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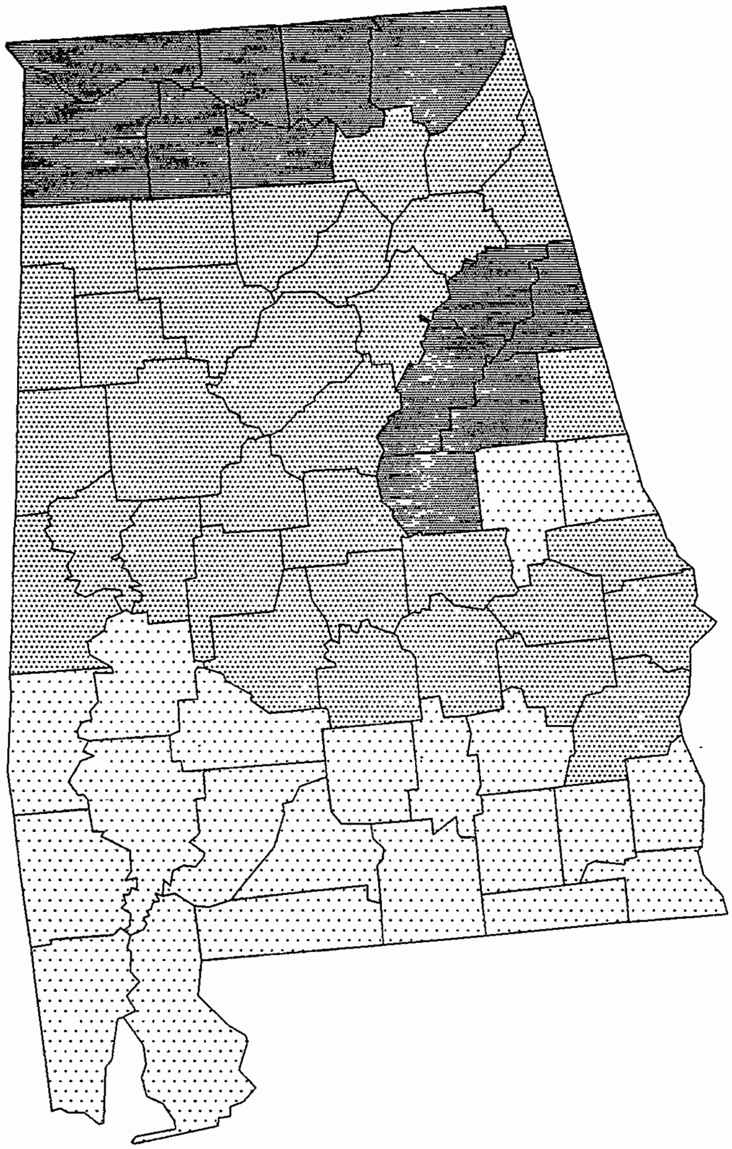
# EPA's Map of Radon Zones

## ALABAMA



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# EPA'S MAP OF RADON ZONES
# ALABAMA

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

SEPTEMBER, 1993

## ACKNOWLEDGEMENTS

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## OVERVIEW

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

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

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

## BACKGROUND

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

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

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

## Purpose of the Map of Radon Zones

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

- o Zone 1 counties have a predicted average indoor screening level > than 4 pCi/L
- o Zone 2 counties have a predicted average screening level ≥ 2 pCi/L and ≤ 4 pCi/L
- o Zone 3 counties have a predicted average screening level < 2 pCi/L

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

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

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

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

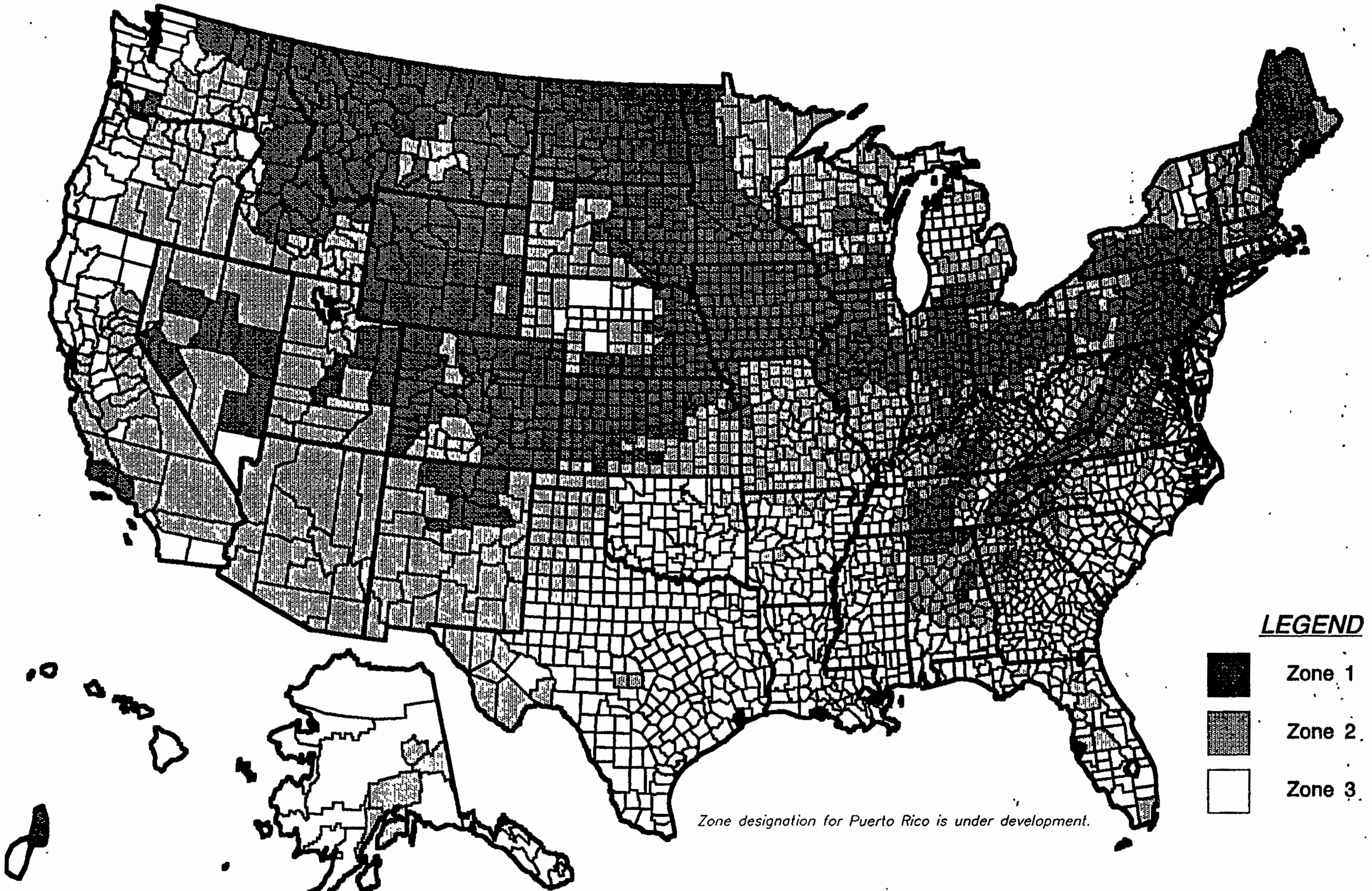
The Map of Radon Zones and its supporting documentation establish no regulatory requirements. Use of this map by State or local radon programs and building code officials is voluntary. The information presented on the Map of Radon Zones and in the supporting documentation is not applicable to radon in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

## Development of the Map of Radon Zones

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

Figure 1

# EPA Map of Radon Zones




*Guam – Preliminary Zone designation.*

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

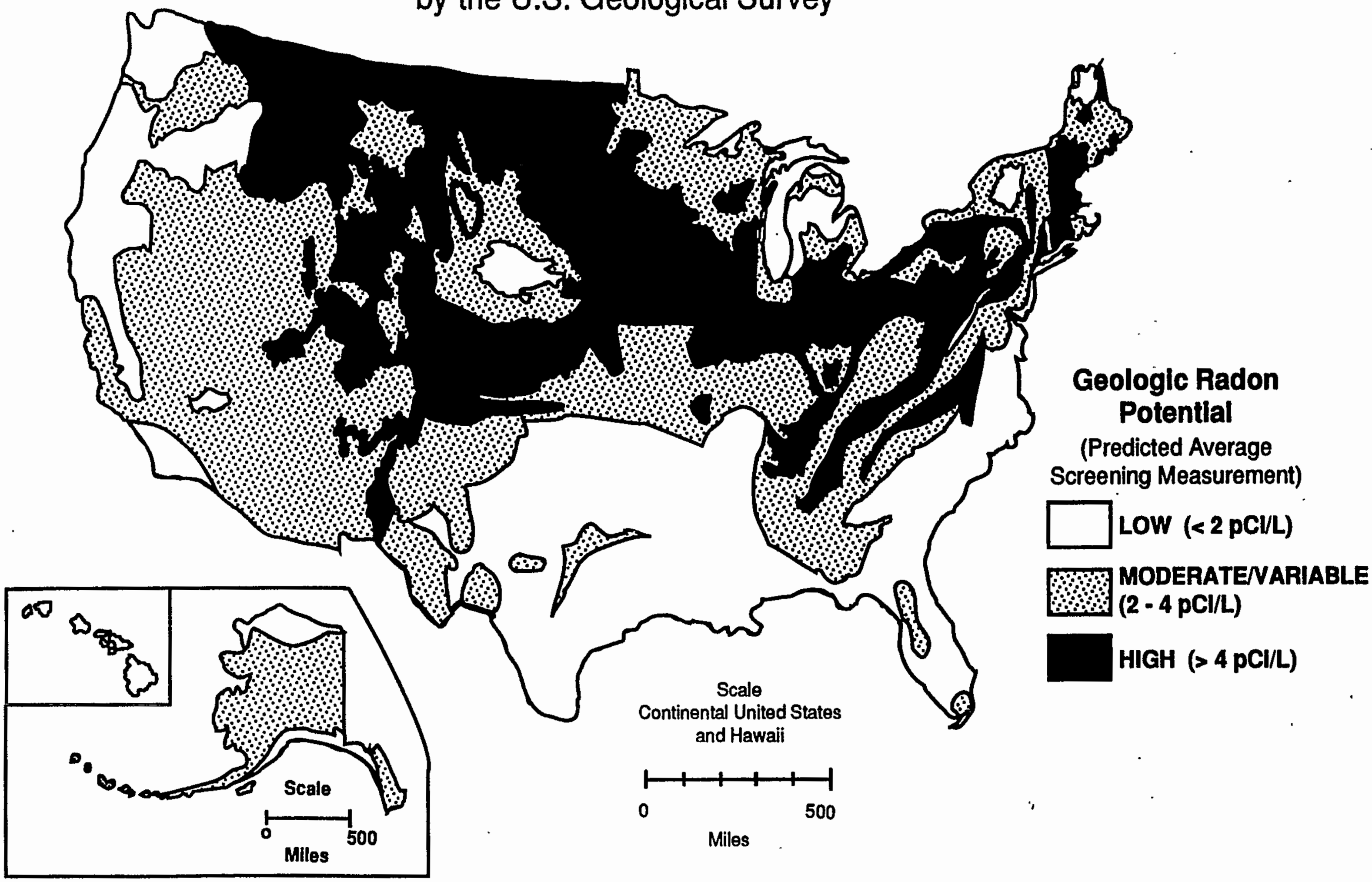
*This map is not intended to be used to determine if a home in a given zone should be tested for radon. Homes with elevated levels of radon have been found in all three zones.* ***All homes should be tested, regardless of geographic location.***

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

Figure 2

# GENERALIZED GEOLOGIC RADON POTENTIAL OF THE UNITED STATES

by the U.S. Geological Survey

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

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

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

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

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

Map Validation

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

Figure 3

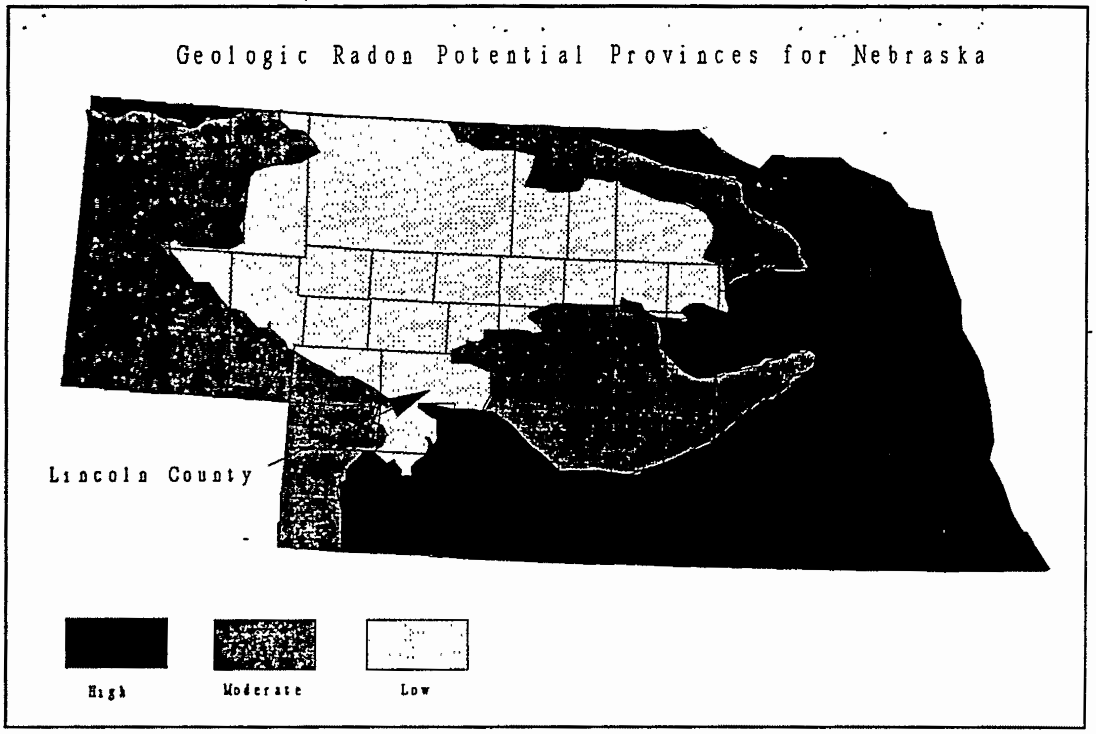
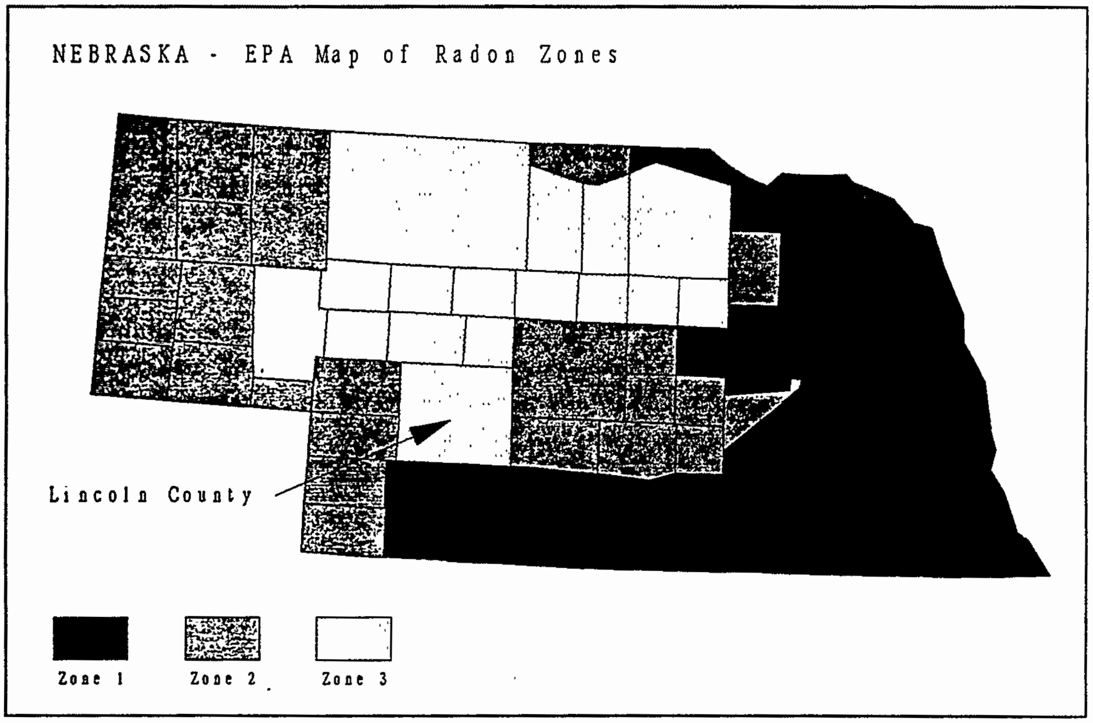



Figure 4



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

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

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

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

## Review Process

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

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

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

# THE USGS/EPA RADON POTENTIAL ASSESSMENTS: AN INTRODUCTION

*by*
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## BACKGROUND

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

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

Because of constraints on the scales of maps presented in these reports and because the smallest units used to present the indoor radon data are counties, some generalizations have been made in order to estimate the radon potential of each area. Variations in geology, soil characteristics, climatic factors, homeowner lifestyles, and other factors that influence radon concentrations can be quite large within any particular geologic area, so these reports cannot be used to estimate or predict the indoor radon concentrations of individual homes or housing tracts. Within any area of a given geologic radon potential ranking, there are likely to be areas where the radon potential is lower or higher than that assigned to the area as a whole, especially in larger areas such as the large counties in some western states.

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

## RADON GENERATION AND TRANSPORT IN SOILS

Radon ($^{222}Rn$) 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

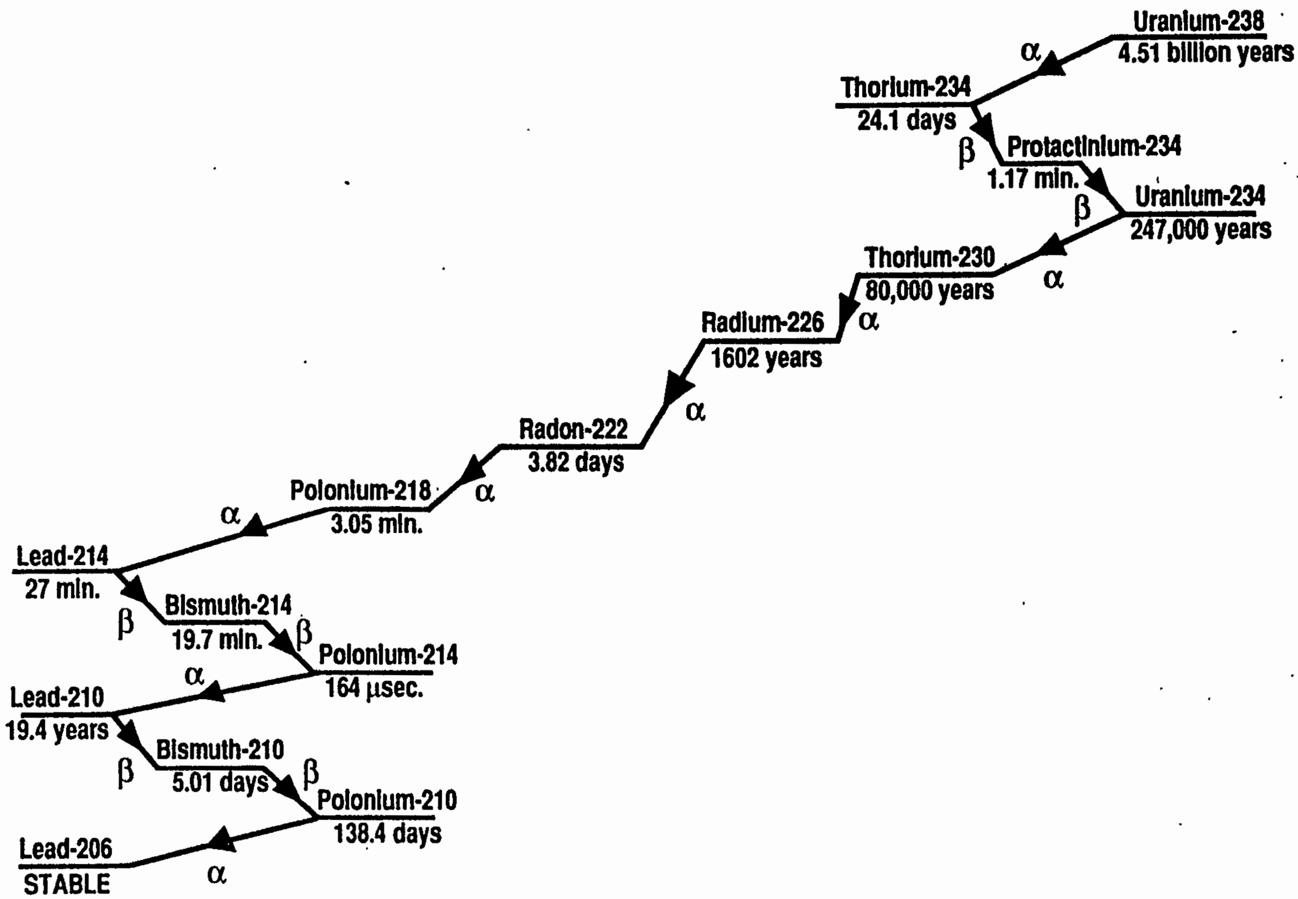


Figure 1. The uranium-238 decay series, showing the half-lives of elements and their modes of decay (after Wanty and Schoen, 1991). α denotes alpha decay, β denotes beta decay.

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

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

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

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

Homes in hilly limestone regions of the southern Appalachians were found to have higher indoor radon concentrations during the summer than in the winter. A suggested cause for this phenomenon involves temperature/pressure-driven flow of radon-laden air from subsurface solution cavities in the carbonate rock into houses. As warm air enters solution cavities that are higher on the hillslope than the homes, it cools and settles, pushing radon-laden air from lower in the cave or cavity system into structures on the hillslope (Gammage and others, 1993). In contrast, homes built over caves having openings situated below the level of the home had higher indoor radon levels in the winter, caused by cooler outside air entering the cave, driving radon-laden air into cracks and solution cavities in the rock and soil, and ultimately, into homes (Gammage and others, 1993).

## RADON ENTRY INTO BUILDINGS

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

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

## METHODS AND SOURCES OF DATA

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

### GEOLOGIC DATA

The types and distribution of lithologic units and other geologic features in an assessment area are of primary importance in determining radon potential. Rock types that are most likely to cause indoor radon problems include carbonaceous black shales, glauconite-bearing sandstones, certain kinds of fluvial sandstones and fluvial sediments, phosphorites, chalk, karst-producing carbonate rocks, certain kinds of glacial deposits, bauxite, uranium-rich granitic rocks, metamorphic rocks of granitic composition, silica-rich volcanic rocks, many sheared or faulted rocks, some coals, and certain kinds of contact metamorphosed rocks. Rock types least likely to cause radon problems include marine quartz sands, non-carbonaceous shales and siltstones, certain kinds of clays, silica-poor metamorphic and igneous rocks, and basalts. Exceptions exist within these general lithologic groups because of the occurrence of localized uranium deposits, commonly of the hydrothermal type in crystalline rocks or the "roll-front" type in sedimentary rocks. Uranium and radium are commonly sited in heavy minerals, iron-oxide coatings on rock and soil grains, and organic materials in soils and sediments. Less common are uranium associated with phosphate and carbonate complexes in rocks and soils, and uranium minerals.

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

## NURE Aerial Radiometric Data

Aerial radiometric data are used to quantify the radioactivity of rocks and soils. Equivalent uranium (eU) data provide an estimate of the surficial concentrations of radon parent materials (uranium, radium) in rocks and soils. Equivalent uranium is calculated from the counts received by a gamma-ray detector from the 1.76 MeV (mega-electron volts) emission energy corresponding to bismuth-214 ($^{214}Bi$), 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).

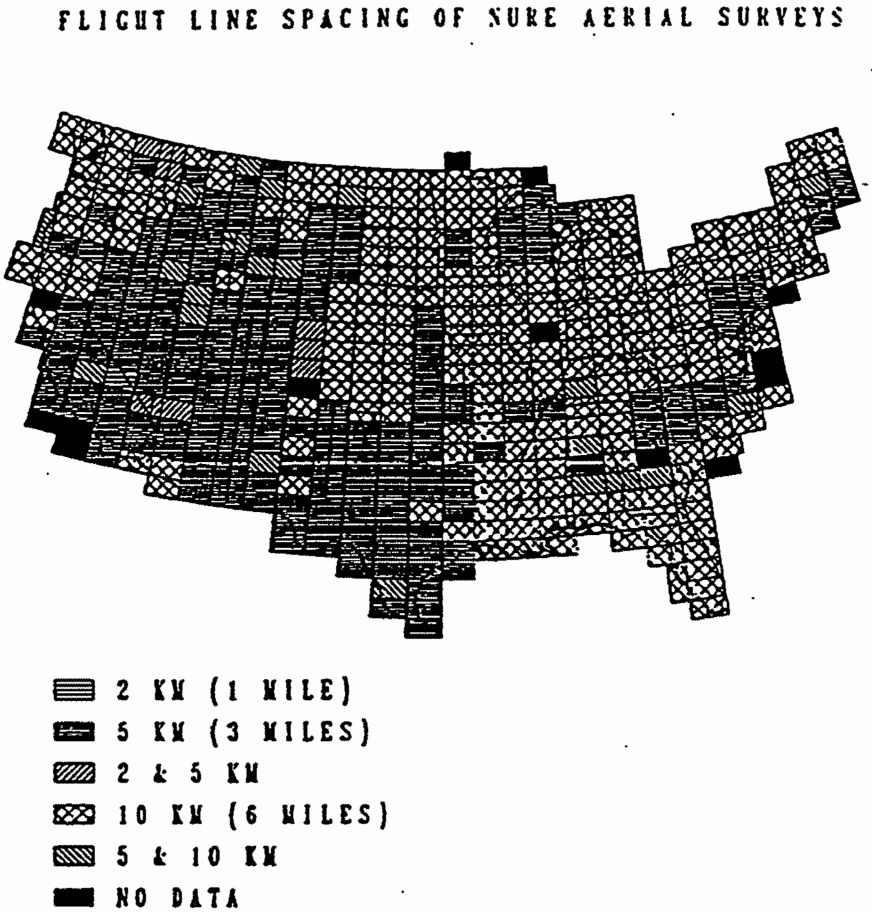


Figure 2. Nominal flightline spacings for NURE aerial gamma-ray surveys covering the contiguous United States (from Duval and others, 1990). Rectangles represent 1°x2° quadrangles.

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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.

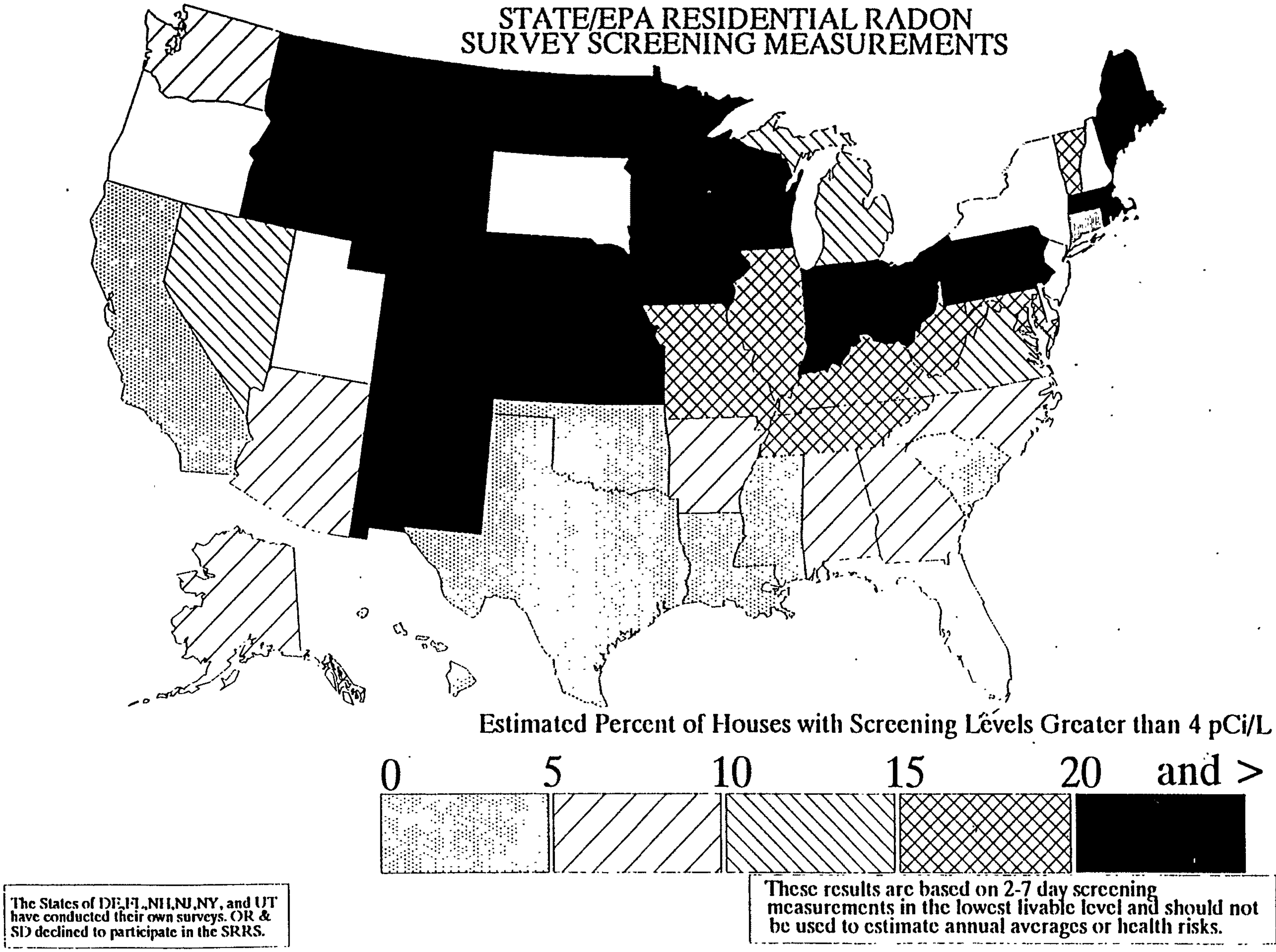


Figure 3. Percent of homes tested in the State/EPA Residential Radon Survey with screening indoor radon levels exceeding 4 pCi/L.

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

## RADON INDEX AND CONFIDENCE INDEX

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

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

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

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

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

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, localizeddistribution of uranium, or other factors. Geologic information indicates not only how much uranium is present in the rocks and soils but also gives clues for predicting general radon emanation and mobility characteristics through additional factors such as structure (notably the presence of faults or shears) and geochemical characteristics (for example, a phosphate-rich sandstone will likely contain more uranium than a sandstone containing little or no phosphate because the phosphate forms chemical complexes with uranium). "Negative", "variable", and "positive" geology were assigned 1, 2, and 3 points, respectively.

In cases where additional reinforcing or contradictory geologic evidence is available, Geologic Field Evidence (GFE) points were added to or subtracted from an area's score (Table 1). Relevant geologic field studies are important to enhancing our understanding of how geologic processes affect radon distribution. In some cases, geologic models and supporting field data reinforced an already strong (high or low) score; in others, they provided important contradictory data. GFE points were applied for geologically-sound evidence that supports the prediction (but which may contradict one or more factors) on the basis of known geologic field studies in the area or in areas with geologic and climatic settings similar enough that they could be applied with full confidence. For example, areas of the Dakotas, Minnesota, and Iowa that are covered with Wisconsin-age glacial deposits exhibit a low aerial radiometric signature and score only one RI point in that category. However, data from geologic field studies in North Dakota and Minnesota (Schumann and others, 1991) suggest that eU is a poor predictor of geologic radon potential in this area because radionuclides have been leached from the upper soil layers but are present and possibly even concentrated in deeper soil horizons, generating significant soil-gas radon. This positive supporting field evidence adds two GFE points to the score, which helps to counteract the invalid conclusion suggested by the radiometric data. No GFE points are awarded if there are no documented field studies for the area.

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

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

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

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

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

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

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

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

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

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# APPENDIX A
# GEOLOGIC TIME SCALE

| Subdivisions (and their symbols) | | | | | | Age estimates of boundaries in mega-annum (Ma)[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 (Pe) | 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 (TR) | | Late | Upper | |
| | | | | Middle | Middle | |
| | | | | Early | Lower | ~240 |
| | Paleozoic[2] (Pz) | Permian (P) | | Late | Upper | |
| | | | | Early | Lower | 290 (290–305) |
| | | Carboniferous Systems (C) | Pennsylvanian (IP) | 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 (P) | Late Proterozoic (Z) | None defined | | | | 900 |
| | Middle Proterozoic (Y) | None defined | | | | 1600 |
| | Early Proterozoic (X) | None defined | | | | 2500 |
| Archean (A) | Late Archean (W) | None defined | | | | 3000 |
| | Middle Archean (V) | None defined | | | | 3400 |
| | Early Archean (U) | None defined | | | | 3800 ? |
| pre-Archean (pA)[4] | | | | | | |

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

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

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

[4] Informal time term without specific rank.

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## 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

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Philadelphia, PA 19107
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EPA Region 4
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Atlanta, GA 30365
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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
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EPA Region 7
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Kansas City, KS 66101
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San Francisco, CA 94105
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| 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 |

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# STATE GEOLOGICAL SURVEYS
May, 1993

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EPA REGION 4 GEOLOGIC RADON POTENTIAL SUMMARY

*by*

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

Major geologic/physiographic provinces for Region 4 are shown in figure 1 and are referred to in the summary that follows. The moderate climate, use of air conditioning, evaporative coolers, or open windows for ventilation, and the small proportion of homes with basements throughout much of Region 4 contribute to generally low indoor radon levels in spite of the fact that this area has substantial areas of high surface radioactivity.

Maps showing arithmetic means of measured indoor radon levels are shown in figure 2. Indoor radon data for Alabama, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, and Tennessee are from the State/EPA Residential Radon Survey. Data for Florida are from the Florida Statewide Radon Study. County screening indoor radon averages range from less than 1 pCi/L to 4.6 pCi/L. The geologic radon potential areas in Region 4 have been summarized from the individual state chapters and are shown in figure 3.

## ALABAMA

### *The Plateaus*

The Interior Low Plateaus have been ranked high in geologic radon potential. The Mississippian carbonate rocks and shales that underlie this province appear to have high (>2.5 ppm eU) to moderate (1.5-2.5 ppm eU) radioactivity associated with them. The carbonates and shales are also associated with most of the highest county indoor radon averages for the State, particularly in Colbert, Madison, Lawrence, and Lauderdale Counties. The geologic units that may be the source of these problems, as indicated by the radioactivity, appear to be parts of the Fort Payne Chert, the Tuscumbia Limestone, the Monteagle, Bangor, Pride Mountain, and Parkwood Formations, and the Floyd Shale. Indoor radon levels in homes built on the St. Genevieve Limestone, Tuscumbia Limestone, and Fort Payne Chert averaged between 3.0 and 4.3 pCi/L. Soils developed from carbonate rocks are often elevated in uranium and radium. Carbonate soils are derived from the dissolution of the $CaCO_3$ that makes up the majority of the rock. When the $CaCO_3$ has been dissolved away, the soils are enriched in the remaining impurities, predominantly

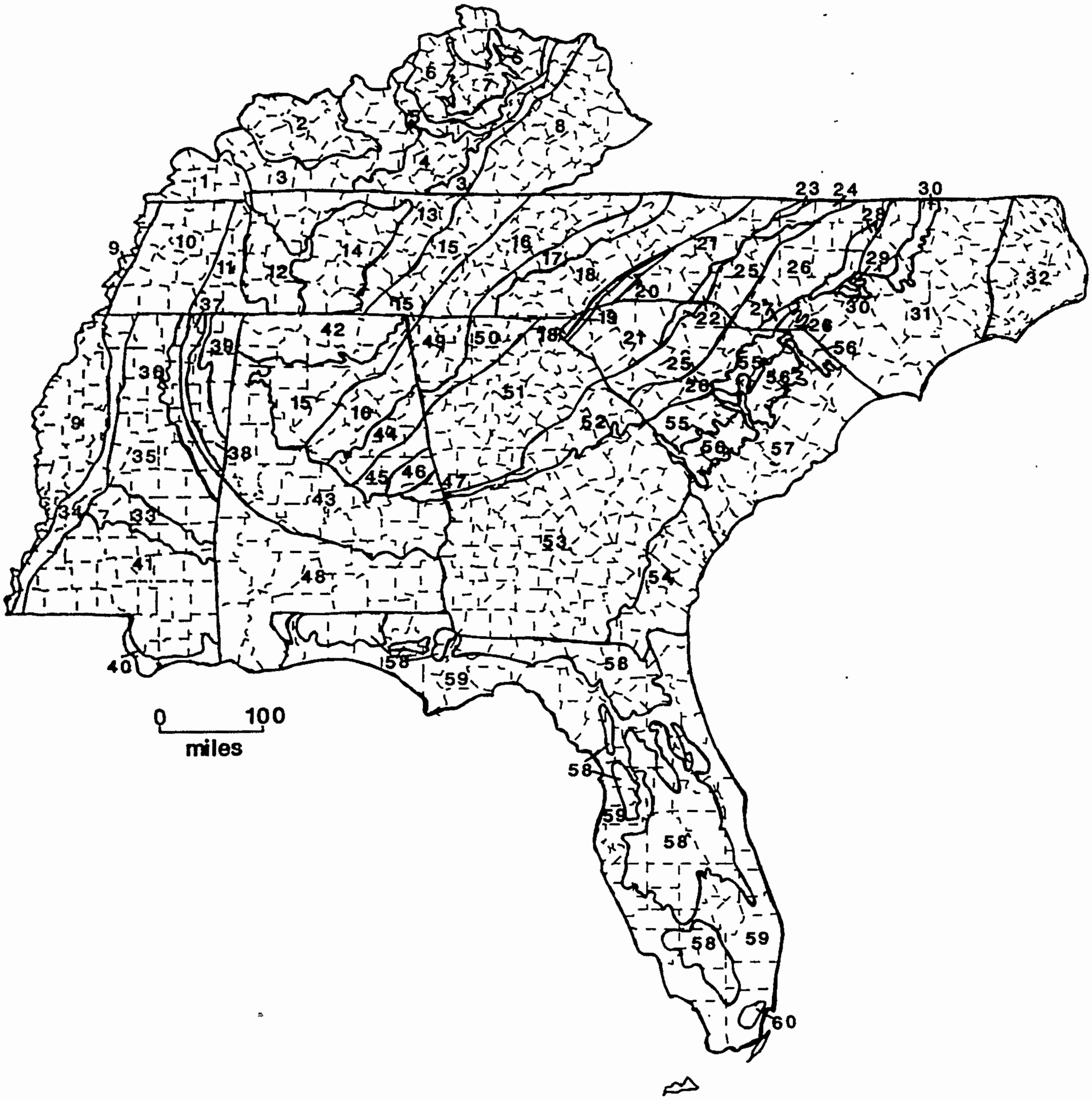


Figure 1. Geologic radon potential areas of EPA Region 4. See next page for names of numbered areas.

Figure 1 (continued). Geologic radon potential areas of EPA Region 4. Note: although some areas, for example, the Coastal Plain, are contiguous from state to state, they are sometimes referred to by slightly different names or are subdivided differently in different states, thus are numbered and labelled seperately on this figure.

1–Jackson Purchase (Coastal Plain)
2–Western Coalfield
3–Mississippian Plateau
4–Eastern Pennyroyal
5–New Albany Shale
6–Outer Bluegrass
7–Inner Bluegrass
8–Cumberland Plateau (Appalachian Plateau)
9–Mississippi alluvial plain
10–Loess-covered Coastal Plain
11–Eastern Coastal Plain
12–Cherty Highland
13–Highland Rim
14–Nashville Basin
15–Appalachian Plateau
16–Ridge and Valley
17–Unaka Mountains
18–Blue Ridge Belt
19–Brevard Fault Zone
20–Chauga Belt
21–Inner Piedmont
22–Kings Mountain Belt
23–Dan River Basin
24–Milton Belt
25–Charlotte Belt
26–Carolina Slate Belt
27–Wadesboro sub-basin
28–Sanford-Durham sub-basins
29–Raleigh Belt
30–Eastern Slate Belt
31–Inner Coastal Plain
32–Outer Coastal Plain
33–Jackson Prairies
34–Loess Hills
35–North Central Hills
36–Flatwoods
37–Pontotoc Ridge
38–Black Prairies
39–Tombigbee Hills
40–Coastal Pine Meadows
41–Pine Hills
42–Interior Low Plateaus
43–Inner Coastal Plain (Cretaceous)
44–Northern Piedmont (faults, phylite and granite rocks)
45–Wedowee and Emuckfaw Groups
46–Inner Piedmont/Dadeville Complex
47–Southern Piedmont
48–Inner and Outer Coastal Plain (Tertiary Rocks)
49–Rome-Kingston Thrust Stack
50–Georgiabama Thrust Stack (north of Allatoona Fault)
51–Georgiabama Thrust Stack (south of Allatoona Fault)
52–Little River Thrust Stack
53–Coastal Plain (Cretaceous/Tertiary)
54–Coastal Plain (Quaternary/Pliocene-Pleistocene gravels)
55–Upper Coastal Plain
56–Middle Coastal Plain
57–Lower Coastal Plain
58–Highlands
59–Lowlands
60–Dade County anomalous area.

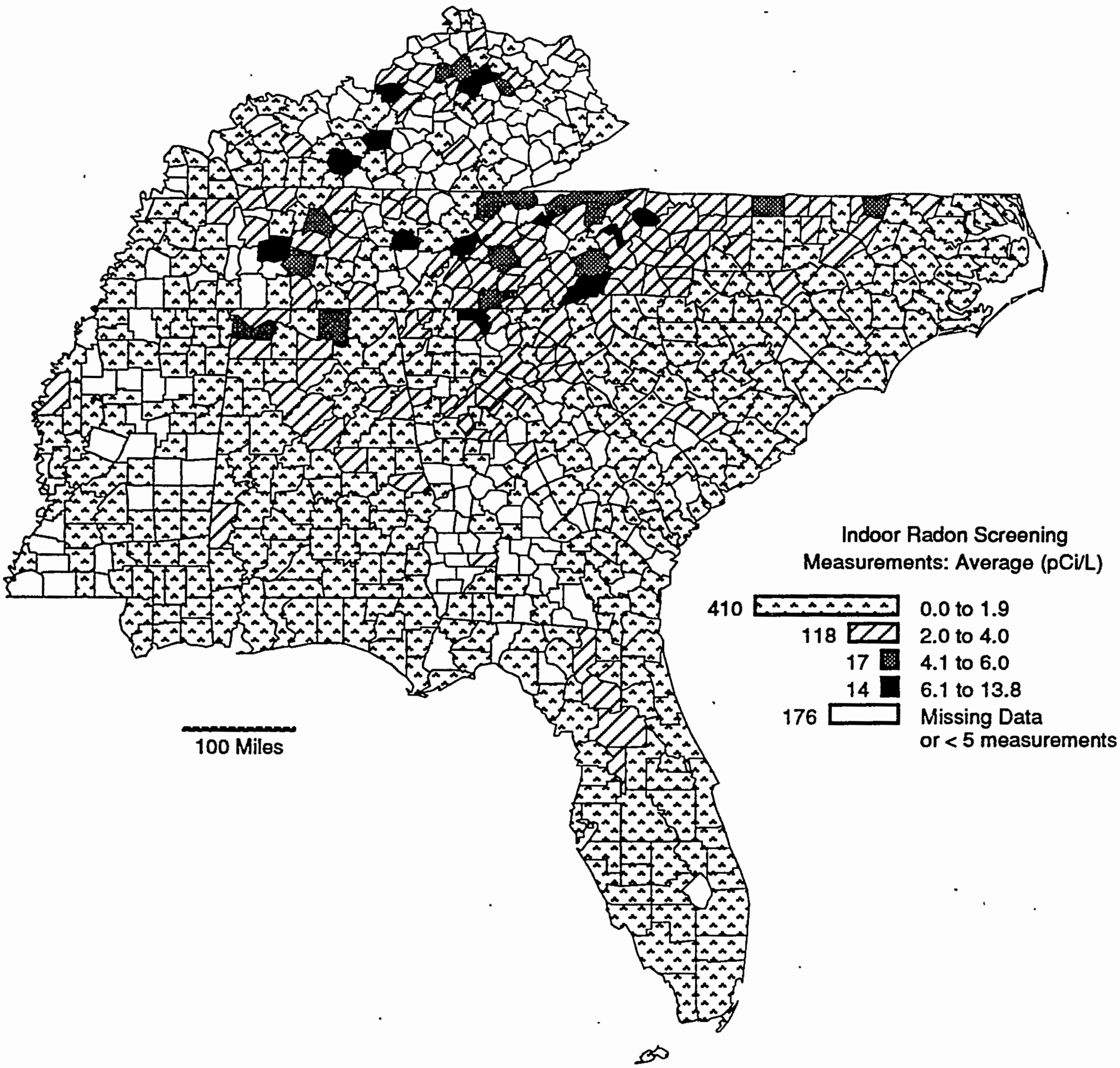


Figure 2. Screening indoor radon averages for counties with 5 or more measurements in EPA Region 4. Data for all states in Region4 except Florida from the State/EPA Residential Radon Survey. Data for Florida are from the Florida Statewide Radon Study. Histograms in map legend show the number of counties in each category.

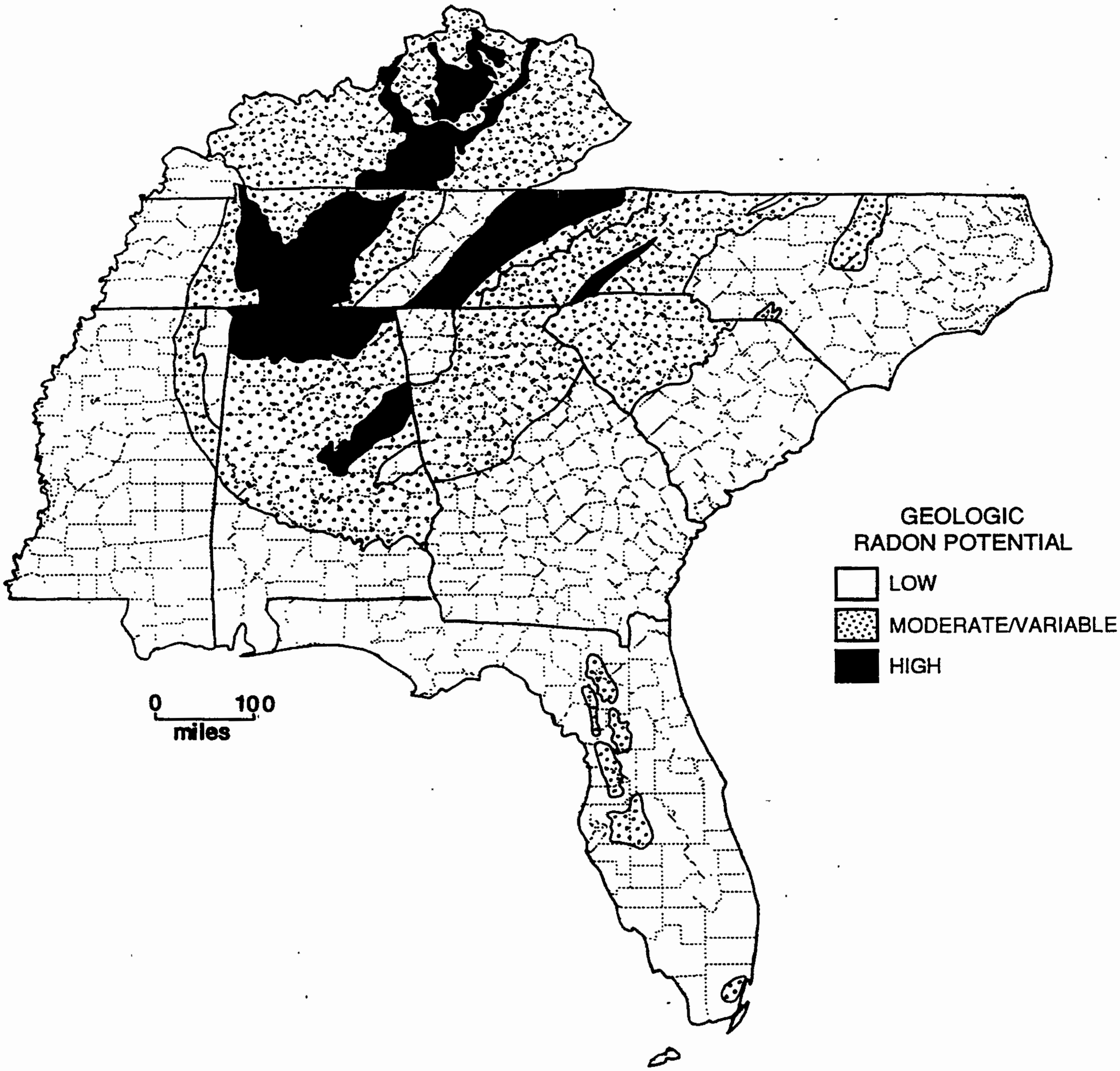


Figure 3. Geologic radon potential areas of EPA Region 4. For more detail, refer to individual state radon potential chapters.

base metals, including uranium. Rinds containing high concentrations of uranium and uranium minerals can be formed on the surfaces of rocks affected by $CaCO_3$ dissolution and karstification. Karst and cave morphology is also thought to promote the flow and accumulation of radon. Because carbonate soils are clayey, they have a tendency to crack when they dry and may develop very high permeability from the fractures. Under moist conditions, however, the soils derived from carbonates have generally low permeability.

The Appalachian Plateaus region is ranked moderate in radon potential. Indoor radon is generally low (< 2 pCi/L) to moderate (2-4 pCi/L). Radioactivity is low to moderate and soil permeability is moderate. The sandstone of the Pottsville Formation is not noted for being uranium-bearing, but uraniferous carbonaceous shales interbedded with the sandstone may be the cause of locally moderate to high (>4 pCi/L) indoor radon. Cullman County had several indoor radon measurements greater than 4 pCi/L, including one measurement of 19.8 pCi/L. Winston and Walker Counties also had several indoor radon levels greater than 4 pCi/L in the Alabama Department of Public Health data set.

*Valley and Ridge*

The Valley and Ridge province has been ranked moderate in geologic radon potential. Radioactivity is generally moderate in the Valley and Ridge, with high radioactivity occurring along the southeastern border with the Piedmont. Indoor radon is highly variable, with generally low county averages and one high county average. Most of the counties had a few readings greater than 4 pCi/L. The soils of the Valley and Ridge have low to moderate permeability. The permeability may be locally high in dry clayey soils and karst areas. Carbonate soils derived from Cambrian-Ordovician rock units of the Valley and Ridge province cause known indoor radon problems in eastern Tennessee, western New Jersey, western Virginia, eastern West Virginia and central and eastern Pennsylvania. Further, the Devonian Chattanooga Shale crops out locally in parts of the Valley and Ridge. This shale is widely known to be highly uraniferous and has been identified as a source of high indoor radon in Kentucky.

*Piedmont*

Where it is possible to associate high radioactivity and/or high indoor radon levels with particular areas, parts of the Piedmont have been ranked moderate to high in radon potential. Radiometric anomalies occur over the Talladega Fault zone, which separates the Paleozoic carbonates from the metamorphic rocks. Some of the metamorphic rocks in the Northern Piedmont, including the Poe Bridge Mountain Group, the Mad Indian Group, parts of the Wedowee Group, and the Higgins Ferry Group, also have high radioactivity associated with them. In many cases the radiometric anomalies appear to be associated with rocks in fault zones, graphitic schists and phyllites, felsic gneiss, and other granitic rocks. Furthermore, Talladega, Calhoun, Cleburne, and Randolph Counties all have some high indoor radon measurements. Uranium in graphitic phyllite with an assay value of 0.076 percent $U_3O_8$ has been reported from Cleburne County and similar graphitic phyllites from the Georgia Piedmont average 4.7 ppm uranium. Graphitic phyllites and schists in other parts of the Piedmont are known sources of radon and have high indoor radon levels associated with them . Another source of uranium in Piedmont metamorphic rocks is monazite, which contains high amounts of both uranium and thorium. It is a common accessory mineral in gneisses and granites throughout the Piedmont and its resistance to weathering and high density result in local monazite concentrations in saprolite. A uraniferous monazite belt that crosses the Piedmont in northern Chambers and Tallapoosa County may provide a source of radon. Soils of the Northern and Southern Piedmont have moderate to high permeability, whereas soils developed from mafic rocks of the Dadeville Complex have low permeability. Because the Dadeville Complex consists primarily of mafic rocks with low radioactivity and low permeability, the Dadeville Complex was ranked separately from other Piedmont rocks and is ranked low in geologic radon potential.

*Coastal Plain*

More than half of Alabama is covered by the sediments of the Coastal Plain. Indoor radon levels are generally less than 4 pCi/L and commonly less than 2 pCi/L in this province. Soil permeability is variable–generally low in clays and moderate to high in silts and sands. A distinct radiometric high is located over the central belt of marly sandy clay and chalk known as the Selma Group. Within the Selma Group high radioactivity is associated with the Demopolis Chalk, Mooreville Chalk, Prairie Bluffs Chalk, and the Ripley Formation in central and western Alabama. In eastern Alabama and into Georgia these rocks are dominated by the glauconitic sands and clays of the Providence Sand, Cusseta Sand, and Blufftown Formation. These units have overall moderate geologic radon potential.

As part of a study by the U.S. Geological Survey and the U.S. EPA to assess the radon potential of the Coastal Plain sediments in the United States, data on radon in soil gas, surface gamma-ray activity, and soil permeability were collected and examined. Data were collected in the Alabama Coastal Plain along a transect running from just north of Montgomery, Alabama, to just south of De Funiak Springs, Florida. The highest soil-gas radon concentrations and equivalent uranium were found in the Cretaceous Mooreville Chalk, carbonaceous sands and clays of the Providence Sand, and the glauconitic sands of the Eutaw and Ripley Formations. However, permeability in many of these units is slow—generally less than $1 \times 10^{-12}$ cm$^2$, and soil-gas radon was difficult to collect. Geologic units that have the lowest soil-gas radon concentrations and eU include the quartz sands of the Cretaceous Gordo Formation and quartz sands and residuum of the undifferentiated upper Tertiary sediments. Low to moderate radon and uranium concentrations were measured in the glauconitic sands and clays of the Tertiary Porters Creek Formation and in the glauconitic sands, limestones, and clays of the Tertiary Nanafalia, Lisbon Formation, and the Tuscahoma Sand. The indoor radon in some counties underlain by the Selma Group is in the 2-4 pCi/L range with a few measurements greater than 4 pCi/L, higher than in most other parts of the Alabama Coastal Plain. High uranium and radon concentrations in the sediments of the Jackson Group, locally exceeding 8 ppm U, but generally in the 1-4 ppm U range, and high soil-gas radon concentrations, are associated with faults and oil and gas wells in Choctaw County. Indoor radon measurements are generally low in these areas, but may be locally high.

FLORIDA

Florida lies entirely within the Coastal Plain, but there are six distinctive areas in Florida for which geologic radon potential may be evaluated—the Northern Highlands, Central Highlands, the Central and Northern Highlands anomalous areas, the Gulf Coastal Lowlands, Atlantic Coastal Lowlands, and an area here termed the Dade County anomalous area.

The Northern Highlands province has generally low geologic radon potential. All counties entirely within this province have average indoor radon levels less than 1 pCi/L. Leon County averaged 1.7 and 1.8 pCi/L in the two surveys of the Florida Statewide Radon Study. Most of these data likely come from Tallahassee, which lies within an area of moderately elevated eU. This area and those parts of southern Columbia, western Union, and northern Alachua County which are underlain by phosphatic rocks, and limited areas where coarse gravels occur in river terraces in the western panhandle, are likely to have elevated radon potential.

The Central Highlands province has variable geologic radon potential. Generally low radon potential occurs in low eU areas in the eastern and southern parts of this province. Moderate radon potential occurs in the western part of this province where uraniferous phosphatic rocks are close to the surface. Localized areas in which uranium contents of soils and shallow subsoils exceed 100 ppm are likely, and indoor radon levels may exceed 20 pCi/L or more where this occurs. Alachua (lies in both the Central and Northern Highlands), Marion, and Sumter Counties report indoor radon values exceeding 20 pCi/L. Excessively well-drained hillslopes may also contribute to higher radon potential.

The Gulf Coastal Lowland Province generally has low radon potential. High rainfall and high water tables cause very moist soils which inhibit radon movement. Equivalent uranium is low in most areas except in some coastal bay areas of western peninsular Florida. Some isolated areas of elevated radon potential may occur in these areas of higher eU.

The Atlantic Coastal Lowland area generally has low radon potential. High rainfall and high water tables cause very moist soils that inhibit radon movement. Equivalent uranium is low in most areas. In some beach sand areas in northern Florida, elevated eU seems to be associated with heavy minerals; however, there is no evidence to suggest that elevated indoor radon occurs in these areas.

An area in southwestern Dade County, underlain by thin sandy soils covering shallow limestone bedrock, has equivalent uranium values as high as 3.5 ppm. Unusually high levels of radium are present in soils formed on the Pleistocene Key Largo Limestone and perhaps on other rock formations in certain areas of the Florida Keys and in southwestern Dade County. Areas of elevated eU and elevated indoor radon in Dade County are likely related to these unusual soils. These soils may be responsible for the modestly elevated eU in soils and for the elevated indoor radon levels, and they may extend into Collier County as well.

## GEORGIA

### *Piedmont and Blue Ridge*

The oldest rocks in Georgia form the mountains and rolling hills of the Blue Ridge Province and most of the Piedmont Province. These highly deformed rocks are separated by a series of thrust faults superimposing groups of older rocks over younger rocks, comprising the Georgiabama Thrust Stack. The igneous and metamorphic rocks in the Georgiabama Thrust Stack north of the Altoona Fault have been ranked moderate overall in geologic radon potential, but the radon potential of the area is variable. Mafic rocks are expected to have low radon potential whereas phyllite, slate, some metagraywacke, granitic gneiss and granite have moderate to high radon potential. Soil permeability is slow to moderate in most soils. Counties in this area have average indoor radon levels that vary from low to high (< 1 pCi/L to > 4 pCi/L), but the measurements are predominantly in the moderate range. The highest indoor radon reading, 18.7 pCi/L, was measured in the northern Blue Ridge in Fannin County, which is underlain predominantly by metagraywacke, slate, phyllite, and mica schists. Equivalent uranium concentrations in rocks and soils of this area are moderate to high.

The Georgiabama Thrust Stack south of the Alatoona Fault has also been ranked moderate in geologic radon potential. The majority of this part of the Georgiabama Thrust Stack is underlain by schist and amphibolite of the Zebulon sheet, which have generally low radioactivity where not intruded by granites or where not highly sheared, particularly south of the Towaliga Fault. An area with distinctly low aeroradiometric readings which is underlain by mafic metamorphic rocks lies between the Brevard and Allatoona Faults in the northwestern Georgiabama Thrust Stack. All of these rocks have slow to moderate permeability, and indoor radon values are generally low to moderate. A central zone of biotite gneiss, granitic gneiss, and granite has elevated uranium concentrations and high equivalent uranium (>2.5 ppm) on the NURE map. Soil permeability is generally low to locally moderate. Indoor radon levels are generally moderate. Recent soil-gas radon studies in the Brevard zone and surrounding rocks show that this zone may yield unusually high soil-gas radon where the zone crosses the Ben Hill and Palmetto granites. Surface gamma-ray spectrometer measurements yielded equivalent uranium from 4 to 17 ppm over granite and granitic biotite gneiss (Lithonia gneiss). Soil-gas radon concentrations commonly exceeded 2,000 pCi/L and the highest soil-gas radon measured was 26,000 pCi/L in faulted Ben Hill granite. Undeformed Lithonia gneiss had average soil radon of more than 2,000 pCi/L. Mica schist averaged less than 1,000 pCi/L where it is undeformed. The Stone Mountain granite and mafic rocks yielded low soil-gas radon. The Grenville Basement granite and granite gneiss have moderate to locally high radon potential. Radioactivity is generally moderate to high and soil permeability is generally moderate.

The Little River Thrust Stack is generally low to moderate in geologic radon potential. It is underlain primarily by mafic metamorphic rocks with low radon potential, but each belt contains areas of rocks with moderate to locally high radon potential. Metadacites have moderate radon potential and moderate radioactivity. Faults and shear zones have local areas of mineralization and locally high permeability. Granite intrusives may also have moderate radon potential. Aeroradioactivity is generally low and soil permeability is generally moderate.

*Ridge and Valley*

The Rome-Kingston Thrust Stack is ranked low in geologic radon potential; however, some of the limestones and shales in this area may have moderate to high radon potential. Indoor radon is variable but generally low to moderate. Permeability of the soils is low to moderate. Equivalent uranium is moderate to locally high, especially along the Carters Dam and Emerson faults. Carbonate soils of the Valley and Ridge Province are likely to cause indoor radon problems. The Devonian Chattanooga Shale, which crops out locally in parts of the Valley and Ridge, is highly uraniferous and has been identified as a source of high indoor radon levels in Kentucky. Numerous gamma radioactivity anomalies are associated with the Pennington Formation, Bangor Limestone, Fort Paine Chert, Chattanooga Shale, Floyd Shale, the Knox Group, and the Rome Formation.

*Appalachian Plateau*

The Appalachian Plateau has been ranked low in geologic radon potential. Sandstone is the dominant rock type and it generally has low uranium concentrations. Equivalent uranium is low to moderate. Permeability of the soils is moderate and indoor radon levels are low.

*Coastal Plain*

The Coastal Plain has been ranked low in radon potential, but certain areas of the Coastal Plain in which glauconitic, carbonaceous, and phosphatic sediments are abundant may have moderate geologic radon potential. The highest soil-gas radon concentrations (>1000 pCi/L) and equivalent uranium (eU) concentrations (>2 ppm) in studies of radon in soil-gas in the Coastal Plain of Alabama were found in the carbonaceous sands and clays of the Providence Sand and the glauconitic sands of the Eutaw and Ripley Formations. Low to moderate soil-gas radon and uranium concentrations were measured in the glauconitic sands, limestones, and clays of the Tertiary Nanafalia and Lisbon Formations, and the Tuscahoma Sand. Equivalent rock units in Georgia are also likely to be sources of high radon levels. Equivalent uranium is moderate in the Cretaceous and Tertiary-age sediments and low, with local highs, in the Quaternary sediments. Radioactivity highs in much of the Coastal Plain are related to phosphate and heavy-mineral concentrations. In the shoreline complexes and in several sediment units such as the Hawthorn Formation, the phosphate concentrations are naturally occurring. In the Black Lands and in many portions of the central Coastal Plain that have abundant agricultural activity, the radioactivity may be related to the use of phosphate fertilizers. Indoor radon in the Coastal Plain is generally low.

## KENTUCKY

Three primary areas in Kentucky are identified as being underlain by rock types and geologic features suspected of producing elevated radon levels: (1) areas underlain by Devonian black shales in the Outer Bluegrass region; (2) areas underlain by the Ordovician Lexington Limestone, particularly the Tanglewood Member, in the Inner Bluegrass region; and (3) areas of the Mississippian Plateau underlain by karsted limestones or black shales. In addition, some homes underlain by, or in close proximity to, major faults in the Western Coalfield and Inner Bluegrass regions may have locally elevated indoor radon levels due to localized concentrations of radioactive minerals and higher permeability in fault and fracture zones.

*Appalachian Plateau*

The black shale and limestone areas in the Mississippian Plateau region have associated high surface radioactivity, and the Western Coalfield contains scattered radioactivity anomalies. The arcuate pattern of radioactivity anomalies along the southern edge of the Outer Bluegrass region corresponds closely to the outcrop pattern of the New Albany Shale. A group of radiometric anomalies in the vicinity of Warren and Logan counties appears to correspond to outcrops of the Mississippian Ste. Genevieve and St. Louis Limestones. The clastic sedimentary rocks of the Cumberland Plateau region are characterized by relatively low surface radioactivity and generally have low indoor radon levels.

In the Mississippian Plateau Region, locally elevated indoor radon levels are likely in areas with high soil permeability, solution cavities, or localized concentrations of radioactive minerals in karst regions, and in areas underlain black shale along the State's southern border. Of particular concern are the Devonian-Mississippian Chattanooga Shale (equivalent to the New Albany Shale), limestones in the Mississippian Fort Payne Formation, and the Mississippian Salem, Warsaw, Harrodsburg, St. Louis, and Ste. Genevieve Limestones in south-central Kentucky.

Caves, produced by limestone solution and relatively common in central Kentucky, are natural concentrators of radon and can be a local source of high radon levels. Levels of radon decay products approaching a maximum of 2.0 working levels (WL), which corresponds to about 400 pCi/L of radon (assuming that radon and its decay products are in 50 percent equilibrium), and averaging about 0.70 WL, or about 140 pCi/L of radon, have been recorded in Mammoth Cave. Although these levels are not considered hazardous if the exposure is of short duration, such as would be experienced by a visitor to the cave, it could be of concern to National Park Service employees and other persons that spend longer periods of time in the caves. Another potential hazard is the use of cave air for building air temperature control, as was formerly done at the

Mammoth Cave National Park visitor center. The cave air, which averages 54°F, was pumped into the visitor center for cooling, but this process has been discontinued due to the relatively high radioactivity associated with the cave air.

*Coastal Plain*

The majority of homes in the Jackson Purchase Region (Coastal Plain) have low indoor radon levels, although the area is underlain in part by loess with an eU signature in the 2.0-3.0 ppm range. The poor correspondence with surface radioactivity in this area appears to be due to a combination of low soil permeability and high water tables. The Coastal Plain is the only part of the State in which seasonal high water tables were consistently listed in the SCS soil surveys as less than 6 ft, and commonly less than 2 ft.

## MISSISSIPPI

Examination of the available data reveals that Mississippi is generally an area of low radon potential. Indoor radon levels in Mississippi are generally low; however, several counties had individual homes with radon levels greater than 4 pCi/L. Counties with maximum levels greater than 4 pCi/L are concentrated in the northeastern part of the State within the glauconitic and phosphatic sediments of the Tombigbee Hills and Black Prairies. Readings greater than 4 pCi/L also occur in the Mississippi Alluvial Plain, the eastern part of the Pine Hills Province, and in loess-covered areas. Glauconitic and phosphatic sediments of the Coastal Plain, particularly the Cretaceous and lower Tertiary-age geologic units located in the northeastern portion of the State, have some geologic potential to produce radon. Based on radioactivity and studies of radon in other parts of the Coastal Plain, the Black Prairies and Pontotoc Ridge have been assigned moderate geologic radon potential; all other parts of Mississippi are considered to be low in geologic radon potential. The climate, soil, and lifestyle of the inhabitants of Mississippi have influenced building construction styles and building ventilation which, in general, do not allow high concentrations of radon to accumulate.

*Coastal Plain*

A study of the radon in the Coastal Plain of Texas, Tennessee, and Alabama suggests that glauconitic, phosphatic, and carbonaceous sediments and sedimentary rocks, equivalent to those in Mississippi, can cause elevated levels of indoor radon. Ground-based surveys of radioactivity and radon in soils in that study indicate that the Upper Cretaceous through Lower Tertiary Coastal Plain sediments are sources of high soil-gas radon (> 1,000 pCi/L) and soil uranium concentrations. The high equivalent uranium found over the Coastal Plain sediments in northeastern Mississippi supports the possibility of a similar source of high radon levels. Chalks, clays and marls tend to have low permeability when moist and higher permeability when dry due to desiccation fractures and joints.

The youngest Coastal Plain sediments, particularly Oligocene and younger, have decreasing amounts of glauconite and phosphate and become increasingly siliceous and therefore less likely to be significant sources of radon. Some carbonaceous units may be possible radon sources.

Loess in Tennessee, and probably elsewhere, is known to generate high levels of radon in both dry and saturated soils. Both thin and thick loess units can easily be traced on the radioactivity map of Mississippi by following the highest of the moderate equivalent uranium anomalies. Loess tends to have low permeability when moist and higher permeability when dry.

*Mississippi Alluvial Plain*

The Mississippi Alluvial Plain contains several areas with locally high eU, as well as having moderate radioactivity overall. These high eU areas are located close to the river in Bolivar and Washington Counties. The highest indoor radon level recorded in Mississippi in the State/EPA Residential Radon Survey (22.8 pCi/L) occurs within Bolivar County and the second highest radon level of homes measured to date in the State (16.1 pCi/L) occurs in Washington County. It is not apparent from the data available whether the high eU and indoor radon levels are correlative, and only a few indoor radon readings in each county are greater than 4 pCi/L. The geology of the region is not generally conducive to high uranium concentrations, except possibly in heavy-mineral placer deposits. Further, elevated radioactivity in the Mississippi Alluvial Plain may be due in part to uranium in phosphatic fertilizers. Locally high soil permeability in some of the alluvial sediments may allow locally high indoor radon levels to occur.

The southeastern half of Mississippi has low radioactivity and low indoor radon levels. The few indoor radon readings greater than 4 pCi/L were between 4.1 and 5.8 pCi/L. The lowest eU is associated with the coastal deposits and the Citronelle Formation, which are predominantly quartz sands with low radon potential. Slightly higher eU, though still low overall, is associated with the Pascagoula and Hattiesburg Formations and Catahoula Formation. Soils in this area are variably poorly to well drained with slow to moderate permeabilities.

The Chattanooga Shale and related sedimentary rocks in the northeastern part of the State have the potential to be sources of high indoor radon levels. In Tennessee and Kentucky, the Chattanooga Shale has high uranium concentrations and is associated with high indoor radon levels in those states. The extent of these rocks in Mississippi is minor.

## NORTH CAROLINA

*Blue Ridge*

The Blue Ridge has been ranked moderate overall in geologic radon potential, but it is actually variably moderate to high in radon potential. The province has highly variable geology and because of the constraints imposed by viewing the indoor radon data at the county level, it is impossible to assign specific geologic areas of the Blue Ridge to specific moderate or high indoor radon levels. Average indoor radon levels are moderate (2-4 pCi/L) in the majority of counties. However, two counties have indoor radon averages between 4.1 and 6 pCi/L (Cherokee and Buncomb Counties) and three counties in the northern Blue Ridge (Alleghany, Watauga, and Mitchell) have indoor radon averages greater than 6 pCi/L. These three counties are generally underlain by granitic gneiss, mica schist, and minor amphibolite and phyllite. Transylvania and Henderson Counties, which are underlain by parts of the Blue Ridge and Inner Piedmont, also have indoor radon averages greater than 6 pCi/L. The Brevard fault zone, Henderson Gneiss, and Ceasars Head Granite are possible sources of high indoor radon in these two counties. Equivalent uranium is variable from low to high in the Blue Ridge. The highest eU appears to be associated with the Ocoee Supergroup in the southern Blue Ridge, rocks in the Grandfather Mountain Window, and metamorphic rocks in parts of Haywood and Buncomb Counties. Soils are generally moderate in permeability.

The Chauga belt and Brevard fault zone are ranked high in geologic radon potential. The Chauga belt consists predominantly of the Henderson Gneiss. High eU and high uranium in stream sediments appears to be associated with the Brevard fault zone, Henderson Gneiss, and Ceasars Head Granite in this area. Average indoor radon levels in the two counties that the main part of the Chauga belt and the southern portion of the Brevard fault zone passes through are high. The soils have moderate permeability.

*Piedmont*

The Inner Piedmont and Kings Mountain belts have been ranked moderate in geologic radon potential. Indoor radon levels are generally moderate. Granitic plutons, granitic gneiss, monazite-rich gneiss and schist, pegmatites, and fault zones appear to have high eU and high uranium concentrations in stream sediment samples. Many of the granitic plutons are known to be enriched in uranium and recent studies suggest that the soils developed on many of the uraniferous granitic plutons and related fault zones in the Blue Ridge and Piedmont are possible sources of radon. Measured soil-gas radon concentrations commonly exceeded 1,000 pCi/L in soils developed on the Cherryville Granite, Rolesville Suite, and the Sims, Sandy Mush, and Castalia plutons. Soils developed on the Rocky Mount, Spruce Pine, Toluca, Mt. Airy, and Stone Mountain plutons had relatively low soil-gas radon concentrations. Soil permeabilities in the Inner Piedmont, Brevard fault zone, and Kings Mountain belt are variably low to moderate which, together with the large proportion of homes without basements, may account for the abundance of moderate indoor radon levels.

Most shear zones in the Piedmont and Blue Ridge should be regarded as having the potential to produce very localized moderate to high indoor radon levels. Geochemical and structural models developed from studies of shear zones in granitic metamorphic and igneous rocks from the Reading Prong in New York to the Piedmont in Virginia indicate that uranium enrichment, the redistribution of uranium into the rock foliation during deformation, and high radon emanation, are common to most shear zones. Because they are very localized sources of radon and uranium, shear zones may not always be detected by radiometric or stream sediments surveys.

The Charlotte belt has been ranked low in geologic radon potential but it is actually quite variable–dominantly low in the southern portion of the belt and higher in the northern portion of the belt. Equivalent uranium is generally low, with locally high eU occurring in the central and northern portions of the belt, associated with the Concord and Salisbury Plutonic Suites. Permeability of the soils is generally low to moderate and indoor radon levels are generally low.

The Carolina slate belt has been ranked low in radon potential where it is underlain primarily by metavolcanic rocks. Where it crops out east of the Mesozoic basins it has been ranked moderate. Aeroradioactivity over the Carolina slate belt, uranium in stream sediment samples, and indoor radon levels are markedly low. Permeability of many of the metavolcanic units is generally low to locally moderate. East of the Wadesboro subbasin in Anson and Richmond Counties lies a small area of the slate belt that is intruded by the Lilesville Granite and Peedee Gabbro. It has high eU and high uranium concentrations in stream sediments, and moderate to high permeability in the soils, and is a likely source of moderate to high indoor radon levels.

The Raleigh belt has been ranked moderate in geologic radon potential. Equivalent uranium in the Raleigh belt is generally moderate to high and appears to be associated with granitic intrusive rocks, including the Castalia and Wilton plutons and the Rolesville Suite. A belt of monazite-bearing rocks also passes through the Raleigh belt and may account for part of the observed high radioactivity. Soils have variably low to moderate permeability. Indoor radon levels are generally moderate.

*Coastal Plain*

In the Coastal Plain province, moderate to hig' is associated with the Cretaceous and Tertiary sediments of the Inner Coastal Plain. Permeability of the soils is highly variable but generally moderate to low, and may be locally high in sands and gravels. Seasonally high water tables are common. Indoor radon levels in the Coastal Plain are generally low. The Inner Coastal Plain is ranked low in geologic radon potential but may be locally moderate to high, especially in areas underlain by Cretaceous sediments. Glauconitic, phosphatic, monazite-rich, and carbonaceous sediments and sedimentary rocks in the Coastal Plain of Texas, New Jersey, and Alabama, similar to some Coastal Plain sediments in North Carolina, are the source for moderate indoor radon levels seen in parts of the Inner Coastal Plain of these states.

The Outer Coastal Plain has low eU, low indoor radon levels, and is generally underlain by sediments with low uranium concentrations. Soil permeability is variable but generally moderate. Seasonally high water tables are common. A few isolated areas of high radioactivity in the Outer Coastal Plain may be related to heavy mineral and phosphate deposits in the shoreline sediments. The area has been ranked low in geologic radon potential, but may have local moderate or high indoor radon occurrences related to heavy minerals or phosphate deposits.

SOUTH CAROLINA

*Blue Ridge and Piedmont*

The Blue Ridge and Piedmont Provinces have moderate geologic radon potential. Possible sources of radon include uraniferous granites, biotite and granitic gneiss, and shear zones. Soils developed on many of the uraniferous granitic plutons and some fault zones within the Piedmont and Blue Ridge of North and South Carolina yield high soil-gas radon (>1,000 pCi/L). In the Blue Ridge, sheared graphitic rocks may be a local source for high indoor radon concentrations.

More than 10 percent of the homes tested in Greenville and Oconee Counties, in the Blue Ridge and Piedmont, have indoor radon levels greater than 4 pCi/L. Greenville County also has the highest indoor radon measurement in the State, 80.7 pCi/L, the highest radioactivity, associated with the Silurian-Devonian Ceasers Head Granitic Gneiss, and with biotite gneiss in the Carolina monazite belt. In Oconee County, the Toxaway Gneiss and graphitic rocks in the Brevard Fault Zone may account for the higher incidence of indoor radon levels exceeding 4 pCi/L and the higher overall indoor radon average of the county. Average indoor radon levels in the Blue Ridge and Piedmont are generally higher than in the rest of the State, and moderate to high radioactivity is common. Most of the soils formed on granitic rocks have moderate permeability and do not represent an impediment to radon mobility. Mafic rocks in the Blue Ridge and Piedmont have low radon potential. These rocks have low concentrations of uranium, and soils formed from them have low permeability.

*Coastal Plain*

In the Coastal Plain Province, moderate to high radioactivity is associated with the Cretaceous and Tertiary sediments of the upper Coastal Plain. Glauconitic, phosphatic, monazite-rich, and carbonaceous sediments and sedimentary rocks in the Coastal Plain of Texas, New Jersey, and Alabama, similar to some of those in South Carolina, cause elevated levels of indoor radon. Orangeburg County is the only other county besides Greenville and Oconee Counties that has an average indoor radon level greater than 2 pCi/L. It is underlain by Lower Tertiary sediments in an extremely dissected part of the Coastal Plain. Radioactivity is moderate to low. Soils are highly variable in the county because of the complicated erosion patterns. The few high values of indoor radon for this county create an overall higher indoor radon average for the county. These locally high readings may be due to local accumulations of monazite, glauconite, or phosphate that can occur within these particular sediments.

The lower Coastal Plain has low to locally high radioactivity and low indoor radon levels. Most of the sediments have low uranium concentrations with the exception of the uraniferous, phosphatic sediments of the Cooper Group and local, heavy-mineral placer deposits within some of the Quaternary units. The area has been ranked low in geologic radon potential overall, but the radon potential may be locally high in areas underlain by these uraniferous sediments.

## TENNESSEE

### *Coastal Plain and Mississippi Alluvial Plain*

The Mississippi Alluvial Plain has low geologic radon potential. The high soil moisture, high water tables, and the lack of permeable soils lower the radon potential in spite of moderate eU values. Some areas with very sandy or excessively-drained soils may cause homes to have indoor radon levels exceeding 4 pCi/L.

The loess-covered parts of the Coastal Plain have low radon potential in spite of moderate eU values and elevated soil-gas radon concentrations. The radon potential is lowered by the high moisture content and low permeability of the soils. The lack of basements in homes also lowers the potential. If prolonged dry periods were to occur in this area, some homes might see a significant increase in indoor radon, especially those with basements or crawl spaces. The eastern Coastal Plain has moderate geologic radon potential. NURE data show elevated eU values compared to the rest of the Coastal Plain. Soil-gas radon levels are locally elevated.

### *Highland Rim and Nashville Basin*

The Highland Rim and Nashville Basin are underlain by sedimentary rocks of Paleozoic age, principally limestone, shale, chert, and dolostone. The part of the Highland Rim that is underlain by cherty limestone (Fort Payne Formation) has high geologic radon potential. This area has moderate to locally high eU and soils that are cherty and excessively well drained. The limestone and shale part of the Highland Rim has moderate radon potential. The Nashville Basin has high geologic radon potential. The elevated eU, the presence of abundant phosphatic soils, local karst, and the presence of generally well-drained soils all contribute to this high geologic radon potential. Very high (>20 pCi/L) to extreme indoor radon values (>200 pCi/L) are possible where homes are sited on soils developed on the Chattanooga shale, on phosphate-rich residual soils, or on karst pinnacles.

### *Appalachian Plateau*

Sandstones and shales underlie most of the Appalachian Plateau, which generally has moderate geologic radon potential. These rocks are typically not good sources of radon and values for eU are among the lowest in the State. However, many sandy, well-drained to excessively-drained soils are present in this region, and may be a source of locally elevated radon levels because of their high permeability.

*Ridge and Valley*

Folded and faulted Paleozoic limestone, shale, chert, dolostone, and sandstone underlie most of the Ridge and Valley region, with sandstone and cherty dolostone forming most of the ridges and limestone and shale forming most of the valleys. The Ridge and Valley region has high geologic radon potential because of elevated eU values, karst, and well drained soils. Very high (>20 pCi/L) to extreme indoor radon values (>200 pCi/L) are possible where homes are sited on soils developed on black shales, phosphate-rich residual soils, or karst pinnacles. Homes with basements are more likely to yield elevated indoor radon levels than homes with slab-on-grade construction.

*Unaka Mountains*

The Unaka Mountains are underlain by siltstone, sandstone, conglomerate, quartzite, phyllite, gneiss, granite, and metamorphosed volcanic rocks of Precambrian and Paleozoic age that have moderate geologic radon potential. Values of eU are generally moderate, although they are locally high. Some very high (>20 pCi/L) to extreme (>200 pCi/L) indoor radon levels are possible where homes are sited on phosphate-rich residual soils developed on phosphatic carbonate rocks, or on pegmatite in the metamorphic rock areas, but the former are much less common in this region than in the Nashville Basin and the Ridge and Valley region.

# PRELIMINARY GEOLOGIC RADON POTENTIAL ASSESSMENT OF ALABAMA

*by*
*Linda C.S. Gundersen*
*U.S. Geological Survey*

## INTRODUCTION

This is a generalized assessment of geologic radon potential of rocks, soils, and surficial deposits of Alabama. 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. Elevated levels of indoor radon have been found in every State, and EPA recommends that all homes be tested. For more information on radon, the reader is urged to consult the local or State radon program or EPA regional office. More detailed information on state or local geology may be obtained from the state geological survey. Addresses and phone numbers for these agencies are listed in chapter 1 of this booklet.

## PHYSIOGRAPHIC AND GEOGRAPHIC SETTING

The physiography of Alabama (fig. 1) is in part a reflection of the underlying bedrock geology (fig. 2). Alabama is divided into four major physiographic provinces: the Plateau, the Valley and Ridge, the Coastal Plain, and the Piedmont. Most of these are subdivided into several smaller regions which will be referred to throughout this report. The Plateau is subdivided into the Interior Low Plateaus and the Appalachian Plateaus. Elevation ranges from 700 ft in the south to 1,000 ft in the north. The Plateau surface is heavily dissected and hilly in the eastern portion.

The Valley and Ridge province consists of parallel ridges and valleys with a conspicuous northeast-southwest trend. The ridges are underlain by sandstone and chert, whereas the valleys are developed on carbonate rocks and shales. The Valley and Ridge province is divided into western and eastern halves. Elevation ranges from 500 to 1,200 ft.

The Piedmont is subdivided into northern, inner, and southern parts (fig. 1). It is a mature, dissected peneplain surface that is underlain by igneous and metamorphic rocks of Precambrian and Paleozoic age. Most of the Piedmont is rolling hills and valleys with several hundred feet of relief. The highest point in Alabama, Mount Cheaha, at 2,407 feet above sea level, is located in the Piedmont.

The Coastal Plain is underlain by relatively unconsolidated sediments of Cretaceous to Tertiary age. For the purposes of this report, it has been divided into the Inner Coastal Plain and Outer Coastal Plain based on the age and character of the sediments. The relief of the Coastal Plain is characterized by lines of low hills (cuestas) separated by lowland areas; the alternating hills and valleys are called a belted plain. Elevation varies from sea level to 300 ft.

Alabama has a humid subtropical climate controlled by warm, moist air from the Gulf of Mexico and rare cool, continental air from Canada and Alaska. Summers are hot and humid, winters are temperate; below-freezing temperatures usually last less than 48 hours. Rainfall averages 53 inches annually and is fairly well distributed throughout the year (fig. 3).

# PHYSIOGRAPHIC PROVINCES

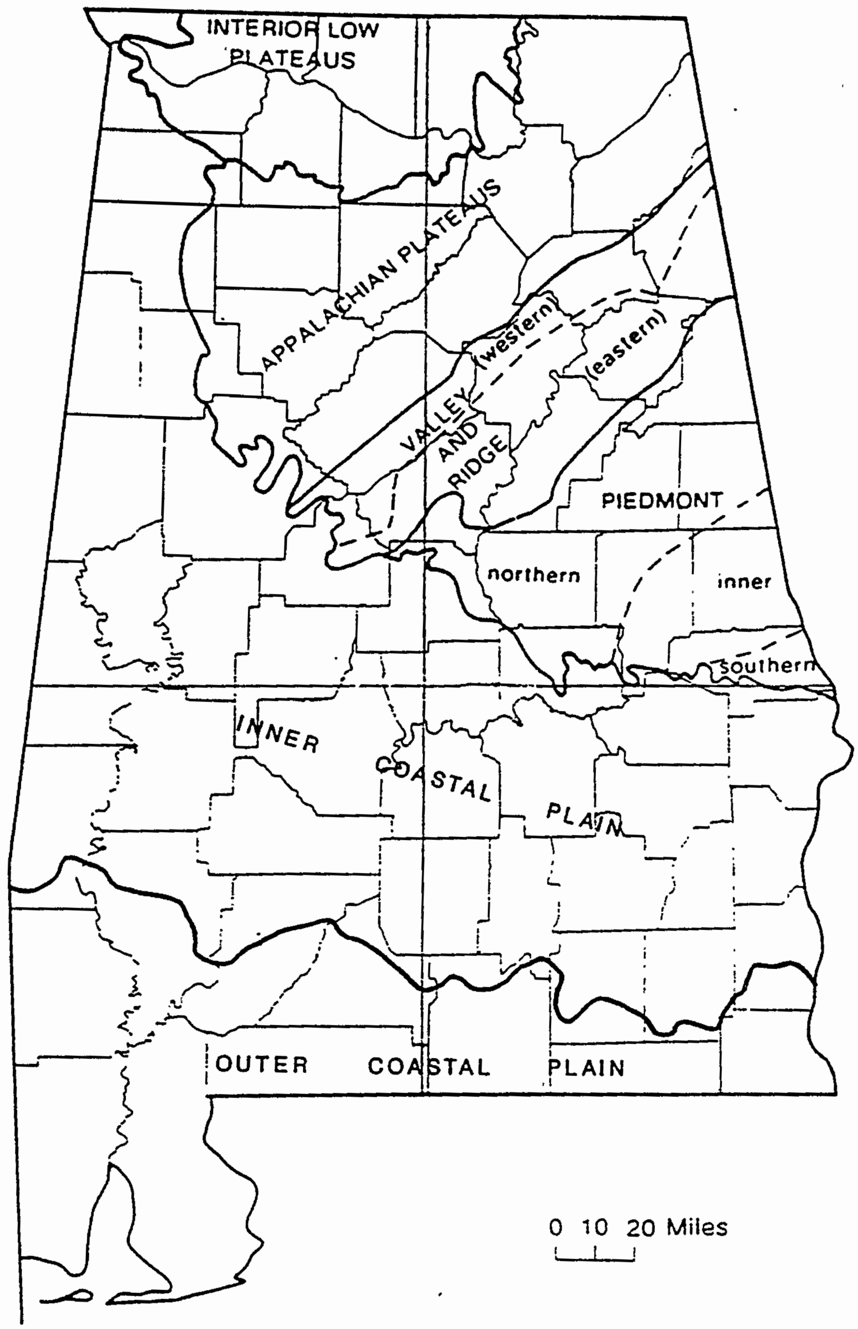


Figure 1. Physiographic provinces of Alabama (from Szabo and others, 1988).

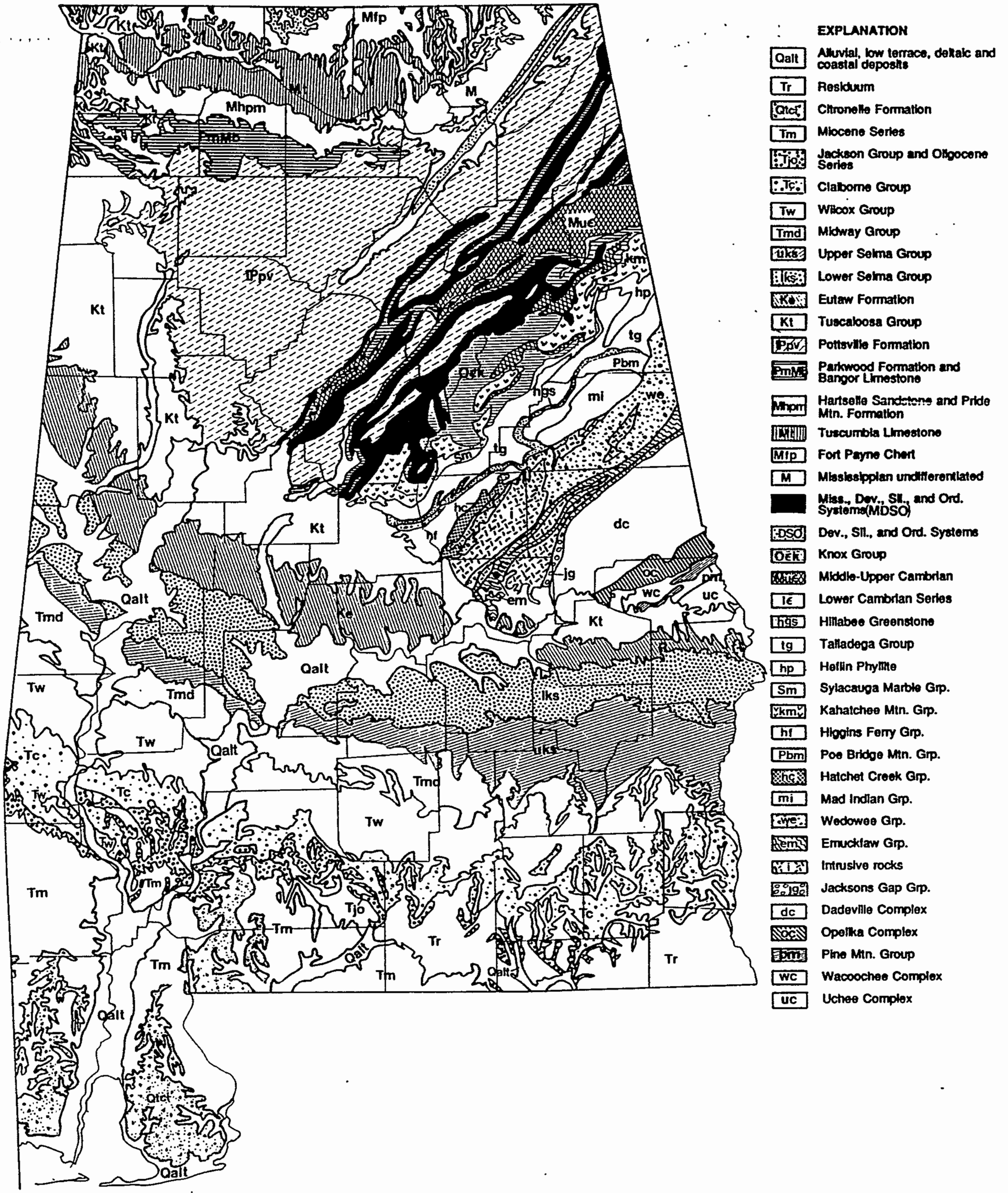


Figure 2. Generalized geologic map of Alabama (modified from Szabo and others, 1989).

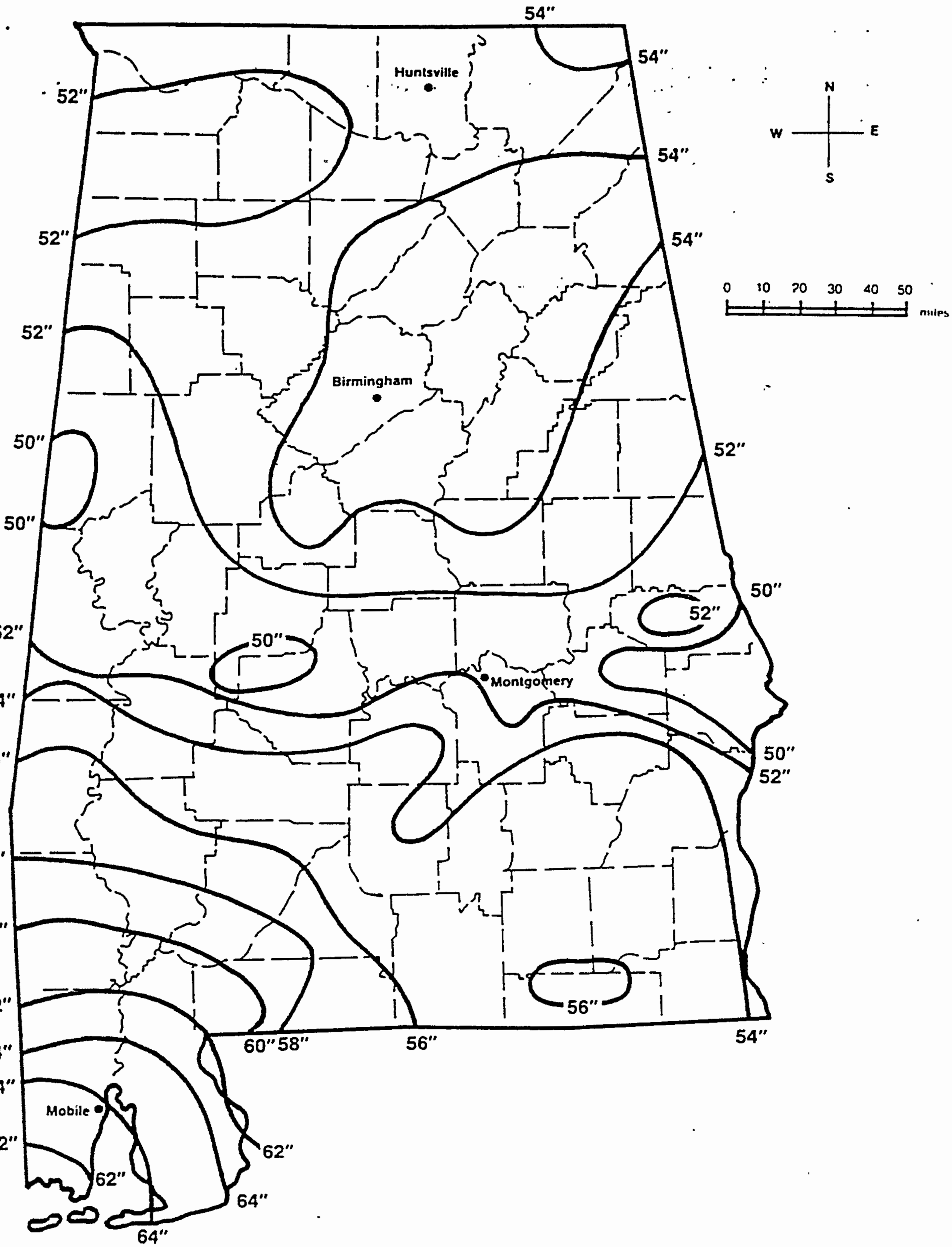


Figure 3. Average annual precipitation in Alabama (from Facts on File, 1984).

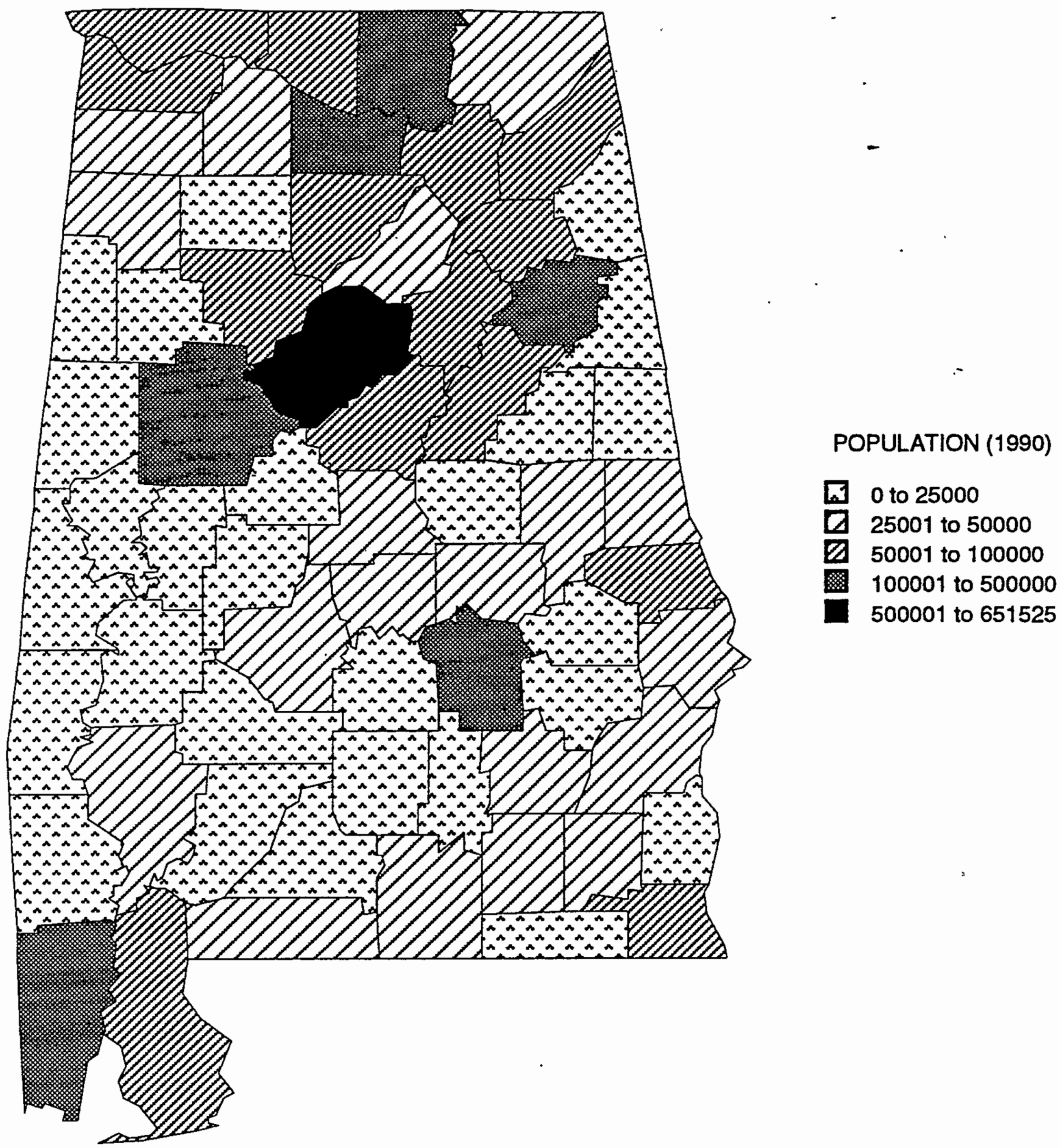


Figure 4. Population of counties in Alabama (1990 U.S. Census data).

In 1990 the population was 4,040,587, of which 60 percent is urban (fig. 4). Land use in Alabama reflects in part the geology, topography, and climate of the State. Nearly 50 percent of the State is forested. The Coastal Plain, which covers the southern two-thirds of the State, is dominated by agriculture, with products including peanuts, cotton, soybeans, hay corn, wheat, potatoes, pecans, sweet potatoes, and cottonseed.

## GEOLOGY AND SOILS

The following discussion of geology and soils is derived from Szabo and others (1988); Richmond and Fullerton (1988); Richmond and others (1988); U.S. Soil Conservation Service (1987); and selected county soil reports. A general geologic map for reference is given in figure 2. It is suggested, however, that the reader refer to the published State Geologic Map of Alabama by Szabo and others (1988). A general soil map of Alabama is given in figure 5.

### The Plateau

The Interior Low Plateaus province is dominated by Mississippian limestones. The Fort Payne chert is at the base of the Mississippian section and consists of thin-to thick-bedded limestone with abundant chert interbeds. Shale, siltstone and shaly limestone occur as minor interbeds throughout the formation. The Fort Payne Chert is exposed in the northernmost part of the Plateau. Lower Paleozoic-age shale and carbonate rocks, including the uraniferous Chattanooga Shale, also crop out in drainages along several streams. To the south, the Fort Payne Chert is succeeded by the Tuscumbia Limestone. This limestone forms a broad band of exposure from west to east across the Plateau. The Tuscumbia Limestone has abundant chert interbeds and nodules and forms an extensive karst terrain. Just south of the Tuscumbia Limestone outcrop area, three geologic units are exposed in a thinner band across the plateau from west to east. These are, in ascending order, the Pride Mountain Formation, the Monteagle Limestone, and the Hartselle Sandstone. The Pride Mountain Formation is a dark gray shale with variable amounts of sandstone and limestone in its lower part. The Monteagle Limestone is an oolitic limestone with argillaceous dolomite and gray shale. The Hartselle Sandstone is a thick-bedded to massive quartz sandstone with dark-gray shale interbeds. The overlying Bangor Limestone is the southernmost of the Mississippian limestones and it forms a broad outcrop band from west to east. It is an oolitic limestone with red and green mudstone interbeds towards the top. The Bangor Limestone is overlain by a thin unit of interbedded gray shale, limestone, dolomite, sandstone, red and green mudstone, and minor clayey and shaly coal, named the Pennington Formation. The Parkwood Formation is composed of interbedded gray shale and sandstone and locally contains red to grayish-green mudstone, argillaceous limestone, and clayey coal. In places, the Parkwood and Pennington Formations are grouped together. The Parkwood and Pennington Formations contain both Pennsylvanian and Mississippian rocks where undifferentiated.

Soils developed on the non-cherty Mississippian limestones form a solution residuum of reddish-orange silty to sandy clay, locally with shale fragments. The Tuscumbia Limestone and Fort Payne Chert form a chert-fragment solution residuum of reddish-orange silty to sandy clay with abundant chert and shale fragments. Permeability is slow and the soils are poorly to moderately drained. South of the Tuscumbia Limestone the soils are variable. These include clayey sand, clay loam, and sandy clay developed on limestone and dolomite. These soils are poorly drained, slowly permeable and have a high shrink-swell potential. Soils developed on sandstone are clayey sand to sandy clay, are porous and contain abundant iron oxide, and contain

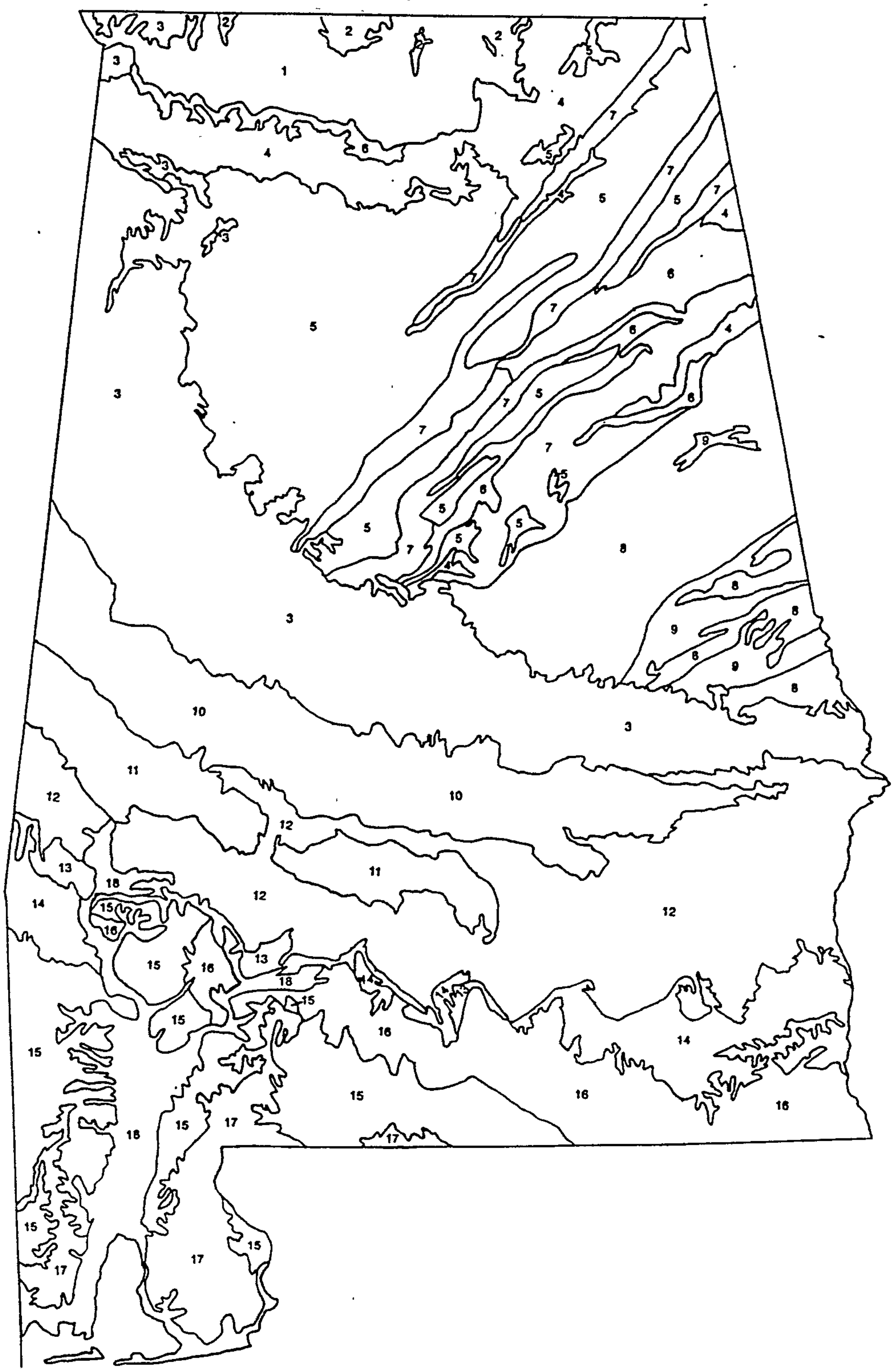

Figure 5. Generalized soil and surficial deposits map of Alabama (after Richmond and Fullerton, 1988, and Richmond and others, 1988).

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FIGURE 5 (cont.) GENERALIZED SOILS AND SURFICIAL DEPOSITS MAP OF ALABAMA

## DESCRIPTION OF UNITS

1. *Cherty clay residual soil*, contains minor sand and silt, low permeability.

2. *Cherty clay to silty clay residual soil*, locally phosphatic, low permeability.

3. *Sand and gravel residual soil*, locally cherty, locally limonitic, high permeability.

4. *Cherty clay, silty clay, and sandy clay residual soil*, low permeability, moderate shrink-swell potential, solution and collapse features common. Where soils are shallow, solution cavities impart high permeability to the soil.

5. *Sand to clayey sand residual soil*, high shrink-swell potential where developed on shale, moderate permeability.

6. *Clay, clay loam, sandy clay, and sand residual soil*, poorly drained, moderate shrink-swell potential, low to moderate permeability.

7. *Cherty clay to silty clay residual soil*, low permeability.

8. *Micaceous sandy clayey silt saprolite* developed on felsic schist, gneiss, phyllite, and granite, low shrink-swell potential, moderate to high permeability.

9. *Clayey sand to sandy clay saprolite* developed on amphibolite and other mafic rocks, variable (low-high) shrink-swell potential, low to moderate permeability.

10. *Clay loam and clay residual soil* formed on limestone, low permeability.

11. *Clay residual soil*, high shrink-swell potential, low permeability.

12. *Medium to coarse sand, clayey sand, and sandy clay residual soil*, moderate shrink-swell potential, moderate to high permeability.

13. *Siliceous clay and clayey silt residual soil* formed on clay bedrock, low permeability.

14. *Fine to coarse sand residual soil*, limonitic, locally clayey, generally high permeability.

15. *Fine sandy clay residual soil*, locally includes medium to coarse sand, moderate permeability.

16. *Clayey sand residual soil*, ferruginous, locally contains pebbles to boulders of chert and limestone, karst features common, moderate permeability.

17. *Alluvial pebble gravel and sand*, contains lenses of sandy clay, moderate to high permeability.

18. *Intermixed clay, silt, and sandy loam, peat, and muck*, commonly wet, low to moderate permeability.

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fragments of sandstone. These soils are moderately well drained, with slow to moderate permeability. Areas of shale are overlain by clay and silty clay decomposition residuum containing shale chips and hematitic zones. Permeability is slow.

The Appalachian Plateaus province includes Mississippian rocks like the ones just described but most of the province is underlain by Pennsylvanian sandstone, shale, and coal. Mississippian units crop out in the northeastern part of the plateau (especially the Tuscumbia, Monteagle, and Bangor Limestones) and along the north side of Sand Mountain in the Sequatchie Valley. The central part of the Sequatchie Valley is underlain by Cambrian-Devonian sedimentary rocks and is rimmed by the Tuscumbia Limestone, Fort Payne Chert, Monteagle Limestone, Bangor Limestone, Pride Mountain Formation, Hartselle Sandstone, and Pennington Formation. The Cambrian-Devonian rocks of the Sequatchie Valley include: dolomite and limestone comprising the Knox Group; the Stones River Group limestones and shales; the Nashville Group limestones; the shales and limestones of the Inman Formation; the Leipers Limestone; the Sequatchie Formation shale, glauconitic limestone, mudstone, and minor sandstone; the Red Mountain Formation sandstone, siltstone, shale and limestone; and the Chattanooga Shale. The soils are mostly cherty solution clay residuum with slow permeability and poor drainage.

Most of the Pennsylvanian rocks of the Appalachian Plateaus are included in the Pottsville Formation. This massive formation is sometimes divided into lower and upper parts and generally consists of cyclic sequences of sandstone, siltstone, shale, and coal. The sandstones are thin- to thick-bedded, quartzose, and partly conglomeratic. Shales are dark gray to black, carbonaceous, and coaly. Coals are usually thin and discontinuous, but some thicker, producing coal seams occur in several parts of the plateaus. Soils are coarse to fine sand, clayey sand, and sandy clay, and may include chips of sandstone and shale. Soils have moderate to moderately rapid permeability and are well drained. Where clayey, the soils have a high shrink-swell potential and have slow permeability when moist.

Valley and Ridge

The Valley and Ridge province is underlain by Paleozoic sedimentary rocks, many of which have already been described. The majority of the area is underlain by two major rock groups: Cambrian through Ordovician rocks and upper Mississippian through Pennsylvanian rocks. Very thin outcrops of Silurian and Devonian sandstones and shales, predominantly the Silurian Red Mountain Formation and the Devonian Chattanooga Shale, lie between the two major rock groups. The Cambrian through Ordovician rocks include sandstone, mudstone, shale, limestone, and dolomite. The oldest Cambrian rocks are predominantly clastic and consist of various sandstones, conglomerates, mudstones, and siltstones of the Chilhowee Group, including the Cochran, Nichols, Weisner, and Wilson Ridge Formations. The middle to upper Cambrian rocks contain progressively more carbonate units, beginning with the Shady Dolomite; the Rome Formation, consisting of sandstone, shale, mudstone, and siltstone interbedded with limestone and dolomite; and the Conasauga Formation, a thick-bedded dolomite with limestone and shale. Of all these units, the Conasauga has the most extensive outcrop pattern, especially in the western part of the Valley and Ridge province, in the Coosa River Valley surrounding Weiss Reservoir, and in the Canoe Creek Valley.

The Upper Cambrian and Ordovician-age rocks of the Valley and Ridge province are dominated by limestone and dolomite. Much of the Valley and Ridge is underlain by the undifferentiated Knox Group dolomite, limestone, and chert; the Chickamauga Limestone and conglomerates; and the interbedded calcareous shales and argillaceous limestone of the Sequatchie

Formation. The Chepultepec and Copper Ridge Dolomites of the Knox Group also underlie significant parts of the western Valley and Ridge province. Other Ordovician limestone units of lesser extent include the Newala, Little Oak, and Lenoir Limestones, the Athens Shale, shale, limestone, mudstone, siltstone, and sandstone of the Greensport Formation, and the Colvin Mountain Sandstone.

Much of the western Valley and Ridge province is underlain by upper Mississippian through Pennsylvanian sedimentary rocks, including many of the units previously described. The three units that crop out most extensively are the Pottsville and Parkwood Formations and the Floyd Shale. The Floyd Shale is a dark-gray sideritic shale with minor limestone and chert.

Soils in the Valley and Ridge are predominantly a solution residuum of reddish-orange silty to sandy clay developed on limestone. Chert and shale fragments are found in the soil in places. Permeability is slow and the soils are poorly to moderately drained. Clayey sand, clay loam, and sandy clay are developed on some limestone and most dolomite. This soil is poorly to moderately drained, slowly to moderately permeable, and where clayey, the soils have a high shrink-swell potential. Over sandstones, the soils are clayey sand to sandy clay with abundant iron oxide and fragments of sandstone. These soils are moderately well drained, with slow to moderate permeability. Areas of shale have clay and silty clay decomposition residuum containing shale chips and hematitic zones. Permeability is slow.

Piedmont

The Piedmont is underlain by the oldest rocks in Alabama. They range in age from 200 million years to nearly 1 billion years and consist of a complicated sequence of igneous and metamorphic rocks that have been folded and faulted to form the southern extent of the Appalachian Mountains. A map of the major faults in the Piedmont and other provinces is given in figure 6. The Towaliga fault, an extensive zone of mylonite (ductily sheared rock) separates the Southern Piedmont from the Inner Piedmont. The Southern Piedmont is underlain by a northeast-trending sequence of gneiss, schist, quartzite, and marble, with a minor granite intrusive known as the Hospilika Granite hosted in the Phenix City Gneiss. The gneisses are generally quartz-rich diorite gneiss and the schists are micaceous with biotite or muscovite. Quartzite forms layers within schist, and towards the top of the section, it is associated with the Chewacla Marble. The southern part of the Inner Piedmont is underlain by complexly-folded amphibolites and ultramafic rocks that form a distinct pattern on the geologic map. The rest of the Inner Piedmont is underlain by feldspathic gneiss, mica schist, and minor granite.

The Brevard Fault zone is an extensive fault with a complex movement history that separates the Inner Piedmont from the Northern Piedmont. The fault zone occurs in the Jacksons Gap Group, which includes schist, phyllonite, and mylonite, and the Tallassee Metaquartzite, composed of quartzite, conglomerate, and schist. The Northern Piedmont rocks consist of several complex sequences of low-to high-grade metasedimentary rocks intruded by igneous rocks of varying composition. Just to the north of the Brevard fault is the Emuckfaw Group, consisting of muscovite-garnet-biotite schist, metagraywacke, quartzite, calc-silicate rock, and minor amphibolite. The rock is sheared to mylonite in places and hosts the Zana Granite, a gneissic quartz monzonite. The Glenlock Schist, a muscovite-graphite-garnet schist and metagraywacke, is also found within the Emuckfaw Group. The Wedowee Group crops out north of the Emuckfaw Group and is dominated by aluminosilicate schists with variable composition including muscovite, garnet, graphite, chlorite, biotite, sericite, and kyanite. Phyllite, quartzite, and feldspathic gneiss are also found in the section. Southwest along strike of the Wedowee Group is a complicated

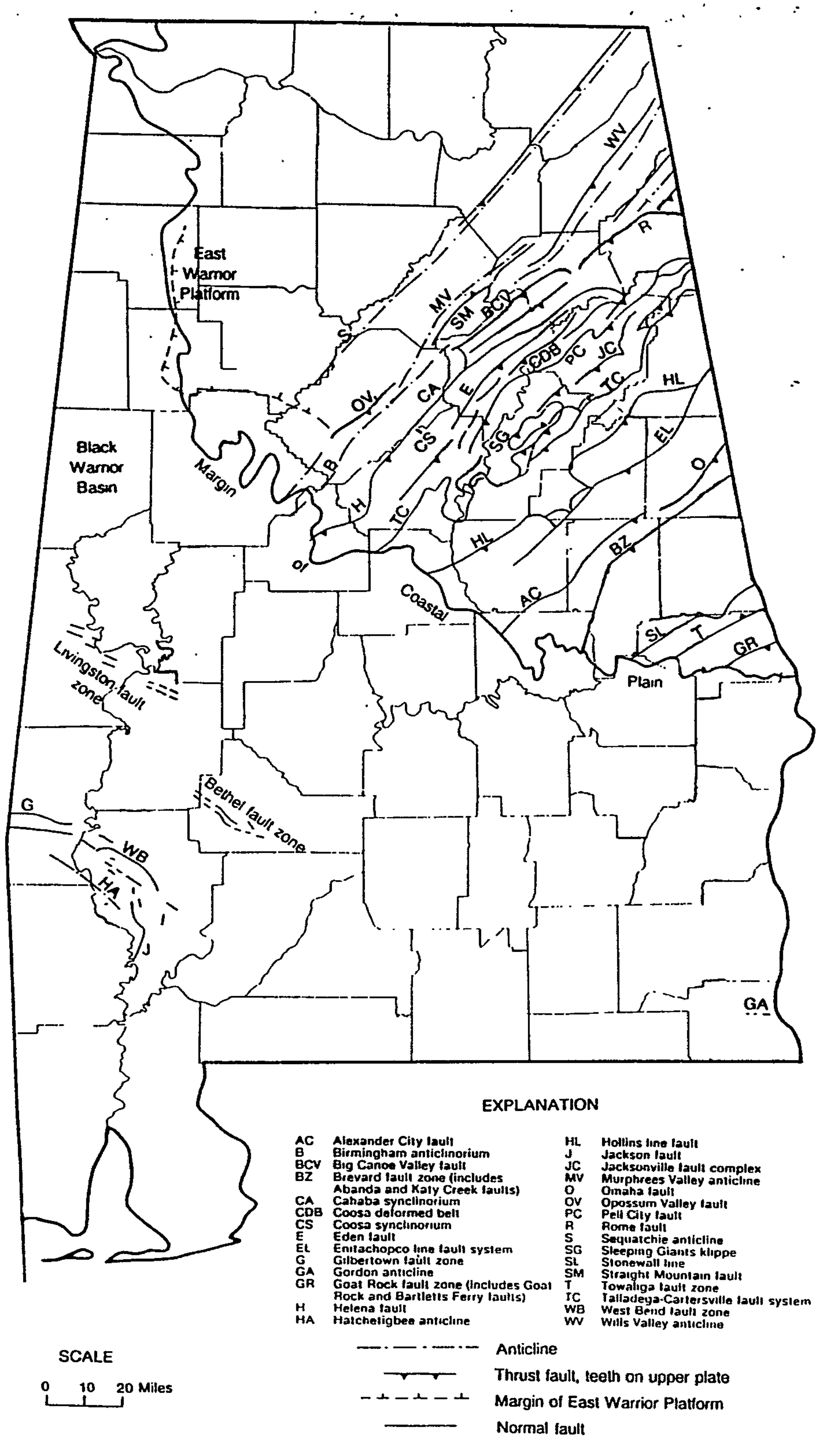



Figure 6. Major structural features of Alabama (from Szabo and others, 1988).

sequence of igneous rocks. The Elkahatchee Quartz Diorite Gneiss underlies most of this area and locally contains the Hissop Granite. To the northwest, the Elkahatchee Quartz Diorite Gneiss is bounded by Wedowee Group schists, the Hatchet Creek Group biotite schists and gneisses, and the Rockford Granite. A complicated, thinly-layered sequence of metasedimentary rocks comprising the Mitchell Dam Amphibolite, the Poe Bridge Mountain Group, and the Higgins Ferry Group, consists of variable aluminosilicate schists, feldspathic gneiss, quartzite, and amphibolite. These rocks crop out just northwest of the Hatchet Creek Group.

The Mad Indian Group, consisting of gneisses and schists, crops out to the north of the main sequence of the Wedowee Group. It is bounded to the north by the Ketchepedrakee Amphibolite, interlayered with Poe Bridge Mountain Group quartzite and schist. The Hillabee Greenstone, which consists of massive fine-grained greenstone, mafic phyllite, and minor quartz dacite, crops out in a long sinuous band across the Northern Piedmont from northeast to southwest and separates the Higgins Ferry and Poe Bridge Mountain Group metamorphic rocks from the low-grade Paleozoic metasedimentary rocks of the Talladega Group. The northernmost part of the Northern Piedmont consists of low-grade metasedimentary rocks of the Talladega Group, followed to the north by the Kahatchee Mountain Group, the Sylacauga Marble Group, and the Heflin Phyllite. The Talladega Group consists predominantly of various quartzite members, metagraywacke, metaconglomerate, metasiltstone, chert, and phyllite. Parts of the Talladega Group contain marine invertebrate fossils of Devonian age. The Heflin Phyllite is made up of metasiltstone, metasandstone, marble, and phyllite. The Sylacauga Marble consists of dolomite and calcite marble, dolomite, phyllite, and chert. The Kahatchee Mountain Group is predominantly slate and phyllite with metasiltstone, quartzite, marble, metasandstone, and metaconglomerate.

Soils of the Piedmont are saprolite with clay in the subsurface and with drainage and permeability characteristics determined by the mineral content of the saprolite. Silty to clayey sandy saprolite, sandy clay, and slightly clayey sandy soils are developed on gneissic granite, felsic schist and gneiss, and other foliated granitic rocks. Saprolite thickness is 2 m or more, and the saprolite is generally well drained and moderately permeable. Argillaceous saprolite, consisting of micaceous clayey sand to sandy clay or clayey silt, is developed on amphibolite, mafic metavolcanic rocks, and ultramafic rocks. These soils have variable shrink-swell potential, are slowly permeable, and are poorly drained. Micaceous saprolite and micaceous sandy silt are developed on the felsic micaceous schist, phyllitic rock, aluminous schist, and graphitic schist. These soils and saprolite are well drained and moderately permeable. Quartz-rich saprolite and slightly clayey to very sandy saprolite are developed on quartzite, quartz-mica schist, and quartz-rich metasedimentary rocks. These soils are moderately to rapidly permeable and well drained.

The Coastal Plain

More than half of Alabama is underlain by the relatively unconsolidated sediments of the Coastal Plain. The oldest rocks and sediments exposed in the northern Coastal Plain of Alabama are the Tuscaloosa Group, which includes the sands and locally indurated sandstones of the generally nonmarine Gordo and Coker Formations. The Coker Formation consists of micaceous, very fine- to coarse-grained sand, gravel, and interbedded clay. In Elmore County, the Coker Formation includes marine glauconitic sands. The Gordo Formation is sand and gravelly sand with partly carbonaceous clay beds.

Sands also dominate the Eutaw Formation; however, it is predominantly marine in origin. The Eutaw is a micaceous, fossiliferous, fine to medium quartz sand, with interbeds of micaceous sandy clay, carbonaceous clay, and thin glauconitic, fossiliferous sandstone.

The Selma Group crops out to the south of the Eutaw Formation and consists of fossiliferous, glauconitic chalk to the west and fossiliferous, micaceous, carbonaceous clays and sands in the east, near the Georgia-Alabama state line. At the base of the Selma Group is the Mooreville Chalk, a finely sandy, argillaceous, fossiliferous chalk with several thin limestone and clay beds at the top (the Arcola Limestone Member). The Blufftown Formation extends from the Chattahoochee River westward into Russell County where it is divided by an eastward-extending tongue of the Mooreville Chalk. The Blufftown consists of glauconitic, calcareous fine sand, fossiliferous sand and clay, micaceous clay and marl, and carbonaceous clay and silt. The Blufftown merges to the west with the Mooreville Chalk and the lower part of the Demopolis Chalk. The Demopolis Chalk overlies the Mooreville Chalk in the western and central part of the outcrop belt; to the east it merges with the Cusseta Sand Member of the Ripley Formation. In the west, the Demopolis Chalk consists of fossiliferous chalk with thin beds of marly chalk. In the east it splits into two tongues of fine sandy, micaceous chalk. The Cusseta Sand is a crossbedded medium to coarse glauconitic sand with beds of fossiliferous fine sand and fossiliferous, carbonaceous clay. The Ripley Formation extends all the way across Alabama and is a massive, micaceous, glauconitic, fossiliferous sand with sandy calcareous clay, and thin indurated beds of fossiliferous sandstone. The Prairie Bluff Chalk and the Providence Sand crop out south of the Ripley Formation . The Prairie Bluff Chalk is a sandy, fossiliferous, brittle chalk with silty, sandy, calcareous, glauconitic, fossiliferous clay and limestone. The Prairie Bluff thins eastward where it interfingers with the Providence Sand. The Providence Sand consists of crossbedded fine to coarse sand and mottled clay containing lignite, sand, and kaolin. The lower part of the unit is thin-bedded silty clay and micaceous, carbonaceous, fossiliferous fine sand.

The oldest Tertiary sediments in Alabama make up the Midway Group. These are the Clayton Formation, the Porters Creek Formation, and the Naheola Formation. The Clayton Formation, at the base of the Midway Group, consists of sandy fossiliferous limestones, fossiliferous calcareous silt, and fine sand. Limonite-goethite, reddish sand, and chert boulders characterize the residuum of the Clayton. The Porters Creek Formation is a massive plastic clay grading eastward into calcareous micaceous clayey sand, sandy clay, and fossiliferous clayey limestone. A thin glauconitic shell marl occurs at the top (Matthews Landing Marl Member). The Naheola Formation is interbedded glauconitic sand, clay, silt, and lignite.

To the south, the Midway Group is succeeded by the Wilcox Group, consisting of the Nanafalia, Tuscahoma, and Hatchetigbee Formations. The Nanafalia Formation contains several members of clay, fossiliferous clay, fine sand, glauconitic fossiliferous sand, gravel, and some lignite. The Tuscahoma Sand is a laminated, thin-bedded carbonaceous silt and clay interbedded with fine sand. At its base is glauconitic fine sand with coarse sand and gravel. The Eocene Hatchetigbee Formation forms a narrow band of laminated, carbonaceous clay, silt, and sand, with glauconitic fossiliferous sand and sandstone concretions.

The Claiborne and Jackson Groups are Eocene in age. The Claiborne Group consists of the sandy clay, fossiliferous and glauconitic sands, and limestone of the Tallahatta Formation, and the glauconitic fossiliferous sand, marl, and carbonaceous clay of the Lisbon Formation and Gosport Sand. The Jackson Group is subdivided into three formations--the Yazoo Clay, the Crystal River Formation, and the Moodys Branch Formation. Glauconitic, calcareous, fossiliferous sand and sandy limestone make up the Moodys Branch Formation, which occurs at the base of the Jackson Group. The Yazoo Clay occurs in the western part of the State and grades eastward into the Crystal River Formation. The Yazoo Clay is predominantly fossiliferous, calcareous clay to clayey glauconitic limestone, marl, and sand. The Crystal River Formation is a very fossiliferous, chalky limestone.

The Oligocene sediments are predominantly fossiliferous, calcareous sands, sandy fossiliferous, glauconitic limestones, glauconitic marls, and various clays. In descending order the Oligocene Series consists of the locally fossiliferous, calcareous, argillaceous sand of the Paynes Hammock Sand; the fossiliferous glauconitic limestone and marl of the Chikasawhay Limestone; the Byram Formation, which consists of carbonaceous, locally fossiliferous, clay and sand, sandy glauconitic fossiliferous marl, and coquinoid, crystalline limestone with tubular cavities; the porous, fossiliferous limestone of the Marianna Limestone; the carbonaceous clay and glauconitic fossiliferous sand of the Forest Hill Sand; the Red Bluff Clay, consisting of carbonaceous clay with selenite crystals, glauconitic fossiliferous limestone, and interbedded silty clay and sand; and the Bumpnose Limestone, a chalky, glauconitic, fossiliferous argillaceous limestone.

The Miocene Series, which is not differentiated into individual units, consists of thin-bedded to massive sands interbedded with clays and gravelly sands. In the southeastern part of the State, residuum is formed over many parts of the Jackson Group, and Oligocene and Miocene sediments. This residuum, derived from the solution and collapse of limestone in the lowest units and slumping of the other sediments, is described as sandy clay with scattered layers of medium to coarse sand, chert and limestone boulders, and limonitic sand masses.

The youngest extensive outcrop of sediments in the Coastal Plain is Quaternary in age and is mapped as the Citronelle Formation. The Citronelle Formation consists of deeply-weathered fine to very coarse quartz sand and lenticular beds of clay and gravel. Other Quaternary age sediments include alluvial, coastal and low terrace deposits, as well as older high terrace deposits. The terrace deposits consist of sand, clay, and gravel, with some heavy mineral deposits associated with the major rivers and streams within the State. The coastal deposits are quartz sand with shell fragments, except in the Mississippi sound, bays, lagoons, and lakes; and in estuaries, where clay, peat, and mud are found.

## RADIOACTIVITY

An aeroradiometric map of Alabama (fig. 7) was compiled from spectral gamma-ray data acquired during the U.S. Department of Energy's National Uranium Resource Evaluation (NURE) program (Duval and others, 1989). For the purposes of this report, low equivalent uranium (eU) is defined as less than 1.5 parts per million (ppm), moderate eU is defined as 1.5-2.5 ppm, and high eU is defined as greater than 2.5 ppm. In figure 7, low eU is found in the southernmost outer Coastal Plain associated with the upper Tertiary and Quaternary sediments. These are mostly quartz sands. Moderate eU covers most of the State and is associated with the older Coastal Plain rocks and sediments, the Mississippian and Pennsylvanian-age sedimentary rocks of the Appalachian Plateau, and the Paleozoic and Proterozoic rocks of the Valley and Ridge and Piedmont. High eU is associated with the Upper Cretaceous highly glauconitic and locally phosphatic chalks, marls, and sands of the Mooreville and Demopolis Chalk, and the Blufftown and Ripley Formations. High eU is also associated with Mississippian limestones, Proterozoic granites, and faulted metamorphic rocks. Counties in which eU exceeds 2.5 ppm in approximately 25 percent or more of their area include: Sumter, Perry, Dallas, Greene, Hale, Lowndes, Marengo, Montgomery, Bullock, Russell, and Macon in the Coastal Plain; Coosa, Clay, Randolph, and Lee in the Piedmont; Talladega in the Valley and Ridge; and Madison, Lawrence, Limestone and Lauderdale Counties in the Plateaus.

Figure 7. Aerial radiometric map of Alabama (after Duval and others, 1989). Contour lines at 1.5 and 2.5 ppm equivalent uranium (eU). Pixels shaded at 0.5 ppm eU increments.

## INDOOR RADON DATA

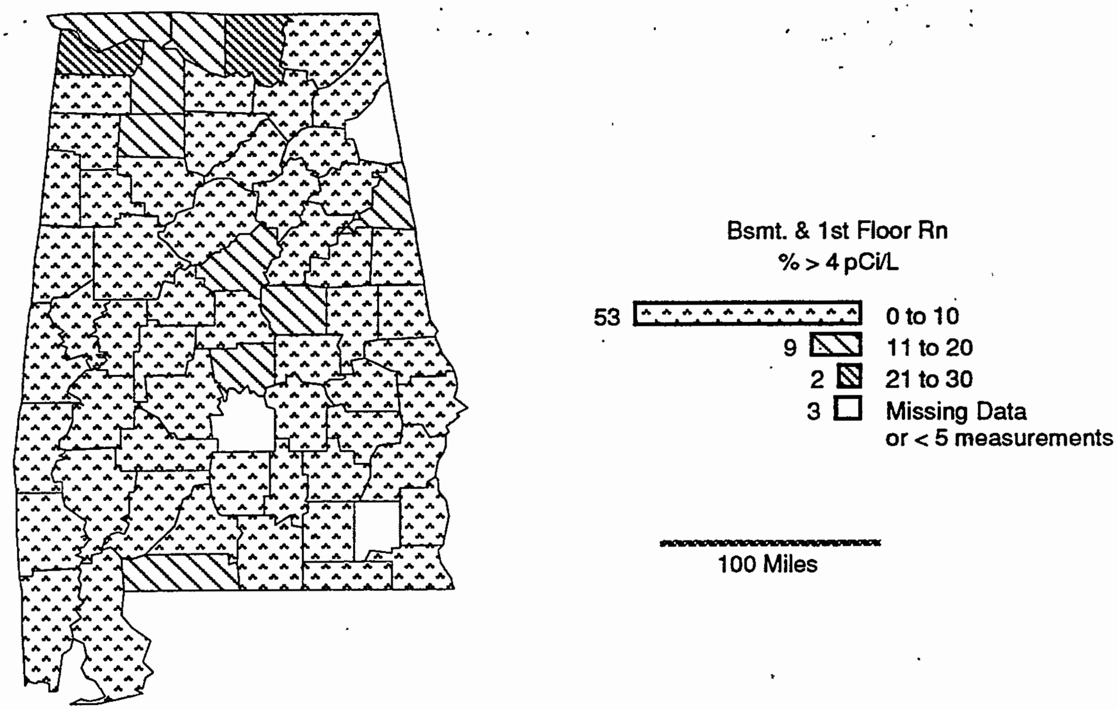
Indoor radon data from 1,180 homes sampled in the State/EPA Residential Radon Survey conducted in Alabama during the winter of 1986-87 are shown in figure 8a and Table 1. Data are shown in figure 8a only for those counties with five or more measurements. First-floor measurements (taken in homes without basements) far outnumber basement measurements and are distributed throughout the State. The basement measurements, however, are restricted to the northern part of the State. The maximum value recorded in the survey was 180 pCi/L in Calhoun County. The average for the State was 1.7 pCi/L and 6.9 percent of the homes tested had indoor radon levels greater than 4 pCi/L. Counties with low average indoor radon levels (< 2 pCi/L) are found throughout the State, but are the most consistently low in the Coastal Plain province. Counties with moderate (2-4 pCi/L) indoor radon averages occur in parts of the Piedmont and Plateaus provinces. Only Calhoun County, in the Valley and Ridge province, and Lawrence County, in the Interior Low Plateaus province, have high (>4 pCi/L) indoor radon averages.

The Alabama Department of Public Health has compiled more than 8000 indoor radon measurements from commercial vendors across Alabama. These data are shown in figure 8b and consist of indoor radon measurements collected between 1987-1992. The data include both long- and short-term measurements, as well as data from basement and non-basement homes. The measurements were made during all seasons of the year. In this data set, Colbert and Madison Counties had indoor radon averages greater than 4 pCi/L (fig. 9 is a map of counties for reference). However, the general regional distribution of high, moderate, and low indoor radon levels is similar to that from the randomly-sampled State/EPA Residential Radon Survey.

## GEOLOGIC RADON POTENTIAL

### The Plateaus

In the Interior Low Plateaus have been ranked high in geologic radon potential. The Mississippian carbonate rocks and shales that underlie this province appear to have high to moderate radioactivity associated with them. The carbonates and shales are also associated with most of the highest county indoor radon averages for the State, particularly in Colbert, Madison, Lawrence, and Lauderdale Counties. The geologic units that may be the source of these problems, as indicated by the radioactivity, appear to be parts of the Fort Payne Chert, the Tuscumbia Limestone, the Monteagle, Bangor, Pride Mountain, and Parkwood Formations, and the Floyd Shale. Gammage and Wilson (1992) and Wilson and others (1991) found that indoor radon levels in homes built on the St. Genevieve Limestone, Tuscumbia Limestone, and Fort Payne Chert averaged between 3.0 and 4.3 pCi/L. Soils developed from carbonate rocks are often elevated in uranium and radium. Carbonate soils are derived from the dissolution of the $CaCO_3$ that makes up the majority of the original carbonate rock. After the $CaCO_3$ has been dissolved away, the soils are enriched in the remaining impurities, predominantly base metals, including uranium. Rinds containing high concentrations of uranium and uranium minerals can be formed on the surfaces of rocks affected by $CaCO_3$ dissolution and karstification. Karst and cave morphology is also thought to promote the flow and accumulation of radon. Because carbonate soils are clayey, they have a tendency to crack when they dry and may develop very high permeability due to the fractures. Under moist conditions, however, the soils derived from carbonate rocks generally have low permeability.



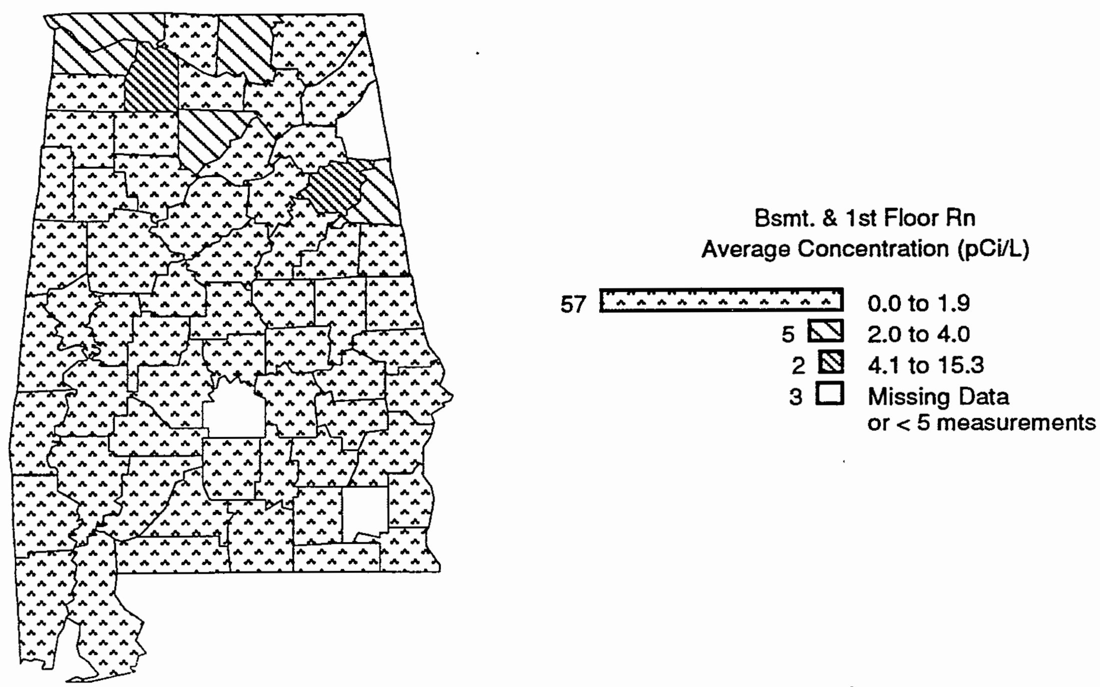




Figure 8a. Screening indoor radon data from the EPA/State Residential Radon Survey of Alabama, 1986-87, for counties with 5 or more measurements. Data are from 2-7 day charcoal canister tests. Histograms in map legends show the number of counties in each category. The number of samples in each county (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.

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TABLE 1. Screening indoor radon data from the EPA/State Residential Radon Survey of Alabama 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 |
|---|---|---|---|---|---|---|---|---|
| AUTAUGA | 9 | 1.5 | 0.8 | 0.6 | 2.0 | 6.3 | 11 | 0 |
| BALDWIN | 31 | 1.0 | 0.5 | 0.6 | 1.8 | 8.5 | 6 | 0 |
| BARBOUR | 9 | 0.4 | 0.3 | 0.4 | 0.3 | 0.8 | 0 | 0 |
| BIBB | 7 | 0.8 | 0.6 | 0.5 | 0.6 | 1.9 | 0 | 0 |
| BLOUNT | 11 | 0.9 | 0.7 | 1.1 | 0.6 | 1.9 | 0 | 0 |
| BULLOCK | 6 | 0.3 | 0.3 | 0.4 | 0.2 | 0.4 | 0 | 0 |
| BUTLER | 18 | 0.7 | 0.4 | 0.4 | 0.7 | 2.5 | 0 | 0 |
| CALHOUN | 23 | 9.3 | 1.4 | 1.3 | 37.2 | 180.0 | 9 | 4 |
| CHAMBERS | 9 | 0.4 | 0.3 | 0.3 | 0.4 | 1.4 | 0 | 0 |
| CHEROKEE | 1 | 0.5 | 0.5 | 0.5 | 0.0 | 0.5 | 0 | 0 |
| CHILTON | 9 | 0.6 | 0.5 | 0.5 | 0.4 | 1.3 | 0 | 0 |
| CHOCTAW | 15 | 0.6 | 0.4 | 0.5 | 0.4 | 1.7 | 0 | 0 |
| CLARKE | 8 | 0.7 | 0.4 | 0.4 | 0.9 | 2.9 | 0 | 0 |
| CLAY | 11 | 1.7 | 1.0 | 1.1 | 2.3 | 8.2 | 9 | 0 |
| CLEBURNE | 6 | 2.8 | 1.8 | 1.6 | 2.9 | 8.2 | 17 | 0 |
| COFFEE | 18 | 1.1 | 0.8 | 0.8 | 1.0 | 3.7 | 0 | 0 |
| COLBERT | 10 | 4.0 | 3.2 | 3.3 | 2.9 | 10.0 | 30 | 0 |
| CONECUH | 14 | 0.6 | 0.4 | 0.5 | 0.5 | 1.7 | 0 | 0 |
| COOSA | 8 | 1.4 | 0.8 | 0.9 | 1.8 | 5.7 | 13 | 0 |
| COVINGTON | 16 | 0.9 | 0.7 | 0.8 | 0.6 | 1.8 | 0 | 0 |
| CRENSHAW | 13 | 0.6 | 0.4 | 0.6. | 0.5 | 1.6 | 0 | 0 |
| CULLMAN | 30 | 2.0 | 0.9 | 1.0 | 3.7 | 19.8 | 7 | 0 |
| DALE | 3 | 1.5 | 1.1 | 1.9 | 1.1 | 2.3 | 0 | 0 |
| DALLAS | 18 | 0.7 | 0.5 | 0.5 | 0.5 | 2.2 | 0 | 0 |
| DE KALB | 31 | 1.6 | 0.9 | 0.8 | 2.4 | 11.7 | 6 | 0 |
| ELMORE | 25 | 1.1 | 0.8 | 0.8 | 1.0 | 5.0 | 4 | 0 |
| ESCAMBIA | 9 | 0.9 | 0.4 | 0.5 | 1.3 | 4.1 | 11 | 0 |
| ETOWAH | 21 | 0.7 | 0.5 | 0.6 | 0.7 | 3.1 | 0 | 0 |
| FAYETTE | 7 | 0.9 | 0.7 | 0.8 | 0.7 | 2.0 | 0 | 0 |
| FRANKLIN | 8 | 0.9 | 0.5 | 0.7 | 0.7 | 1.7 | 0 | 0 |
| GENEVA | 7 | 0.5 | 0.5 | 0.4 | 0.3 | 1.2 | 0 | 0 |
| GREENE | 8 | 0.9 | 0.8 | 0.7 | 0.6 | 2.2 | 0 | 0 |
| HALE | 10 | 0.9 | 0.5 | 0.5 | 1.2 | 4.1 | 10 | 0 |
| HENRY | 8 | 1.0 | 0.7 | 0.6 | 0.8 | 2.6 | 0 | 0 |
| HOUSTON | 10 | 0.8 | 0.6 | 0.8 | 0.5 | 1.8 | 0 | 0 |
| JACKSON | 21 | 1.0 | 0.7 | 0.9 | 0.6 | 2.4 | 0 | 0 |
| JEFFERSON | 78 | 1.5 | 1.0 | 0.9 | 1.6 | 10.3 | 8 | 0 |
| LAMAR | 12 | 1.0 | 0.7 | 0.8 | 0.8 | 2.6 | 0 | 0 |
| LAUDERDALE | 44 | 2.6 | 1.5 | 1.3 | 3.2 | 16.0 | 18 | 0 |
| LAWRENCE | 9 | 15.3 | 1.4 | 1.0 | 42.7 | 129.1 | 11 | 11 |
| LEE | 20 | 0.9 | 0.6 | 0.6 | 1.0 | 4.6 | 5 | 0 |

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

| COUNTY | NO. OF MEAS. | MEAN | GEOM. MEAN | MEDIAN | STD. DEV. | MAXIMUM | %>4 pCi/L | %>20 pCi/L |
|---|---|---|---|---|---|---|---|---|
| LIMESTONE | 35 | 1.6 | 1.0 | 1.0 | 1.7 | 6.8 | 11 | 0 |
| LOWNDES | 4 | 0.6 | 0.4 | 0.4 | 0.7 | 1.6 | 0 | 0 |
| MACON | 5 | 0.5 | 0.4 | 0.5 | 0.3 | 0.7 | 0 | 0 |
| MADISON | 119 | 3.5 | 2.1 | 2.0 | 4.7 | 36.6 | 25 | 2 |
| MARENGO | 11 | 0.9 | 0.7 | 0.8 | 0.9 | 3.6 | 0 | 0 |
| MARION | 10 | 1.3 | 0.9 | 0.9 | 1.2 | 3.4 | 0 | 0 |
| MARSHALL | 34 | 1.1 | 0.6 | 0.5 | 1.8 | 10.0 | 6 | 0 |
| MOBILE | 43 | 0.6 | 0.4 | 0.5 | 0.5 | 2.3 | 0 | 0 |
| MONROE | 9 | 0.9 | 0.7 | 0.9 | 0.7 | 2.0 | 0 | 0 |
| MONTGOMERY | 25 | 0.9 | 0.7 | 0.7 | 0.7 | 2.8 | 0 | 0 |
| MORGAN | 47 | 1.6 | 0.9 | 1.0 | 2.3 | 12.4 | 6 | 0 |
| PERRY | 9 | 1.1 | 0.5 | 0.5 | 1.2 | 3.3 | 0 | 0 |
| PICKENS | 11 | 0.4 | 0.3 | 0.4 | 0.2 | 0.6 | 0 | 0 |
| PIKE | 8 | 1.1 | 0.8 | 1.1 | 0.7 | 2.2 | 0 | 0 |
| RANDOLPH | 9 | 1.1 | 0.9 | 1.3 | 0.6 | 1.9 | 0 | 0 |
| RUSSELL | 9 | 0.6 | 0.5 | 0.6 | 0.4 | 1.4 | 0 | 0 |
| SHELBY | 27 | 1.6 | 0.9 | 0.8 | 2.5 | 11.6 | 11 | 0 |
| ST. CLAIR | 14 | 1.4 | 1.1 | 0.9 | 1.3 | 5.0 | 7 | 0 |
| SUMTER | 8 | 0.3 | 0.2 | 0.2 | 0.4 | 1.1 | 0 | 0 |
| TALLADEGA | 37 | 1.4 | 1.0 | 1.1 | 1.2 | 5.4 | 5 | 0 |
| TALLAPOOSA | 19 | 1.3 | 0.8 | 0.8 | 1.3 | 5.3 | 5 | 0 |
| TUSCALOOSA | 14 | 1.1 | 0.9 | 0.9 | 0.7 | 2.7 | 0 | 0 |
| WALKER | 14 | 1.4 | 1.0 | 1.1 | 1.1 | 4.5 | 7 | 0 |
| WASHINGTON | 13 | 0.6 | 0.4 | 0.6 | 0.5 | 1.7 | 0 | 0 |
| WILCOX | 7 | 0.6 | 0.4 | 0.5 | 0.5 | 1.6 | 0 | 0 |
| WINSTON | 8 | 1.7 | 1.1 | 1.2 | 1.9 | 6.2 | 13 | 0 |

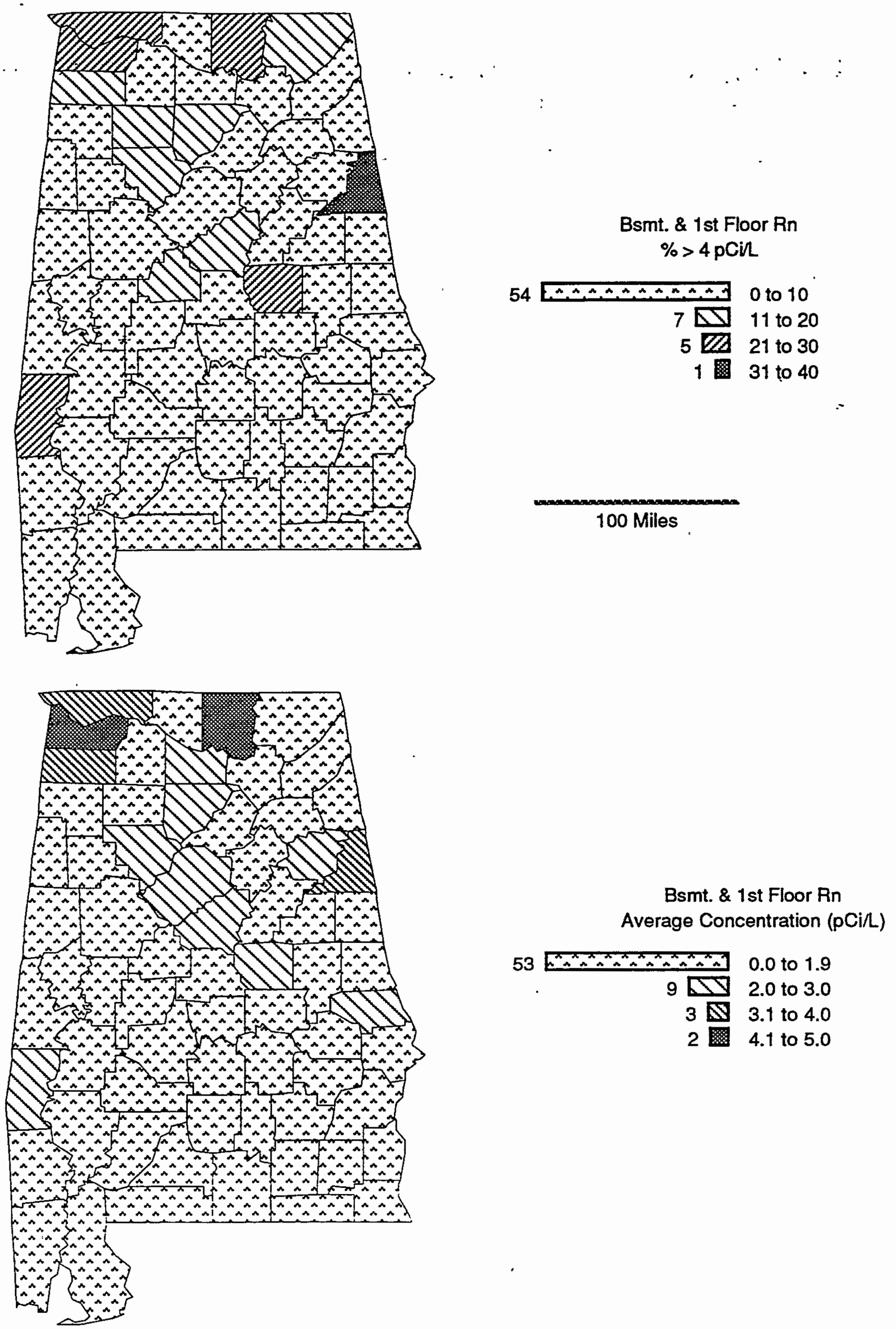


Figure 8b. Indoor radon for Alabama collected by the Alabama Department of Public Health. Data are from charcoal canister and alpha-track radon detectors purchased from commercial vendors by homeowners during the period 1987-1992. Histograms in map legends show the number of counties in each category. Unequal category intervals were chosen to provide reference to decision and action levels.

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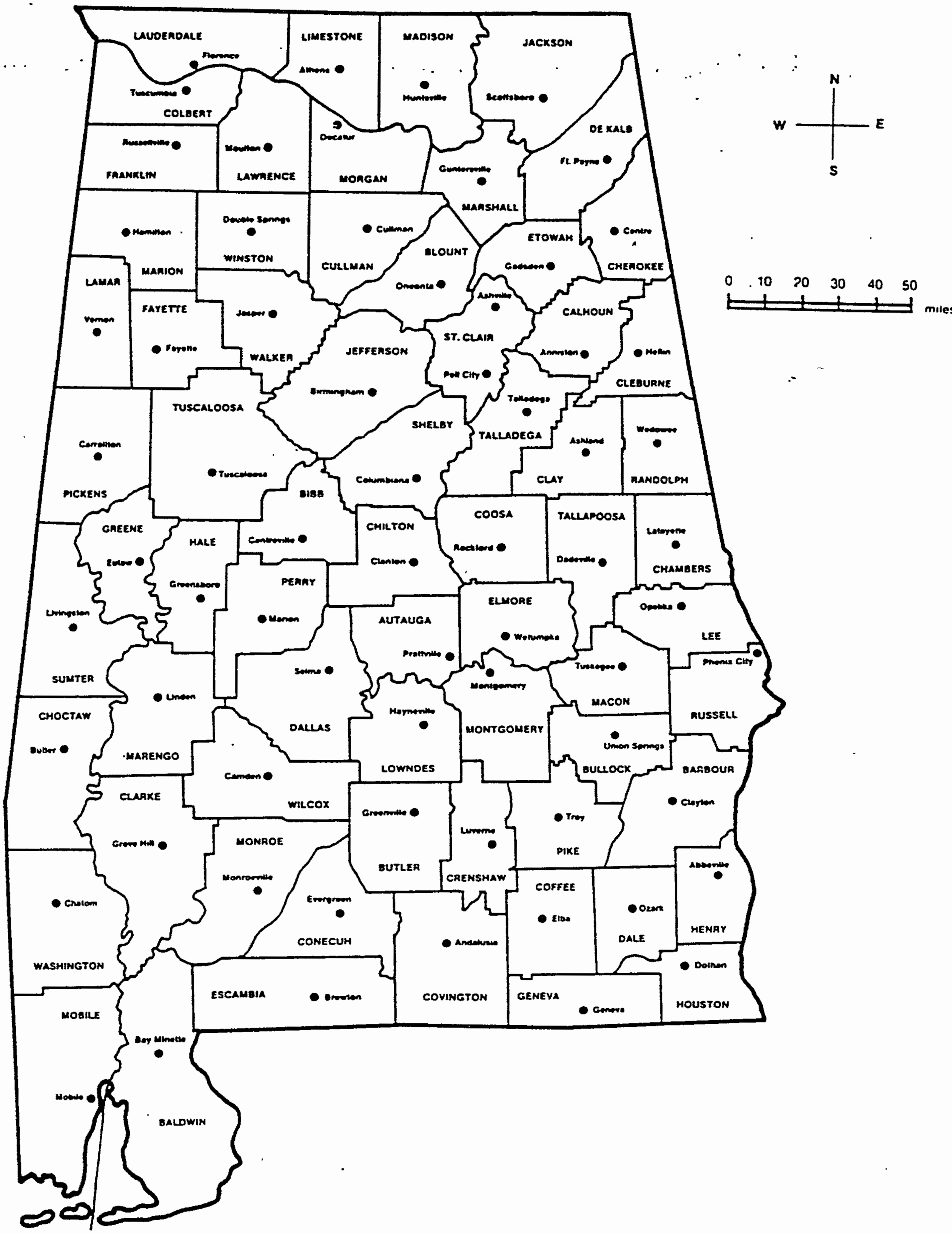


Figure 9. Counties and county seats in Alabama (from Facts on File, 1984).

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The Appalachian Plateaus has been ranked moderate in geologic radon potential. Indoor radon levels are generally low to moderate. Radioactivity is low to moderate and soil permeability is moderate. The sandstone of the Pottsville Formation is not noted for being uraniferous, but uraniferous carbonaceous shales interbedded with the sandstone may be the cause of locally moderate to high indoor radon levels. Cullman County had several indoor radon measurements greater than 4 pCi/L, including one measurement of 19.8 pCi/L. Winston and Walker Counties also had several indoor radon levels greater than 4 pCi/L in the Alabama Department of Public Health data set.

Valley and Ridge

The Valley and Ridge province has been ranked moderate in geologic radon potential. Radioactivity is generally moderate in the Valley and Ridge, with high radioactivity occurring along the southeastern border with the Piedmont. Indoor radon levels are highly variable, with generally low county averages and one high county average. Most of the counties had a few readings greater than 4 pCi/L. The soils of the Valley and Ridge have low to moderate permeability. The permeability may be locally high in dry clayey soils and karstic areas. Carbonate soils derived from Cambrian-Ordovician rock units of the Valley and Ridge province cause known indoor radon problems in eastern Tennessee, western New Jersey, western Virginia, eastern West Virginia (Schultz and others, 1992), and central and eastern Pennsylvania. Further, the Devonian Chattanooga Shale crops out locally in parts of the Valley and Ridge. This shale is known to be highly uraniferous (Glover, 1959) and has been identified as a source of high indoor radon in Kentucky (Peake and Schumann, 1991).

Piedmont

Where it is possible to associate high radioactivity and/or high indoor radon levels with particular areas, parts of the Piedmont have been ranked moderate to high in radon potential. Radiometric anomalies occur over the Talladega Fault zone, which separates the Paleozoic carbonate rocks from the metamorphic rocks. Some of the metamorphic rocks in the Northern Piedmont, including the Poe Bridge Mountain Group, the Mad Indian Group, parts of the Wedowee Group, and the Higgins Ferry Group, also have high radioactivity associated with them. In many cases the radiometric anomalies appear to be associated with rocks in fault zones, graphitic schists and phyllites, felsic gneiss, and other granitic rocks. Furthermore, Talladega, Calhoun, Cleburne, and Randolph Counties all have some high indoor radon measurements. Uranium in graphitic phyllite with an assay value of 0.076 percent $U_3O_8$ has been reported from Cleburne County (Grauch and Zarinski, 1976), and similar graphitic phyllites from the Georgia Piedmont average 4.7 ppm uranium (McConnell and Costello, 1980). Graphitic phyllites and schists in other parts of the Piedmont are known sources of radon and have high indoor radon concentrations associated with them (Gundersen and others, 1988). Another source of uranium in Piedmont metamorphic rocks is monazite, which contains high amounts of both uranium and thorium. It is a common accessory mineral in gneisses and granites throughout the Piedmont and its resistance to weathering and high density result in local monazite concentrations in saprolite. Mertie (1953) describes a uraniferous monazite belt that crosses the Piedmont in northern Chambers and Tallapoosa Counties that may be a source of radon. Soils of the Northern and Southern Piedmont have moderate to high permeability, whereas soils developed from mafic rocks of the Dadeville Complex have low permeability. Because the Dadeville Complex consists primarily of mafic rocks

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with low radioactivity and low soil permeability, the Dadeville Complex was ranked separately from other Piedmont rocks and is ranked low in geologic radon potential.

Coastal Plain

More than half of Alabama is covered by the sediments of the Coastal Plain. Indoor radon levels are generally less than 4 pCi/L and are commonly less than 2 pCi/L in this province. Soil permeability is variable, generally low in clays and moderate to high in silts and sands. A distinct radiometric high is located over the central belt of marly sandy clay and chalk known as the Selma Group. Within the Selma Group, high radioactivity is associated with the Demopolis Chalk, Mooreville Chalk, Prairie Bluffs Chalk, and the Ripley Formation in central and western Alabama, and in eastern Alabama and into Georgia, where these rocks are dominated by the glauconitic sands and clays of the Providence Sand, Cusseta Sand, and Blufftown Formation. These units have moderate geologic radon potential overall.

As part of a study by the U.S. Geological Survey and the U.S. EPA to assess the radon potential of the Coastal Plain sediments in the United States, data on radon in soil gas, surface gamma-ray activity, and soil permeability were collected and examined (Gundersen and Peake, 1992). Data were collected in the Alabama Coastal Plain along a transect running from just north of Montgomery, Alabama, to just south of De Funiak Springs, Florida. The highest soil-gas radon and equivalent uranium concentrations were found in the Cretaceous Mooreville Chalk, carbonaceous sands and clays of the Providence Sand, and the glauconitic sands of the Eutaw and Ripley Formations. However, permeability in many of these units is slow—generally less than $1x10^{-12}$ $cm^2$, and soil-gas samples for radon analysis were difficult to collect. Geologic units that have the lowest soil-gas radon and eU concentrations include the quartz sands of the Cretaceous Gordo Formation and quartz sands and residuum of the undifferentiated upper Tertiary sediments. Low to moderate radon and uranium concentrations were measured in the glauconitic sands and clays of the Tertiary Porters Creek Formation and in the glauconitic sands, limestones, and clays of the Tertiary Nanafalia and Lisbon Formations, and the Tuscahoma Sand. The indoor radon levels in some counties underlain by the Selma Group are in the 2-4 pCi/L range, with a few measurements greater than 4 pCi/L—higher than in most other parts of the Alabama Coastal Plain. Chase (1984) reports high uranium and radon concentrations in the sediments of the Jackson Group, locally exceeding 8 ppm U, but generally in the 1-4 ppm U range, and high soil-gas radon concentrations associated with faults and oil and gas wells in Choctaw County (fig. 6). Indoor radon levels are generally low in these areas, but may be locally high.

## SUMMARY

For the purpose of this assessment, Alabama has been divided into eight geologic radon potential areas and each area assigned a Radon Index (RI) and a Confidence Index (CI) score (Table 2). The RI is a relative measure of radon potential based on geologic, soil, radioactivity, architecture, and indoor radon data. The CI is a measure of the confidence of the RI assessment based on the quality and quantity of the data used to assess the geologic radon potential (please see the introduction chapter to this regional book for a detailed discussion of the indexes). Figure 10 is a map showing the geologic radon potential of the eight designated areas in Alabama.

In the northern, more temperate part of the State, in which some basement architecture is present, winters are less mild, and where geologic radon potential is higher, indoor radon levels are significantly higher than in the remainder of the State. Of particular concern are the soils developed on carbonate rocks of the Interior Low Plateaus and the Valley and Ridge, which appear to be the source of many of the high radon levels recorded in the State. The Interior Low Plateau is rated high in geologic radon potential, but the Valley and Ridge province has been rated moderate because of generally lower indoor radon levels and the moderate radioactivity of the area. In the Piedmont, rocks in fault zones, graphitic schists and phyllites, felsic gneiss and other granitic rocks may be associated with locally high indoor radon concentrations and these rocks are abundant in the Northern Piedmont. The Dadeville Complex is low in radon potential because of the low radioactivity of the mafic rocks that comprise it.

Within the Inner Coastal Plain, glauconitic, phosphatic, and carbonaceous sediments are a documented source of radon, although these areas had only a few high indoor radon levels and generally low soil permeability. This area has therefore been ranked moderate in geologic radon potential. The climate, soil, and lifestyle of the inhabitants of much of southern Alabama have influenced building construction styles and building ventilation which, in general, do not allow high concentrations of radon to accumulate in structures. Much of the outer Coastal Plain is underlain by sediments with low to moderate radioactivity that are poor sources of radon. The outer Coastal Plain has therefore been ranked low in geologic radon potential.

This is a generalized assessment of the State's geologic radon potential and there is no substitute for having a home tested. The conclusions about radon potential presented in this report cannot be applied to individual homes or building sites. Indoor radon levels, both high and low, can be quite localized, and within any radon potential area there will likely be areas with higher or lower radon potential than assigned to the area as a whole. Any local decisions about radon should <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.

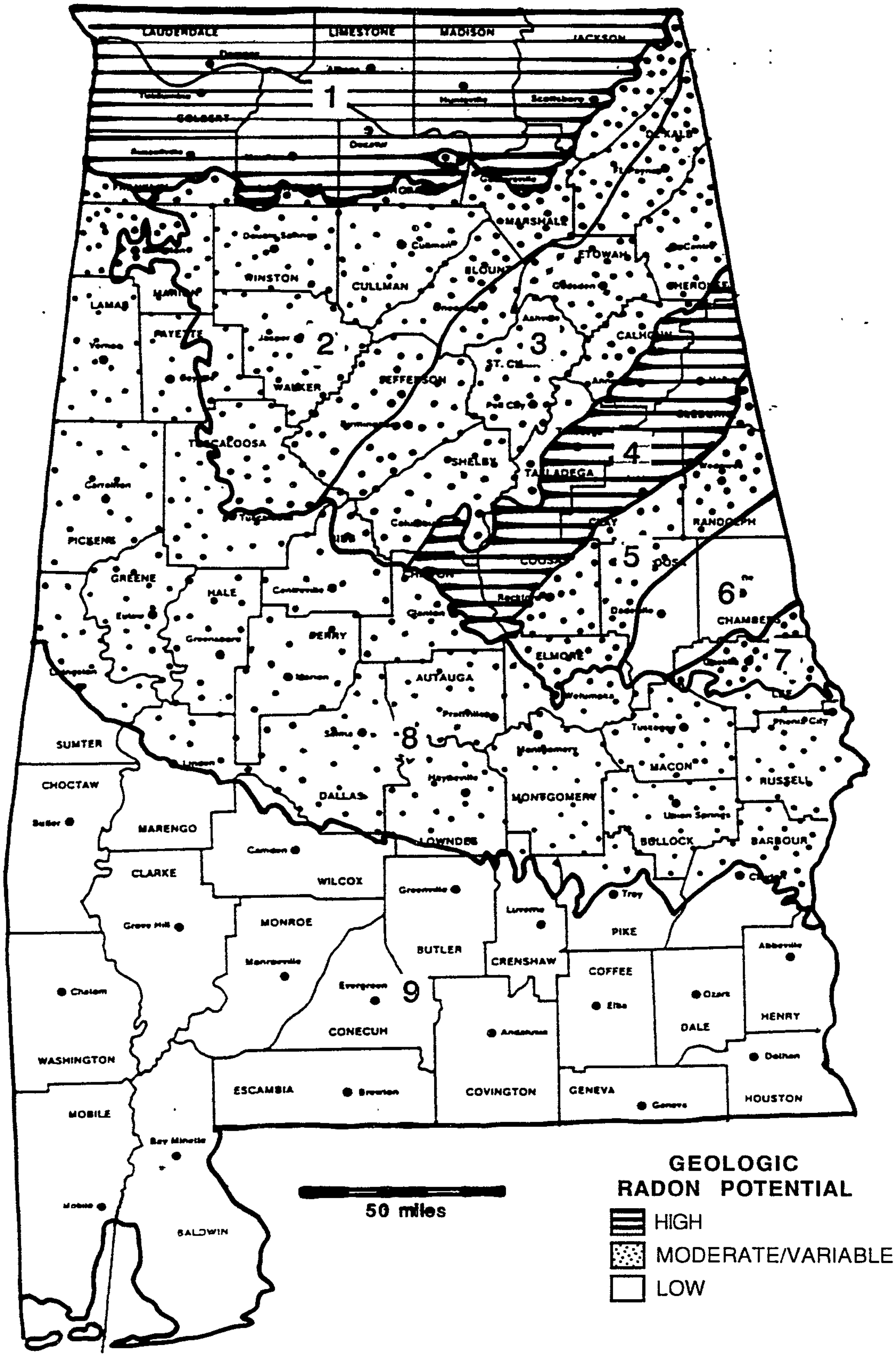


Figure 10. Geologic radon potential areas of Alabama. Numbers correspond to listings in Table 2. See text for discussion of areas.

TABLE 2: RI and CI scores for geologic radon potential areas of Alabama. Numbers refer to areas shown on figure 10.

| FACTOR | Interior Low Plateaus (1) RI | CI | Appalachian Plateaus (2) RI | CI | Valley and Ridge (3) RI | CI |
|---|---|---|---|---|---|---|
| INDOOR RADON | 2 | 2 | 2 | 2 | 2 | 2 |
| RADIOACTIVITY | 2 | 3 | 2 | 3 | 2 | 3 |
| GEOLOGY | 3 | 2 | 2 | 2 | 2 | 2 |
| SOIL PERM. | 2 | 3 | 2 | 3 | 2 | 3 |
| ARCHITECTURE | 1 | - | 1 | - | 1 | - |
| GFE POINTS | 2 | - | 0 | - | 0 | - |
| TOTAL | 12 | 10 | 9 | 10 | 9 | 10 |
| | High | High | Mod | High | Mod | High |

| FACTOR | Southern Piedmont (7) Wedowee, Emuckfaw Grps (5) RI | CI | Northern Piedmont-faults, phyllite, granitic rocks (4) RI | CI | Inner Piedmont/ Dadeville Complex (6) RI | CI |
|---|---|---|---|---|---|---|
| INDOOR RADON | 2 | 2 | 2 | 2 | 1 | 3 |
| RADIOACTIVITY | 2 | 3 | 3 | 3 | 1 | 3 |
| GEOLOGY | 2 | 2 | 3 | 3 | 2 | 3 |
| SOIL PERM. | 2 | 3 | 3 | 3 | 2 | 3 |
| ARCHITECTURE | 1 | - | 1 | - | 1 | - |
| GFE POINTS | 0 | - | 0 | - | 0 | - |
| TOTAL | 9 | 10 | 12 | 11 | 7 | 12 |
| | Mod | High | High | High | Low | High |

| FACTOR | Cretaceous of the Inner Coastal Plain (8) RI | CI | Tertiary of Inner Coastal Plain and the Outer Coastal Plain (9) RI | CI |
|---|---|---|---|---|
| INDOOR RADON | 1 | 2 | 1 | 3 |
| RADIOACTIVITY | 3 | 3 | 1 | 3 |
| GEOLOGY | 3 | 2 | 2 | 3 |
| SOIL PERM. | 2 | 3 | 2 | 3 |
| ARCHITECTURE | 1 | - | 1 | - |
| GFE POINTS | 0 | - | 0 | - |
| TOTAL | 10 | 10 | 7 | 12 |
| | 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

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# EPA's Map of Radon Zones

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

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

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

## ALABAMA MAP OF RADON ZONES

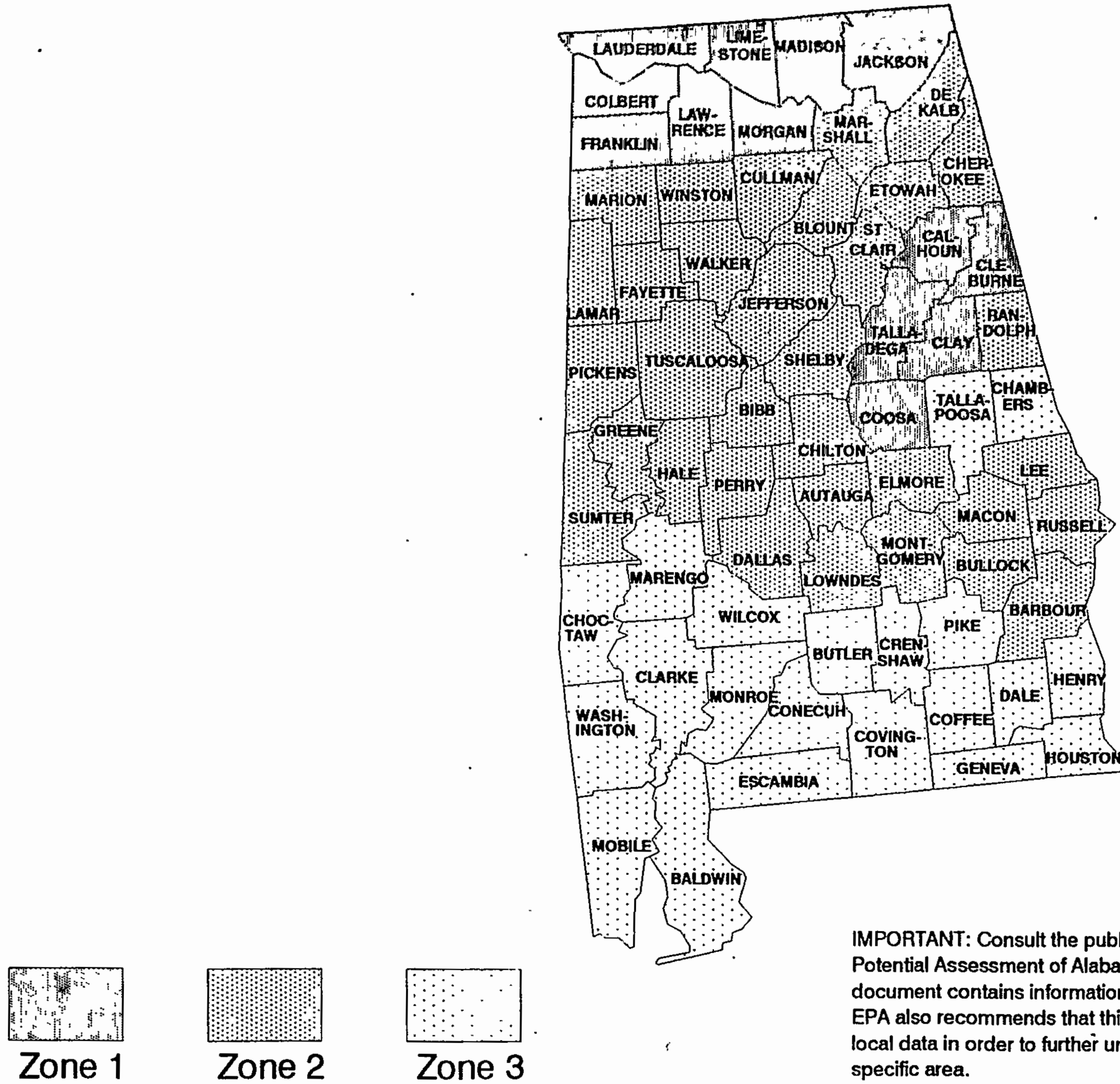
The Alabama Map of Radon Zones and its supporting documentation (Part IV of this report) have received extensive review by Alabama geologists and radon program experts. The map for Alabama generally reflects current State knowledge about radon for its counties. Some States have been able to conduct radon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

Although the information provided in Part IV of this report -- the State chapter entitled "Preliminary Geologic Radon Potential Assessment of Alabama" -- may appear to be quite specific, it cannot be applied to determine the radon levels of a neighborhood, housing tract, individual house, etc. **THE ONLY WAY TO DETERMINE IF A HOUSE HAS ELEVATED INDOOR RADON IS TO TEST.** Contact the Region 4 EPA office or the Alabama radon program for information on testing and fixing homes. Telephone numbers and addresses can be found in Part II of this report.

# ALABAMA - EPA Map of Radon Zones

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

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




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