 10 | 9 | 10 | 7 |
| RANKING | HIGH | MOD | MOD | MOD | MOD | 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

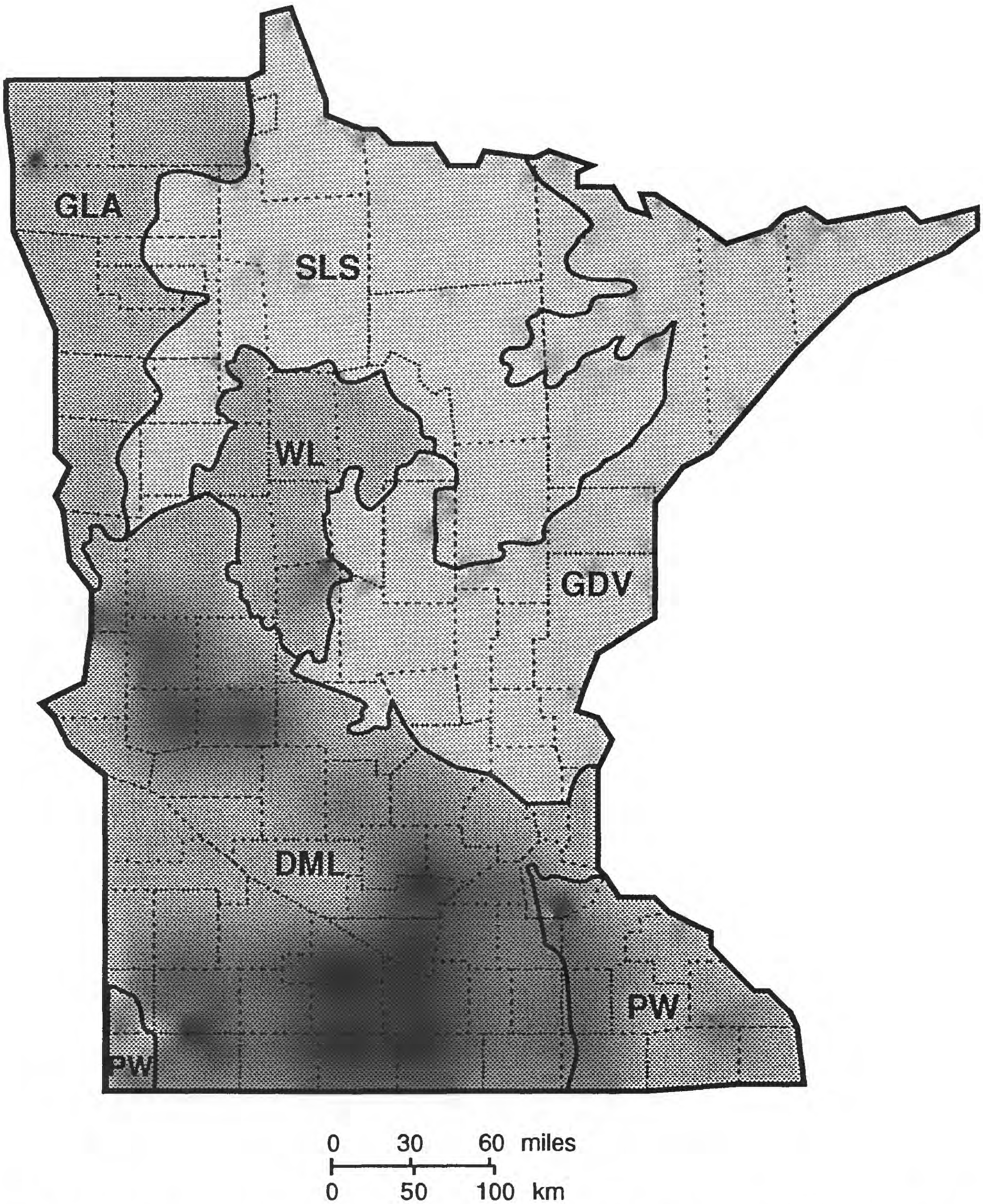



Figure 12. Geologic radon potential areas of Minnesota. GLA, glacial Lake Agassiz; SLS, deposits of the St. Louis sublobe of Des Moines lobe; GDV, glacial deposits derived primarily from volcanic rocks; WL, deposits of the Wadena lobe; DML, deposits of the Des Moines lobe; PW, pre-Wisconsinan deposits (includes Wisconsinan loess and older bedrock). Dark shading indicates high radon potential; lighter shading indicates moderate or variable radon potential. See Table 2 for radon index and confidence index rankings.

## REFERENCES USED IN THIS REPORT AND GENERAL REFERENCES PERTAINING TO RADON IN MINNESOTA


Adams, J.A.S., 1972, Emanation characteristics of rocks, soils and Rn-222 loss effect on the U-Pb system discordance, *in* Development of Remote Methods for Obtaining Soil Information and Location of Construction Materials Using Gamma Ray Signatures for Project THEMIS: Rice Univ., Dep. Geol., Annual Report, U.S. Army Eng. Waterways Experiment. Station, p. 1-157.

Belthuis, Lyda, 1966, Minnesota in Maps: Duluth, University of Minnesota, 78 p.

Duval, J.S., Jones, W.J., Riggle, F.R., and Pitkin, J.A., 1989, Equivalent uranium map of the conterminous United States: U.S. Geological Survey Open-File Report 89-478, 10 p.

Grasty, R.L., 1989, The relationship of geology and gamma-ray spectrometry to radon in homes: EOS, v. 70, p. 496.

Hobbs, H.C., and Goebel, J.E., 1982, Quaternary geologic map of Minnesota: Minnesota Geological Survey Map S-1, scale 1:500,000.

Jenny, H., 1935, The clay content of the soil as related to climatic factors, particularly temperature: Soil Science, v. 40, p. 111-128.

Kanivetsky, Roman, 1979, Hydrogeologic Map of Minnesota: Quaternary Hydrogeology: Minnesota Geological Survey Map S-3, scale 1:500,000.

Keighin, C.W., Morey, G.B., and Goldich, S.S., 1972, East-central Minnesota, *in* Sims, P.K., and Morey, G.B. (eds), Geology of Minnesota: A centennial volume: St. Paul, MN, Minnesota Geological Survey, p. 240-255.

Lively, R.S. and Morey, G.B., 1980, Hydrogeochemical distribution of uranium and radon in east-central Minnesota: Eos, Transactions, American Geophysical Union, v. 61, p. 1192 .

Lively, R.S. and Morey, G.B., 1982 , Hydrogeochemical distribution of uranium and radon in east-central Minnesota, *in* Perry, E. C., Jr., and Montgomery, C. W. (eds), Isotope studies of hydrologic processes; selected papers from a symposium: De Kalb, IL, Northern Illinois University Press, p. 91-107.

Lively, R.S. and Southwick, D.L., 1981, Radon activity in ground waters of seven test areas in Minnesota: Minnesota Geological Survey Report of Investigations 25, 60 p.

Lively, Richard, Steck, Daniel, and Brasaemle, Bruce, 1991, A site study of soil characteristics and soil gas radon in Rochester, Minnesota: Center for Urban and Regional Affairs report CURA 91-2, 15 p.

Morey, G.B., 1976, Geologic map of Minnesota, bedrock geology: Minnesota Geological Survey Miscellaneous Map Series Map M-24, scale 1:3,168,000.

Morey, G.B., 1981, Geologic terranes of Minnesota and their uranium potential: Minnesota Geological Survey Information Circular 19, 40 p.

Morey, G.B., 1982, Geologic map of Minnesota, bedrock outcrops: Minnesota Geological Survey State Map Series Map S-10, scale 1:3,168,000.

Morey, G.B., and Lively, R.S., 1980, Detailed geochemical survey for east-central Minnesota, geology and geochemistry of selected uranium targets: U.S. Department of Energy Open-File Report GJBX-60(80) [K/UR-32], 178 p.

Ojakangas, R.W., and Matsch, C.L. ,1982, Minnesota's geology: Minneapolis, Minn., University of Minnesota Press, 255 p.

Schumann, R.R., Peake, R.T., Schmidt, K.M., and Owen, D.E., 1991, Correlations of soil-gas and indoor radon with geology in glacially derived soils of the northern Great Plains, *in* Proceedings of the 1990 International Symposium on Radon and Radon Reduction Technology, Volume 2, Symposium Oral Papers: U.S. Environmental Protection Agency report EPA/600/9-91/026b, p. 6-23--6-36.

Schwartz, G.M., and Thiel, G.A., 1963, Minnesota's rocks and waters: Minnesota Geological Survey Bulletin 37, 366 p.

Setterholm, D.R., 1990, Geologic maps of the Late Cretaceous rocks, southwestern Minnesota: Minnesota Geological Survey Miscellaneous Map Series Map M-69, scale 1:750,000.

Sims, P.K., 1970, Geologic map of Minnesota: Bedrock geology: Minnesota Geological Survey Miscellaneous Map M-14, scale 1:1,000,000.

Sims, P.K., and Morey,. G.B., 1972, Résumé of geology of Minnesota, *in* Sims, P.K., and Morey, G.B. (eds), Geology of Minnesota: A centennial volume: St. Paul, Minn., Minnesota Geological Survey, p. 3-17.

Southwick, D.L. and Lively, R.S., 1984, Hydrogeochemical anomalies associated with the basal contact of the Sioux Quartzite along the north margin of the Cottonwood County basin, *in* D.L. Southwick (ed), Shorter contributions to the geology of the Sioux Quartzite (early Proterozoic), southwestern Minnesota: Minnesota Geological Survey Report of Investigations 32, p. 45-58.

Southwick, D.L., Morey, G.B., and Mossler, J.H., 1986, Fluvial origin of the lower Proterozoic Sioux Quartzite, southwestern Minnesota: Geological Society of America Bulletin, v. 97, p. 1432-1441.

Steck, D.J., 1987 , Geological variation of radon sources and indoor radon concentrations along the southwestern edge of the Canadian Shield: Health Physics, v. 52, p. S40.

Steck, D.J., 1988 , Geological variation of radon sources and indoor radon along the southwestern edge of the Canadian Shield, *in* M.A. Marikos and R.H. Hansman (ed), Geologic causes of natural radionuclide anomalies: Proceedings of GEORAD conference St. Louis, MO, United States Apr. 21-22, 1987, Missouri Department of Natural Resources Special Publication 4, p. 17-23.

U.S. Department of Agriculture, Soil Conservation Service, 1987, Soils: U.S. Geological Survey National Atlas sheet 38077-BE-NA-07M-00, scale 1:7,500,000.

Wright, H.E., Jr., 1972a, Physiography of Minnesota, in Sims, P.K., and Morey, G.B. (eds), Geology of Minnesota: A centennial volume: St. Paul, Minn., Minnesota Geological Survey, p. 561-578.

Wright, H.E., Jr., 1972b, Quaternary history of Minnesota, *in* Sims, P.K., and Morey, G.B. (eds), Geology of Minnesota: A centennial volume: St. Paul, Minn., Minnesota Geological Survey, p. 515-547.

Wright, H.E., Jr., and Ruhe, R.V., 1965, Glaciation of Minnesota and Iowa, *in* Wright, H.E., Jr., and Frey, D.G. (eds.), The Quaternary of the United States: Princeton, NJ, Princeton University Press, p. 29-41.

# PRELIMINARY GEOLOGIC RADON POTENTIAL ASSESSMENT OF OHIO

*by*
*Douglass E. Owen*
*U.S. Geological Survey*

## INTRODUCTION

Ohio is one of the Great Lakes States and is located south of Lake Erie. Ohio is highly industrialized, but also has significant agricultural activity. The State is subdivided into 88 counties (fig. 1). The population distribution by county is shown on figure 2. All 88 counties in Ohio have more than 10,000 residents, 20 counties have between 100,000 and 500,000 residents, and 5 counties have more than 500,000 residents.

This is a generalized assessment of geologic radon potential of rocks, soils, and surficial deposits of Ohio. 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.

## GEOGRAPHIC SETTING OF OHIO

Approximately the eastern third of Ohio is part of the Allegheny Plateau. The remainder of the State is part of the Interior Lowlands physiographic province (fig. 3). The Allegheny Plateau, which is drained by the Ohio River, is much more dissected than the Interior Lowlands. The Allegheny Plateau is subdivided into two physiographic sections, the unglaciated plateau and the glaciated plateau (fig. 4). Valleys in the unglaciated section tend to be deeper and steeper sided than in the glaciated section. The Interior Lowlands are subdivided into three physiographic sections–the Till Plains, the Lake Plains, and the Lexington Plain (fig. 4). The Till Plains formed during the glaciation of the Pleistocene Epoch and are either flat or gently undulating. The undulations are due either to variations in the underlying bedrock or to other glacial deposits such as moraines, kames, and eskers. Water trapped between the retreating ice of the last continental ice sheet and the glacial deposits of west-central Ohio produced lakes. The Lake Plains resulted when these lakes drained, exposing the flat lake bottoms. The Lexington Plain is unglaciated and was formed by stream erosion of limestone bedrock. The areas between stream dissections in the Lexington Plain are flat-topped and also contain a large number of sinkholes.


**Fig. 1. Counties**

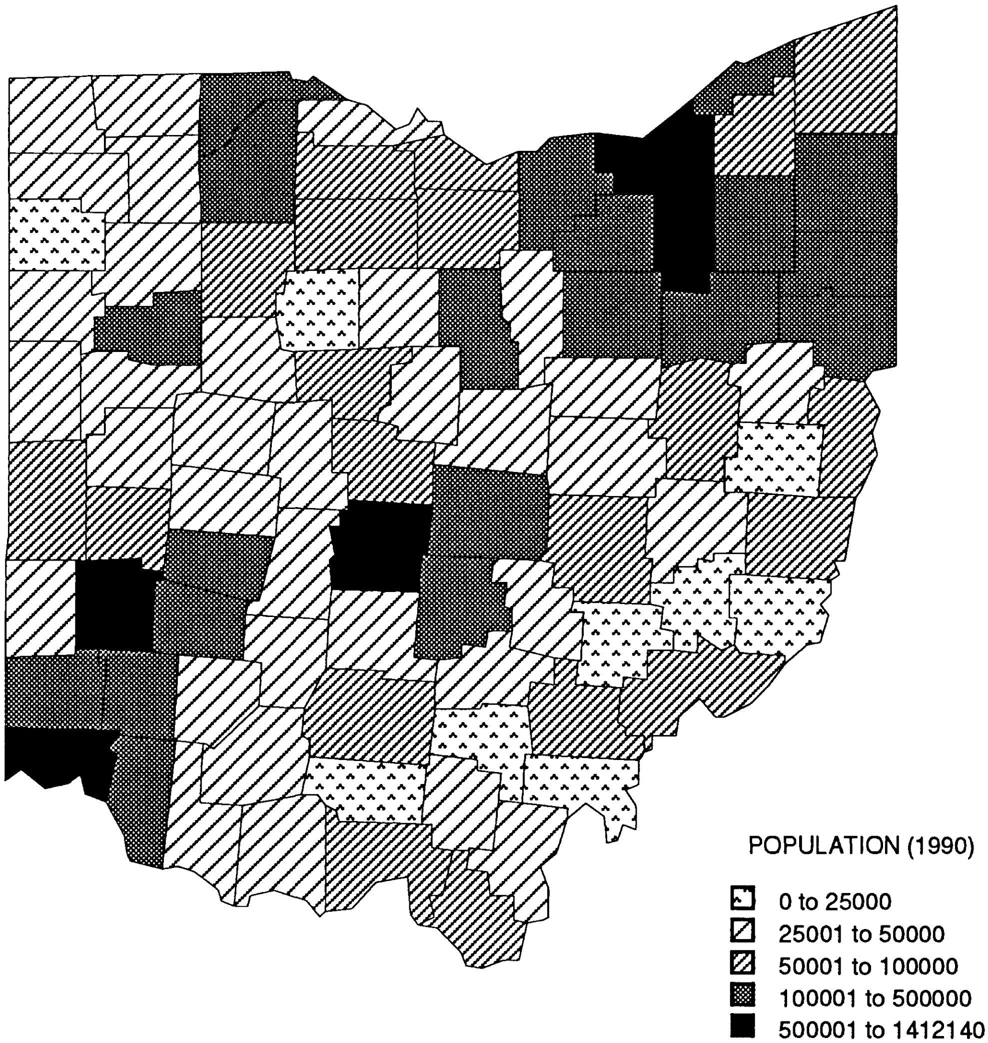
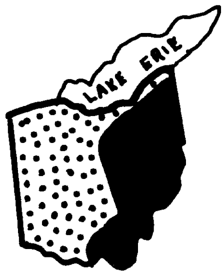



Figure 2. Population of counties in Ohio (1990 U.S. Census data).

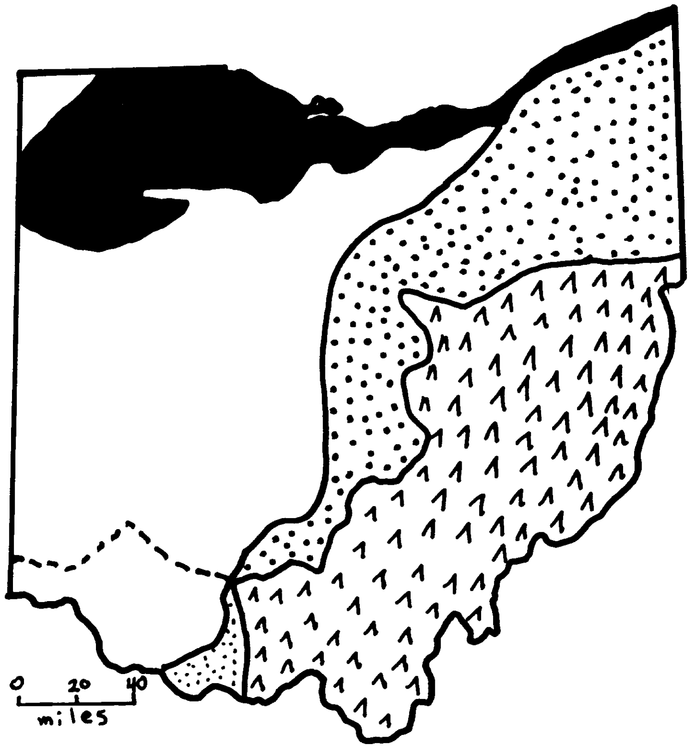



Interior Lowlands

Allegheny Plateau

(modified from Wright, 1953)

Fig. 3. Physical Setting




(modified from Noble and Korsok, 1975)

Till Plains (Southern limit of Wisconsinan glaciation)

Lake Plains

Glaciated Plateau

Lexington Plain

Unglaciated Plateau

Fig. 4. Physiographic Sections

## GEOLOGIC SETTING OF OHIO

The bedrock in Ohio ranges in age from Ordovician to Permian. (Note--a Geologic Time Scale is presented in the appendix to the introduction.) Only rocks of sedimentary origin crop out in Ohio; however, igneous and metamorphic material is present in the deposits left behind by the continental glaciers. In general, rocks become younger from west to east in Ohio (fig. 5). A generalized section of rocks of Ohio, listing formation names, member names, and other geologic information for each of the geologic time periods can be found in Stout (1947). The stratigraphy of western Ohio is dominated by carbonate rocks, and numerous thin limestones are present in eastern Ohio along with shales, sandstones, and coals (fig. 6). The abundance of carbonates is also reflected in the soils. Devonian shales crop out in a north-south band in the center of the State and along Lake Erie (fig. 5).

About two-thirds of Ohio was glaciated during the Pleistocene Epoch. Deposits left behind by three of the four major glacial advances have been identified in Ohio. The oldest, pre-Illinoian (formerly called Kansan), is of limited extent and is only found in the southwest corner of the State. The next oldest, Illinoian, is exposed in a band just below the furthest advance of the youngest glacial deposits, the Wisconsinan (fig. 7). Wisconsinan lake deposits, kames and eskers, ground moraine, and end moraines are shown on figure 7.

## SOILS

The soil regions found in Ohio are shown on figure 8 and the drainage characteristics of the soils are shown on figure 9. Drainage characteristics give an indication of the soil permeability, which influences radon migration. Because the amount of moisture available to soils affects both emanation and transport of radon, a map showing annual precipitation has been included (fig. 10).

## INDOOR RADON DATA

Figure 11 presents screening indoor radon data from the State/EPA Residential Radon Survey graphically, and Table 1 presents the data from which figure 11 was derived, including data from those counties with less than 5 measurements (which are not shown on figure 11). Figure 1 shows the Ohio counties and can be used in conjunction with the indoor radon maps shown in figure 11. Forty-two of the counties in Ohio had average radon concentrations greater than 4 pCi/L (fig. 11 & Table 1). Five counties had greater than 60 percent of the homes with radon concentrations greater than 4 pCi/L (fig. 11, Table 1). Twenty-five counties had between 40 and 60 percent of the homes with radon concentrations greater than 4 pCi/L (fig. 11, Table 1).

In general, counties with average radon concentrations greater than 4 pCi/L seem to be associated with the north-south trending Ohio Shale outcrop band that has been redistributed by glaciers, with limestone glacial soils, and with some residual limestone soils (figs. 5, 7, 8, 11). In a study of Franklin County (located over the N-S outcrop band of Ohio Shale), Grafton (1990) found that 92 percent of the homes in a random survey using screening indoor radon measurements had indoor radon concentrations greater than 4 pCi/L. The counties around the precipitation high in the northeastern corner of the State (fig. 10) in general have a low percentage of homes with radon concentrations exceeding 4 pCi/L. This may partially be due to inhibited radon transport caused by the precipitation.

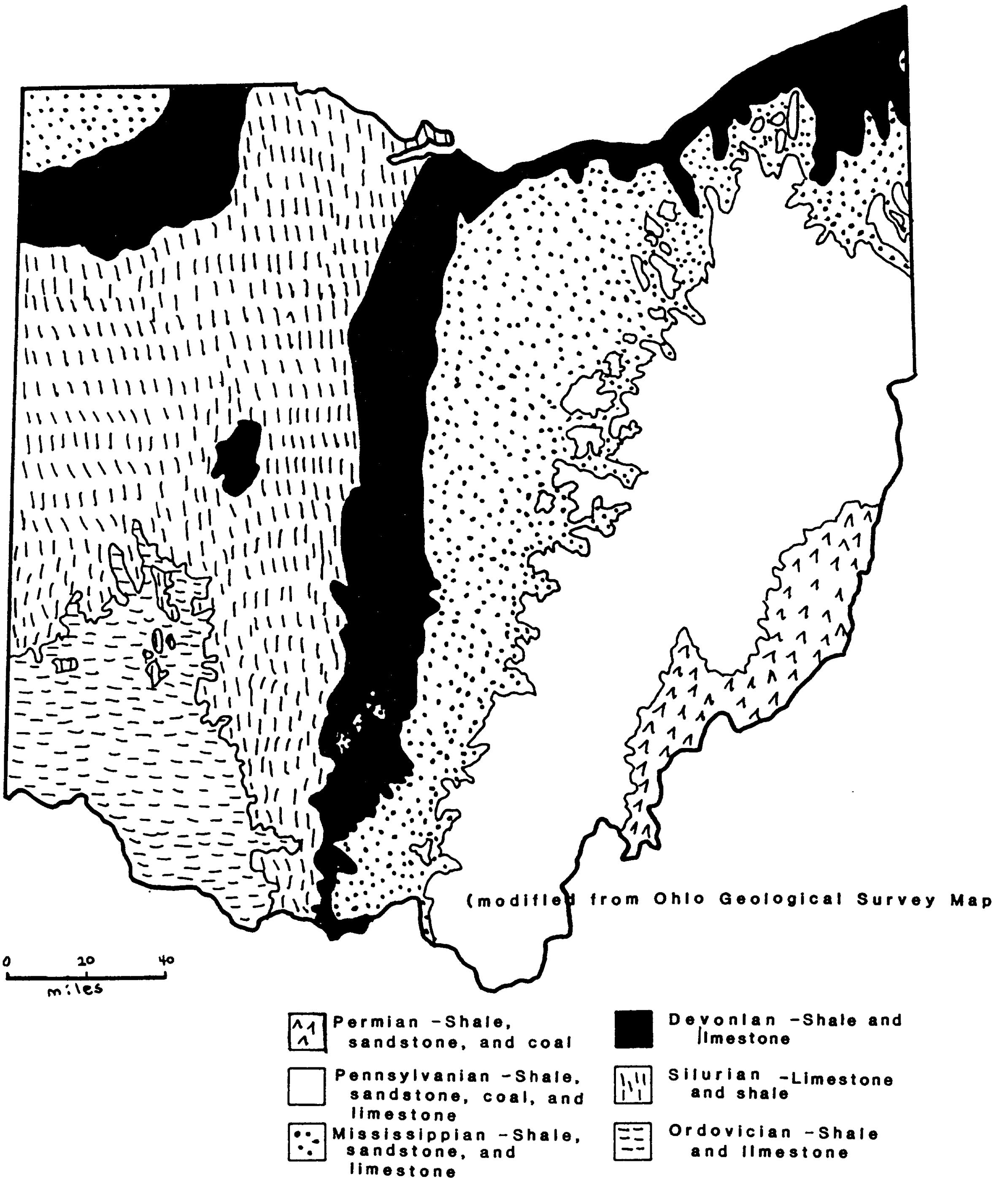
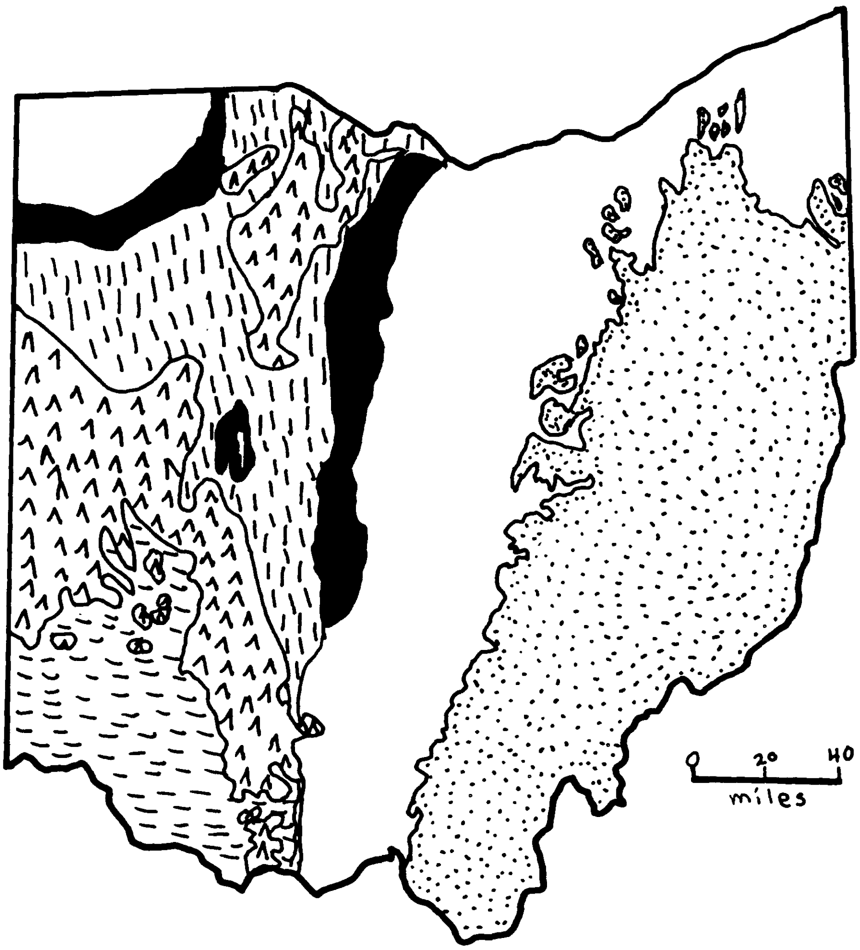



Fig. 5. Geologic Map




(modified from Wright, 1953)

Numerous thin undifferentiated limestones

Deleware and Columbus Limestones

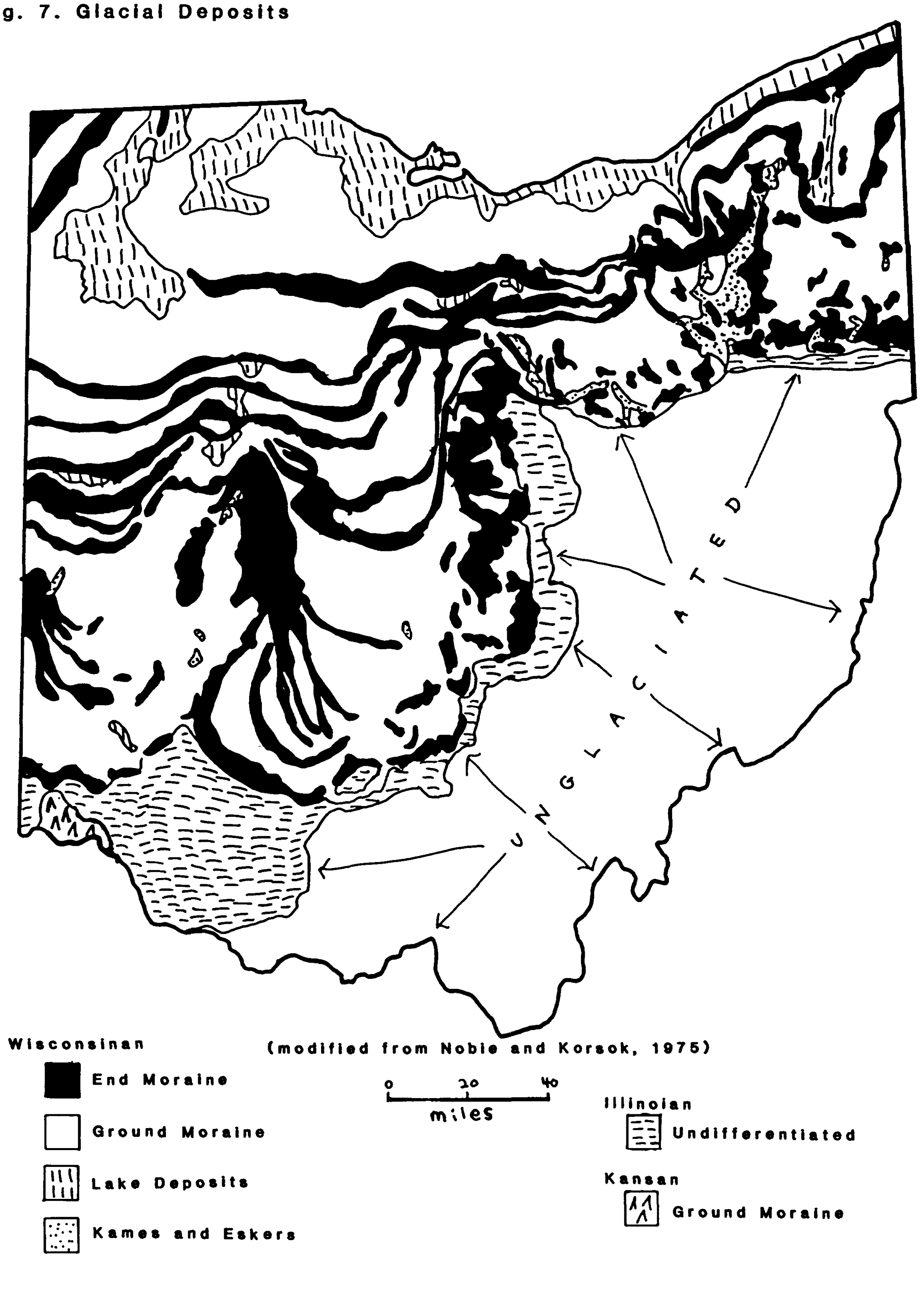
Bass Island and Detroit River Groups (dolomites)

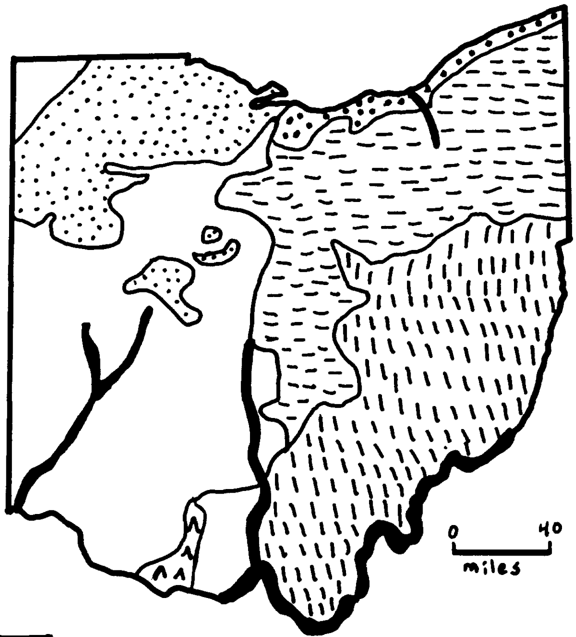
Niagra Group (dolomite)

Richmond, Maysville and Eden Groups (limestones and shales)

Fig. 6. Limestone and Dolomite Resources

Fig. 7. Glacial Deposits






Bottom, terrace, and outwash soils

Glacial limestone soils

Glacial and lacustrine soils over limestone

Glacial sandstone and shale soils

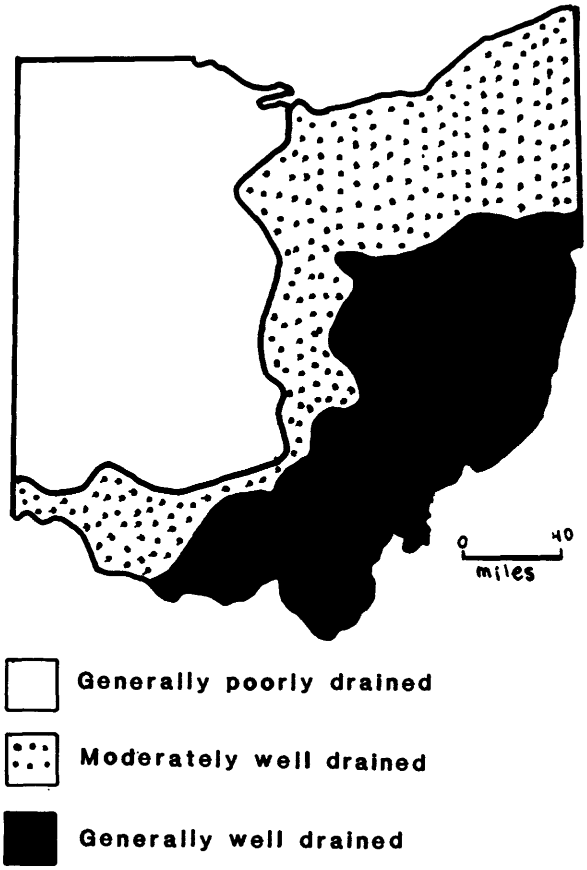
Lacustrine sandstone and shale soils

Residual limestone soils

Residual sandstone and shale soils

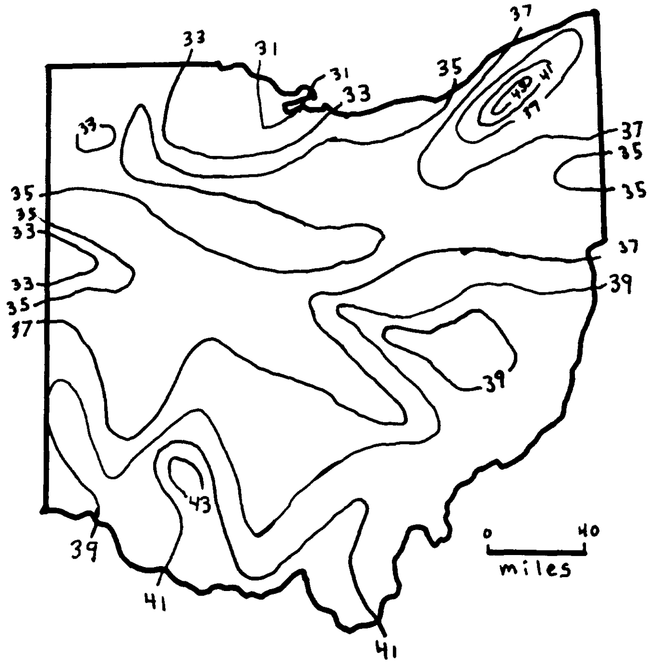
(modified from Noble and Korsok, 1975)

Fig. 8. Soils




(modified from Noble and Korsok, 1975)

**Fig. 9. Soil Drainage Characteristics**




(modified from Noble and Korsok, 1975)

Fig. 10. Mean Annual Precipitation (inches)

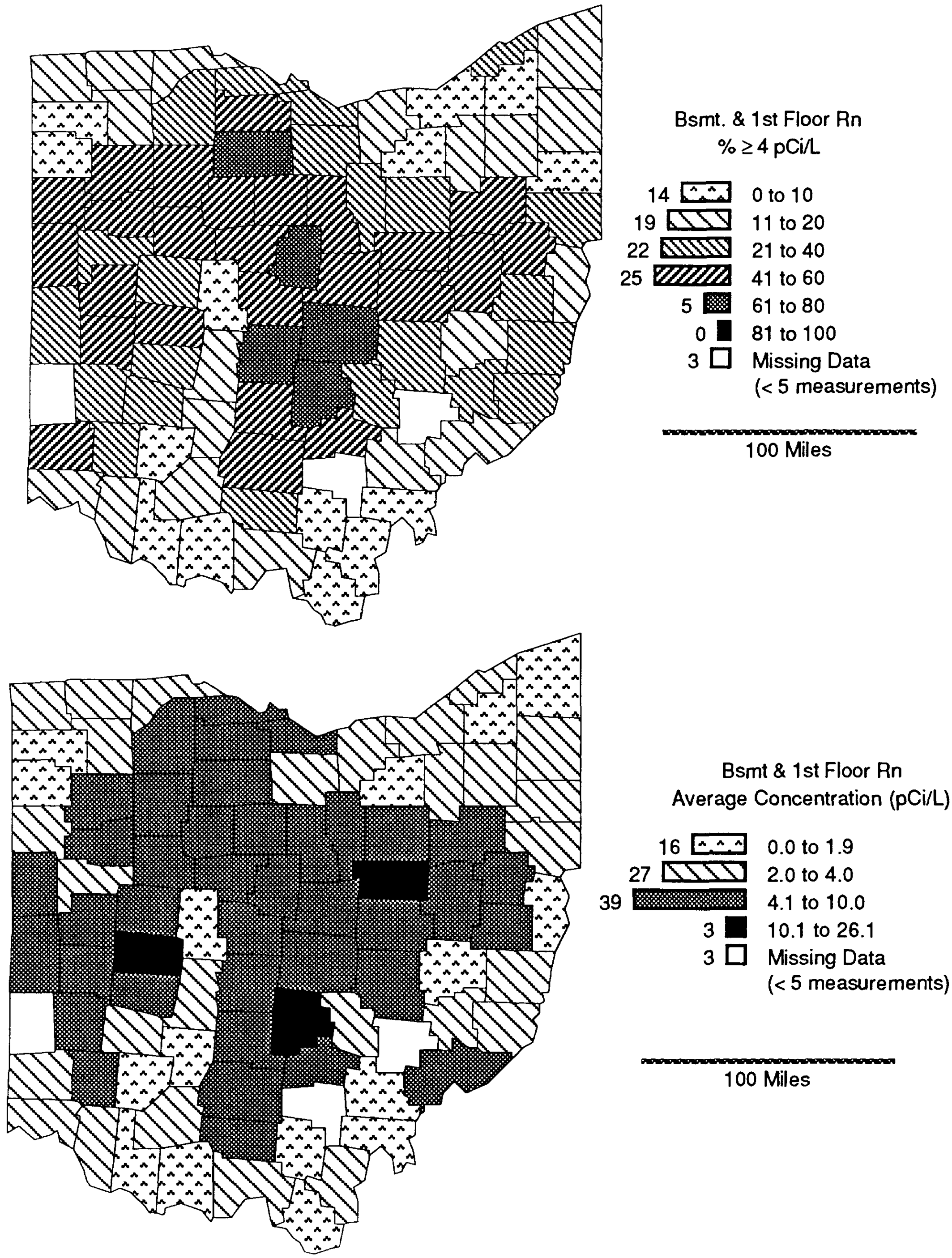



Figure 11. Screening indoor radon data from the EPA/State Residential Radon Survey of Ohio, 1988-89, for counties with 5 or more measurements. Data are from 2-7 day charcoal canister tests. Histograms in map legends show the number of counties in each category. The number of samples in each county (see Table 1) may not be sufficient to statistically characterize the radon levels of the counties, but they do suggest general trends. Unequal category intervals were chosen to provide reference to decision and action levels.

TABLE 1. Screening indoor radon data from the EPA/State Residential Radon Survey of Ohio conducted during 1988-89. Data represent 2-7 day charcoal canister measurements from the lowest level of each home tested.

| COUNTY | NO. OF MEAS. | MEAN | GEOM. MEAN | MEDIAN | STD. DEV. | MAXIMUM | %>4 pCi/L | %>20 pCi/L |
|---|---|---|---|---|---|---|---|---|
| ADAMS | 10 | 1.9 | 1.1 | 2.1 | 1.5 | 4.8 | 10 | 0 |
| ALLEN | 28 | 7.2 | 3.6 | 3.9 | 12.9 | 62.6 | 50 | 7 |
| ASHLAND | 20 | 6.0 | 3.4 | 2.7 | 8.8 | 36.6 | 30 | 10 |
| ASHTABULA | 15 | 1.9 | 1.2 | 0.9 | 2.2 | 7.5 | 13 | 0 |
| ATHENS | 14 | 1.9 | 1.0 | 1.2 | 2.0 | 6.4 | 14 | 0 |
| AUGLAIZE | 10 | 2.8 | 1.5 | 1.6 | 2.6 | 7.9 | 30 | 0 |
| BELMONT | 12 | 3.3 | 2.3 | 2.2 | 2.9 | 10.1 | 33 | 0 |
| BROWN | 5 | 1.2 | 0.9 | 1.1 | 0.8 | 2.1 | 0 | 0 |
| BUTLER | 33 | 4.0 | 2.6 | 3.0 | 3.6 | 14.9 | 42 | 0 |
| CARROLL | 7 | 8.6 | 4.7 | 3.5 | 10.2 | 27.7 | 43 | 14 |
| CHAMPAIGN | 12 | 26.1 | 3.2 | 4.3 | 75.4 | 265.2 | 50 | 8 |
| CLARK | 15 | 7.8 | 3.3 | 2.0 | 10.6 | 33.7 | 40 | 13 |
| CLERMONT | 12 | 2.6 | 1.2 | 1.5 | 3.1 | 10.7 | 17 | 0 |
| CLINTON | 9 | 1.6 | 1.1 | 2.1 | 1.2 | 3.4 | 0 | 0 |
| COLUMBIANA | 13 | 2.7 | 1.7 | 1.9 | 2.3 | 7.8 | 23 | 0 |
| COSHOCTON | 18 | 9.7 | 4.3 | 3.4 | 14.0 | 56.9 | 50 | 11 |
| CRAWFORD | 14 | 5.3 | 4.0 | 5.3 | 3.1 | 11.6 | 57 | 0 |
| CUYAHOGA | 120 | 2.0 | 1.0 | 1.1 | 6.8 | 74.5 | 4 | 1 |
| DARKE | 15 | 5.1 | 2.6 | 2.9 | 4.6 | 13.0 | 40 | 0 |
| DEFIANCE | 8 | 1.9 | 1.6 | 1.9 | 1.0 | 3.9 | 0 | 0 |
| DELAWARE | 20 | 6.2 | 4.1 | 5.6 | 5.5 | 21.7 | 55 | 5 |
| ERIE | 19 | 4.5 | 2.8 | 2.5 | 4.9 | 21.1 | 37 | 5 |
| FAIRFIELD | 31 | 19.9 | 6.1 | 8.1 | 45.0 | 238.5 | 61 | 26 |
| FAYETTE | 6 | 1.7 | 1.0 | 1.3 | 1.6 | 4.5 | 17 | 0 |
| FRANKLIN | 170 | 7.4 | 5.3 | 5.4 | 6.9 | 46.0 | 64 | 5 |
| FULTON | 6 | 2.5 | 1.9 | 2.3 | 1.6 | 4.8 | 17 | 0 |
| GALLIA | 11 | 2.2 | 1.4 | 1.2 | 2.5 | 9.2 | 9 | 0 |
| GEAUGA | 6 | 1.1 | 0.8 | 1.2 | 0.8 | 2.4 | 0 | 0 |
| GREENE | 25 | 4.0 | 2.5 | 2.7 | 3.5 | 11.1 | 40 | 0 |
| GUERNSEY | 13 | 1.8 | 1.2 | 1.4 | 1.6 | 4.9 | 15 | 0 |
| HAMILTON | 90 | 2.1 | 1.4 | 1.4 | 2.2 | 16.2 | 14 | 0 |
| HANCOCK | 15 | 5.6 | 3.6 | 3.0 | 5.4 | 16.1 | 47 | 0 |
| HARDIN | 17 | 6.0 | 3.2 | 3.7 | 6.7 | 26.2 | 41 | 6 |
| HARRISON | 7 | 4.5 | 3.5 | 2.7 | 3.8 | 10.1 | 29 | 0 |
| HENRY | 16 | 2.5 | 1.5 | 2.2 | 1.9 | 6.1 | 13 | 0 |
| HIGHLAND | 8 | 2.4 | 1.7 | 1.7 | 2.2 | 7.3 | 13 | 0 |
| HOCKING | 9 | 4.7 | 3.6 | 5.4 | 2.9 | 8.2 | 56 | 0 |
| HOLMES | 9 | 10.4 | 4.4 | 4.4 | 15.7 | 50.5 | 56 | 11 |
| HURON | 14 | 3.7 | 2.2 | 3.4 | 3.3 | 11.8 | 36 | 0 |
| JACKSON | 15 | 1.3 | 1.0 | 1.1 | 0.9 | 3.4 | 0 | 0 |
| JEFFERSON | 7 | 1.9 | 1.2 | 1.5 | 2.1 | 6.4 | 14 | 0 |

TABLE 1 (continued). Screening indoor radon data for Ohio.

| COUNTY | NO. OF MEAS. | MEAN | GEOM. MEAN | MEDIAN | STD. DEV. | MAXIMUM | %>4 pCi/L | %>20 pCi/L |
|---|---|---|---|---|---|---|---|---|
| KNOX | 14 | 7.2 | 4.5 | 5.2 | 7.4 | 28.8 | 57 | 7 |
| LAKE | 28 | 3.9 | 1.6 | 1.5 | 6.7 | 31.2 | 21 | 4 |
| LAWRENCE | 9 | 1.0 | 0.9 | 0.8 | 0.5 | 1.7 | 0 | 0 |
| LICKING | 29 | 8.0 | 5.1 | 5.3 | 6.8 | 28.9 | 72 | 7 |
| LOGAN | 19 | 5.4 | 2.5 | 2.4 | 6.8 | 24.1 | 37 | 5 |
| LORAIN | 21 | 2.7 | 1.4 | 1.4 | 4.0 | 17.1 | 19 | 0 |
| LUCAS | 71 | 2.6 | 1.8 | 1.8 | 2.9 | 15.8 | 17 | 0 |
| MADISON | 10 | 2.4 | 1.7 | 1.6 | 1.9 | 5.9 | 20 | 0 |
| MAHONING | 20 | 2.1 | 1.6 | 1.9 | 1.4 | 5.1 | 10 | 0 |
| MARION | 17 | 4.9 | 3.1 | 2.9 | 5.2 | 20.8 | 41 | 6 |
| MEDINA | 9 | 1.4 | 1.1 | 1.3 | 1.0 | 3.3 | 0 | 0 |
| MEIGS | 9 | 1.1 | 0.9 | 1.0 | 0.9 | 3.2 | 0 | 0 |
| MERCER | 12 | 5.6 | 2.4 | 3.0 | 9.9 | 36.5 | 42 | 8 |
| MIAMI | 22 | 8.3 | 4.9 | 5.4 | 10.3 | 46.8 | 55 | 9 |
| MONROE | 6 | 3.5 | 2.6 | 2.8 | 2.7 | 8.2 | 33 | 0 |
| MONTGOMERY | 67 | 4.3 | 2.5 | 2.5 | 6.8 | 46.8 | 28 | 3 |
| MORGAN | 2 | 9.2 | 1.0 | 9.2 | 12.9 | 18.3 | 50 | 0 |
| MORROW | 8 | 6.3 | 5.3 | 5.9 | 3.8 | 12.7 | 63 | 0 |
| MUSKINGUM | 24 | 4.6 | 3.1 | 2.9 | 4.6 | 19.4 | 38 | 0 |
| NOBLE | 6 | 3.2 | 3.0 | 2.9 | 1.3 | 4.8 | 33 | 0 |
| OTTAWA | 9 | 5.4 | 0.9 | 1.0 | 7.9 | 19.5 | 33 | 0 |
| PAULDING | 8 | 1.3 | 0.9 | 0.8 | 1.3 | 3.5 | 0 | 0 |
| PERRY | 12 | 3.8 | 1.9 | 1.8 | 5.3 | 18.8 | 25 | 0 |
| PICKAWAY | 7 | 4.5 | 3.3 | 4.6 | 3.2 | 8.2 | 57 | 0 |
| PIKE | 8 | 8.5 | 2.6 | 2.7 | 9.9 | 22.8 | 38 | 25 |
| PORTAGE | 6 | 4.1 | 2.0 | 1.8 | 6.3 | 16.8 | 17 | 0 |
| PREBLE | 4 | 4.1 | 3.1 | 2.7 | 3.6 | 9.3 | 25 | 0 |
| PUTNAM | 18 | 5.7 | 4.1 | 4.1 | 4.9 | 20.2 | 50 | 6 |
| RICHLAND | 29 | 5.4 | 3.5 | 2.7 | 6.6 | 32.7 | 41 | 3 |
| ROSS | 10 | 6.9 | 3.5 | 4.0 | 7.7 | 26.7 | 50 | 10 |
| SANDUSKY | 11 | 5.7 | 4.4 | 4.0 | 4.5 | 17.0 | 45 | 0 |
| SCIOTO | 13 | 2.5 | 1.7 | 1.5 | 2.5 | 9.5 | 15 | 0 |
| SENECA | 21 | 6.0 | 3.9 | 5.4 | 4.4 | 15.3 | 62 | 0 |
| SHELBY | 9 | 8.3 | 4.6 | 3.8 | 8.4 | 21.7 | 44 | 11 |
| STARK | 50 | 5.5 | 3.5 | 3.8 | 5.5 | 25.0 | 46 | 4 |
| SUMMIT | 60 | 3.2 | 2.0 | 2.1 | 4.0 | 22.7 | 20 | 3 |
| TRUMBULL | 34 | 2.2 | 1.5 | 1.6 | 2.0 | 7.9 | 12 | 0 |
| TUSCARAWAS | 13 | 6.5 | 3.4 | 3.5 | 7.5 | 26.2 | 46 | 8 |
| UNION | 6 | 1.5 | 0.9 | 1.6 | 1.1 | 2.9 | 0 | 0 |
| VAN WERT | 18 | 3.8 | 2.8 | 3.8 | 2.8 | 9.6 | 44 | 0 |
| VINTON | 2 | 2.2 | 2.1 | 2.2 | 0.4 | 2.4 | 0 | 0 |
| WARREN | 15 | 4.5 | 3.3 | 3.6 | 3.7 | 14.8 | 40 | 0 |
| WASHINGTON | 16 | 7.6 | 2.3 | 2.1 | 21.4 | 87.6 | 19 | 6 |

TABLE 1 (continued). Screening indoor radon data for Ohio.

| COUNTY | NO. OF MEAS. | MEAN | GEOM. MEAN | MEDIAN | STD. DEV. | MAXIMUM | %>4 pCi/L | %>20 pCi/L |
|---|---|---|---|---|---|---|---|---|
| WAYNE | 12 | 4.2 | 2.0 | 2.2 | 6.3 | 22.8 | 25 | 8 |
| WILLIAMS | 8 | 3.5 | 1.8 | 2.2 | 5.3 | 16.4 | 13 | 0 |
| WOOD | 18 | 4.9 | 2.8 | 2.5 | 6.5 | 27.3 | 28 | 6 |
| WYANDOT | 10 | 7.0 | 4.8 | 4.8 | 7.6 | 27.4 | 50 | 10 |

The American Lung Association of Ohio (address in Bibliography) tested a total of 1,148 homes in the State, of which 48.9 percent had less than 4 pCi/L, 27.4 percent had 4 to 10 pCi/L, 12.7 percent had 10 to 20 pCi/L, 5.4 percent had 20 to 100 pCi/L, and 5.7 percent had greater than 100 pCi/L indoor radon. Their data appears to compare reasonably well with the State/EPA data.

## GEOLOGIC RADON POTENTIAL

The first rock units to be investigated as potential source rocks of radon in Ohio were the organic-rich marine shales of the Devonian. The Upper Devonian Ohio Shale averages 30 ppm uranium and is the largest source of uranium in Ohio (Belisto and others, 1988). Stout (1947) divides the Ohio Shale into three members, in ascending order: the Huron, the Chagrin, and the Cleveland. Ghahremani (1981) found higher soil-gas radon concentrations associated with thicker portions of the Cleveland and Huron Members in northeast Ohio. Hume and others (1989) found radon levels as high as 3,000 pCi/L in ground water associated with the Huron Member in Erie, Huron, and Seneca counties. In northeastern Ohio, Ghahremani (1988) found a good correlation among the bedrock type (Cleveland or Huron Members of Ohio Shale), the amount of fracturing in the rock, and the migration of soil-gas radon to the surface and into structures.

Harrell and others (1991) found a strong positive correlation among uranium, indoor radon, and organic carbon content in the Ohio Shale. They discovered that radon escaping from the shale varies in direct proportion to the uranium content; the uranium content increases with the organic content, and because the organic carbon content of the shale increases from east to west, so does the radon emanating from the Ohio Shale. They predicted that high indoor radon values will be found along the north-south Ohio Shale outcrop. They further state that a thick layer of glacial material would serve to retard or act as a barrier to radon migration provided that the glacial material does not contain clasts of Ohio Shale. They also believe that large-scale advective transport is occurring because of the abundant vertical fractures in the Ohio Shale.

Limestones and dolomites generally do not contain much uranium (i.e. they are below the crustal average of 2.5 ppm [Carmichael, 1989]) unless they are rich in phosphate. However, Harrell and others (1991) found higher radon in basements over the phosphate-poor limestones and dolomites of the Columbus and Delaware Limestones (Middle Devonian) and the "Monroe Formation" [A name replaced by the Bass Islands (Upper Silurian) and Detroit River (Lower Devonian) Groups, fig. 6.] than they did in basements over the Ohio Shale in the same area. When carbonate rocks weather, the uranium and other metals that were widely dispersed in the rock can be concentrated in the iron-rich soils that form as a result of the weathering. This phenomenon may explain the higher radon values observed by Harrell and others (1991). Much of Ohio is underlain by limestones and dolomites (fig. 6) and approximately 2/3 of the soils present in Ohio are described as glacial limestone soils or as residual limestone soils (fig. 8). Because uranium may have been concentrated in these soils formed from carbonate rocks, they represent a potential radon source material.

Approximately two-thirds of Ohio is covered by glacial material (fig. 7). Smith and Mapes (1989) found that the permeability of the glacial sediment appears to be the most important physical attribute controlling surface radon concentrations, regardless of sediment thickness (see fig. 9 for estimates of soil permeabilities). They found that the influence of bedrock is twofold: (1) the rocks may be producing radon themselves, and (2) they may contribute radon-producing materials to glacial sediments derived from them. Smith and Mapes (1989) also found that, as a general rule, areas underlain by end moraines had the lowest indoor radon measurements and that areas

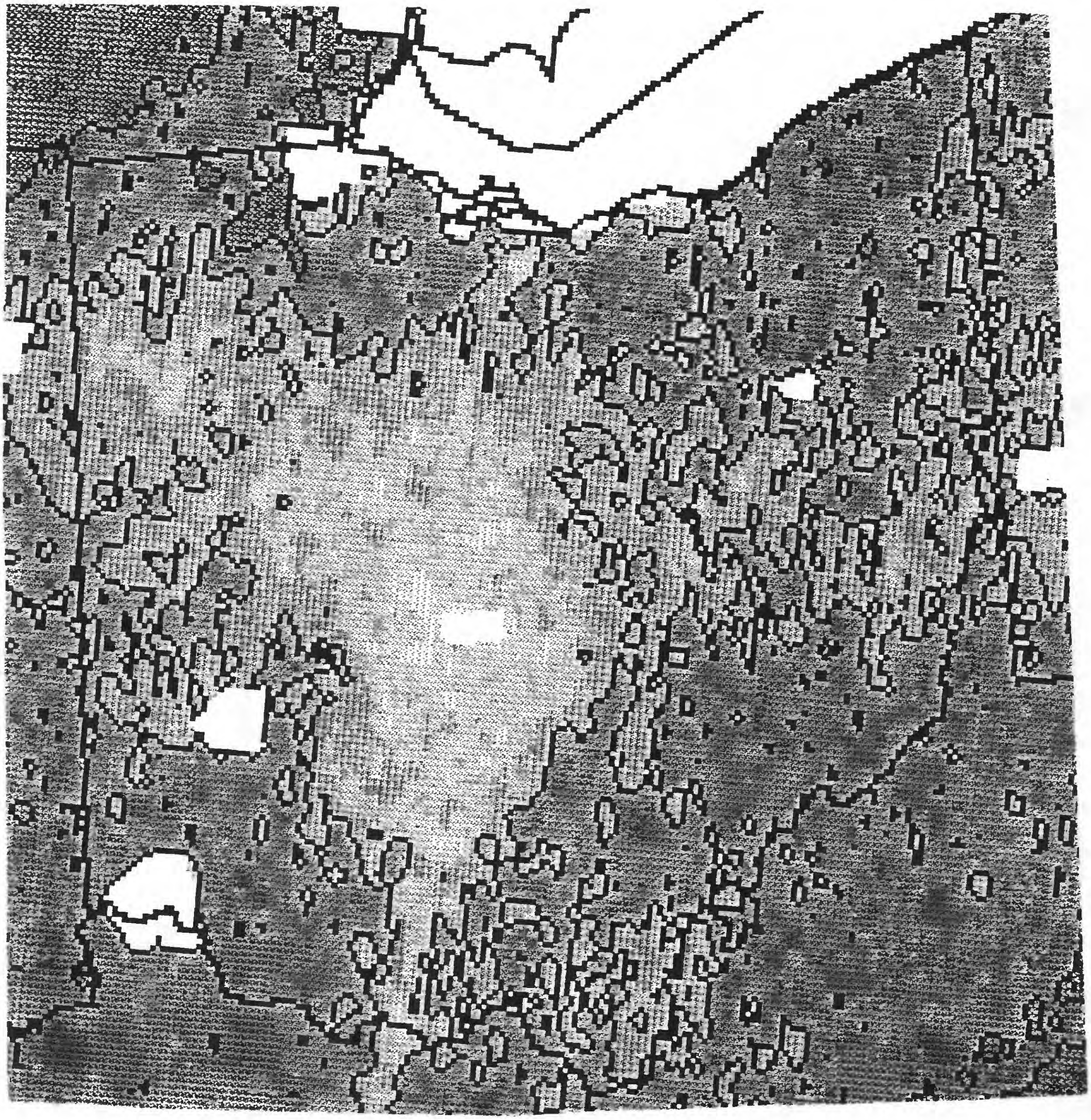


Figure 12. Aerial radiometric map of Ohio (after Duval and others, 1989). Contour lines at 1.5 and 2.5 ppm equivalent uranium (eU). Pixels shaded from 0 to 6.0 ppm eU at 0.5 ppm eU increments; darker pixels have lower eU values; white indicates no data.

underlain by glacial outwash and alluvium had the highest radon measurements (probably a permeability influence).

Figure 12 is an aerial radiometric map of Ohio produced from the NURE data (Duval and others, 1989). The north-south-trending Ohio Shale belt and several of the terminal moraines can be distinguished by their equivalent uranium (eU) signature on the map (see figs. 5, 7, and 12). A series of 1:500,000 aerial radiometric contour maps showing eU, eTh, and percent K are available for Ohio (Duval, 1985). A series of color aerial radiometric maps (scale of 1:1,000,000) are also available for Ohio (Duval, 1987). Overall, the radiometric map corresponds well with the geology.

## SUMMARY

Ohio has a moderate to high radon potential in general. Its radon potential has been summarized using the Radon Index (RI) Matrix and the Confidence Index (CI) Matrix, which are discussed and described in the introduction to this volume. Table 2 presents the Radon Index and Confidence Index scores for the generalized radon potential areas shown on figure 13.

Area 1 has a moderate radon potential (RI=11) and comprises those parts of both the glaciated and unglaciated plateau that in general have less than 2.5 ppm eU (fig. 12). The rocks in Area 1 are dominantly Mississippian through Permian in age and have a diversity of lithologies (i.e. shale, sandstone, coal, and limestone). Area 2 has a high radon potential (RI=12) and comprises those parts of the glaciated and unglaciated plateau that in general have more than 2.5 ppm eU (fig. 12). Area 3, the Till Plains of Wisconsinan age, has a high radon potential (RI=14). The bedrock in Area 3 is dominantly Ordovician through Devonian in age, with the exception of the northwestern corner of the State, where it is Mississippian. The lithology of these rocks is dominantly limestone and shale. Area 3 was given 2 GFE points for the known high radon potential of the Devonian shales and glacial limestone soils (Harrell and others, 1991). Area 4, the Lake Plains, has a moderate radon potential (RI=10) and has generally poorly drained clayey soils. Area 5, the Lexington Plain, has a high radon potential (RI=13). Area 5 has generally well-drained limestone and shale soil soils developed on Ordovician and Silurian-age bedrock. Area 6, the Pre-Wisconsinan Till Plains (i.e. Till Plains south of the southern limit of Wisconsinan glaciation on figure 4), has a moderate radon potential (RI=11). Area 6 in general has a lower eU than the Wisconsinan Till Plains to the north.

This is a generalized assessment of the State's geologic radon potential and there is no substitute for having a home tested. The conclusions about radon potential presented in this report cannot be applied to individual homes or building sites. Indoor radon levels, both high and low, can be quite localized, and within any radon potential area there will likely be areas with higher or lower radon potential that assigned to the area as a whole. Any local decisions about radon should not be made without consulting all available local data. 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 2. Radon Index (RI) and Confidence Index (CI) scores for generalized radon potential areas of Ohio shown on figure 13.

AREA

| | 1 | | 2 | | 3 | |
|---|---|---|---|---|---|---|
| FACTOR | RI | CI | RI | CI | RI | CI |
| INDOOR RADON | 2 | 3 | 2 | 3 | 2 | 3 |
| RADIOACTIVITY | 2 | 2 | 3 | 2 | 3 | 2 |
| GEOLOGY | 2 | 2 | 2 | 2 | 3 | 2 |
| SOIL PERM. | 2 | 2 | 2 | 2 | 1 | 2 |
| ARCHITECTURE | 3 | -- | 3 | -- | 3 | -- |
| GFE POINTS | 0 | -- | 0 | -- | +2 | -- |
| TOTAL | 11 | 9 | 12 | 9 | 14 | 9 |
| RANKING | MOD | MOD | HIGH | MOD | HIGH | MOD |

| | 4 | | 5 | | 6 | |
|---|---|---|---|---|---|---|
| FACTOR | RI | CI | RI | CI | RI | CI |
| INDOOR RADON | 2 | 3 | 2 | 3 | 2 | 3 |
| RADIOACTIVITY | 2 | 2 | 3 | 2 | 2 | 2 |
| GEOLOGY | 2 | 2 | 3 | 2 | 2 | 2 |
| SOIL PERM. | 1 | 2 | 3 | 2 | 2 | 2 |
| ARCHITECTURE | 3 | -- | 3 | -- | 3 | -- |
| GFE POINTS | 0 | -- | 0 | -- | 0 | -- |
| TOTAL | 10 | 9 | 14 | 9 | 11 | 9 |
| RANKING | MOD | MOD | HIGH | MOD | MOD | 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

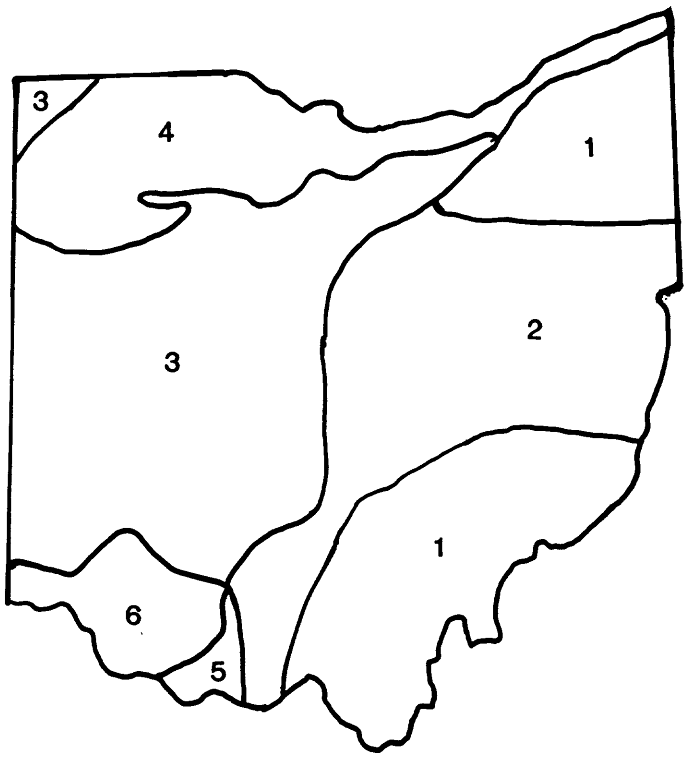



Fig. 13. Generalized Radon Potential Areas

(Described in Table 2)

## REFERENCES CITED IN THIS REPORT AND GENERAL REFERENCES PERTAINING TO RADON IN OHIO


American Lung Association of Ohio, 1700 Arlingale Lane, P.O. Box 16677, Columbus, Ohio 43216

Banks, P.O. and Ghahremani, D.T., 1983, Detection of Gas Seeps in Northeastern Ohio--Potential Strategy for Developing Devonian Shale Gas: Ohio Journal of Science, v. 83, no. 2, p. 24.

Bates, R.G., 1965, Natural Gamma Aeroradioactivity Map of Central Ohio and East-Central Indiana: U.S. Geological Survey Map GP-524.

Belisto, M.E., Harrell, J.A., Kumar, A., and Akkari, J., 1988, Radon Hazards Associated with Outcrops of the Devonian Ohio Shale: GSA Abstracts with Programs, v. 20, no. 5, p. 334.

Bownocker, J.A., 1981, Geologic Map of Ohio: State of Ohio Department of Natural Resources Division of Geological Survey.

Carmichael, R.S., 1989, Practical Handbook of Physical Properties of Rocks and Minerals: CRC Press, Inc., 741 p.

Dotson, G.K. and Smith, T.R., 1958, Our Ohio Soils: Ohio Department of Natural Resources Division of Lands and Soil, 95 p.

Durrance, E.M., 1986, Radioactivity In Geology, Principles and Applications: John Wiley & Sons, 441 p.

Duval, J.S., 1985, Aerial Radiometric Contour Maps of Ohio: U.S. Geological Survey Map GP-968.

Duval, J.S., 1987, Aerial Radiometric Color Contour Maps and Composite Color Map of Regional Surface Concentrations of Uranium, Potassium, and Thorium in Ohio: U.S. Geological Survey Map GP-966.

Duval, J.S., 1989, Radioactivity And Some Of Its Applications In Geology in Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems: Society of Engineering and Mineral Exploration Geophysicists, p. 1-61.

Eisenbud, M., 1987, Environmental Radioactivity From Natural, Industrial, and Military Sources: Academic Press Inc., 475 p.

Ghahremani, D.T., 1981, Radon Prospecting for Shale Gas in Northeastern Ohio: GSA Abstracts with Programs, v. 13, no. 6, 278 p.

Ghahremani, D.T. and Banks, P., 1982, Radon and Hydrocarbons in Soil Gases of Northeastern Ohio: AAPG Bulletin, v. 66, no. 2, p. 244.

Ghahremani, D.T. and Banks, P., 1984, Detection of Light Hydrocarbons in Soil Gases of Northeastern Ohio: Ohio Journal of Science, v. 84, no. 2, p. 13.

Ghahremani, D.T., 1987, Radon Occurrences in Northeast Ohio--An Environmental Hazard?: Ohio Journal of Science, v. 87, no. 2, p. 11.

Ghahremani, D.T., 1988, Radon Technology--A Scientific Review and Hazard Analysis in Ohio: Ohio Journal of Science, v. 88, no. 2, p. 13.

Grafton, H.E., 1990, Indoor Radon Levels in Columbus and Franklin County, Ohio Residences, Commercial Buildings, and Schools in The 1990 International Symposium on Radon and Radon Reduction Technology: EPA/600/9-90/005a, v. 1-Preprints, A-I-1, 14 p.

Hansen, M.C., 1986, Radon: Ohio Geology Newsletter- Fall 1986, Ohio Department of Natural Resources Division of Geological Survey, p. 1-6.

Harrell, J.A. and Kumar, A., 1988, Radon Hazards Associated With Outcrops Of The Devonian Ohio Shale: Ohio Air Quality Development Authority, 83 p.

Harrell, J.A., Belsito, M.E., and Kumar, A., 1991, Radon Hazards Associated With Outcrops Of The Ohio Shale In Ohio: Environmental Geology and Water Sciences, v. 18, p. 17-26.

Hoover, K.V., 1960, Devonian-Mississippian Shale Sequence in Ohio: Ohio Department of Natural Resources, Division of Geological Survey, Information Circular No. 27, 154 p.

Hume, D.S., Dean, S.L., and Harrell, J.A., 1989, Radon Occurrence Along Upper Devonian-Upper Middle Devonian Outcrop Belt In Erie, Huron and Seneca Counties, Ohio: GSA Abstracts with Programs, v. 21, no. 4, p. 15.

Lewis, T.L. and Schwietering, J.F., 1971, Distribution of the Cleveland Black Shale in Ohio: GSA Bulletin, v. 82, p. 3477-3482.

Nobel, A.G. and Korsok, A.J., 1975, Ohio- An American Heartland: Ohio Department of Natural Resources Division of Geological Survey Bulletin 65, 230 p.

Roen, J.B., Wallace, L.G., and De Witt, W., 1978, Preliminary Stratigraphic Cross Section Showing Radioactive Zones of the Devonian Back Shales in Eastern Ohio and West-Central Pennsylvania: U.S. Geological Survey Oil and Gas Investigations Chart OC-82.

Smith, G.W. and Mapes, R.H., 1989, Radon Hazards Associated With Glacial Deposits In Ohio: Report to The Ohio Air Quality Development Authority, 60 p.

Soller, D.R., 1986, Preliminary Map Showing the Thickness of Glacial Deposits in Ohio: U.S. Geological Survey Miscellaneous Field Studies Map MF-1862.

State of Ohio, 1958, The Story of Ohio's Mineral Resources: Ohio Department of Natural Resources Division of Geological Survey Information Circular No. 9, 14 p.

State of Ohio, 1958, Our Ohio Soils: Ohio Department of Natural Resources, Division of Lands and Soil, 95 p.

State of Ohio, 1983, Geologic Map and Cross Section of Ohio: State of Ohio Department of Natural Resources Division of Geological Survey.

State of Ohio, 1983, Glacial Deposits of Ohio: State of Ohio Department of Natural Resources Division of Geological Survey.

State of Ohio, 1982, Physiographic Sections of Ohio: State of Ohio Department of Natural Resources Division of Geological Survey.

State of Ohio, 1982, Map Showing County Outlines: State of Ohio Department of Natural Resources Division of Geological Survey.

Stout, W., 1947, Generalized Section of Rocks of Ohio: Geological Survey of Ohio Information Circular No. 4.

Tanner, A.B., 1988, Rock And Soil As Sources Of Indoor Radon In Ohio: Proceedings of the Northeastern Ohio Radon Conference, October 27, 1988, Youngstown State University, (Abstract).

Wallace, L.G., Roen, J.B., and De Witt, W., 1977, Preliminary Stratigraphic Cross Section Showing Radioactive Zones in the Devonian Black Shales in the Western Part of the Appalachian Basin: U.S. Geological Survey Oil and Gas Investigations Chart OC-80.

Wright, A.J., 1953, Economic Geography of Ohio: State of Ohio Department of Natural Resources Division of Geological Survey Bulletin 50, 217 p.

# PRELIMINARY GEOLOGIC RADON POTENTIAL ASSESSMENT OF WISCONSIN

*by*
*R. Randall Schumann*
*U.S. Geological Survey*

## INTRODUCTION

This is a generalized assessment of geologic radon potential of rocks, soils, and surficial deposits of Wisconsin. 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 landscape of Wisconsin ranges from flat plains to dissected uplands. Elevations range from 595 m (1952 ft) at Timms Hill, near Ogema, to 177 m (580 ft) along the shore of Lake Michigan in eastern Wisconsin (Dutton, 1976). Parts of two major physiographic provinces are represented in Wisconsin: the Superior Upland province in the northern part of the State and the Central Lowlands province in the south. Within the State these are further subdivided into physiographic regions (fig. 1). The Superior Lowland and Northern Highland regions are parts of the Superior Upland province; the Western Upland, Central Plain, and Eastern Ridges and Lowlands regions (fig. 1) are included in the Central Lowlands province.

The Western Upland is a dissected highland in the southwestern part of Wisconsin. Most of this area lies within the Driftless Area, which is not covered by glacial deposits and is generally more dissected than the glaciated parts of the State. Most of the area is underlain by nearly flat-lying sandstone and dolomite, with the notable exception of the Baraboo Range in Columbia and Sauk Counties (fig. 2 is a map of counties), which is composed primarily of quartzite (Crowns, 1976). Numerous caves have formed in dolomite in southwestern Wisconsin.

The Central Plain is a crescent-shaped belt of relatively flat landscape, interrupted only locally by pinnacles and hills resulting from differential erosion of the sandstone. Much of the area is covered by glacial drift, and the central part of the region is a flat-lying plain occupying the former basin of glacial Lake Wisconsin, covering most of Adams and Juneau Counties and parts of nearby counties. Wetlands are common in the central and eastern parts of the Central Plain.

The Eastern Ridges and Lowlands comprises gently rolling plains with tilted limestone ledges (forming cuestas), moraines, and drumlins providing local relief. Wetlands and part of the bed of glacial Lake Oshkosh cover the northern part of the area. This region contains the State's greatest density of population, as it contains most of Wisconsin's major cities, including Milwaukee, Green Bay, and Madison. Figure 3 is a map showing population distribution by county.

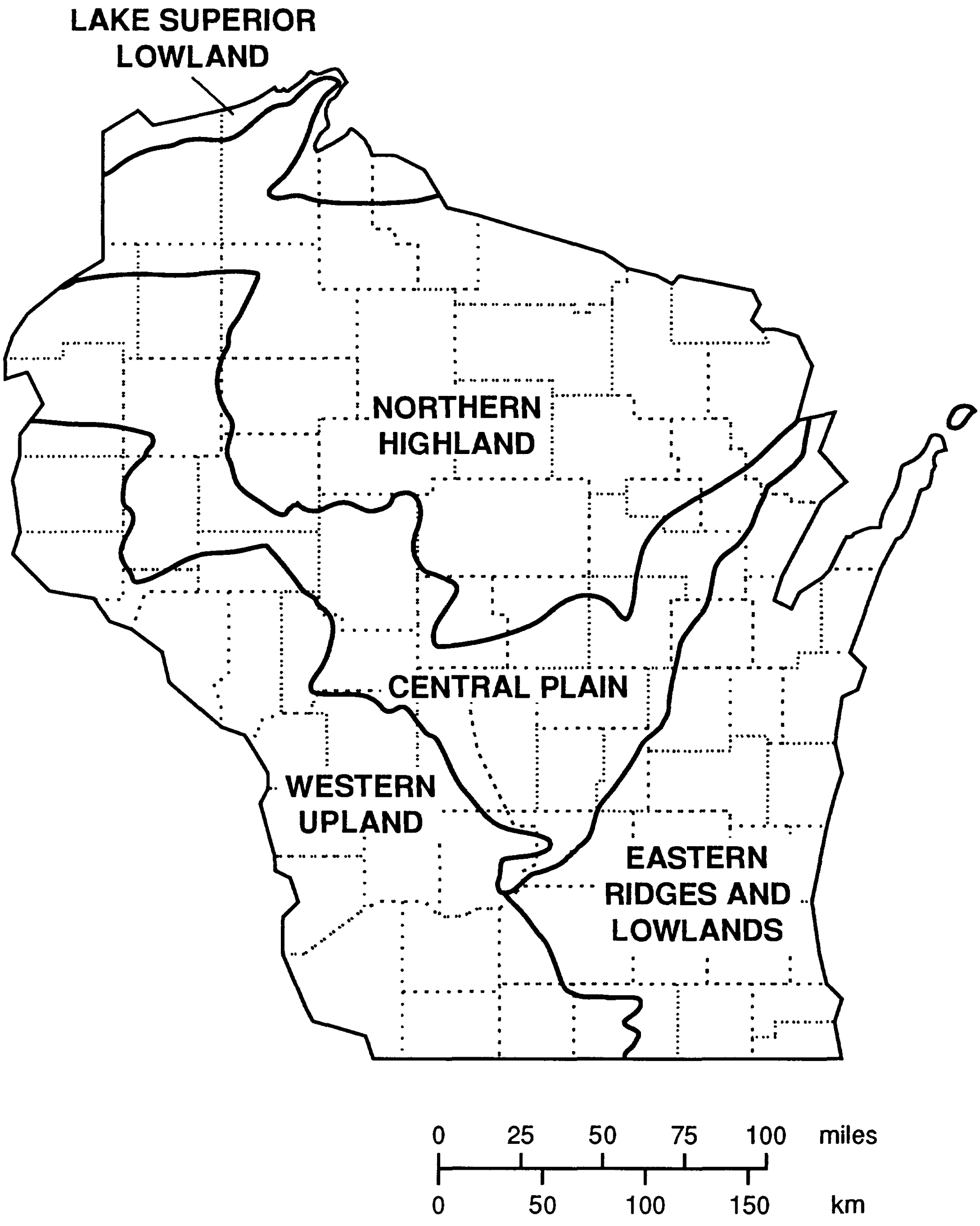



Figure 1. Physiographic regions of Wisconsin (after Martin, 1916).


Figure 2. Wisconsin counties.

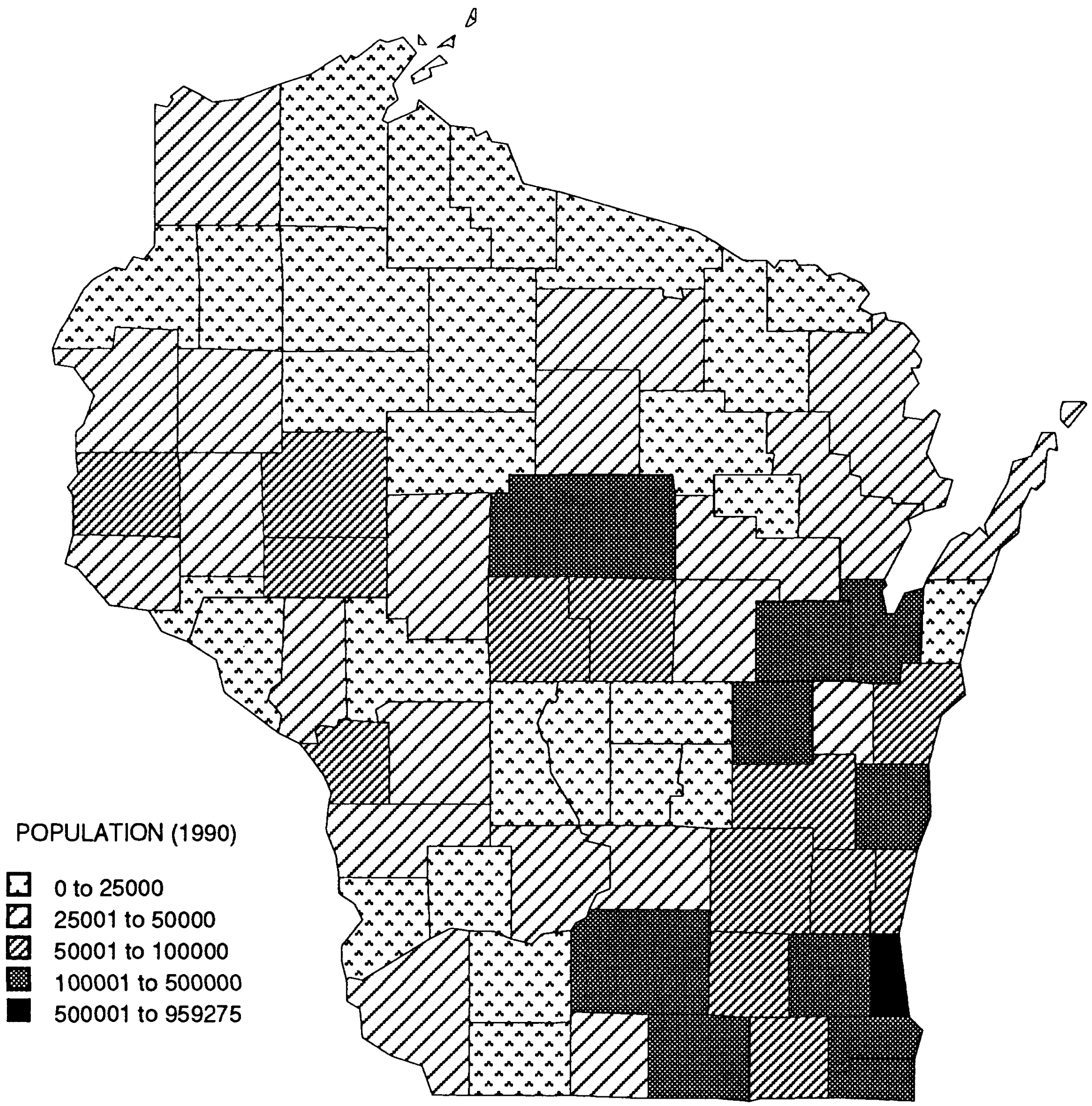



Figure 3. Population of counties in Wisconsin (1990 U.S. Census data).

The Northern Highland (fig. 1) is an undulating plain sloping gently toward the south with occasional hills and ridges, including Timms Hill, Pearson Hill, Rib Mountain, and Sugarbush Hill, the highest points in the State. The Northern Highland is underlain by Precambrian rock of the North American Shield (also referred to as the Canadian Shield) and covered by Pleistocene glacial deposits. The area is heavily forested and contains numerous lakes and wetlands.

The Lake Superior Lowland is located on the southern shore of Lake Superior and slopes toward the lake. The edge of the Lowland is marked by a steep escarpment with local relief as much as 107 m (350 ft), which has formed rocky cliffs and waterfalls where bedrock is exposed (Crowns, 1976).

## GEOLOGY

The discussion of geology is divided into three sections: bedrock geology, glacial geology, and a discussion of uranium in rocks and soils. "Bedrock" refers to pre-glacial rock units, which are covered by glacial deposits in most parts of the State. A bedrock geologic map (fig. 4) shows rock units that underlie glacial deposits or are exposed at the surface in some areas. The glacial deposits are composed of material derived from underlying bedrock and from rock units to the north and northeast. The discussion of bedrock geology is summarized from Dutton (1976), Ostrom (1976), Mudrey and others (1982), and Sims (1992). The section on glacial geology is summarized from Frye and others (1965), Hadley (1976), and Richmond and Fullerton (1983a, 1983b, 1984, 1991). For more detailed discussions and maps of the geology, the reader is encouraged to consult these and other reports.

*Bedrock geology:* Wisconsin's bedrock geology divides the State into two major areas: an area of Precambrian rock, mostly metamorphic and igneous, in the north, and an area of Paleozoic sedimentary rock that overlies the older rock in the south, east, and west (fig. 4). The northwesternmost area of Precambrian rock in Wisconsin is composed of a thick sequence of volcanic and sedimentary rock (fig. 4). Beds of shale, sandstone, and conglomerate are interbedded with thick, massive basaltic and some andesitic lava flows. Gabbros with essentially the same composition as the lavas also underlie this area. A thick sequence of Precambrian sedimentary rock called the Lake Superior Sandstone, consisting of shale, sandstone, and conglomerate, also occurs in this area (fig. 4).

The Gogebic Range, in Bayfield, Ashland, and Iron Counties (figs. 2, 4), is underlain by Middle Precambrian quartzite, iron-formation, and locally, dolomite. South and east of the Gogebic Range are gneisses, metavolcanic rock of mafic to intermediate composition, and lesser amounts of metasedimentary rock and iron-formation. The western edge of the Precambrian rock area is underlain by quartzite (fig. 4). The southwestern part of the area lies along the Black River and contains mainly gneisses and schists with local areas of felsic and mafic intrusive rock and iron-formation. The south-central part of the area contains numerous exposures of Precambrian bedrock at the surface in the Wausau and Wisconsin Rapids area. Rocks in this area are primarily felsic and mafic igneous intrusive and volcanic rock, with lesser amounts of gneiss and quartzite. The southeastern part of the area is dominated by the Wolf River batholith, an extensive area of primarily granite and quartz monzonite (Fig. 4). Precambrian rock exposed outside of the northeastern part of the State includes outcrops of quartzite, iron-formation, and slate in the Baraboo area in Sauk and Columbia Counties (fig. 4). Precambrian granite and rhyolite directly underlie glacial deposits in Marquette, Green Lake, and Waushara Counties.

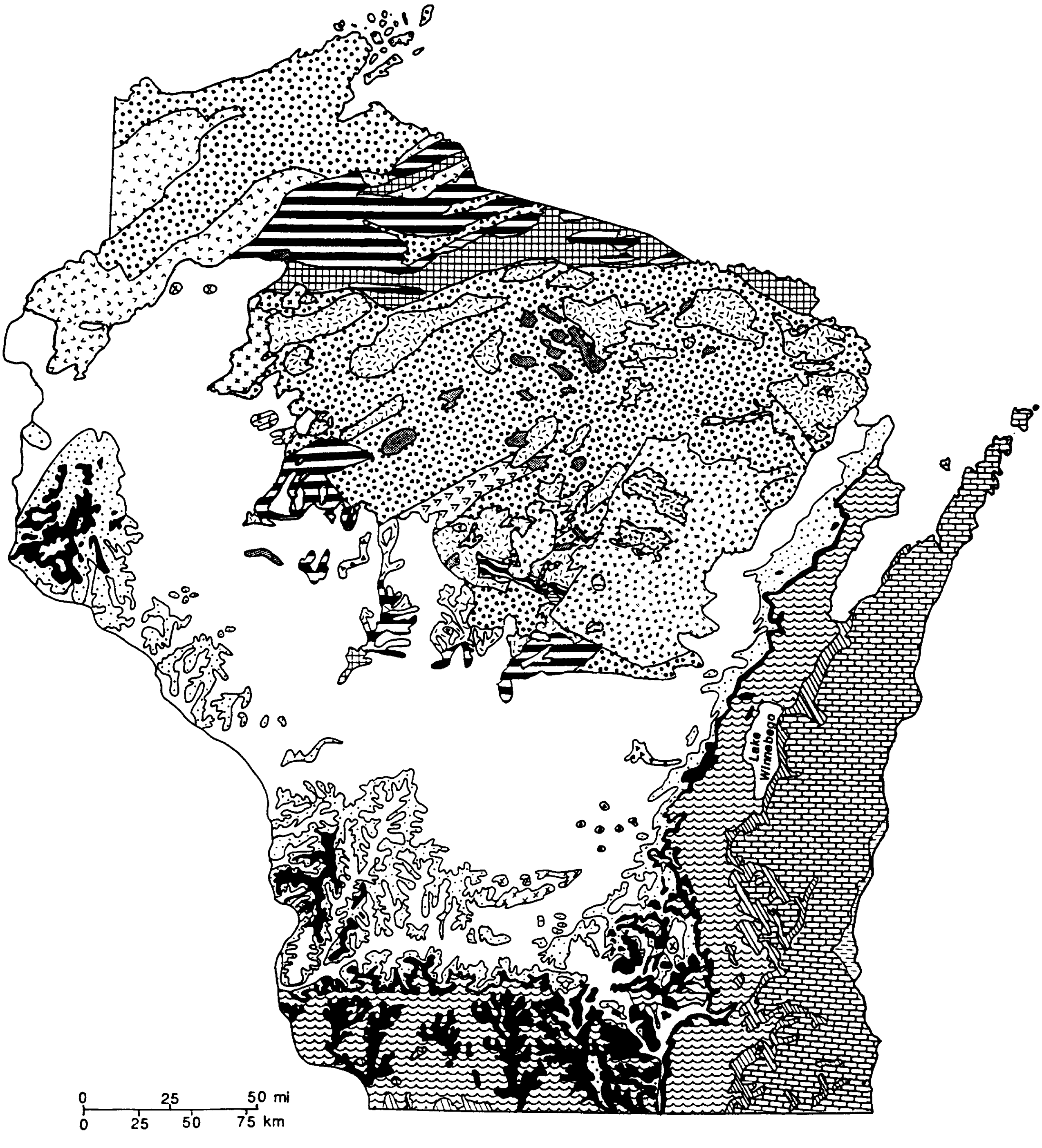



Figure 4. Generalized bedrock geologic map of Wisconsin (after Mudrey and others, 1982, and Sims, 1992).

## GENERALIZED BEDROCK GEOLOGIC MAP OF WISCONSIN
## EXPLANATION

*Devonian* dolomite and shale

*Silurian* dolomite

*Ordovician* Maquoketa Formation–shale and dolomite

*Ordovician* Sinnipee Group–dolomite with some limestone and shale

*Ordovician* St. Peter Formation–sandstone with some limestone, shale, and conglomerate

*Ordovician* Prairie du Chien Group–dolomite with some sandstone and shale

*Cambrian* sandstone with some dolomite and shale

*Proterozoic Y* sandstone and conglomerate with some shale

*Proterozoic Y* basalt, andesite, and felsite (includes *Upper Archean* metagabbro in Iron and Ashland Counties)

*Proterozoic Y* granite and syenite (in Wolf River Batholith and Wausau and Stettin plutons)

*Proterozoic Y* anorthosite

*Proterozoic X* quartzite

*Proterozoic X* metasedimentary rocks (argillite, siltstone, quartzite, graywacke) and iron-formation

*Proterozoic X* granite, granodiorite, tonalite, and some quartz diorite and granite gneiss

*Proterozoic X* gneiss and amphibolite

*Proterozoic X* mafic to felsic volcanic and metavolcanic rocks

*Proterozoic X* gabbro and metagabbro (includes *Upper Archean* metagabbro in Eau Claire County)

*Lower Proterozoic and Upper Archean* gneiss, migmatitic gneiss, amphibolite, and some granitic gneiss and granite

*Lower to Middle Proterozoic and Upper Archean* mylonite (in Eau Pleine shear zone)

Lower Paleozoic sedimentary rock overlies Precambrian rock in the western, southern, and eastern parts of the State (fig. 4). They consist of a sequence of alternating clastic (sandstone, shale) and carbonate (limestone, dolomite) rock ranging in age from Cambrian to Devonian. Upper Cambrian rocks (fig. 4) include the Mount Simon (sandstone), Eau Claire (sandstone and shale), Wonewoc (sandstone), Lone Rock (sandstone, shale, and dolomite), Mazomanie (sandstone), St. Lawrence (dolomite and siltstone), and Jordan (sandstone) Formations. The oldest Ordovician rock overlies Cambrian rock on the west, south, and east, and includes the Prairie du Chien Group and the St. Peter Formation (fig. 4). The Prairie du Chen Group comprises the Oneota Dolomite and the Shokapee Formation. The Shokapee Formation consists of the New Richmond Sandstone Member (composed of sandstone, sandy dolomite, and shale) and the Willow River Dolomite. The St. Peter Formation is composed of sandstone, shaly conglomerate, and shale. It is overlain by the Ordovician Sinnipee Group, consisting of dolomite, shaly dolomite, and shale, and the Maquoketa Shale (fig. 4).

Silurian rock includes thin-to thick bedded dolomites occurring in a wide band along the State's eastern coastline from the Door Peninsula southward to the Illinois border. Devonian rock occurs in a small area in southeastern Wisconsin near Milwaukee (fig. 4) and consists of dolomite, shaly limestone, and shale.

*Glacial geology:* More than three-quarters of Wisconsin's land area is covered by Pleistocene (and possibly older) glacial deposits ranging in thickness from less than one to more than 100 meters. Pre-Wisconsinan deposits are exposed along the southern border of the State in Green and Lafayette Counties (fig. 5). These deposits, along with Altonian (earliest Wisconsinan) drift in the same area, are thought to have been deposited by glaciers which entered the area from the east. Late Altonian drift to the north of the Driftless Area (fig. 5) was deposited by the Lake Michigan and Green Bay lobes, which moved westward across the State, and by the Superior and Des Moines lobes, which entered from the northwest, moving southeastward. This unit consists of sandy to loamy till containing fragments of gabbro, felsite, red sandstone, and limestone in the west, and granite, gneiss, schist, and sandstone in central Wisconsin.

During the Woodfordian substage (middle to late Wisconsinan), ice advanced from the north, northeast, and east in several distinct lobes and sublobes, leaving a prominent moraine that stretches across the State from Minnesota to Illinois. The Lake Michigan and Green Bay lobes advanced roughly south-southeastward along the troughs of Lake Michigan and Green Bay (fig. 5). The Lake Michigan lobe deposits are primarily clayey tills containing clasts of limestone and dolomite. The Green Bay lobe deposited silty- and sandy-clay loam tills and loamy tills containing clasts of limestone and dolomite, with locally scattered clasts of igneous and metamorphic rocks (Richmond and Fullerton, 1984). The Chippewa, Wisconsin Valley, and Langlade sublobes of the Superior lobe advanced from the north and northeast across the Lake Superior basin and northern Michigan. These lobes deposited mainly clayey, silty, sandy till derived from granite, mafic metavolcanic rocks, gabbro, and schist.

Deposits of the Grantsburg sublobe of the Des Moines lobe, which entered the State from the west, are found in Burnett and Polk counties (fig. 5). Till from the Grantsburg sublobe contains fragments of limestone, shale, and other rocks from northwestern Minnesota, and red sandstone, basalt, and gabbro from the Lake Superior district (Wright and others, 1973). As the ice retreated near the end of the Woodfordian stage, many of the glacial lakes in Wisconsin were formed, including ancestral Lake Michigan, known as Lake Chicago, and Lake Wisconsin. During late Wisconsinan time, the Superior lobe advanced southwestward along the Lake Superior basin, carrying mostly basalt, gabbro, and red sandstone, the Green Bay lobe

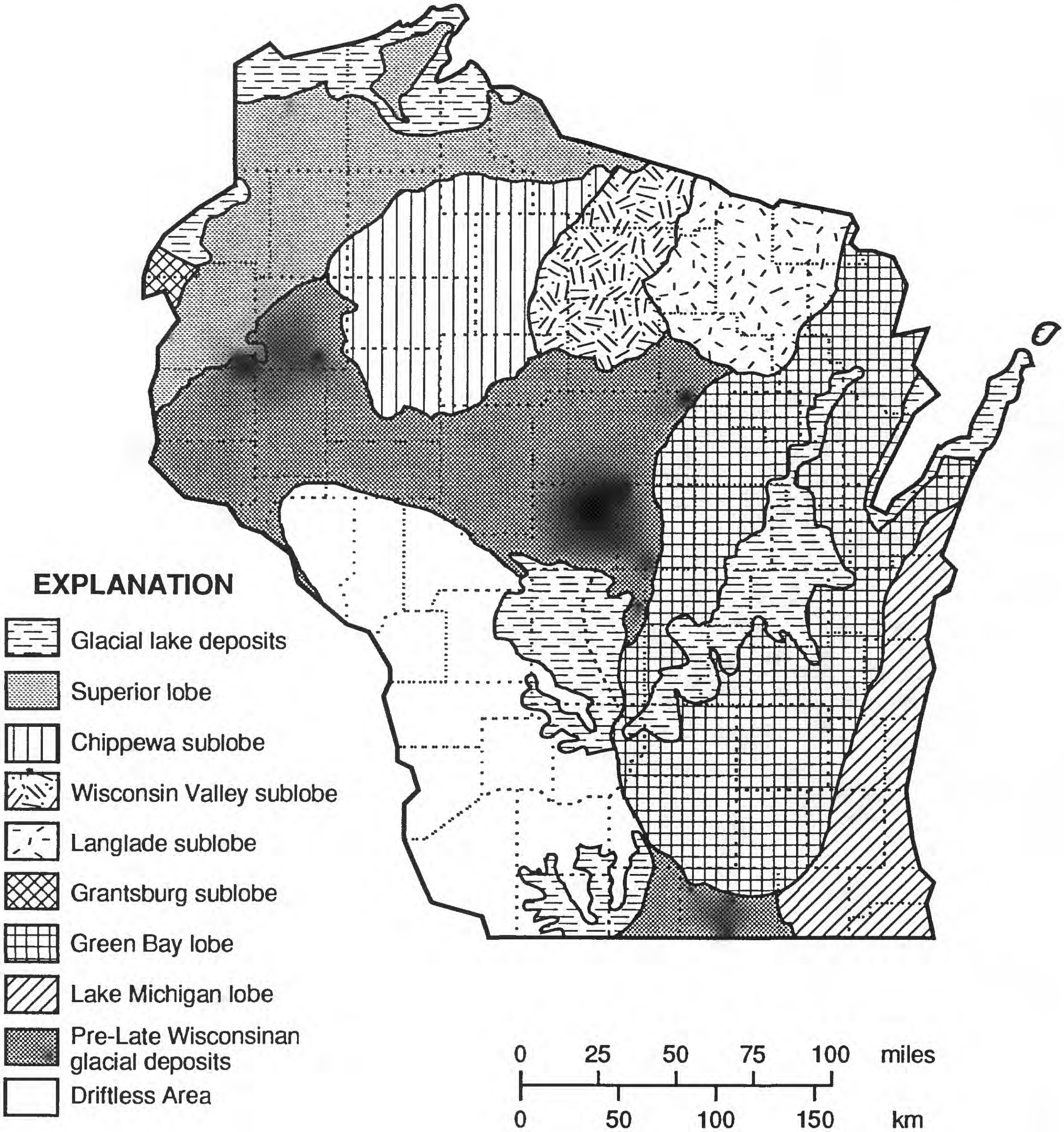



Figure 5. Glacial lobes and deposits in Wisconsin (after Richmond and Fullerton, 1983, 1984, 1991; and Thwaites, 1960).

re-advanced as far as the southern end of modern Lake Winnebago, and the Lake Michigan lobe advanced down the Lake Michigan Basin as far as Milwaukee (Hadley, 1976). The final retreat of ice from Wisconsin occurred about 9,500 years ago.

Loess deposits (windblown silt derived from glacial drift) ranging in thickness from 0 to 5 m occur over much of the State. Most of the loess occurs in the south-central and western parts of Wisconsin, including most of the Driftless Area. The thickest deposits occur along the Mississippi River on the State's western border.

*Uranium geololgy:* Schnabel (1976) describes a fragment of a quartz-pebble conglomerate, presumed to be from the Precambrian McCaslin Formation, found near Mt. McCaslin in southeastern Forest County containing 0.75 percent (7500 ppm) uranium (U). Two other samples of conglomerate also presumed to be from the McCaslin Formation contain 0.12 and 0.33 percent U (Kalliokoski, 1976), but no other radioactive conglomerate samples have since been found in this area and outcrops of the McCaslin Formation are also low in radioactivity. Sandstone of the Cambrian Tunnel City Group in the vicinity of Tomah, Monroe County, yielded as much as 6 ppm U (Schnabel, 1976), probably associated with glauconite (Kalliokoski, 1976; Wisconsin Geological Survey, 1956). Elevated uranium (for purposes of this report, "elevated" is defined as greater than 2.5 ppm U) and elevated soil-gas radon concentrations are associated with glauconitic sediments in a number of areas, such as the Atlantic and Gulf Coastal Plain (Gundersen and others, 1991). Rocks of granitic composition in the northeast and north-central part of the State, particularly rocks of the Wolf River Batholith, contain sufficient uranium to generate radon at levels of concern. In particular, the Red River quartz monzonite in southern Shawano and northern Waupaca Counties and the Wausau Syenite Complex in Marathon County host a number of radioactive anomalies (Kalliokoski, 1976). Shear zones in contact with Wolf River Batholith rocks, such as in Marathon County, may be areas of localized uranium enrichment (Kalliokoski, 1976). Glacial drift containing granitic rock fragments as a major constituent may contain elevated uranium concentrations.

## SOILS

Soils of the orders Entisols, Inceptosols, Mollisols, Alfisols, Spodosols, and Histosols can be found in Wisconsin (Hole, 1976a, 1976b). Figure 6 shows major soil regions of Wisconsin. Soils of southwestern Wisconsin (fig. 6A) are silty and clayey soils developed on sedimentary rocks. Much of this area is covered by loess. Soils of southeastern Wisconsin (fig. 6B) are silty to sandy soils developed on calcareous glacial drift. Most soils of this area have accumulations of calcium carbonate ($CaCO_3$) at 0.5 to 1.5 m depth. The amount of carbonate in the soils roughly follows the carbonate content of the parent tills, which decreases westward from more than 50 percent north of Milwaukee to less than 15 percent in Marquette County (Hole, 1976a). The soils also contain considerable clay in the eastern pert of the region. Soils of the Central Sandy Plain (fig. 6C) are sandy soils developed on coarse glacial deposits. Most of these soils are excessively drained, but some areas are poorly drained, especially in areas underlain by glacial lake deposits, many of which are now occupied by wetlands. The Western Sandstone Uplands and Valleys area occupies much of the Driftless Area (fig. 6D) and contains mostly silty and sandy loams. Some of the Cambrian sandstones in this area contain significant amounts of glauconite, giving the sandstone a green color ("greensands") that is also imparted to the soils developed from this unit (Hole, 1976b).

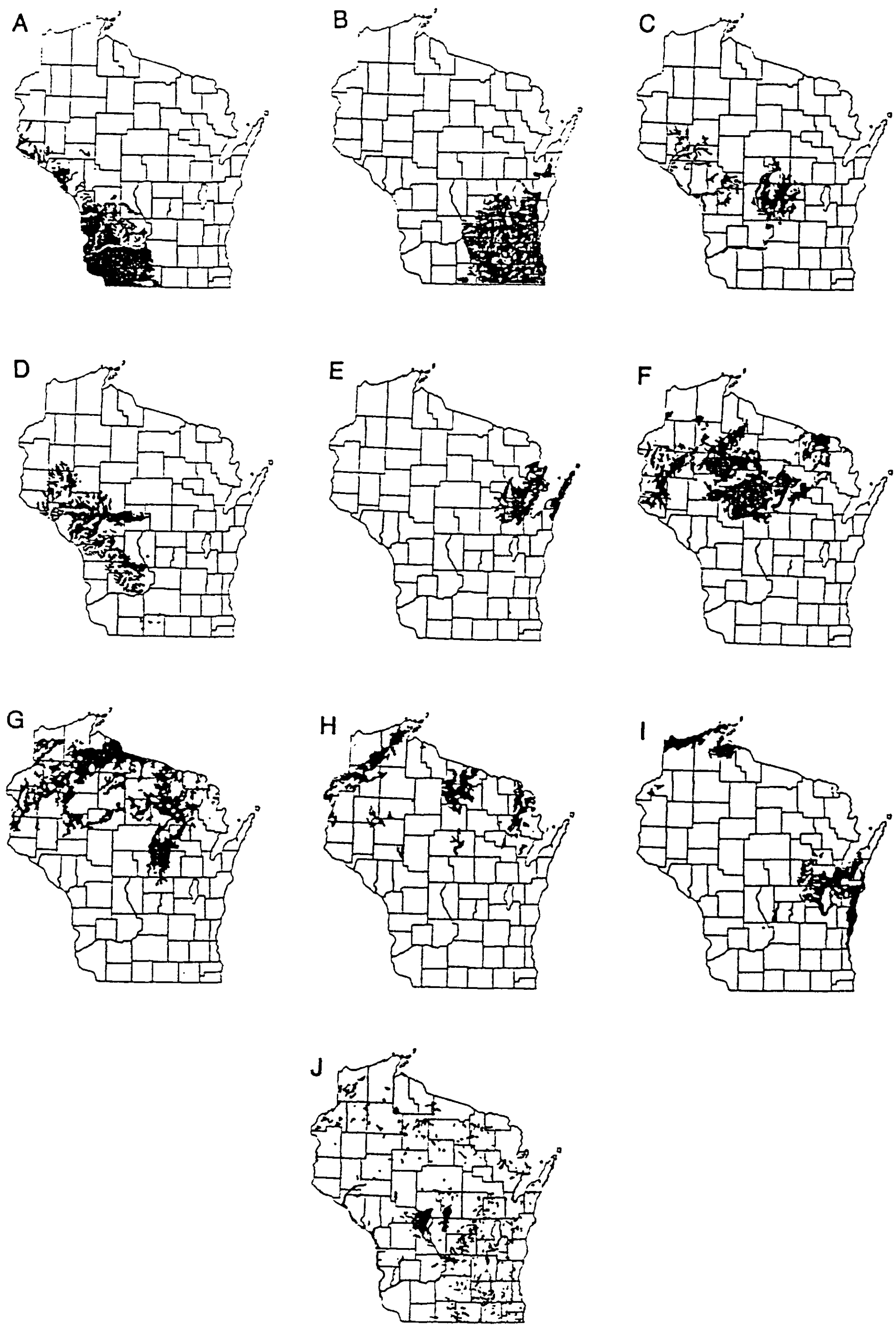



Figure 6. Soils of Wisconsin. A, Soils of Southwestern Wisconsin; B, Soils of Southeastern Wisconsin; C, Soils of the Central Sandy Plain; D, Soils of the Western Sandstone Uplands and Valleys; E, Soils of the Northern and Eastern Sandy and Loamy reddish Drift Uplands and Plains; F, Soils of the Northern Silty Uplands and Plains; G, Soils of the Northern Loamy Uplands and Plains; H, Soils of the Northern Sandy Uplands and Plains; I, Soils of the Northern and Eastern Clayey and Loamy Reddish Drift Uplands and Plains; J, Soils of Stream Bottoms and Major Wetlands (from Hole, 1976a, b).

Soils of the Northern and Eastern Sandy and Loamy Reddish Drift Uplands and Plains lie on either side of Green Bay (fig. 6E). Depth to the dolomite bedrock is very small in many parts of this soil area. These soils are distinct from soils in nearby areas because they are "pink" rather than reddish or brown in color. Some of the soils are developed on glacial lake deposits and consist of silty to very fine sand with little or no clay accumulation in the B horizon. Carbonate content of these soils ranges from fairly high on the Door Peninsula to only a few percent in the northwestern part of the region (Hole, 1976b). Soils of the Northern Silty Uplands and Plains (fig. 6F) consist of silt to silty loam about 0.6 m thick covering acidic reddish-brown till, sand, gravel, outwash, and Precambrian bedrock. The silty material was probably originally loess (Hole, 1976b). Soils of the Northern Loamy Uplands and Plains (fig. 6G) are forest soils developed on glacial drift. These loams, sands, and sandy loams probably incorporated windblown silt into the soil layers during formation, as there is no discrete loess cover on these soils as in other areas. These soils have weak argillic horizons (clayey subsurface layers) and spodic horizons formed from accumulations of organic matter and iron oxides (Hole, 1976b).

Soils of the Northern Sandy Uplands and Plains (fig. 6H) are developed on glacial deposits, mostly outwash, giving the soils a sandy to stony texture. Soils of the Northern and Eastern Clayey and Loamy Reddish Drift Uplands and Plains (fig. 6I) are red clay soils bordering Lake Superior, Green Bay, and Lake Michigan. These soils are associated with Valderan glacial deposits of the Superior, Green Bay, and Lake Michigan lobes. The red clays and silts are colored by glacially-ground Precambrian iron-formation (Hole, 1976b). In the north the clayey soils are associated with sandy soils. These soils contain from 15 percent (near Lake Superior) to 30 percent calcium carbonate (near Lake Michigan). Soils of Stream Bottoms and Major Wetlands are scattered across the State (fig. 6J). These soils are poorly drained and generally have water tables at or near the surface.

A generalized map of soil permeability (fig. 7) was compiled using maps and reports by Hole (1976a, 1976b), Wisconsin Department of Natural Resources and Wisconsin Geological and Natural History Survey (1987), and U.S. Soil Conservation Service county soil surveys. Soil permeability is generally low in soils developed on glacial lake deposits and in soils of regions A, I, and the western part of region F (figs. 6A, 6F, and 6I). Soils of regions C, D, G, and H (figs. 6C, 6D, 6G, and 6H) have generally high permeability in U.S. Soil Conservation Service percolation tests (fig. 7).

## INDOOR RADON DATA

Indoor radon data from 1191 homes sampled in the State/EPA Residential Radon Survey conducted in Wisconsin during the winter of 1986-87 are given in Table 1 and shown in figure 8. Data are only displayed in figure 8 for those counties with 5 or more data values. The maximum value recorded in the survey was 89 pCi/L in Grant County. Counties with average screening indoor radon levels equal to or greater than 4 pCi/L include Dodge, Door, Grant, Iron, Langlade, Marathon, Polk, Portage, Price, Rock, Shawano, St. Croix, Walworth, Washington, Waukesha, and Waupaca (fig. 8; Table 1). In four counties (with 5 or more measurements)—Dodge, Rock, Walworth, and Waukesha—50 percent or more of the homes tested had indoor radon levels exceeding 4 pCi/L (Table 1).

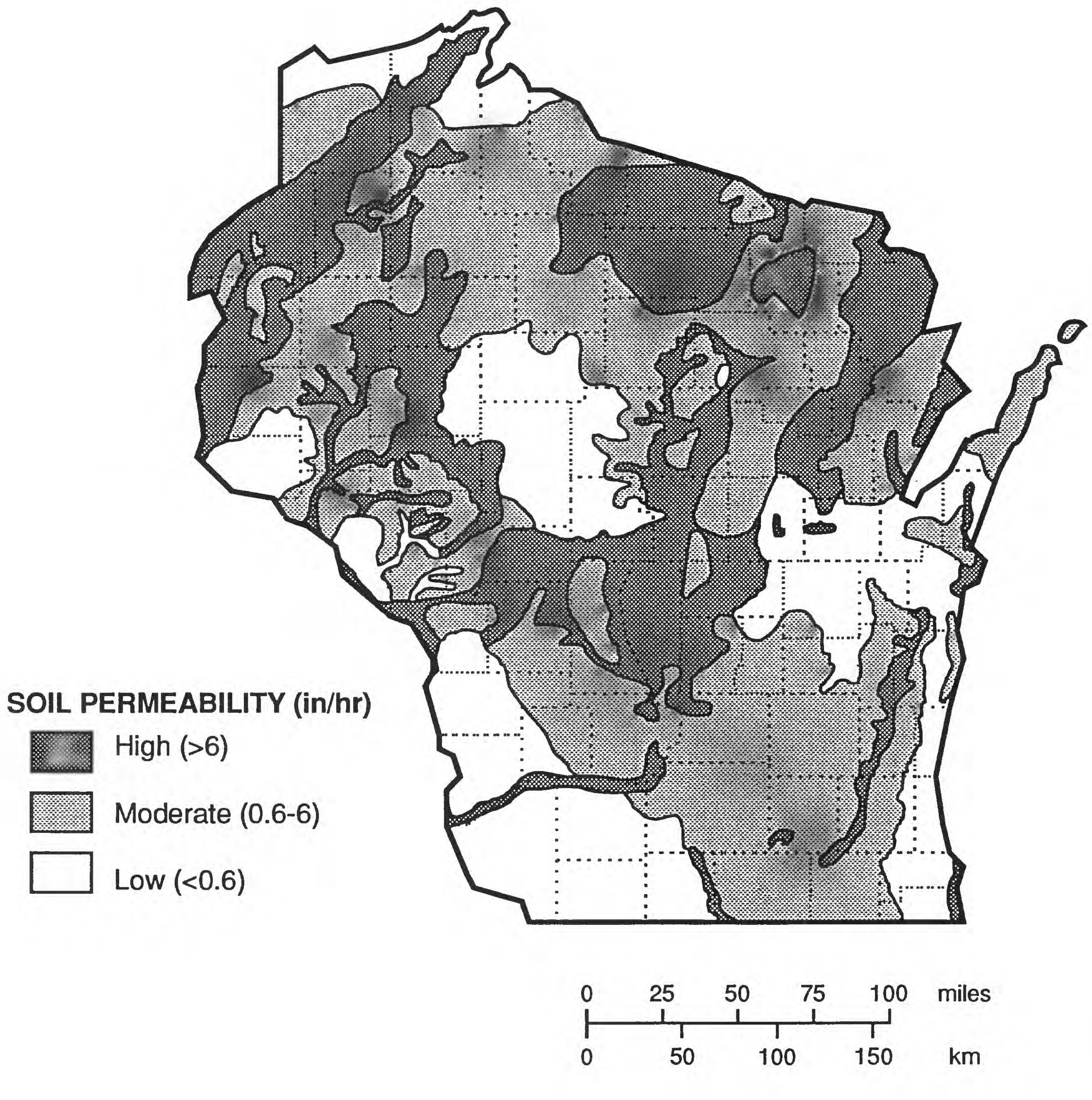
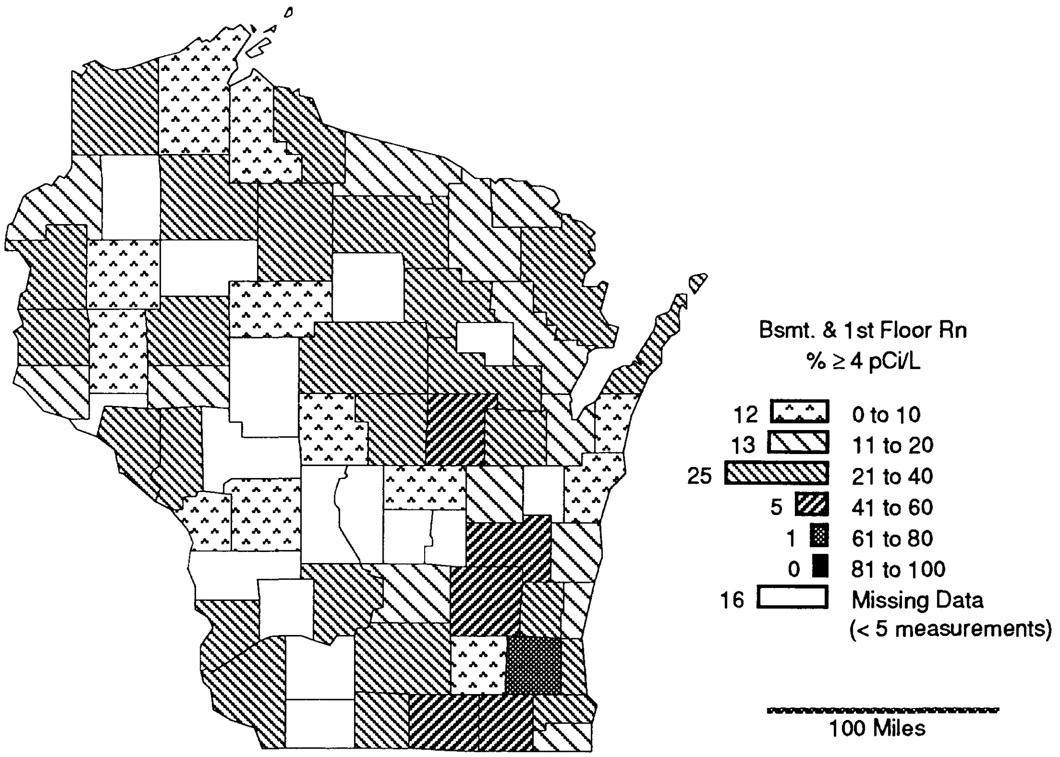



Figure 7. Generalized soil permeability map of Wisconsin. Compiled by Kevin M. Schmidt, U.S. Geological Survey, from Hadley and Pelham (1976), Wisconsin Department of Natural Resources and Wisconsin Geologic and Natural History Survey (1987), and U.S. Soil Conservation Service county soil survey data.



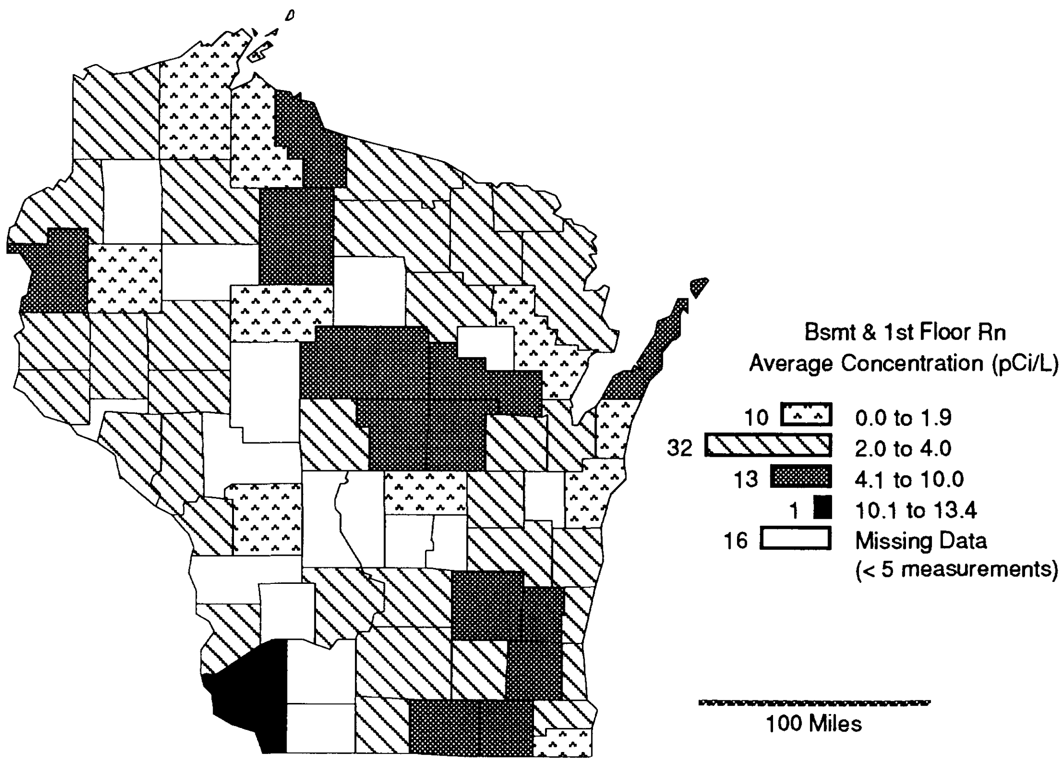




Figure 8. Screening indoor radon data from the EPA/State Residential Radon Survey of Wisconsin, 1986-87, for counties with 5 or more measurements. Data are from 2-7 day charcoal canister tests. Histograms in map legends show the number of counties in each category. The number of samples in each county (see Table 1) may not be sufficient to statistically characterize the radon levels of the counties, but they do suggest general trends. Unequal category intervals were chosen to provide reference to decision and action levels.

TABLE 1. Screening indoor radon data from the State/EPA Residential Radon Survey of Wisconsin conducted during 1986-87. Data represent 2-7 day charcoal canister measurements from the lowest level of each home tested.

| COUNTY | NO. OF MEAS. | MEAN | GEOM. MEAN | MEDIAN | STD. DEV. | MAXIMUM | %>4 pCi/L | %>20 pCi/L |
|---|---|---|---|---|---|---|---|---|
| ADAMS | 2 | 2.6 | 2.4 | 2.6 | 1.4 | 3.6 | 0 | 0 |
| ASHLAND | 8 | 1.0 | 0.8 | 1.1 | 0.5 | 1.8 | 0 | 0 |
| BARRON | 14 | 1.7 | 1.3 | 1.8 | 0.9 | 3.8 | 0 | 0 |
| BAYFIELD | 8 | 1.1 | 0.9 | 1.1 | 0.6 | 2.2 | 0 | 0 |
| BROWN | 28 | 2.2 | 1.7 | 1.6 | 1.6 | 7.3 | 11 | 0 |
| BUFFALO | 8 | 3.2 | 2.9 | 3.0 | 1.6 | 6.4 | 25 | 0 |
| BURNETT | 9 | 2.1 | 1.4 | 1.7 | 1.5 | 4.6 | 11 | 0 |
| CALUMET | 3 | 3.3 | 3.2 | 3.1 | 1.3 | 4.7 | 33 | 0 |
| CHIPPEWA | 18 | 3.7 | 2.3 | 2.7 | 4.3 | 18.5 | 33 | 0 |
| CLARK | 4 | 1.4 | 1.2 | 1.6 | 0.6 | 1.8 | 0 | 0 |
| COLUMBIA | 8 | 2.1 | 1.8 | 2.0 | 1.2 | 4.6 | 13 | 0 |
| CRAWFORD | 5 | 3.8 | 3.0 | 3.7 | 2.3 | 6.3 | 40 | 0 |
| DANE | 87 | 3.2 | 2.0 | 2.2 | 2.9 | 12.9 | 25 | 0 |
| DODGE | 12 | 4.8 | 4.0 | 4.0 | 3.6 | 14.8 | 50 | 0 |
| DOOR | 8 | 6.5 | 2.7 | 2.4 | 8.8 | 25.1 | 38 | 13 |
| DOUGLAS | 9 | 2.3 | 1.0 | 1.2 | 3.0 | 9.6 | 22 | 0 |
| DUNN | 13 | 2.1 | 2.1 | 2.0 | 0.6 | 3.1 | 0 | 0 |
| EAU CLAIRE | 20 | 3.5 | 2.8 | 3.2 | 2.5 | 11.3 | 20 | 0 |
| FLORENCE | 13 | 2.4 | 1.5 | 1.8 | 2.3 | 7.5 | 15 | 0 |
| FOND DU LAC | 22 | 3.2 | 2.5 | 2.7 | 2.1 | 7.2 | 41 | 0 |
| FOREST | 6 | 2.4 | 1.0 | 1.4 | 3.1 | 8.4 | 17 | 0 |
| GRANT | 10 | 13.4 | 4.9 | 3.7 | 26.9 | 89.1 | 40 | 10 |
| GREEN | 6 | 3.3 | 2.4 | 3.2 | 2.4 | 7.0 | 33 | 0 |
| GREEN LAKE | 2 | 10.3 | 2.5 | 10.3 | 14.1 | 20.2 | 50 | 50 |
| IOWA | 1 | 0.9 | 0.9 | 0.9 | 0.0 | 0.9 | 0 | 0 |
| IRON | 5 | 4.4 | 2.3 | 1.4 | 5.8 | 14.5 | 40 | 0 |
| JACKSON | 2 | 1.6 | 1.2 | 1.6 | 1.3 | 2.5 | 0 | 0 |
| JEFFERSON | 15 | 2.2 | 1.9 | 2.2 | 1.2 | 5.1 | 7 | 0 |
| JUNEAU | 2 | 2.6 | 2.3 | 2.6 | 1.6 | 3.7 | 0 | 0 |
| KENOSHA | 21 | 1.9 | 1.5 | 1.3 | 1.6 | 5.5 | 14 | 0 |
| KEWAUNEE | 5 | 1.3 | 0.8 | 1.3 | 1.1 | 2.8 | 0 | 0 |
| LA CROSSE | 26 | 2.5 | 2.2 | 2.5 | 1.2 | 6.4 | 8 | 0 |
| LAFAYETTE | 4 | 3.2 | 2.9 | 3.5 | 1.3 | 4.5 | 25 | 0 |
| LANGLADE | 19 | 4.0 | 2.8 | 2.9 | 3.0 | 11.9 | 26 | 0 |
| LINCOLN | 4 | 3.2 | 2.4 | 2.3 | 2.7 | 6.9 | 25 | 0 |
| MANITOWOC | 18 | 1.4 | 1.2 | 1.1 | 0.9 | 3.7 | 0 | 0 |
| MARATHON | 71 | 5.2 | 3.0 | 3.2 | 6.5 | 37.1 | 38 | 3 |
| MARINETTE | 13 | 2.4 | 1.4 | 1.1 | 2.8 | 10.1 | 23 | 0 |
| MARQUETTE | 4 | 2.1 | 1.3 | 2.0 | 1.9 | 4.3 | 25 | 0 |
| MENOMINEE | 2 | 4.5 | 3.4 | 4.5 | 4.2 | 7.5 | 50 | 0 |
| MILWAUKEE | 124 | 3.1 | 2.1 | 2.4 | 2.6 | 15.3 | 27 | 0 |

TABLE 1 (continued). Screening indoor radon data for Wisconsin.

| COUNTY | NO. OF MEAS. | MEAN | GEOM. MEAN | MEDIAN | STD. DEV. | MAXIMUM | %>4 pCi/L | %>20 pCi/L |
|---|---|---|---|---|---|---|---|---|
| MONROE | 7 | 1.2 | 1.0 | 1.0 | 0.8 | 2.6 | 0 | 0 |
| OCONTO | 30 | 1.6 | 0.9 | 0.8 | 1.8 | 7.2 | 13 | 0 |
| ONEIDA | 8 | 3.0 | 2.6 | 2.7 | 1.6 | 6.1 | 25 | 0 |
| OUTAGAMIE | 23 | 2.7 | 2.2 | 2.1 | 1.6 | 6.2 | 22 | 0 |
| OZAUKEE | 12 | 3.2 | 3.0 | 3.0 | 1.4 | 5.9 | 17 | 0 |
| PEPIN | 4 | 3.8 | 3.4 | 2.9 | 2.2 | 7.0 | 25 | 0 |
| PIERCE | 6 | 2.4 | 1.4 | 2.6 | 1.5 | 4.1 | 17 | 0 |
| POLK | 9 | 4.5 | 2.9 | 3.2 | 5.1 | 17.1 | 22 | 0 |
| PORTAGE | 30 | 4.1 | 2.9 | 2.7 | 3.8 | 16.7 | 30 | 0 |
| PRICE | 10 | 5.1 | 2.6 | 3.5 | 6.4 | 21.5 | 30 | 10 |
| RACINE | 31 | 2.6 | 1.9 | 2.0 | 2.3 | 10.7 | 26 | 0 |
| RICHLAND | 3 | 1.4 | 1.2 | 1.5 | 0.8 | 2.1 | 0 | 0 |
| ROCK | 18 | 4.5 | 3.0 | 4.4 | 3.3 | 14.3 | 56 | 0 |
| RUSK | 4 | 1.7 | 1.6 | 1.6 | 0.5 | 2.4 | 0 | 0 |
| SAUK | 7 | 3.7 | 2.8 | 3.4 | 2.6 | 7.5 | 29 | 0 |
| SAWYER | 34 | 2.5 | 1.9 | 2.6 | 1.6 | 6.0 | 24 | 0 |
| SHAWANO | 30 | 4.2 | 2.8 | 2.6 | 4.3 | 20.5 | 33 | 3 |
| SHEBOYGAN | 20 | 2.1 | 1.6 | 1.5 | 1.6 | 5.2 | 20 | 0 |
| ST. CROIX | 10 | 4.0 | 1.8 | 2.1 | 4.5 | 13.3 | 30 | 0 |
| TAYLOR | 11 | 1.7 | 1.2 | 1.0 | 1.7 | 6.3 | 9 | 0 |
| TREMPEALEAU | 8 | 3.8 | 1.8 | 1.1 | 5.0 | 14.9 | 38 | 0 |
| VERNON | 2 | 5.1 | 4.0 | 5.1 | 4.4 | 8.2 | 50 | 0 |
| VILAS | 45 | 3.2 | 1.7 | 1.5 | 7.1 | 48.2 | 13 | 2 |
| WALWORTH | 8 | 5.8 | 4.2 | 4.2 | 6.3 | 21.0 | 50 | 13 |
| WASHBURN | 1 | 5.8 | 5.8 | 5.8 | 0.0 | 5.8 | 100 | 0 |
| WASHINGTON | 16 | 4.9 | 1.8 | 1.4 | 9.2 | 37.3 | 25 | 6 |
| WAUKESHA | 58 | 6.3 | 4.4 | 4.5 | 5.4 | 33.0 | 64 | 2 |
| WAUPACA | 39 | 4.7 | 2.8 | 3.2 | 4.6 | 21.2 | 46 | 3 |
| WAUSHARA | 7 | 0.9 | 0.6 | 1.3 | 0.6 | 1.3 | 0 | 0 |
| WINNEBAGO | 25 | 3.0 | 2.2 | 2.2 | 2.2 | 8.7 | 20 | 0 |
| WOOD | 16 | 2.0 | 1.6 | 1.7 | 1.2 | 4.3 | 6 | 0 |

## GEOLOGIC RADON POTENTIAL

An aeroradiometric map of Wisconsin (fig. 9) indicates that equivalent uranium (eU) concentrations in surficial materials are 1.0 ppm or less over most of the northern two-thirds of the State, with the exception of an area in the northeastern part of Wisconsin that is underlain by granite and granite-rich glacial deposits from the Wolf River Batholith and associated rocks (fig. 4). Many of the areas with an eU of 0.5 ppm or less, particularly in the northern part of the State, are wetlands or other areas with high water tables. Equivalent uranium concentrations in most of the southern third of the State range from 1.5 to 3.0 ppm (fig. 9). The higher values in this area appear to be associated with carbonate bedrock and carbonate-derived glacial deposits. These rocks (granites and carbonates) have the highest radon potential in the State.

Rocks of the Wolf River Batholith, particularly those of quartz monzonite and syenite composition, and glacial deposits containing these rocks as a major constituent, have high geologic radon potential. Glacial deposits covering the bedrock in this area are generally thin. Other Precambrian granites in northeastern Wisconsin may generate locally high radon levels. Areas of iron-formation, as in the Gogebic Range in Ashland and Iron Counties, may generate locally high indoor radon levels. Metamorphic rocks of mafic composition have low radon potential, but because these rocks are intruded by granites and intensely sheared in many places, and fragments of these rocks are mixed together in glacial tills, the area in northeastern Wisconsin underlain by Precambrian rocks, excluding the Wolf River rocks, has a moderate or variable radon potential.

Ordovician limestones and dolomites along the eastern, southern, and western parts of the State, particularly those of the Sinapee and Prairie du Chien Groups, also have high geologic radon potential. Although carbonate rocks are generally relatively low in uranium content, residual soils formed by weathering and dissolution of much of the calcium carbonate contain heavy mineral concentrates, including uranium minerals. This concentrating mechanism, along with the locally high rock and soil permeabilities developed in fissures and solution cavities, allow carbonate rocks and soils to generate locally high radon levels. In the southwestern part of the State, the carbonate bedrock is exposed and moderately to highly weathered near the surface. Loess in this area may also be a source of locally high radon levels. In the southeastern part of Wisconsin, the bedrock is covered with glacial deposits derived mostly from the carbonate bedrock. The glacial deposits are relatively thin over most of these rocks, with thicker glacial cover east of a line from Green Bay through western Walworth County. Clay-rich soils along the shore of Lake Michigan from Milwaukee north to Kewaunee (fig. 6I) give this area a low radon potential. South of Milwaukee, the soils are also clay-rich, but have more silt and higher surface radioactivity. This area has a moderate geologic radon potential.

Soils and glacial deposits derived from Cambrian sandstones have a moderate radon potential. These deposits cover a large area, and within this area, indoor radon values are expected to range from low to locally high. Areas underlain by greensands (glauconite-bearing sandstones) and soils derived from them (see figure 6D) are most likely to generate locally high indoor radon levels. Sandstones of the Bayfield Group in the Superior Lowland (fig. 1) have generally low radon potential (Bayfield County had an indoor radon average of 1.1 pCi/L). The Precambrian volcanic rocks immediately south of this area also have low to moderate radon potential, but the glacial deposits overlying these rocks generate moderate and locally high indoor radon levels, probably because the soils have moderate to high permeability. This area has an overall moderate or variable geologic radon potential.

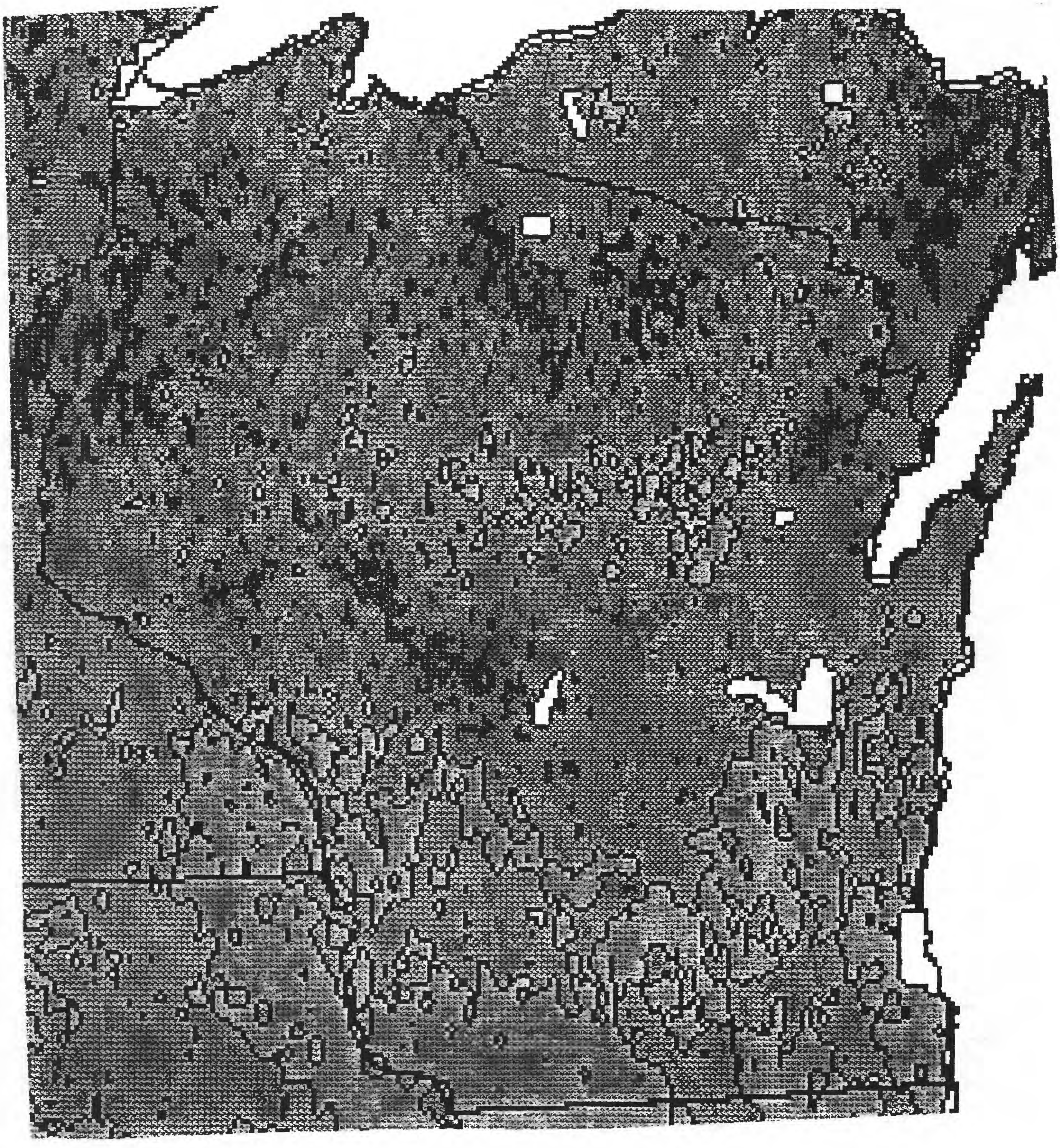


Figure 9. Aerial radiometric map of Wisconsin (after Duval and others, 1989). Contour lines at 1.5 and 2.5 ppm equivalent uranium (eU). Pixels shaded from 0 to 6.0 ppm eU at 0.5 ppm eU increments; darker pixels have lower eU values; white indicates no data.

SUMMARY

Nine areas of Wisconsin were delineated based on bedrock and glacial geology, radioactivity, soil permeability, and indoor radon data (fig. 10), and assigned Radon Index (RI) and Confidence Index (CI) scores (Table 2). A thorough discussion of the methods and data used in determining the RI and CI is given in the introduction chapter to this booklet.

Area SL, named for the Superior lobe and underlain primarily by sandstones and volcanic rocks, has moderate geologic radon potential (RI=10) with moderate confidence (CI=9). Radon levels are probably generally lower in the northern part of this area and generally somewhat higher in the southern part. Bayfield County has a generally low radon potential. Area CWL, underlain by deposits of the Chippewa, Wisconsin Valley, and Langlade sublobes of the Superior lobe, has moderate/variable geologic radon potential (RI=10) with high confidence (CI=10). Areas underlain by granites or granite-derived glacial deposits, and areas in close proximity to shear zones, may have locally high indoor radon levels. Areas underlain by mafic volcanic rocks will likely have low to moderate indoor radon levels. Area OGD, older glacial deposits, has moderate geologic radon potential (RI=10) with moderate confidence (CI=9). Areas underlain by granite bedrock or granite-rich glacial deposits, and areas underlain by greensands, may have locally high radon levels. Area WRB, the Wolf River Batholith, has high geologic radon potential (RI=13) with high confidence in the prediction (CI=10).

Area GBL, underlain by deposits of the Green Bay lobe, has moderate radon potential (RI=10) with moderate confidence (CI=9). Average radon levels in this area are uniformly moderate (2-4 pCi/L), and most homes are expected to have indoor radon levels in this range, but individual homes may have low to high radon levels depending on local conditions. Area CS is unglaciated and underlain by Cambrian sandstones. This area has moderate geologic radon potential (RI=10) with moderate confidence (CI=9). Areas underlain by greensands may have locally high radon levels. Area OC, underlain by Ordovician carbonate rocks, includes areas covered by glacial deposits in the eastern part of the area and areas where the bedrock is exposed in the western part. This area has an overall high radon potential (RI=12) with moderate confidence (CI=9). Area RBC, underlain by red-brown clayey soils, has low radon potential (RI=8) with moderate confidence (CI=9). Area CRC, underlain by clay-rich carbonate soils, has moderate geologic radon potential (RI=10) with moderate confidence (CI=9). Generally lower soil permeability and thicker glacial cover in this area appear to be the primary factors responsible for the slightly lower average indoor radon levels in this area compared to area OC to the west.

This is a generalized assessment of the State's geologic radon potential and there is no substitute for having a home tested. The conclusions about radon potential presented in this report cannot be applied to individual homes or building sites. Indoor radon levels, both high and low, can be quite localized, and within any radon potential area there will likely be areas with higher or lower radon potential that assigned to the area as a whole. Any local decisions about radon should <u>not</u> 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 2. Radon Index (RI) and Confidence Index (CI) scores for geologic radon potential areas of Wisconsin. See figure 10 for locations and abbreviations of areas.

| | AREA | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | SL | | CWL | | OGD | | WRB | |
| FACTOR | RI | CI | RI | CI | RI | CI | RI | CI |
| INDOOR RADON | 2 | 3 | 2 | 3 | 2 | 3 | 3 | 3 |
| RADIOACTIVITY | 1 | 2 | 1 | 2 | 1 | 2 | 2 | 2 |
| GEOLOGY | 2 | 2 | 2 | 3 | 2 | 2 | 3 | 3 |
| SOIL PERM. | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| ARCHITECTURE | 3 | -- | 3 | -- | 3 | -- | 3 | -- |
| GFE POINTS | 0 | -- | 0 | -- | 0 | -- | 0 | -- |
| TOTAL | 10 | 9 | 10 | 10 | 10 | 9 | 13 | 10 |
| RANKING | MOD | MOD | MOD | HIGH | MOD | MOD | HIGH | HIGH |

| | GBL | | CS | | OC | | RBC | | CRC | |
|---|---|---|---|---|---|---|---|---|---|---|
| FACTOR | RI | CI | RI | CI | RI | CI | RI | CI | RI | CI |
| INDOOR RADON | 2 | 3 | 2 | 3 | 2 | 3 | 2 | 3 | 2 | 3 |
| RADIOACTIVITY | 1 | 2 | 1 | 2 | 2 | 2 | 1 | 2 | 2 | 2 |
| GEOLOGY | 2 | 2 | 2 | 2 | 3 | 2 | 1 | 2 | 2 | 2 |
| SOIL PERM. | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 1 | 2 |
| ARCHITECTURE | 3 | -- | 3 | -- | 3 | -- | 3 | -- | 3 | -- |
| GFE POINTS | 0 | -- | 0 | -- | 0 | -- | 0 | -- | 0 | -- |
| TOTAL | 10 | 9 | 10 | 9 | 12 | 9 | 8 | 9 | 10 | 9 |
| RANKING | MOD | MOD | MOD | MOD | HIGH | MOD | LOW | MOD | MOD | 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

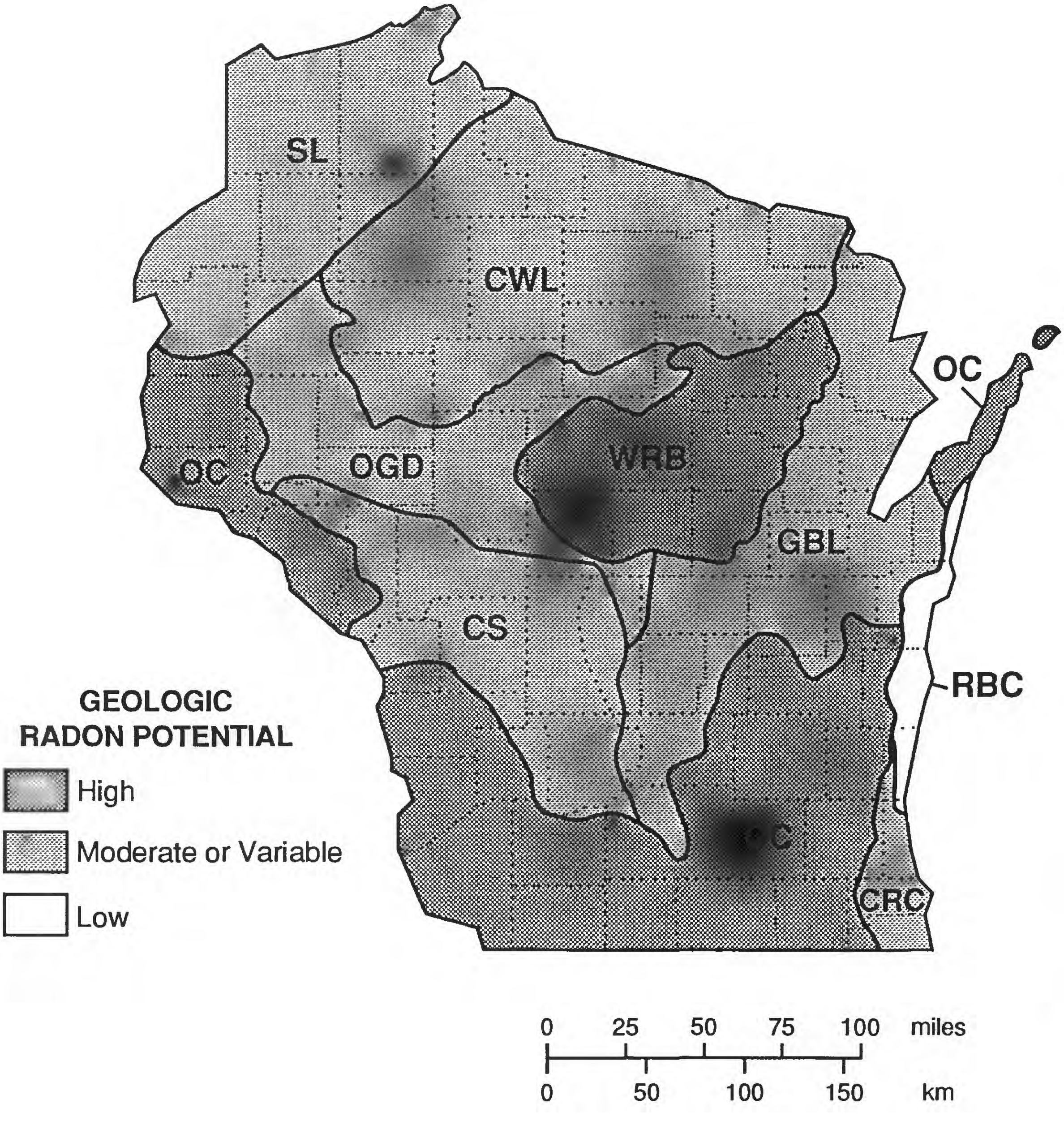



Figure 10. Geologic radon potential areas of Wisconsin. SL, Superior Lobe; CWL, Chippewa, Wisconsin Valley, and Langlade sublobes of the Superior Lobe; OGD, older glacial deposits; WRB, Wolf River Batholith; GBL, Green Bay Lobe; CS, Cambrian sandstones; OC, Ordovician carbonate rocks; RBC, red-brown clayey soils; CRC, clay-rich carbonate soils.

Kalliokoski, J., 1976, Uranium and thorium occurrences in Precambrian rocks, Upper Peninsula of Michigan and northern Wisconsin, with thoughts on other possible settings: Report prepared for the U.S. Energy Research and Development Administration, Grand Junction , CO, GJBX 48(76), 294 p.

Kochis, N.S., Orlovsky, S.J. and Leavitt, S.W., 1989, Radon emanations in surficial geologic deposits of Kenosha, Racine and Waukesha counties in southeastern Wisconsin: Geological Society of America, Abstracts with Programs, v. 21, no. 4, p. 18.

Martin, Lawrence, 1916, The physical geography of Wisconsin: Wisconsin Geological and Natural History Survey Bulletin 36, 549 p.

Mudrey, M.G., Jr., Brown, B.A., and Greenberg, J.K., 1982, Bedrock geologic map of Wisconsin: Wisconsin Geological and Natural History Survey, scale 1:1,000,000.

Ostrom, M.E., 1976, Paleozoic rocks, *in* Dutton, C.E., and Ostrom, M.E. (eds), Mineral and water resources of Wisconsin: Report prepared by the U.S. Geological Survey and the Wisconsin Geological and Natural History Survey for the U.S. Senate Committee on Interior and Insular Affairs: U.S. Government Printing Office, p. 23-37.

Paull, R.K., and Paull, R.A., 1977, Geology of Wisconsin and upper Michigan including parts of adjacent states: Dubuque, Iowa, Kendall/Hunt Publishing Company, 232 p.

Richmond, G.R., and Fullerton, D.S. (eds.), Quaternary Geologic Atlas of the United States: U.S. Geological Survey Miscellaneous Investigations Map I-1420, sheet NL-15, Minneapolis 4°x6° quadrangle, 1983a; sheet NL-16, Lake Superior 4°x6° quadrangle, 1984; sheet NK-15, Des Moines 4°x6° quadrangle, 1991; sheet NK-16, Chicago 4°x6° quadrangle, 1983b; scale 1:1,000,000.

Routledge, R.E., Parrish, I.S. and Leigh, O.E., 1982, Ashland Quadrangle, Wisconsin, Michigan, and Minnesota: U.S Department of Energy, National Uranium Resource Evaluation Report PGJ/F-084(82), 31 p.

Schnabel, R.W., 1976, Uranium-thorium, *in* Dutton, C.E., and Ostrom, M.E. (eds), Mineral and water resources of Wisconsin: Report prepared by the U.S. Geological Survey and the Wisconsin Geological and Natural History Survey for the U.S. Senate Committee on Interior and Insular Affairs: U.S. Government Printing Office, p. 132.

Scott, M.R., Rotter, R.J. and Salter, P.F., 1985, Transport of fallout plutonium to the ocean by the Mississippi River: Earth and Planetary Science Letters, v. 75, p. 321-326.

Steck, D.J., 1987 , Geological variation of radon sources and indoor radon concentrations along the southwestern edge of the Canadian Shield: Health Physics, v. 52, p. S40.

## REFERENCES CITED IN THIS REPORT AND GENERAL REFERENCES RELATED TO RADON IN WISCONSIN


Blackburn, W.H. and Mathews, G.W., 1982, Evaluation of uranium anomalies in the McCaslin Syncline, northeastern Wisconsin: U.S. Department of Energy, National Uranium Resource Evaluation Report GJBX-222(82), p. 43-67.

Crowns, Byron, 1976, Wisconsin through 5 billion years of change: Wisconsin Rapids, WI: Wisconsin Earth Science Center, 318 p.

Dutton, C.E., 1976, Precambrian geology, *in* Dutton, C.E., and Ostrom, M.E. (eds), Mineral and water resources of Wisconsin: Report prepared by the U.S. Geological Survey and the Wisconsin Geological and Natural History Survey for the U.S. Senate Committee on Interior and Insular Affairs: U.S. Government Printing Office, p. 11-22.

Duval, J.S., Jones, W.J., Riggle, F.R., and Pitkin, J.A., 1989, Equivalent uranium map of the conterminous United States: U.S. Geological Survey Open-File Report 89-478, 10 p.

Frye, J.C., Willman, H.B., and Black, R.F., 1965, Outline of glacial geology of Illinois and Wisconsin, *in* Wright, H.E., Jr., and Frey, D.G. (eds.), The Quaternary of the United States: Princeton, NJ, Princeton University Press, p. 29-41.

Gundersen, L.C.S., Peake, R.T., Latzke, G.D., Hauser, L.M., and Wiggs, C.R., 1991, A statistical summary of uranium and radon in soils from the Coastal Plain of Texas, Alabama, and New Jersey, *in* The 1990 International Symposium on Radon and Radon Reduction Technology, Atlanta, Ga., 19-23 February 1990, Proceedings, Vol. 3: Symposium Poster Papers: Research Triangle Park, N.C., U.S. Environmental Protection Agency Rept. EPA600/9-91-026c, p. 6-35--6-47.

Hadley, D.W., and Pelham, J.H., 1976, Glacial deposits of Wisconsin: Wisconsin Geological and Natural History Survey Map 10, scale 1:500,000.

Hadley, D.W., 1976, Glacial geology, *in* Dutton, C.E., and Ostrom, M.E. (eds), Mineral and water resources of Wisconsin: Report prepared by the U.S. Geological Survey and the Wisconsin Geological and Natural History Survey for the U.S. Senate Committee on Interior and Insular Affairs: U.S. Government Printing Office, p. 38-55.

Hole, F.D., 1976a, Soils of Wisconsin: Wisconsin Geological and Natural History Survey Bulletin 87, 223 p.

Hole, F.D., 1976b, Soil guide for Wisconsin land lookers: Wisconsin Geological and Natural History Survey Bulletin 88, 66 p.

Hudson, T.B. and Nelson, R.S., 1989, Analysis of radon concentrations and Pleistocene deposits in Illinois: Transactions of the Illinois State Academy of Science 82, Suppl., p. 49.

Steck, D.J., 1988, Geological variation of radon sources and indoor radon along the southwestern edge of the Canadian Shield, *in* M.A. Marikos and R.H. Hansman (eds), Geologic causes of natural radionuclide anomalies: Proceedings of GEORAD Conference, St. Louis, MO, April 21-22, 1987, Missouri Department of Natural Resources Special Publication 4, p. 17-23.

Sims, P.K., 1976, Precambrian tectonics and mineral deposits, Lake Superior region: Economic Geology, v. 71, p. 1092-1127.

Sims, P.K., 1992, Geologic map of Precambrian rocks, southern Lake Superior region, Wisconsin and northern Michigan: U.S. Geological Survey Miscellaneous Investigations Map I-2185, scale 1:500,000.

Thwaites, F.T., 1960, Ice age deposits of Wisconsin: Wisconsin Geological and Natural History Survey map, scale approximately 1:2,730,000.

Wisconsin Geological Survey, 1956, Uranium prospecting in Wisconsin: Wisconsin Geological Survey Information Circular 2, 6 p.

Wisconsin Geological and Natural History Survey, 1981, Bedrock geology of Wisconsin: Wisconsin Geological and Natural History Survey map, scale approx. 1:2,725,000.

Wisconsin Department of Natural Resources and Wisconsin Geological and Natural History Survey, 1987, Groundwater contamination susceptibility in Wisconsin: Wisconsin Geological and Natural History Survey map, scale 1:1,000,000.

Wright, H.E., Jr., Matsch, C.L., and Cushing, E.J., 1973, Superior and Des Moines lobes, *in* Black, R.F., Goldthwait, R.P., and Willman, H.B. (eds), The Wisconsinan Stage: Geological Society of America Memoir 136, p. 153-85.