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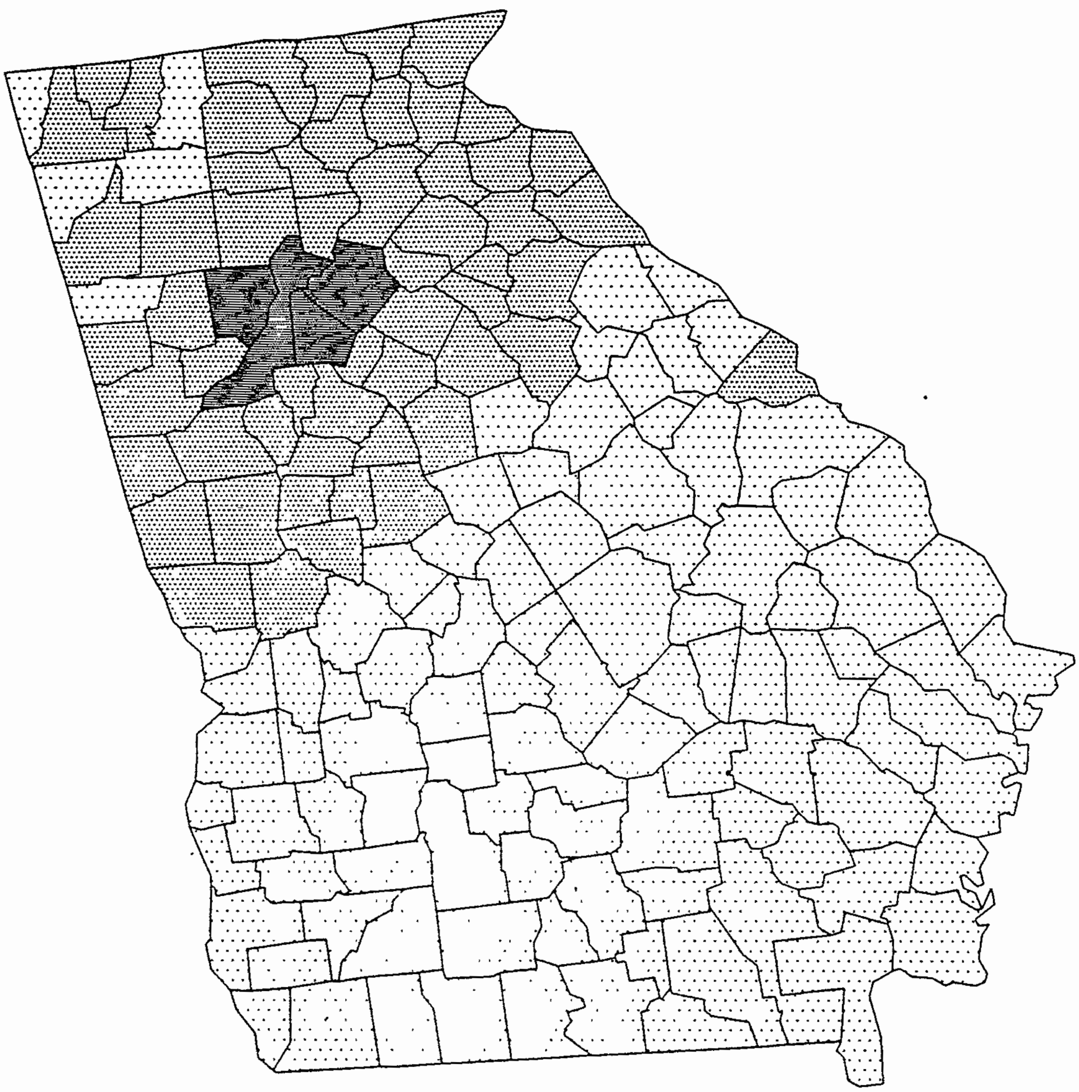
EPA's Map of Radon Zones

GEORGIA



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EPA'S MAP OF RADON ZONES
GEORGIA

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

SEPTEMBER, 1993

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OVERVIEW

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

The Map of Radon Zones is designed to assist national, State and local governments and organizations to target their radon program activities and resources. It is also intended to help building code officials determine areas that are the highest priority for adopting radon-resistant building practices. The Map of Radon Zones should <u>not</u> 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.

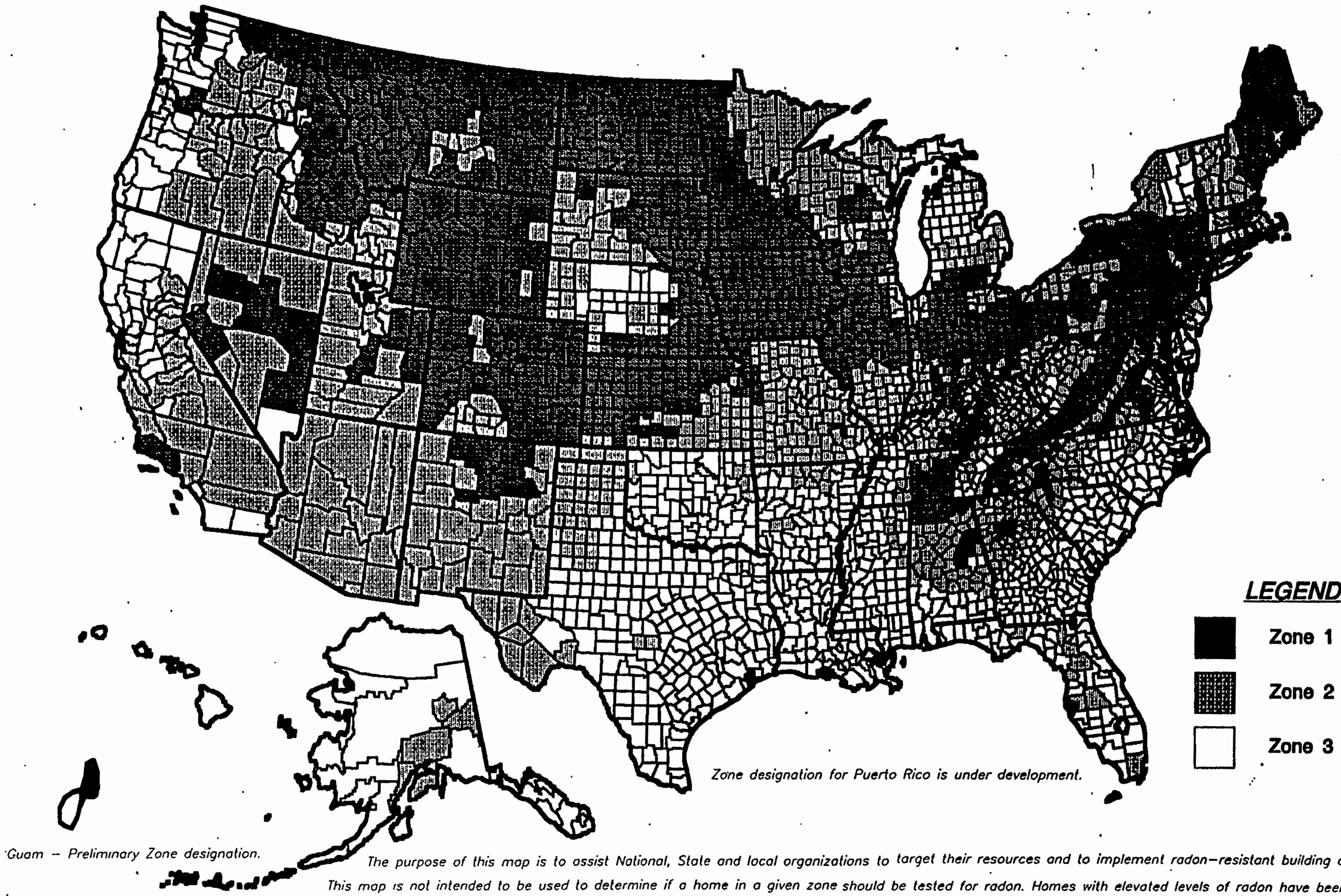
The Map of Radon Zones and its supporting documentation establish no regulatory requirements. Use of this map by State or local radon programs and building code officials is voluntary The information presented on the Map of Radon Zones and in the supporting documentation is not applicable to radon in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



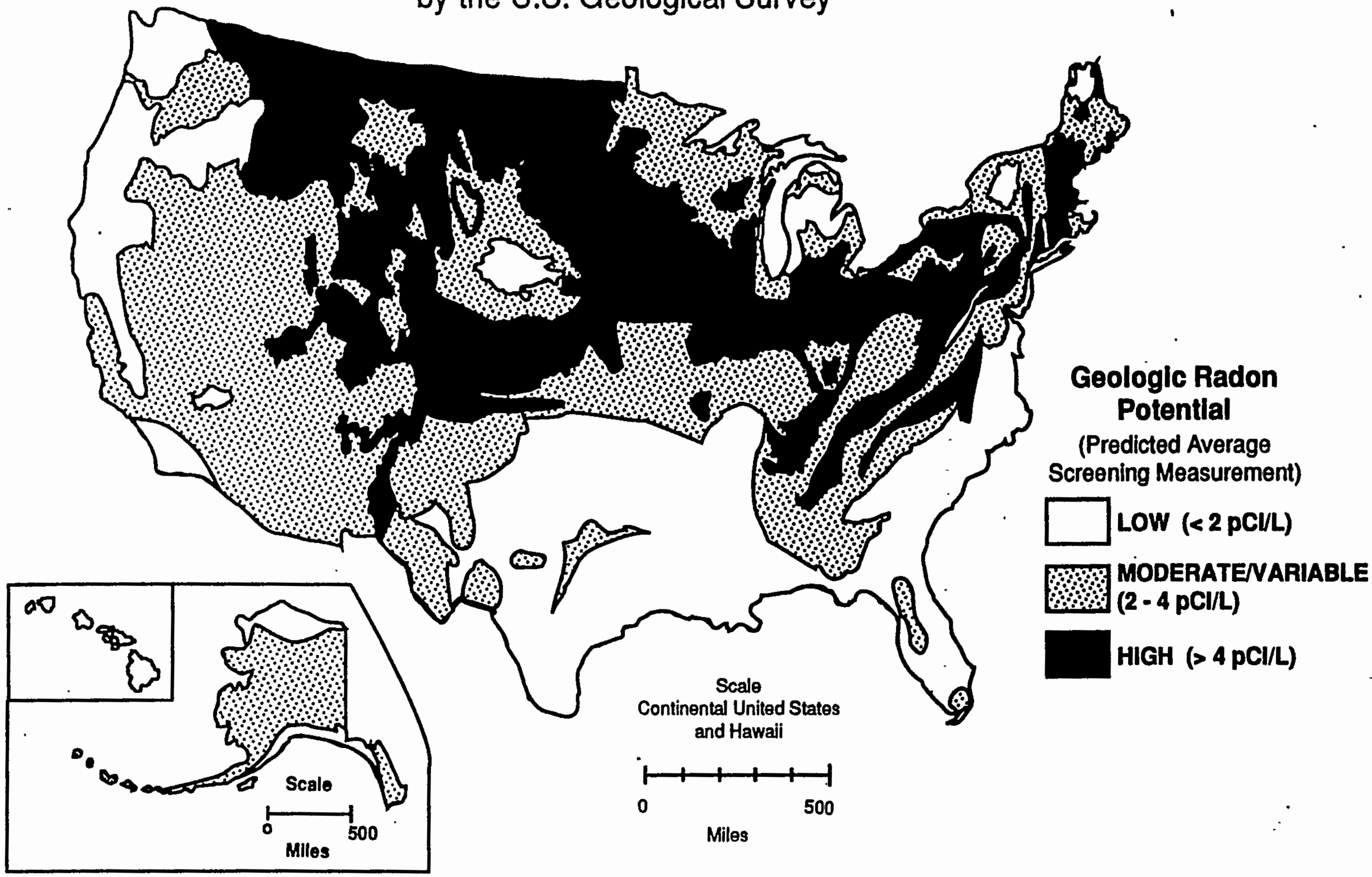
The purpose of this map is to assist National, State and local organizations to target their resources and to implement radon–resistant building codes. This map is not intended to be used to determine if a home in a given zone should be tested for radon. Homes with elevated levels of radon have been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

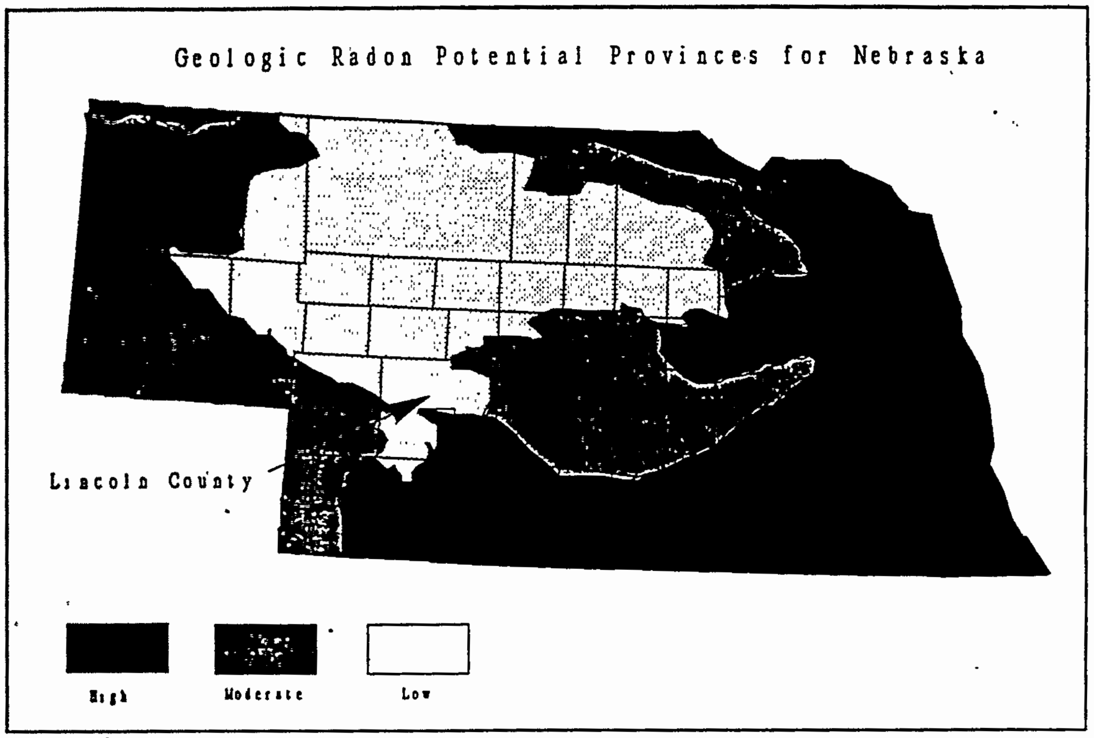
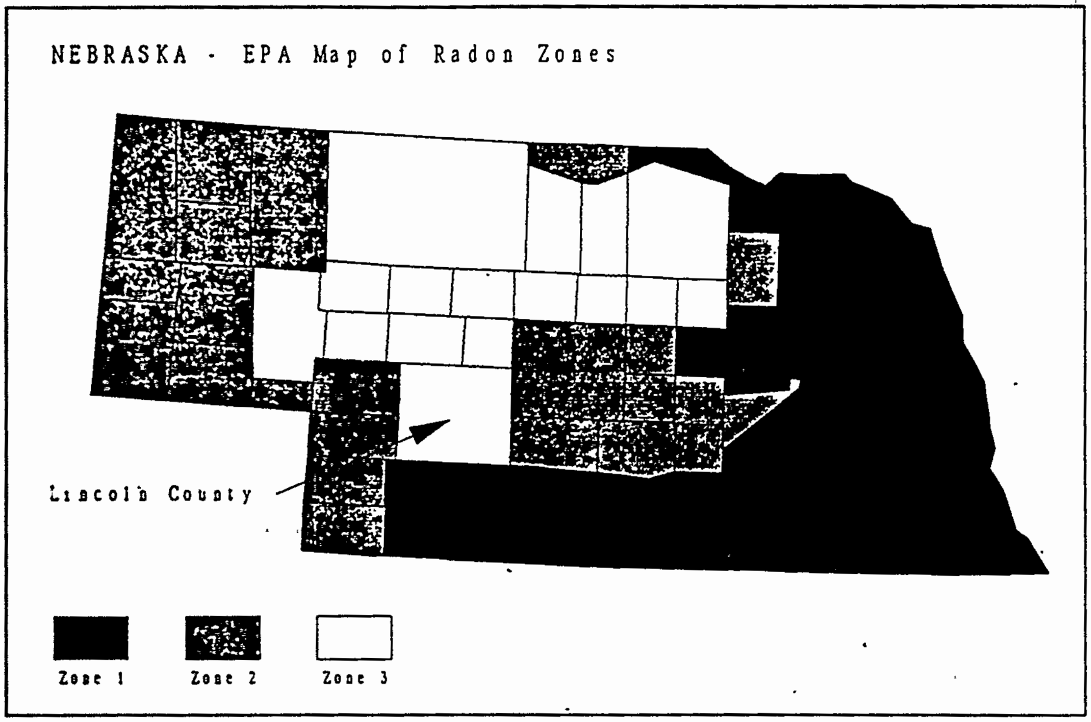


Figure 4



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

BACKGROUND

The Indoor Radon Abatement Act of 1988 (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

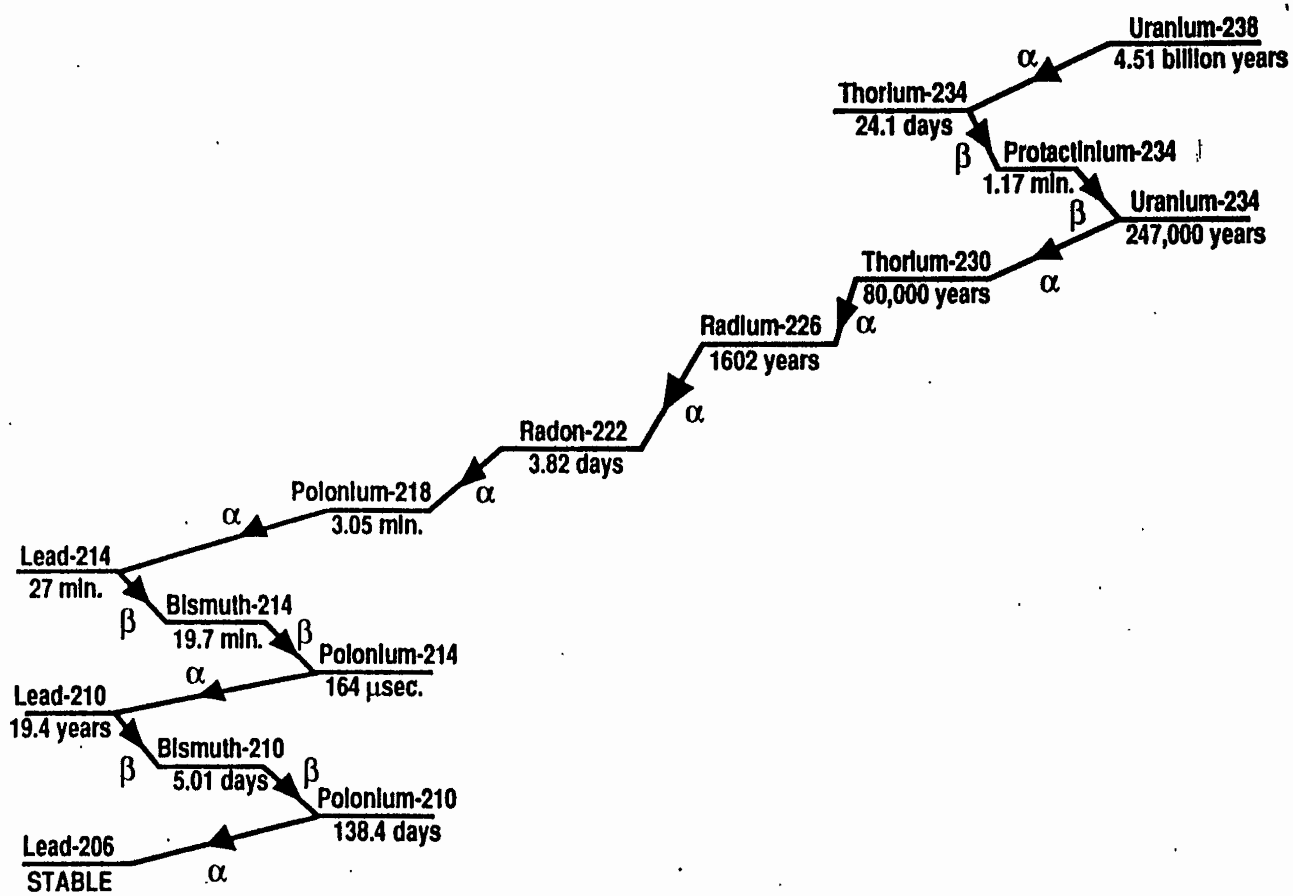


Figure 1. The uranium-238 decay series, showing the half-lives of elements and their modes of decay (after Wanty and Schoen, 1991). α denotes alpha decay, β denotes beta decay.

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 2×10^{-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).

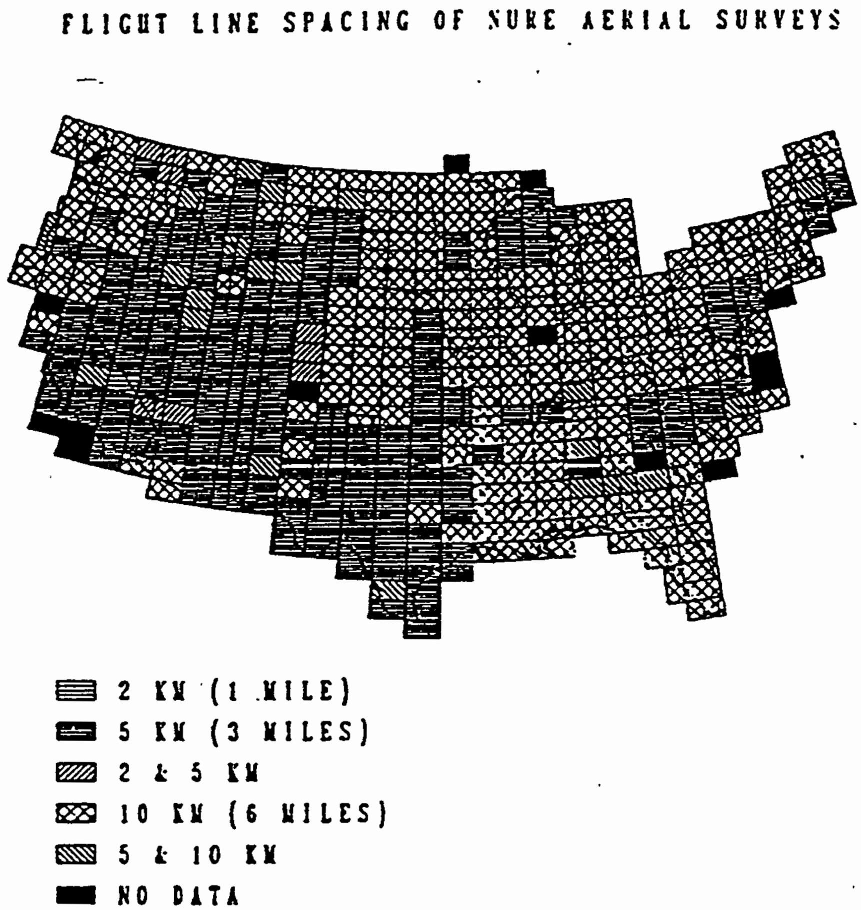


Figure 2. Nominal flightline spacings for NURE aerial gamma-ray surveys covering the contiguous United States (from Duval and others, 1990). Rectangles represent 1°x2° quadrangles.

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

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

SOIL SURVEY DATA

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

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

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

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

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

Indoor Radon Data

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

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

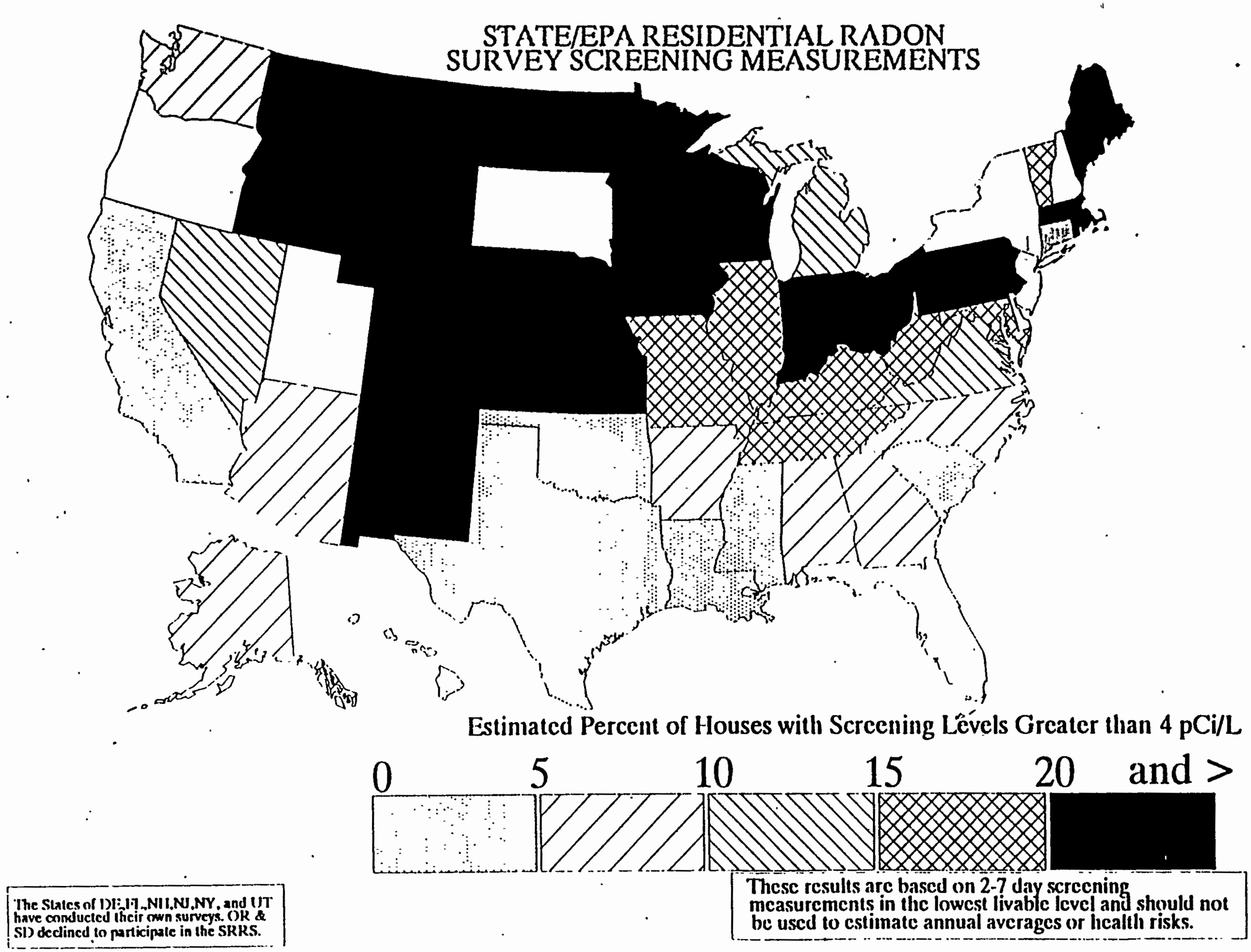


Figure 3. Percent of homes tested in the State/EPA Residential Radon Survey with screening indoor radon levels exceeding 4 pCi/L.

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	POINT VALUE 2	POINT VALUE 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	POINT VALUE 2	POINT VALUE 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

Eon or Eonothem	Era or Erathem	Period, System, Subperiod, Subsystem		Epoch or Series		Age estimates of boundaries in mega-annum (Ma)[1]
Phanerozoic[2]	Cenozoic[2] (Cz)	Quaternary[2] (Q)		Holocene		0.010
				Pleistocene		1.6 (1.6–1.9)
		Tertiary (T)	Neogene[2] Subperiod or Subsystem (N)	Pliocene		5 (4.9–5.3)
				Miocene		24 (23–26)
			Paleogene[2] Subperiod or Subsystem (Pt)	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 (Ŧ)		Late	Upper	
				Middle	Middle	
				Early	Lower	~240
	Paleozoic[2] (Pz)	Permian (P)		Late	Upper	
				Early	Lower	290 (290–305)
		Carboniferous Systems (C)	Pennsylvanian (P)	Late	Upper	
				Middle	Middle	
				Early	Lower	~330
			Mississippian (M)	Late	Upper	
				Early	Lower	360 (360–365)
		Devonian (D)		Late	Upper	
				Middle	Middle	
				Early	Lower	410 (405–415)
		Silurian (S)		Late	Upper	
				Middle	Middle	
				Early	Lower	435 (435–440)
		Ordovician (O)		Late	Upper	
				Middle	Middle	
				Early	Lower	500 (495–510)
		Cambrian (Є)		Late	Upper	
				Middle	Middle	
				Early	Lower	~570[3]
Proterozoic (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-C), a time term without specific rank.

[4] Informal time term without specific rank.

APPENDIX B
GLOSSARY OF TERMS

Units of measure

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

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

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

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

Geologic terms and terms related to the study of radon

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

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

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

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

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

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

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

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

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

carbonate A sedimentary rock consisting of the carbonate (CO_3) compounds of calcium, magnesium, or iron, e.g. limestone and dolomite.

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

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

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

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

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

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

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

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

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

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

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

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

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

dolomite A carbonate sedimentary rock of which more than 50% consists of the mineral dolomite ($CaMg(CO_3)_2$), and is commonly white, gray, brown, yellow, or pinkish in color.

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

eolian Pertaining to sediments deposited by the wind.

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

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

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

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

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

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

formation A mappable body of rock having similar characteristics.

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

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

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

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

heavy minerals Mineral grains in sediment or sedimentary rock having higher than average specific gravity. May form layers and lenses because of wind or water sorting by weight and size and may be referred to as a "placer deposit." Some heavy minerals are magnetite, garnet, zircon, monazite, and xenotime.

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

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

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

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

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

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

limestone A carbonate sedimentary rock consisting of more than 50% calcium carbonate, primarily in the form of the mineral calcite ($CaCO_3$).

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

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

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

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

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

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

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

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

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

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

phosphate, phosphatic, phosphorite Any rock or sediment containing a significant amount of phosphate minerals, i.e., minerals containing PO_4.

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

placer deposit See heavy minerals

residual Formed by weathering of a material in place.

residuum Deposit of residual material.

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

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

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

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

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

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

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

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

shrink-swell clay See clay mineral.

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

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

slope An inclined part of the earth's surface.

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

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

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

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

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

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

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

uraniferous Containing uranium, usually more than 2 ppm.

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

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

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

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

APPENDIX C
EPA REGIONAL OFFICES

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

STATE RADON CONTACTS

May, 1993

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

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

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

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

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

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

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

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

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

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

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

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

Idaho

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

Illinois

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

Indiana

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

Iowa

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

Kansas

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

Kentucky

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

Louisiana

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

Maine

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

Maryland

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

Massachusetts

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

Michigan

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

Minnesota

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Virginia	Shelly Ottenbrite Bureau of Radiological Health Department of Health 109 Governor Street Richmond, VA 23219 (804) 786-5932 1-800-468-0138 in state
Washington	Kate Coleman Department of Health Office of Radiation Protection Airdustrial Building 5, LE-13 Olympia, WA 98504 (206) 753-4518 1-800-323-9727 In State
West Virginia	Beattie L. DeBord Industrial Hygiene Division West Virginia Department of Health 151 11th Avenue South Charleston, WV 25303 (304) 558-3526 1-800-922-1255 In State
Wisconsin	Conrad Weiffenbach Radiation Protection Section Division of Health Department of Health and Social Services P.O. Box 309 Madison, WI 53701-0309 (608) 267-4796 1-800-798-9050 in state
Wyoming	Janet Hough Wyoming Department of Health and Social Services Hathway Building, 4th Floor Cheyenne, WY 82002-0710 (307) 777-6015 1-800-458-5847 in state

STATE GEOLOGICAL SURVEYS

May, 1993

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

EPA REGION 4 GEOLOGIC RADON POTENTIAL SUMMARY

by
Linda C.S. Gundersen, James K. Otton, and R. Randall Schumann
U.S. Geological Survey

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

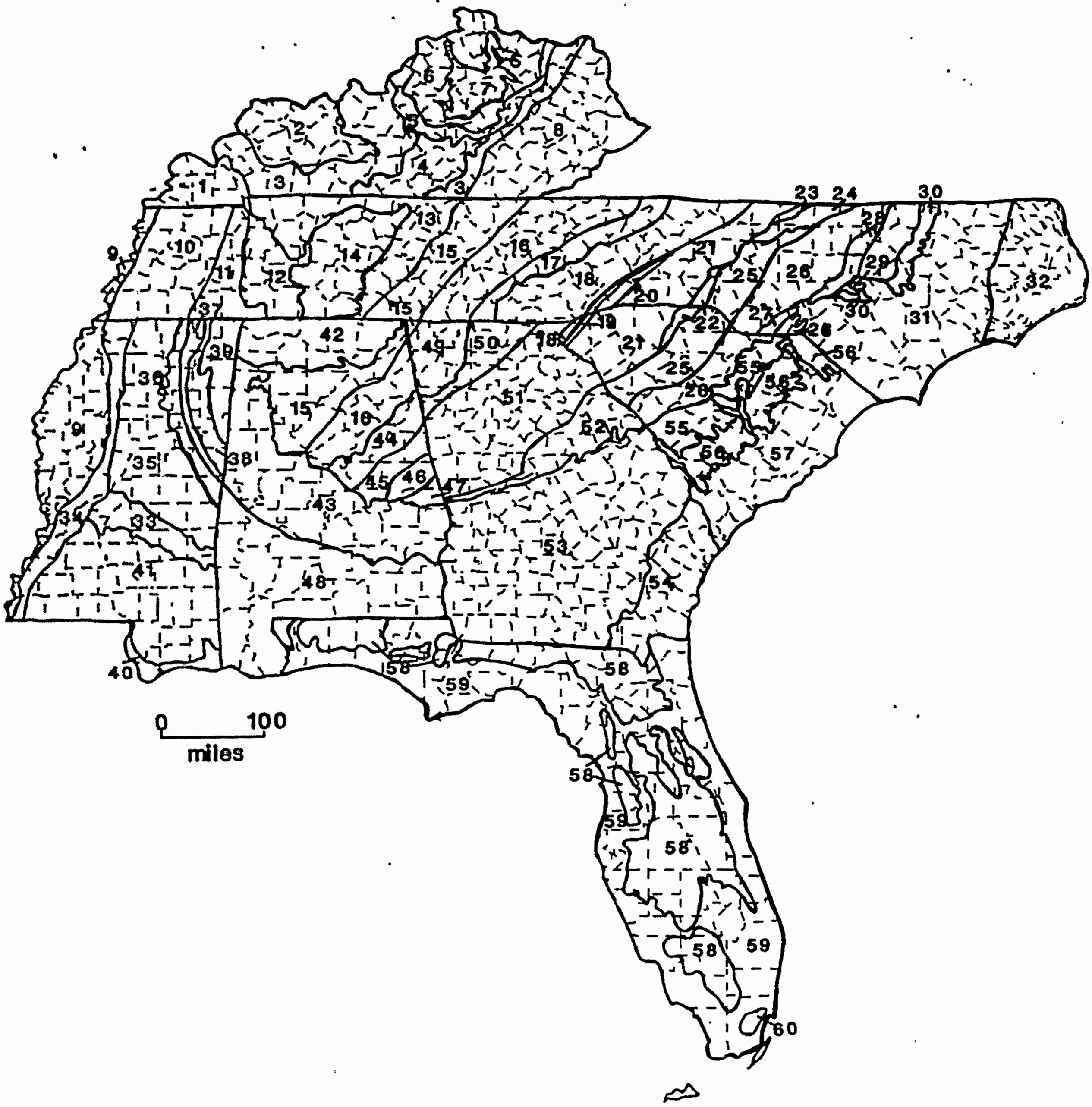


Figure 1. Geologic radon potential areas of EPA Region 4. See next page for names of numbered areas.

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.

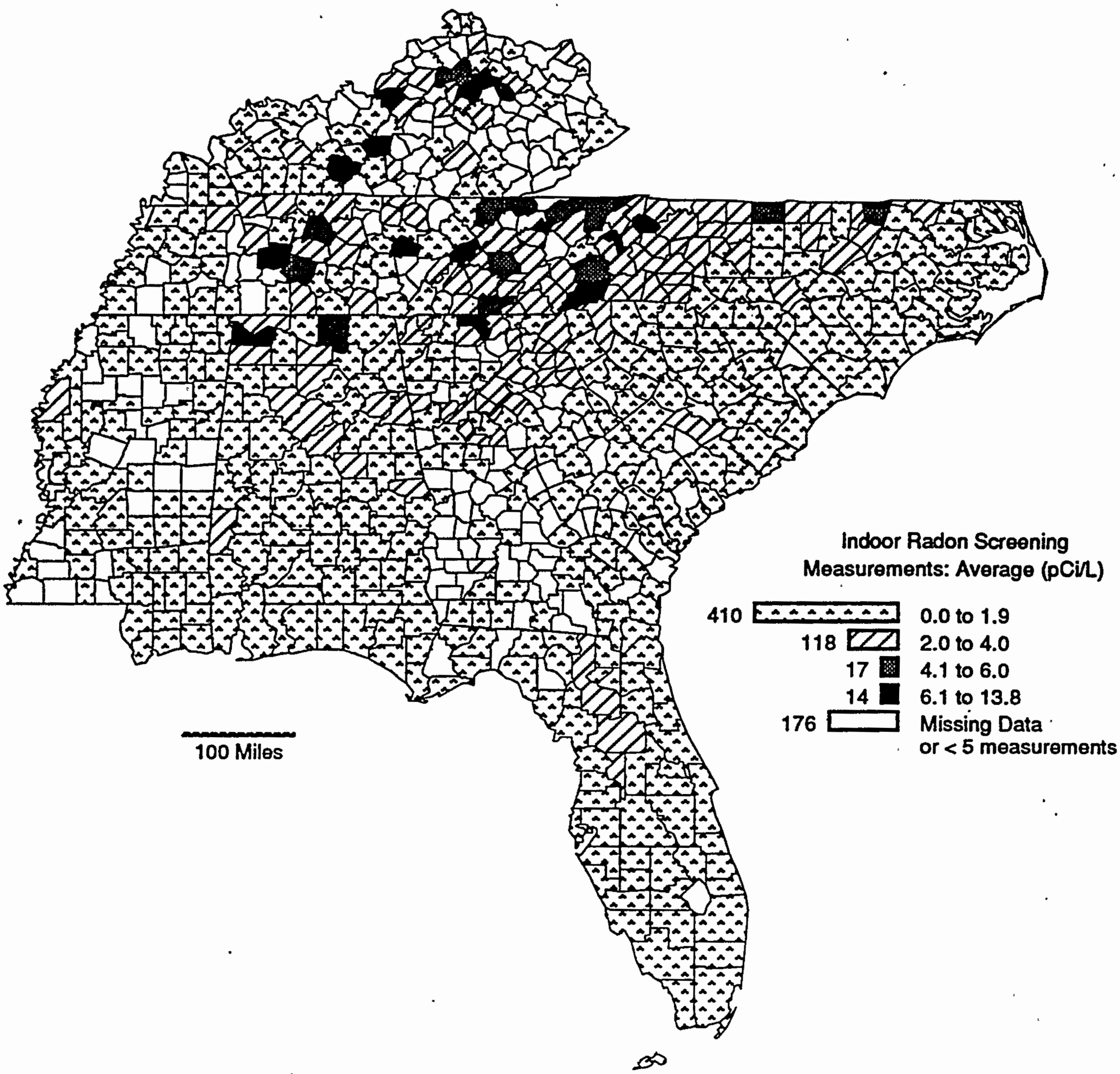


Figure 2. Screening indoor radon averages for counties with 5 or more measurements in EPA Region 4. Data for all states in Region4 except Florida from the State/EPA Residential Radon Survey. Data for Florida are from the Florida Statewide Radon Study. Histograms in map legend show the number of counties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

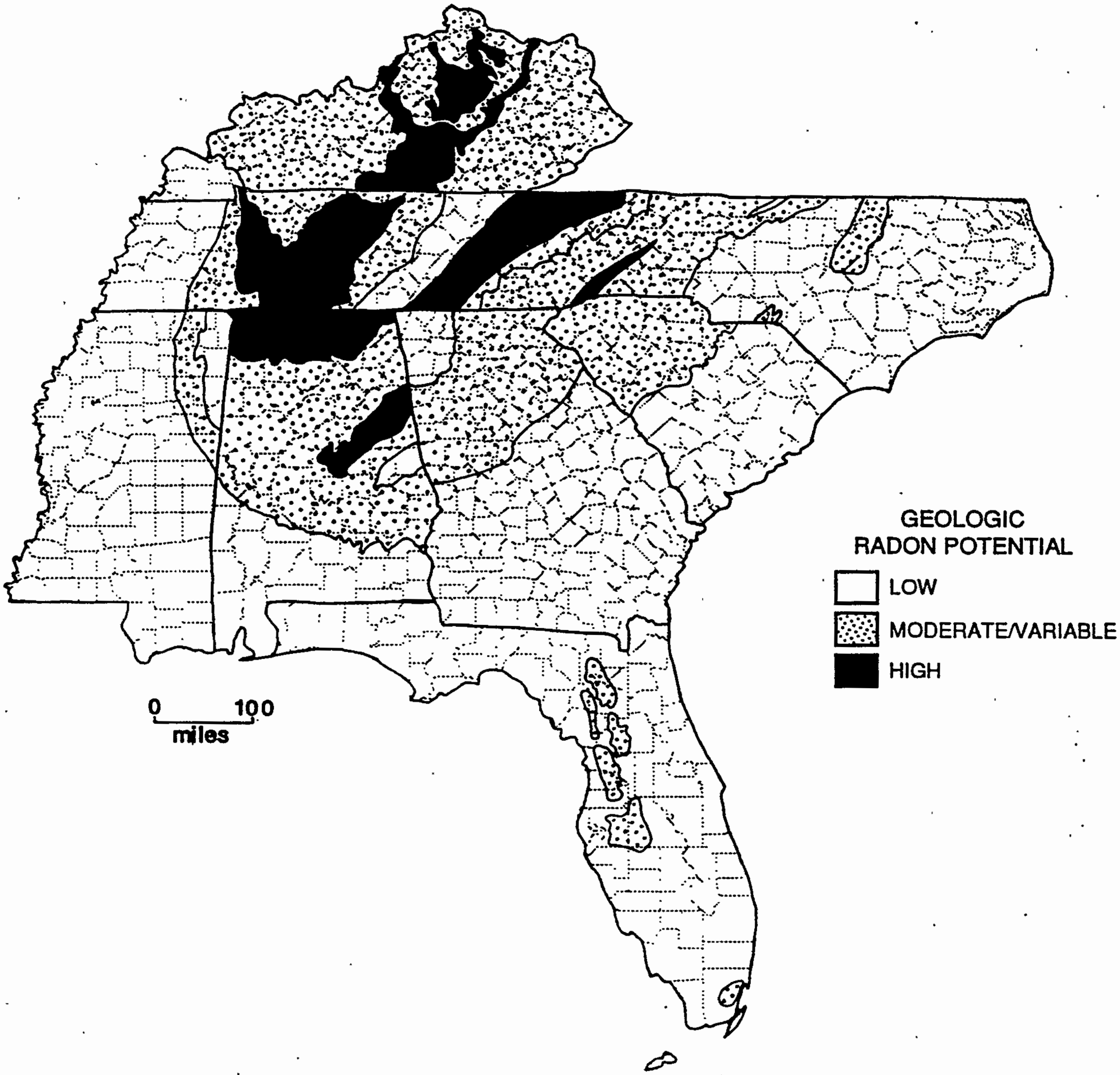


Figure 3. Geologic radon potential areas of EPA Region 4. For more detail, refer to individual state radon potential chapters.

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 1×10^{-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 high eU 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 GEORGIA

by
Linda C.S. Gundersen and Joseph P. Smoot
U.S. Geological Survey

INTRODUCTION

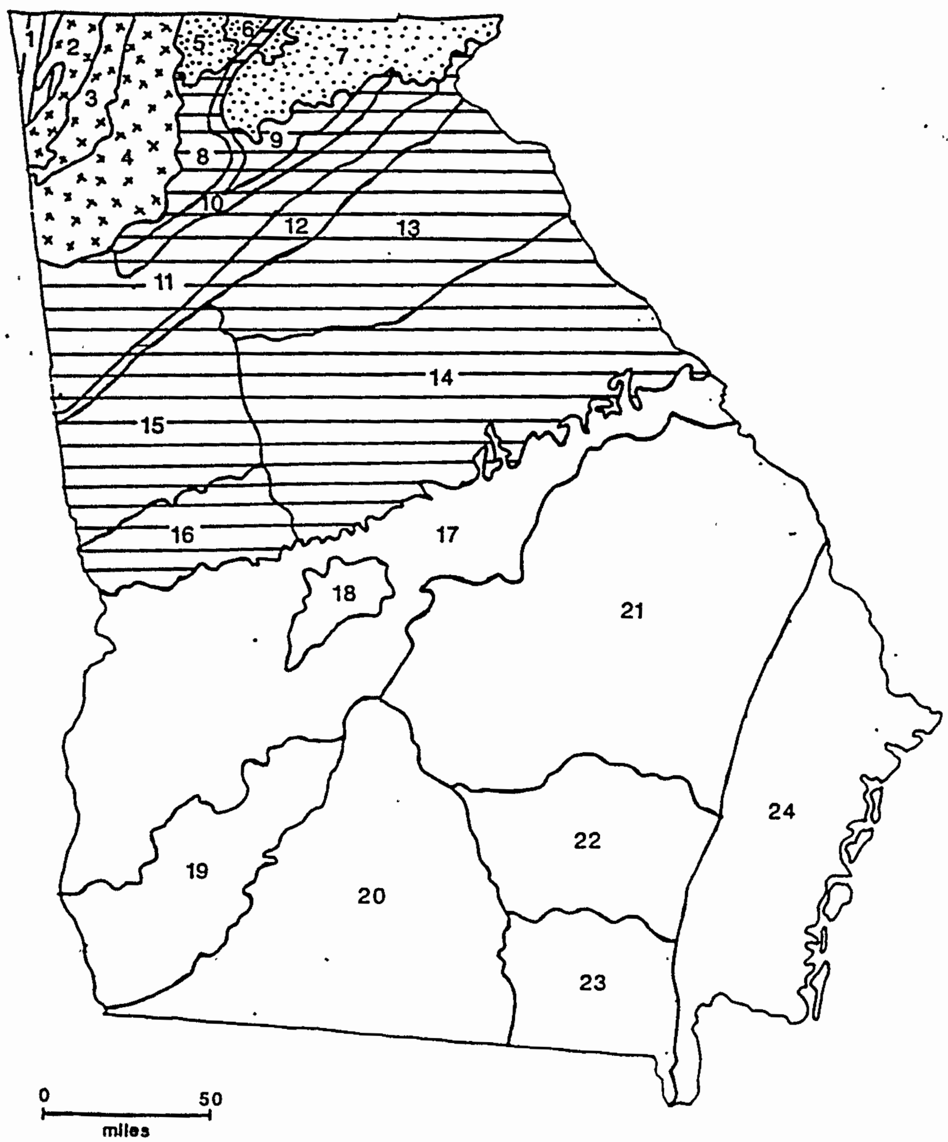
A random sampling of indoor radon levels in 1534 homes was conducted in Georgia as part of the State/EPA Residential Radon Survey during the winter of 1988-89. Indoor radon was measured by charcoal canisters and the average for the State was 1.7 pCi/L. Six and one-half percent of the indoor radon measurements exceeded the U.S. Environmental Protection Agency's guideline of 4 pCi/L. Examination of these data in the context of geology, soil parameters, and radioactivity suggest that soils and rocks of the Piedmont, Valley and Ridge, and Blue Ridge may have the potential to produce generally moderate (2-4 pCi/L) to locally high (>4 pCi/L) indoor radon levels. Rock types and soils with moderate to high geologic radon potential include black shales, soils derived from carbonate rocks, granitic gneiss, graphitic schist and phyllite, and granite. Soils and rocks of the Coastal Plain are generally low to locally moderate in radon potential.

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

GEOGRAPHIC SETTING

Georgia is divided into five major physiographic provinces: the Appalachian Plateau, the Valley and Ridge, the Blue Ridge, the Piedmont, and the Coastal Plain (fig. 1). Except for the Appalachian Plateau, the physiography of each province is subdivided into smaller districts. The Appalachian Plateau in Georgia is a small area in the northwestern part of the State comprising Lookout and Sand Mountains and the adjoining Lookout Valley. Elevation varies between 800 and 2000 feet above sea level, with local relief of up to 1200 feet. Sandstone caps the mountains and limestone underlies the valleys.

The Valley and Ridge Province is divided into three districts: Chickamauga Valley, Armuchee Ridges, and the Great Valley. Chickamauga Valley is a series of gently rolling, northeast-trending valleys separated by low, linear ridges. Elevation is 700-1000 feet above sea level, with local relief of up to 300 feet. Limestone underlies the valley floors and ridges are capped by sandstone and more resistant rock. The Armuchee Ridges are a series of prominent, steep, narrow ridges capped by sandstone with intervening valleys of shale and limestone.



The Appalachian Plateau Province
(1) Lookout and Sand Mountains, Lookout Valley.
The Valley and Ridge Province
(2) Chickamauga Valley (3) Armuchee Ridges
(4) The Great Valley.
The Blue Ridge Province
(5) Cohutta Mountains (6) McCaysville Basin
(7) Blue Ridge Mountains

The Piedmont Province
(8) Cherokee Upland (9) Dahlonega Upland
(10) Hightower-Jasper Ridges
(11) Central Uplands (12) Gainesville Ridges
(13) Winder Slope
(14) Washington Slope (15) Greenville Slope
(16) Pine Mountain.
The Coastal Plain Province
(17) Fall Line Hills (18) Fort Valley Plateau
(19) Dougherty Plain,
(20) Tifton Upland (21) Vidalia Upland
(22) Bacon Terraces
(23) Okefenokee Basin
(24) Barrier Island Sequence.

Figure 1. Physiographic provinces and subdivisions of Georgia (modified from Hodler and Schretter, 1986).

Elevation varies from 900 to 1600 feet above sea level, with local relief of up to 700 feet. The Great Valley is a broad open valley with small scattered hills. The valley is underlain by shale, dolomite, and limestone. Elevation varies from 700 to 800 feet above sea level with local relief of as much as 100 feet.

The Blue Ridge Province is divided into three districts: the Cohutta Mountains, the McCaysville Basin, and the Blue Ridge Mountains. The Cohutta Mountains are underlain by metamorphic rocks and consist of rugged mountains and deep valleys. Elevation is 1500-4000 feet above sea level with local relief of up to 2500 feet. The McCaysville Basin lies to the east of the Cohutta Mountains. It is a gently rolling basin with local relief of only 200-300 feet, except where it is bisected by the Jasper Ridges. Elevation is 1600-1800 feet and the basin is underlain by metamorphic rocks. The Blue Ridge Mountains are rugged mountains with high elevation, up to 4700 feet above sea level, and local relief of up to 2000 feet. Metamorphic and igneous rocks underlie the steep mountains and deep valleys of this province.

The Piedmont Province is underlain by metamorphic and igneous rocks. It separated into nine districts: The Cherokee Upland, the Dahlonega Upland, the Hightower-Jasper Ridges, the Central Uplands, the Gainesville Ridges, the Winder Slope, the Washington Slope, the Greenville Slope, and Pine Mountain. The Cherokee and Dahlonega Uplands comprise part of the northern Piedmont. These districts are characterized by elevations of 1000-1700 feet above sea level with local relief up to 600 feet. The area is hilly with narrow valleys in the north and wider valleys toward the south. These two districts are bordered by the Hightower Ridges to the south. The Jasper Ridges bisect the McCaysville Basin to the north. The Hightower-Jasper Ridges are a series of low parallel ridges separated by narrow valleys. Elevations are the highest of the Piedmont, 1200-2400 feet above sea level, with local relief of up to 800 feet. The Central Uplands and Gainesville Ridges are low ridges separated by shallow valleys with local relief of 100-200 feet. Valleys are narrow in the Gainesville Ridges and elevations vary from 700 to 1600 feet. Valleys are broad in the Central Uplands and elevation varies from 1100 to 1500 feet. The Winder Slope occupies a large area in northeastern Piedmont. It is characterized by a gently rolling surface with deep narrow stream valleys and dome-shaped granitic mountains. Elevation is 700-1000 feet with local relief of up to 200 feet. The Washington Slope lies to the south of the Winder Slope and has a gentle, undulating surface marked by broad valleys and gentle slopes. Elevation is lower, 500-700 feet, and relief is generally 50-100 feet except along the Oconee River, where relief is up to 200 feet. The Greenville Slope is characterized by a rolling topography, with open valleys to the west and narrow valleys to the east. Elevation is 600-1000 feet above sea level with local relief of up to 100 feet. Pine Mountain is in the southwest corner of the Piedmont and is marked by Pine-Oak Mountain, which rises 700 feet above the surrounding area. Elevation varies from 500 to 1300 feet above sea level with local relief of up to 200 feet.

The Coastal Plain Province is subdivided into eight districts: The Fall Line Hills, the Fort Valley Plateau, The Dougherty Plain, the Tifton Upland, the Vidalia Upland, the Bacon Terraces, the Okefenokee Basin, and the Barrier Island Sequence. Elevation varies progressively from 750 feet in the Fall Line Hills to sea level at the Gulf and Atlantic coastlines in the south and east. The Fall Line Hills is a highly dissected hilly area with local relief of 50-250 feet. The Fort Valley Plateau is underlain by more clayey sediments than the surrounding Fall Line Hills and is a broad plateau with little relief. The Dougherty Plain is a flat to gently rolling lowland with numerous sinkholes, ponds and marshes formed on the underlying limestone. The Tifton Upland is characterized by a complicated drainage pattern with narrow stream divides. The Vidalia Upland is the largest subdivision of the Coastal Plain. It is a moderately dissected upland underlain by gravelly clayey sands. The Bacon Terraces parallel the present coastline. Long, narrow interfluves with gently rounded flat summits rise 50-100 feet above narrow marshy floodplains. The Okefenokee Basin is a lowland area characterized by the 600-square-mile Okefenokee Swamp. The Barrier Island Sequence is characterized by a number of shoreline deposits formed during the advance and retreat of sea level over time. Subsequently, a step-like progression of deposits with decreasing elevations have formed parallel to shoreline.

Thirty-three percent of Georgia's population is settled in the Atlanta metropolitan area and approximately 70 percent of the State's population is settled north of the Coastal Plain (fig. 2). The remaining 30 percent of Georgia's population is scattered across the Coastal Plain, including the population centers of Savannah, Columbus, and Albany. The majority of Georgia's land area is forested, and commercial lumbering abounds throughout the State. The Coastal Plain is dominantly agricultural, whereas north of the Coastal Plain, manufacturing, the service industry, and government provide the principal kinds of employment. The climate of Georgia is semi-tropical with hot, humid summers and mild winters. Precipitation in the State varies from 40-60 inches per year (fig. 3).

GEOLOGIC SETTING

The geology of Georgia is diverse and varies from the flat-lying marine and fluvial sequences found in the Coastal Plain to complexly folded and faulted rocks of the Piedmont, Blue Ridge, and Valley and Ridge. The following descriptions of the geology of Georgia are derived from Reinhardt and others (1980), Schamel and others (1980), Bearce and others (1982), McConnell and Abrams (1984), Lindberg (1985), and Higgins and others (1988). A generalized geologic map is given in figure 4. On the geologic map of Georgia in this booklet, local rock unit names have not been used and the units have been grouped and described by rock type for clarity. The reader should refer to the state geologic map of Georgia (Georgia Department of Natural Resources, 1976) and other detailed geologic maps and bulletins from the Georgia Geologic Survey for more information. Georgia has been divided into several tectonic and geologic areas based on rock type and structure (Higgins and others, 1988). These areas and some of the major fault zones are shown in figure 5 and their terminology will be used throughout this report. We will also refer to the major physiographic provinces (fig. 1) for reference. The terms Blue Ridge and Piedmont have also been used in some literature in the Appalachians to refer to geologic provinces. In this report, Blue Ridge and Piedmont refer to the physiographic areas only.

The Georgiabama Thrust Stack

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, which is bounded to the northwest by the Emerson and Carters Dam faults and to the southeast by the Auchumpkee fault. The oldest rocks are Precambrian gneiss, granite, and schist that form a prominent east-west trending belt just south of the Towaliga Fault and a northeasterly-trending belt east of the Towaliga Fault to Athens. North of the Allatoona Fault are Precambrian mica schist, metagraywacke, phyllite, biotite gneiss, and minor conglomerate of the Bill Arp thrust sheet (Higgins and others, 1988). Similar rocks comprise prominent northeast-trending belts immediately north of the Brevard Fault zone, on either side of the Towaliga Fault, and discontinuously along the trend of the Towaliga Fault to the South Carolina border in Hart

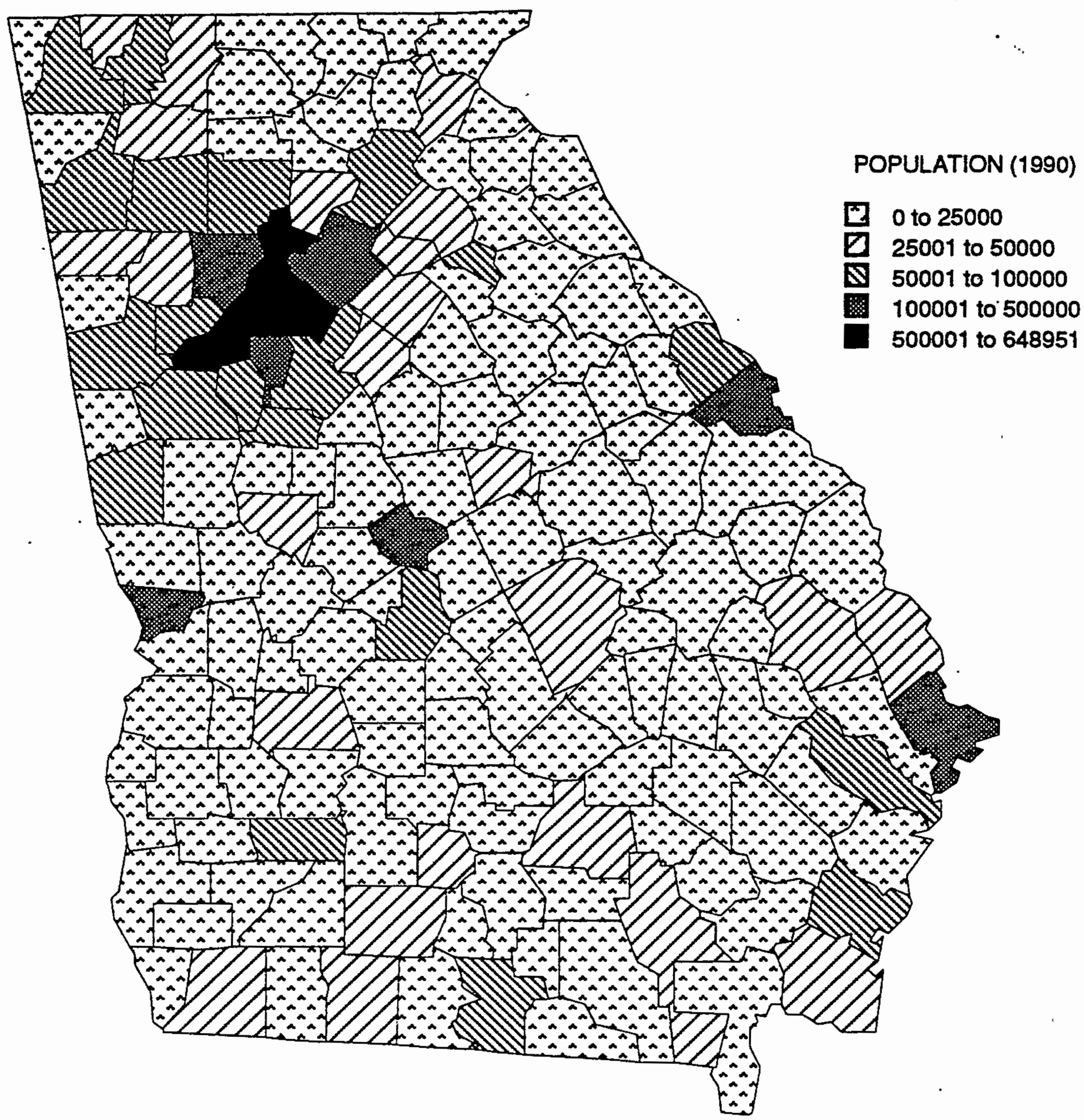


Figure 2. Population of counties in Georgia (1990 U.S. Census data).

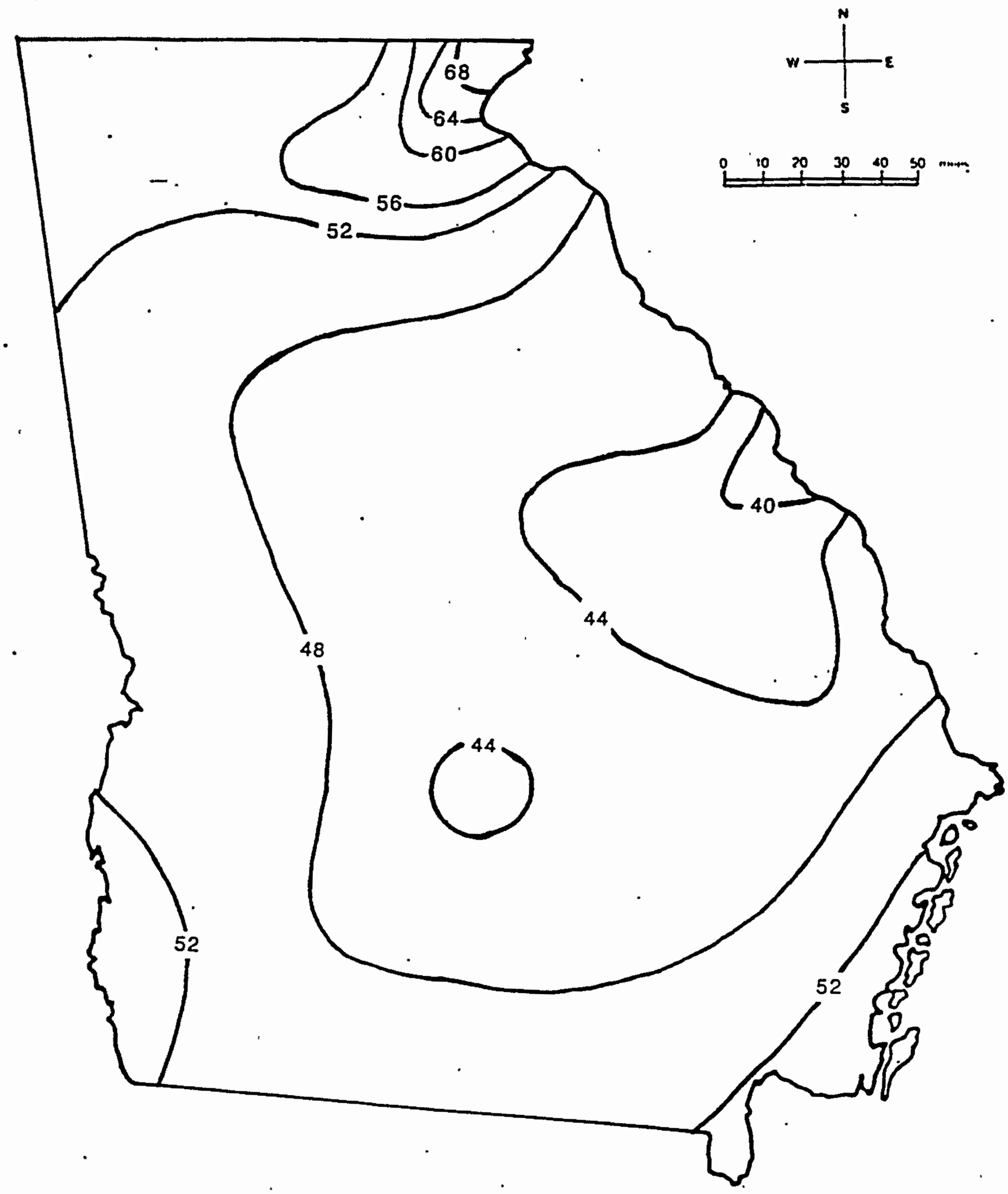


Figure 3. Average annual precipitation in Georgia (redrawn from Perkins and Shaffer, 1977).

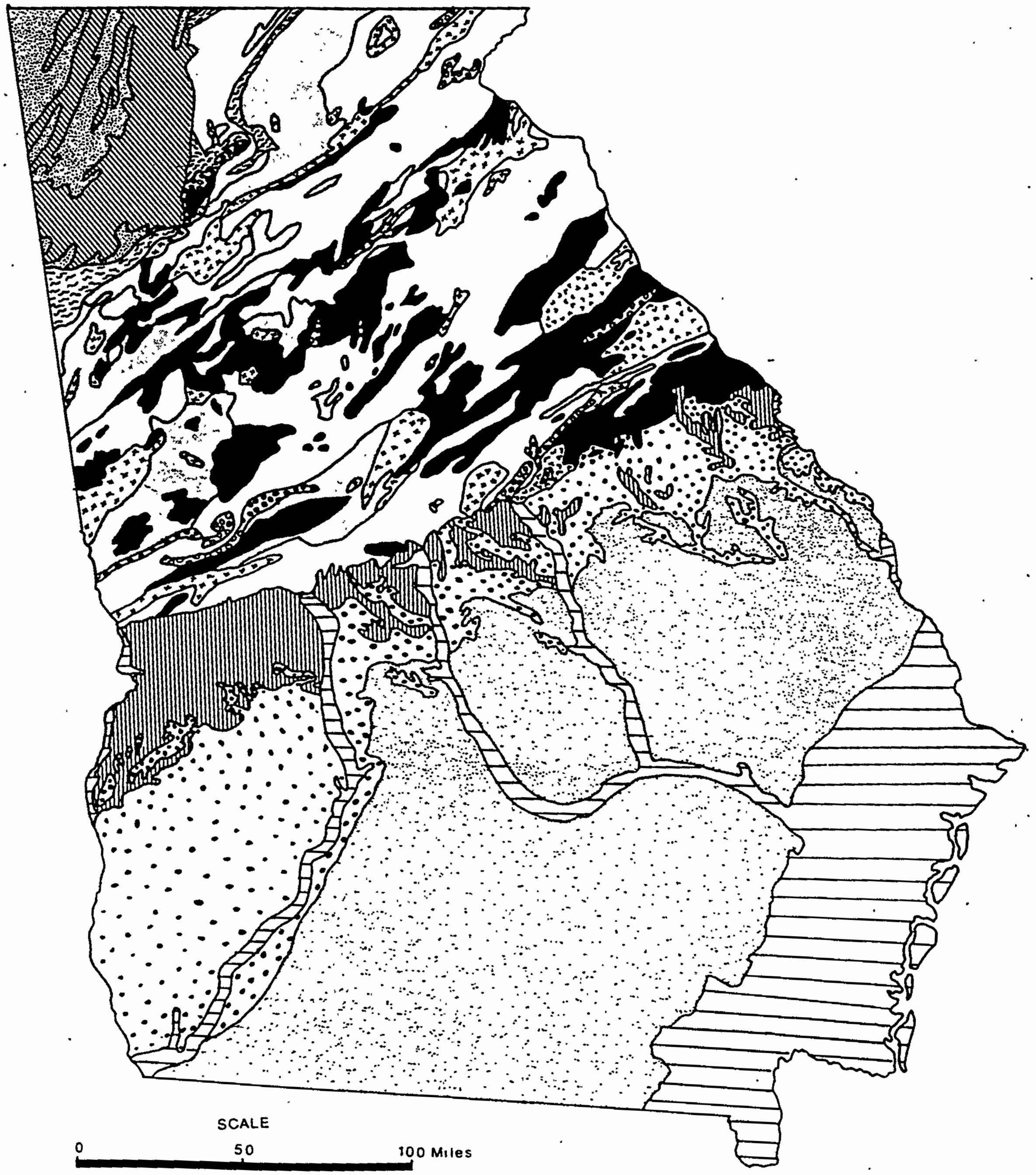


Figure 4. Generalized geologic map of Georgia (after Georgia Department of Natural Resources, 1976).

EXPLANATION
GENERALIZED GEOLOGIC MAP OF GEORGIA

COASTAL PLAIN

QUATERNARY

Well sorted marine and eolian sands, lagoonal and marsh clay and silt, and fluvial terrace sand and gravel.

PLIOCENE- MIOCENE-OLIGOCENE

Pliocene sand and gravel; Miocene sand, pebbly sand, clayey sand, sandy clay, and clay, including the **Hawthorne**, **Miccosukee**, and **Citronelle Formations**, and **Altamaha Grit**; Oligocene limestone and marl, including the **Suwannee Limestone.**

EOCENE AND PALEOCENE

Eocene quartz sand, clay, and calcareous sand, including the **Irwinton Sand**, **Twiggs Clay**, **Clinchfield Sand**, and **McBean Formation**; Eocene limestone, marl, and calcareous clay, including the **Ocala** and **Sandersville Limestones**, **Cooper Marl**, and **Lisbon Formation**; Eocene quartz sand, glauconitic sand, and clay, including the **Talhatta** and **Hatchetigbee Formations**; Paleocene quartz sand, glauconitic sand, carbonaceous clay, and clay, including the **Congaree**, **Huber**, **Lang Syne**, **Tuscahoma**, and **Nanafalia Formations**; Paleocene limestone and quartz sand of the **Clayton Formation.**

CRETACEOUS

Quartz sand, glauconitic sand, sandy clay, carbonaceous clay, and clay including the **Providence Sand**, **Ripley Formation**, **Cusetta Sand**, **Blufftown** and **Eutaw Formations**; arkosic sand and conglomerate, locally carbonaceous, with red clay of the **Tuscaloosa Formation.**

VALLEY AND RIDGE AND APPALACHIAN PLATEAU

PENNSYLVANIAN-MISSISSIPPIAN-DEVONIAN

Pennsylvanian sandstone, conglomerate, and shale with coal seams of the **Pottsville Formation**; Mississippian shale, limestone, sandstone, and chert, including the **Pennington Formation**, **Floyd Shale**, **Bangor**, **Monteagle**, and **Tuscumbia Limestones**, **Fort Payne Chert**, and **Maury Formation**; Devonian **Chattanooga Shale**, **Armuchee Chert**, and **Frog Mountain Sandstone.**

SILURIAN-ORDOVICIAN-CAMBRIAN

Silurian ferruginous sandstone and shale of the **Red Mountain Formation**;Ordovician and Cambrian limestone, dolomite, shale, sandstone, and chert, including the **Chickamauga Group**, **Knox Group**, **Conasauga Group**, **Rome Formation**, and **Shady Dolomite**; Cambrian quartzite and shale of the **Chilhowee Group.**

PIEDMONT AND BLUE RIDGE

PERMIAN to PROTEROZOIC

Granite and granitic gneiss, includes the **Palmetto, Ben Hill, Stone Mountain, Panola, Elberton**, and **Appling** granites in the Georgiabama Thrust Stack and Grenville Basement; and migmatitic biotite and amphibolite gneiss of the Little River Thrust Stack.

Quartzite and quartzite with lesser amounts of mica schist, phyllite, and/or amphibolite.

Phyllite, graphitic phyllite, and mica schist with lesser amounts of quartzite.

Mica schist and graphitic schist with lesser amounts of gneiss and amphibolite.

Hornblende gneiss, amphibolite, and locally metadiabase and metagabbro.

Metadacite and metavolcanics interbedded with phyllite and meta-argillite.

Mica schist, metagraywacke, slate, quartzite, conglomerate, amphibolite, biotite gneiss, hornblende gneiss, granite gneiss, biotite gneiss, mica schist, and amphibolite in the Georgiabama Thrust Stack; biotite granite gneiss, feldspathic biotite gneiss, and amphibolite-hornblende gneiss in the Little River Thrust Stack.

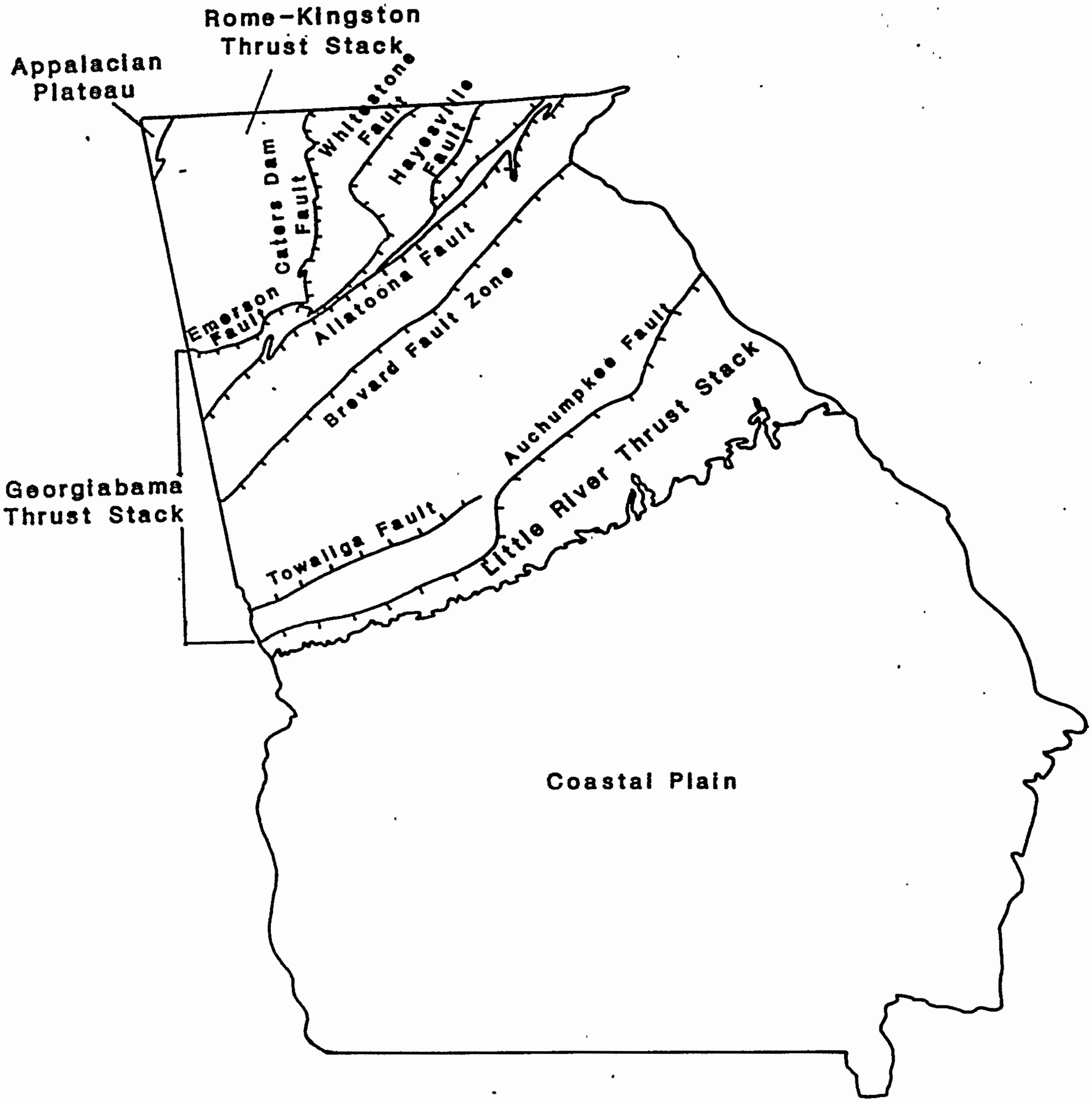


Figure 5. Tectonic/geologic area map of Georgia (after Higgins and others, 1988).

County. Nearly 40 percent of the Georgiabama Thrust Stack in the Piedmont Province is underlain by garnet-rich mica schist, hornblende-plagioclase amphibolites, and biotite gneiss termed the Zebulon Sheet by Higgins and others (1988). In addition, a complex variety of meta-igneous, metavolcanic, and metasedimentary rocks are incorporated into a series of narrow thrust sheets throughout the Piedmont portion of the Georgiabama Thrust Stack. Some of the more spatially important units are: muscovite-plagioclase gneiss and sillimanite-rich plagioclase schist underlying a large part of Elbert and Oglethorpe Counties; a mixed assemblage of amphibolite, biotite schist, metatuffs, and quartzite occurring discontinuously from Dekalb to Coweta County in the north and Butts to Pike County in the south; a narrow belt of quartzite, schist, and minor amphibolite that is within and immediately north of the Brevard Fault zone; and narrow belts of metabasalt that are complexly folded in the area between the Brevard Fault zone and the Allatoona Fault. The Georgiabama Thrust Stack is intruded by numerous granites and granitic gneisses that are complexly folded and faulted. Most of these are Silurian-Devonian or Carboniferous in age.

<u>The Little River Thrust Stack</u>

The area of Piedmont Province south of the Auchumpkee Fault consists of severely sheared, metamorphosed Precambrian to Cambrian volcaniclastic and basinal sedimentary rocks of the Little River Thrust Stack. These rocks comprise thrust sheets that form northeastward-trending belts. The Little River Thrust Stack is dominated by slightly metamorphosed calc-alkaline volcanic and volcaniclastic rocks of the Little River Allochthon (Higgins and others, 1988) east of Putnam County and along a narrow belt on the southern margin that is overlapped by Coastal Plain deposits. Most of the Little River Thrust Stack is underlain by feldspathic and micaceous schist with amphibole-bearing metagraywacke, schistose pebbly mudstone, and tuffaceous metachert. Numerous small bodies of metadiabase, metagabbro, and amphibolite are common in a broad belt just south of the Auchumpkee Fault. These rocks also underlie much of northern Burke County and Richmond and Jefferson Counties. Granites and granitic gneiss that are mostly Silurian-Devonian or Carboniferous in age intrude the Little River Thrust Stack, particularly in the eastern part of the belt.

<u>The Rome-Kingston Thrust Stack</u>

The Valley and Ridge Province is underlain by rocks of the Rome-Kingston Thrust Stack, which is bounded to the south by the Emerson Fault and to the east by the Carter's Dam fault. Paleozoic sedimentary rocks of Cambrian through Pennsylvanian age form tightly folded ridges and valleys separated by northeast-trending thrusts. The majority of the area is underlain by Cambrian through Ordovician limestone, dolomite, and shale with minor sandstone. Narrow outcrop belts of Silurian and Devonian sandstones and shales lie between the Cambrian through Ordovician rock units. Pennsylvanian to Mississippian sandstone, shale, conglomerate and limestone underlie two significant areas: the western edge of the area along the Dade-Walker county line and the northwestern corner of Chattooga County.

The oldest Cambrian rocks are quartzite and shale of the Chilhowee Group, which are restricted to a few small areas in the eastern part of the province. The middle to upper Cambrian rocks have 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 Group, consisting of alternating beds of limestone and shale with sandstone and dolomite. The Conasauga Group outcrops are the most extensive of the middle to upper Cambrian units, underlying one-third of the area between the Rome and Carter's Dam faults.

The Conasauga thins to the west, however, and the westernmost belt of Rome Formation is directly overlain by the upper Cambrian-Ordovician Knox Group.

The upper Cambrian and Ordovician-age rocks of the Rome-Kingston Thrust Stack are dominated by limestone and dolomite. The Knox Group, consisting of dolomite, limestone, and chert, is the most extensive unit, underlying nearly half of the area between the Rome and Great Smoky Faults and forming several prominent belts in the western part of the province. The Knox Group is unconformably overlain by limestone of the middle to upper Ordovician Chickamauga Group, which forms prominent outcrop belts in the western part of the area. The Ordovician Athens Shale and Rockmart Slate comprise several narrow, mostly fault-bounded belts immediately east of the Carter's Dam Fault near the Tennessee border and north of the Emerson Fault.

The Silurian and Devonian-age rocks of the Rome-Kingston Thrust Stack are dominated by the Silurian Red Mountain Formation, consisting of ferruginous sandstone and shale, and narrow belts of the Devonian Chattanooga Shale. These units are separated by the Devonian Frog Mountain Sandstone in the east and the Armuchee Chert in the west.

Mississippian-age shale, limestone, sandstone, and chert underlie the northeastern corner of Chattooga County and comprise narrow belts in the western part of the area. The succession consists of shales of the Maury Formation; Fort Payne Chert, with the Lavender Shale member to the east; the Floyd Shale, with sandstone and limestone members that are equivalent to the Tuscumbia and Monteagle Limestones to the west; the Bangor Limestone; and shale and sandstone of the Pennington Formation.

Pennsylvanian-age rocks are dominated by sandstone, conglomerate, and shale with minor coal beds. These underlie a few small areas capping the Mississippian rocks in northeastern Chattooga County and comprise a broad belt in the west consisting of the Pennington and Pottsville Formations.

Appalachian Plateau

The Appalachian Plateau Province is underlain by gently dipping sandstone, conglomerate, shale, limestone, and coal of Mississippian and Pennsylvanian age. Mississippian rocks are the same as those described for the western part of the Rome-Kingston Thrust Stack, and are restricted to a narrow belt along the edge of that province and the lowest parts of the stream drainages in the northwestern corner of the State. Pennsylvanian fluvial sandstone and conglomerate with shale and coal interbeds of the Pottsville Formation underlie most of the province.

Coastal Plain

Nearly 60 percent of Georgia is underlain by relatively unconsolidated sediments of the Coastal Plain Province. These deposits include sand, silt, clay, marl, limestone, and conglomerate that form a sedimentary wedge which thickens southeastward. The intersection of these gently-dipping beds with the land surface produce northeast-trending belts that are progressively younger to the southeast. Coastal Plain deposits adjacent to the Piedmont Province are incised by dendritic drainages that expose older sediments in the channels. Cretaceous sediments form a broad belt in the northwestern corner of the province that directly overlie weathered rocks of the Piedmont, but they are mostly restricted to the bottoms of drainages in the northeast. A belt of early Tertiary sediments also thins to the northeast and directly overlies the Piedmont rocks in places. Late Tertiary sediments comprise a very broad belt that underlies about half of the province. Quaternary sediments form a broad belt along the Georgia coast and also fill the major river valleys.

The oldest sediments exposed in the northern Coastal Plain of Georgia belong to the Cretaceous Tuscaloosa Formation, which consists of fluvial sand and conglomerate with local lignite concentrations, interbedded with mottled red clay. This is overlain by marine sand and clay of the Eutaw Formation. The older northwestern portion of the Eutaw consists of coarse to fine quartz sand, whereas the younger portion to the southeast consists of micaceous, fossiliferous, fine to medium quartz sand, with interbeds of micaceous sand, sandy clay, and carbonaceous clay. The succeeding Blufftown Formation is cross-bedded marine quartz sand at the base, grading upward to a glauconitic, fine-grained, calcareous sand, fossiliferous fine-grained sand interbedded with micaceous clay, and marl and carbonaceous clay and silt. The Cusseta Sand is a cross-bedded, medium-to coarse-grained, quartz sand with thin beds of carbonaceous clay that increase in frequency toward the top. The Ripley Formation unconformably overlies the Cusseta, commonly having a basal phosphatic lag gravel. Most of the Ripley is a massive, medium-grained, micaceous and glauconitic quartz sand that is finer grained and more calcareous toward the top of the unit, with calcite and siderite concretions common . The Ripley coarsens to the north and is composed mostly of quartz sand near the Ocmulgee River. The youngest Cretaceous unit is the Providence Sand, consisting mostly of cross-bedded, fine- to coarse-grained, marine quartz sand with locally abundant clay clasts, mica, and heavy minerals.

Paleocene sediments are restricted to a narrow belt southwest of the Ocmulgee River, and they are not mapped separately to the north. The Clayton Formation consists of fossiliferous limestone and medium- to coarse-grained quartz sand. Coarse quartz sand, red clay, and concretions of limonite-goethite and chert characterize the residuum on the Clayton. The Nanafalia Formation consists of fluvial quartz sand with clay intraclasts interbedded with sandy clay and carbonaceous clay that is locally bauxitic. The Tuscahoma Formation is a marine clay with laminae of very fine quartz sand and silt. The base of the Tuscahoma is an irregular, undulating surface with pebble lags of clay clasts, phosphatic material, carbonaceous debris, and glauconitic sand. The Tuscahoma pinches out east of the Flint River. The northern occurrences of Paleocene and oldest Eocene deposits are equivalent to the Lang Syne, Huber, and Congaree Formations in South Carolina. The Lang Syne is glauconitic sand and clayey sand at the base with increasing black clay beds toward the top; the Huber is medium- to coarse-grained quartz sand with pebbles at the base, grading upward to mostly pure kaolinitic clay then orange quartz sand with clay clasts at the top; the Congaree is mostly medium- to coarse-grained quartz sand with green clay layers near the base and clay clasts and pebbles near the top.

Eocene-age sediments comprise a broad outcrop band in the south that narrows to the north, where exposure of units is restricted to drainages. The oldest Eocene unit is the Hatchetigbee Formation, which is fine-grained, glauconitic quartz sand interbedded with clay, silt, and fine sand at the base, and cross-bedded with silicified fossils near the top. The Clairborne Group consists of the Talhatta Formation, comprising cross-bedded quartz sand with pebbles and clay clasts near the base, and glauconitic, fossiliferous sand, limestone, and calcareous clay of the Lisbon Formation. Near the South Carolina state line, these rocks are equivalent to the Congaree Formation and the McBean Formation, which is a calcareous sandy clay and clayey sand with quartz sand interbeds. The calcareous Clinchfield Sand directly overlies Paleocene beds in the area between the Flint and Ocmulgee Rivers. In the southern part of the province, the Clairborne Group and the Clinchfield Sand are overlain by the fossiliferous Ocala Limestone, which forms a sandy clay residuum with boulders and cobbles of chert and limestone. The Ocala comprises a broad belt together with residuum from overlying Oligocene calcareous units. North of the Ocmulgee River, Cretaceous and Paleocene sediments are overlain by the Twiggs Clay, which is mostly montmorillonitic clay with calcareous sand interbeds, but has calcareous sand at the base that is equivalent to the Clinchfield Sand. The Twiggs Clay is overlain by the Irwinton Sand, a medium- to coarse-grained quartz sand with minor clay. The Irwinton is equivalent to the Cooper Marl and Sandersville Limestone, which crop out in stream drainages southeast of the outcrop belt.

Oligocene sediments are predominantly limestone and marl, which are highly weathered into residual sandy clay soils. The Suwanee Limestone comprises a narrow band that becomes broader around the Ocmulgee River, then pinches out north of the Oconee River.

Miocene sediments are dominated by fine- to coarse-grained quartz sand and pebbly sand, clay, and sandy clay that comprise a broad belt of sediment underlying about one-third of the Coastal Plain. In the area south of Worth, Tift, and Berrien Counties, the poorly sorted, phosphatic, clayey, coarse sand of the Hawthorn Formation is restricted to river drainages and is overlain by sand and clay of the Miccosukee Formation. North of this area, the Hawthorne Formation, Citronelle Formation, and Altamaha Grit are not differentiated.

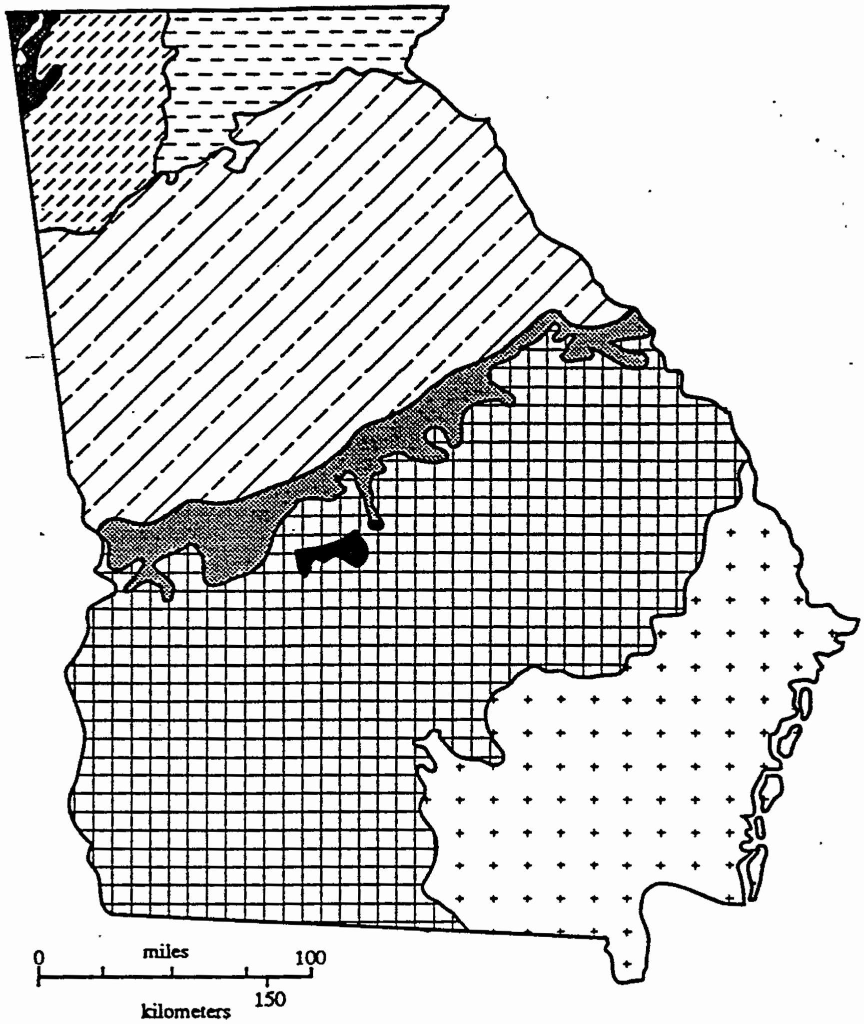
Pliocene-Pleistocene sand and gravel comprise a broad belt from the Florida state line in Echols County northeast to central Jeff Davis and Appling Counties and western Wayne County. Smaller areas underlain by these sediments occur northward along the same trend to the South Carolina state line. The Pliocene Charlton Formation and Duplin Marl comprise a narrow belt along the Savannah River in northeastern Effingham County.

Quaternary deposits near the Atlantic coast consist of broad lowland belts underlain by marsh and lagoonal clay, and narrow ridges composed of well-sorted marine and eolian sand. The belts are progressively younger to the southeast and the lagoonal clay belts are narrower at the present coastline. Quaternary fluvial sand and gravel form terraces along the major rivers.

SOILS

A generalized soil map for Georgia is shown in figure 6. The following discussion is condensed from U.S. Soil Conservation Service (1987) and Perkins and Shaffer (1977). The terminology used on the map and in the following discussion is from these references. It is recommended that the reader consult these, Soil Conservation Service county soil surveys, and other publications for more detailed information.

Soils of the Appalachian Plateau in Georgia are dominantly Ultisols, mature, deeply weathered, light-colored sandy and loamy acidic soils with clayey B horizons. Areas of Inceptisols are located in the northwesternmost part of the Appalachian Plateau. Inceptisols are poorly developed mineral soils with horizons of alteration or accumulation of metal oxides such as iron, aluminum, or manganese, but without horizons of clay accumulation. Soils of the Valley and Ridge, Blue Ridge, and Piedmont consist almost entirely of Ultisols. Alfisols, soils with light-colored, leached surface horizons and thick, clayey B horizons, occur locally in the Piedmont, primarily along gentle slopes adjacent to alluvial valleys. Soils underlying the oldest sediments of the Coastal Plain include Ultisols, Alfisols, and Entisols, the latter of which are immature soils that exhibit little or no evidence of soil development. Soils underlying the youngest sediments of the Coastal Plain include Ultisols, Inceptisols, Spodosols, and Histosols. Inceptisols have formed on beaches and tidal flats along the coastline in the southeastern part of the State. Histosols, organic-rich soils common to swamps and marshes, and Spodosols, soils containing a sandy subsurface horizon cemented by iron, aluminum, and/or organic matter, cover the Okefenokee Basin in the southern part of the Coastal Plain.



Appalachian Plateau: Soils developed from sandstone, shale, and limestone on mountain plateaus with steep sided slopes. Soils are moderately well to well drained, becoming poorly drained in bottom lands. Permeability is generally moderate with local areas of low and high permeability.

Blue Ridge: Deep to shallow soils with a sandy loam surface and sandy clay loam to clay subsoil, formed from material weathered from granite, gneiss, and schist, and locally high in ferromagnesian minerals. Soils on ridges and slopes tend to be well drained, becoming more poorly drained in floodplains and low-lying areas. Permeability is generally moderate.

Fall Line Hills: Steeply sloping to nearly level well drained soils with a sandy surface layer underlain by a friable to firm loamy subsoil. Soils become more poorly drained on floodplains, stream terraces, and low-lying uplands. Permeability is moderate in upland soils, becoming low to moderate in low-lying areas such as floodplains and stream terraces.

Southern Coastal Plain: Generally gently sloping to nearly level, well drained sandy loam to sandy soils underlain by sandy clay loam to clayey subsoils. Upland soils tend to be well to very well drained with low to moderate permeability, becoming more poorly drained away from slopes. Soils on floodplains are poorly drained with moderate permeability.

Valley and Ridge: Soils derived mainly from sandstone and shale on ridges and slopes and from limestone in more gently sloping valleys. Generally soils are moderately to well drained on ridges and steeper slopes, becoming more poorly drained in bottomlands and on gentle slopes. Permeability is moderate on gentle slopes, becoming moderately high on steeper slopes.

Piedmont: Generally well drained, thin red soil on gentle to steep hills and slopes with a loamy surface layer and a friable to firm loamy to clayey subsoil and moderate permeability. Soils in nearly level areas tend to have lower permeability and become more poorly drained. Soils in stream terraces and low-lying uplands have higher permeability and are moderately to poorly drained.

Black Lands: Gently sloping poorly to moderately drained soils on uplands, having a loamy surface layer and a clayey subsoil underlain in places by marl clay or chalk. Permeability is generally low.

Atlantic Coast Flatwoods: Level to nearly level soils that are mostly sandy at the surface or throughout and moderately permeable and poorly drained. Soils sandy only at the surface are underlain by a clayey to loamy subsoil, and are high in organic material on floodplains. Clayey soils occur in tidal marshes. Locally low and high permeability occurrences.

Figure 6. Generalized soil map of Georgia (modified from Hodler and Schretter, 1986, and Perkins and Shaffer, 1977).

Deep to shallow soils with a sandy loam surface and sandy clay loam to clay subsoil, formed from material weathered from granite, gneiss, and schist, and locally high in ferromagnesian minerals, are characteristic of the Blue Ridge. Soils on ridges and slopes tend to be well drained, becoming more poorly drained in floodplains and low-lying areas. Permeability is generally slow to moderate.

Soils of the Piedmont are derived from granite, gneiss, and schist. These soils are generally well drained, thin red soils on gentle to steep hills and slopes with a loamy surface layer and a friable to firm, loam to clayey loam subsoil with slow to moderate permeability. Soils in level areas tend to have lower permeability and are more poorly drained. Soils on stream terraces and low-lying uplands have higher permeability and are moderately to poorly drained. Soil permeability data collected as part of solid waste landfill assessments performed by the State of Georgia indicate that some published permeability measurements for the Piedmont are overestimates, and that Piedmont soil permeability is generally low (W.H. McLemore, written communication, 1992).

Soils in the Valley and Ridge are derived from sandstone and shale on ridges and slopes and from limestone in valleys. Generally, soils are moderately to well drained on ridges and steeper slopes, becoming more poorly drained in bottomlands and on gentle slopes. Permeability is slow in clayey bottomlands, slow to moderate on gentle slopes (<10 percent), becoming moderately high on steeper slopes (10-60 percent). Soils developed on limestones are a solution residuum of reddish-orange silty to sandy clay. Soils derived from sandstones are clayey sand to sandy clay with abundant iron oxide and fragments of sandstone. Chert and shale fragments are found in the soil in places. Areas of shale have clay and silty clay decomposition residuum containing shale chips and hematitic zones.

Soils of the Appalachian Plateau are derived from sandstone, shale, and limestone on mountain plateaus with steep-sided slopes. These soils are moderately well to well drained, becoming poorly drained in bottomlands. Permeability is generally moderate, with local areas of low and high permeability. Soils are coarse to fine sand, clayey sand, and sandy clay and may include chips of sandstone and shale. Where clayey, the soils have a high shrink-swell potential and slow permeability when moist.

Soils of the Coastal Plain have characteristics that are attributable to the underlying sediments. In the Fall Line Hills (Sand Hills), soils are steeply sloping to nearly level, well-drained sand and sandy loam with a sandy surface layer that is underlain by a friable to firm, loamy subsoil. Soils are more poorly drained on floodplains, stream terraces, and low-lying uplands. Permeability is moderate in upland soils and low to moderate in low-lying areas such as floodplains and stream terraces. Soils of the Upper Coastal Plain to the north are mostly saprolitic and have low permeability. In the Black Lands, soils are gently sloping, poorly to moderately drained, clayey loam and loamy clay on uplands, having a loamy surface layer and a clayey subsoil underlain in places by marl clay or chalk. Permeability is generally low. In the southern Coastal Plain, the soils are generally gently sloping to nearly level, well drained, sandy loams underlain by sandy clay loam to clay subsoils. Upland soils tend to be well to very well drained, with low to moderate permeability, becoming more poorly drained away from slopes. Soils on floodplains are poorly drained and have moderate permeability. The Atlantic Coast Flatwoods have poorly drained, level to nearly level soils that are mostly sand throughout the profile and are moderately permeable. Some of the soils are sandy only at the surface and are underlain by a clayey to loamy subsoil, and are high in organic material on floodplains. Clayey soils with low permeability occur in tidal marshes.

RADIOACTIVITY

An aeroradiometric map of Georgia (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 equivalent uranium is defined as 1.5-2.5 ppm, and high equivalent uranium is defined as greater than 2.5 ppm.

Low eU coincides with areas underlain by the youngest barrier island sequences in the Quaternary of the Coastal Plain, the Okefenokee Swamp, and Pliocene-Pleistocene gravel and sand. Low to moderate radioactivity coincides with areas underlain by the Oligocene Suwanee Limestone (or more likely, the swampy clays formed on it), some of the Eocene and Cretaceous sediments, most of the mafic rock bodies and associated biotite gneiss in the Georgiabama Thrust Stack, the mafic volcanic rocks in the Little River Thrust Stack, and most of the Mississippian and Pennsylvanian rocks of the Rome-Kingston Thrust Stack and the Appalachian Plateau. Moderate eU correlates with most of the Tertiary and middle Cretaceous sediments, the migmatitic biotite and amphibolite gneiss that intrudes the eastern part of the Little River Thrust Stack, mica schist and gneiss north of the Towaliga Fault, biotite gneiss, metagraywacke, and phyllite of the northern Georgiabama Thrust Stack, and most of the carbonate rocks and shales of the Rome-Kingston Thrust Stack.

Moderate to locally high eU coincides with the areas underlain by Quaternary shorelines of the barrier ridge sequence (this correlates with the titanium sand deposits of the northern Florida coast). The Pleistocene deposits of the Altamaha River also coincide with mostly moderate to locally high radioactivity, possibly due to mineral concentrates originating in the Piedmont. Areas underlain by the phosphatic Hawthorne Formation and its equivalents to the north are coincident with locally high radioactivity and may account for the areas of 2.5-3.5 ppm eU in Wilcox, Telfair, and Dodge Counties, and in Bleckley, Laurens, and Wilkinson Counties. Local zones of high radioactivity are also coincident with some of the Cretaceous to Eocene sediments. High eU forms a broad belt from northeast to southwest across the north-central part of the State that is coincident with granitic gneisses, uraniferous granites, biotite gneisses, and shear zones within the Georgiabama Thrust Stack, particularly south of the Brevard Zone. High eU is also coincident with areas underlain by felsic volcanics in the Little River Thrust Stack, graphitic phyllite in the Georgiabama Thrust Stack, and shales in the Rome-Kingston Thrust Stack.

The Geochemical Atlas of Georgia (Koch, 1988) presents the NURE stream sediment data for the State. These data are chemical analyses, including uranium, for stream sediments throughout the northern two-thirds of the State. A map of uranium concentration in stream sediments, Plate 35 from the report, is shown in figure 8. Many of the major uranium anomalies seen in figure 8 are related to the mineral monazite. Uranium occurrences in Georgia are well documented in the literature. Furcron (1955), Garvey (1975), and Grauch and Zarinski (1976) provide tables and some analyses of uranium and radioactivity occurrences in Georgia. Grauch and Zarinski (1976) note mineral occurrences of uranium predominantly in pegmatite, granite, and gneiss in the Piedmont and Blue Ridge. The NURE Reports for the Rome, Greenville, Atlanta, Athens, Phenix City, Macon, and Savannah Quadrangles contain extensive reference lists of uranium occurrences and in some reports, chemical analyses. Lee (1980) presents data from extensive chemical analyses of rocks in the Athens Quadrangle. He indicates that contacts between the Piedmont rocks and Cretaceous to Eocene sediments commonly contain uranium concentrations around 4 ppm U_3O_8. Carbonaceous debris in the Coastal Plain sediments locally have uranium

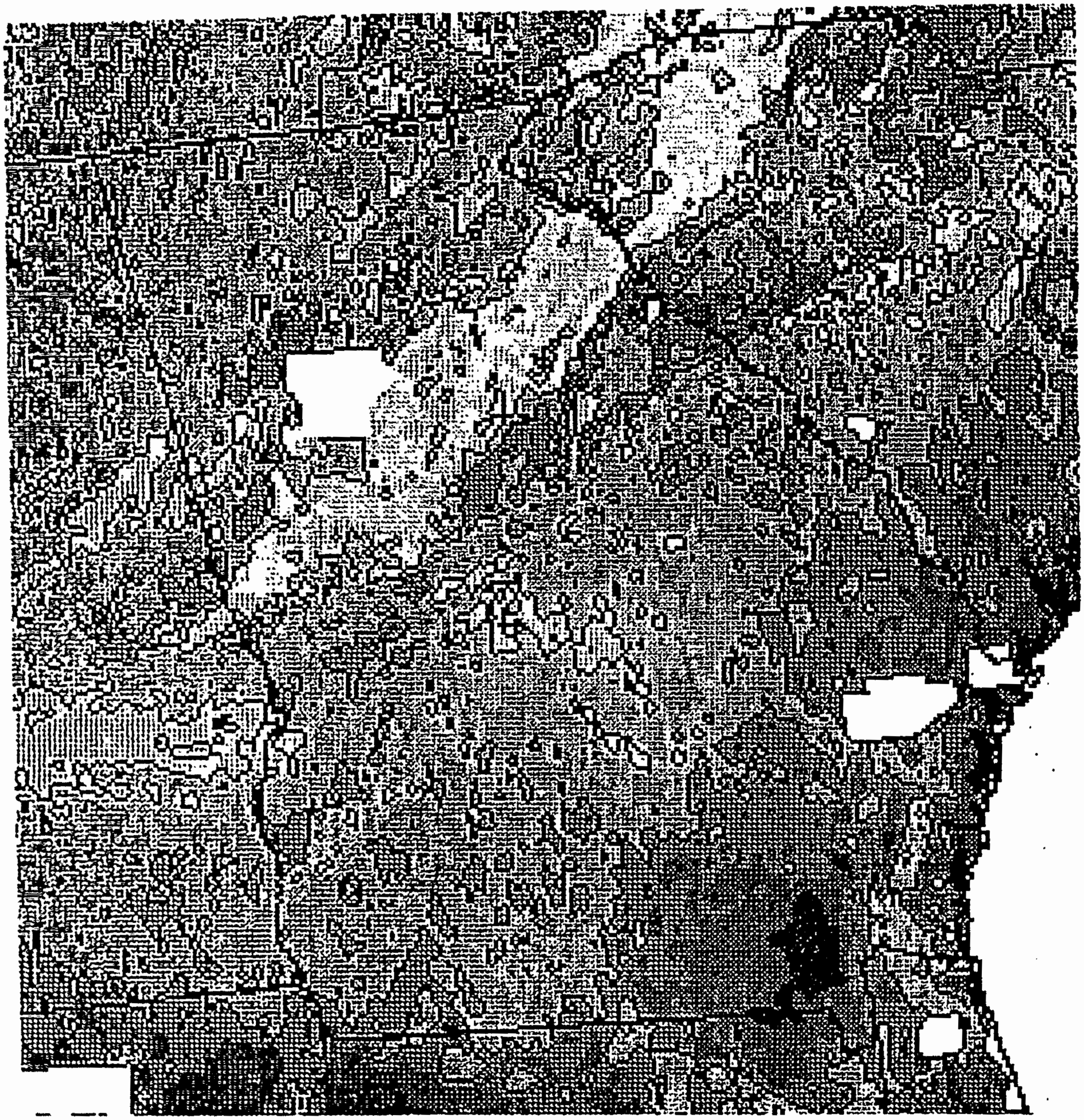


Figure 7. Aerial radiometric map of Georgia (after Duval and others, 1989). Contour lines at 1.5 and 2.5 ppm equivalent uranium (eU). Pixels shaded at 0.5 ppm eU increments.

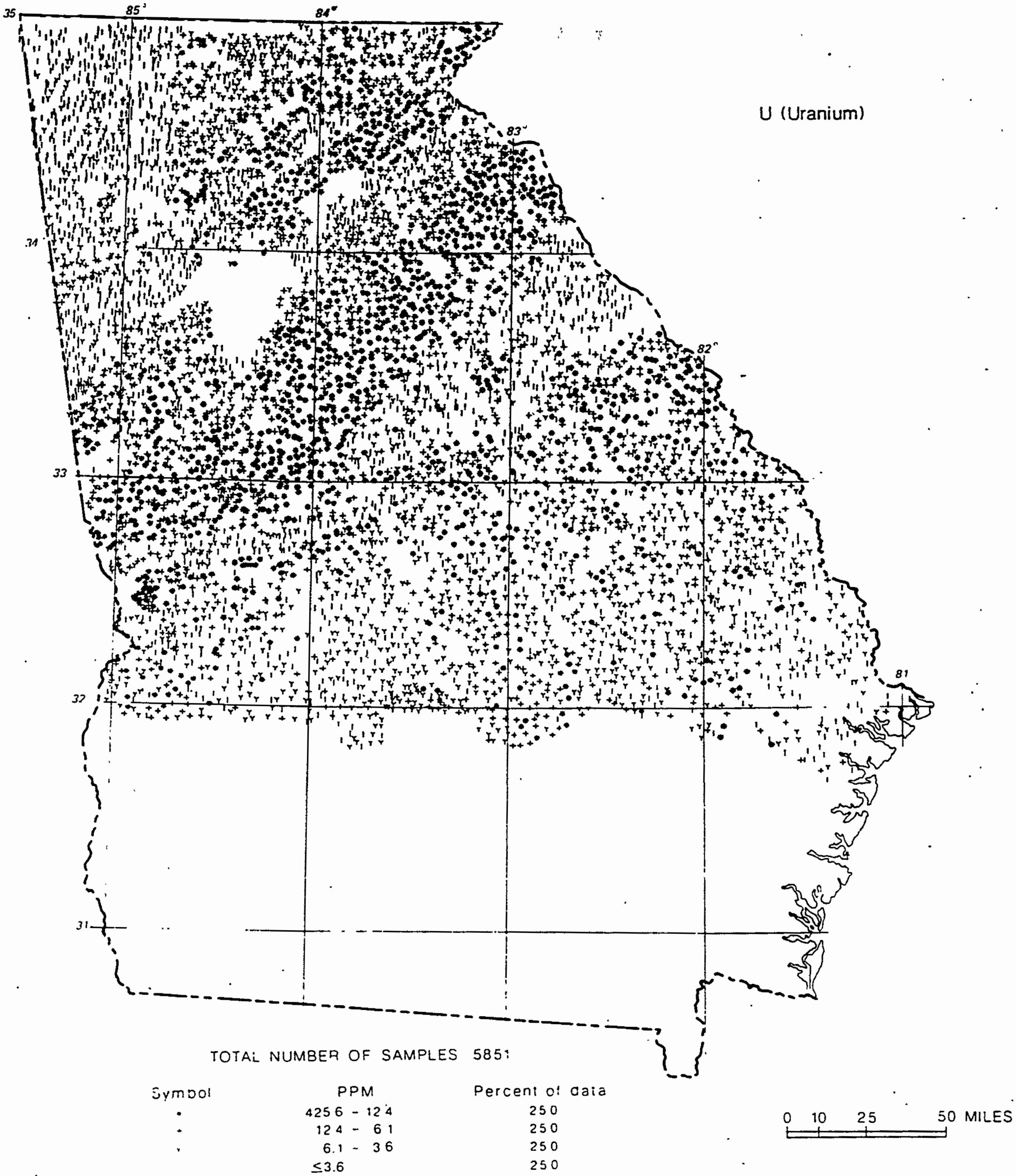


Figure 8. Uranium in stream sediments collected under the National Uranium Resources Evaluation (NURE) program (from Koch, 1988).

concentrations of 8-15 ppm with upper values of 45-50 ppm. Analyses of granites in the Blue Ridge and Piedmont by Lee (1980) yielded average values of 3-10 ppm U_3O_8—the highest concentration was 40 ppm in the large granite body in the eastern Little River Thrust Stack. Granitic gneiss in the Georgiabama Thrust Stack has uranium concentrations between 3-8 ppm, except in the "monazite belt" in Barrow and Gwinnet Counties, which has uranium concentrations of 15-29 ppm. Biotite gneiss and mica schist with gneiss are highly variable, containing 1-13 ppm uranium. Migmatitic biotite and amphibolite gneiss in the southeastern Little River Thrust Stack contain 1-8 ppm uranium. Mafic volcanic rocks in the Little River Thrust Stack and mafic rock bodies in the Georgiabama Thrust Stack average 1-2 ppm (no values less than 1 ppm were reported). The highest concentrations reported by Lee (1980) are 490 and 620 ppm U_3O_8 from a granitic gneiss layer within a mafic body. Lee (1980) suggests that metasedimentary and metavolcanic rocks that are in contact with granites have a high potential for uranium mineralization and range from 1 to 13 ppm U_3O_8, with an average of 4.5 ppm. McConnell and Costello (1980) analyzed graphitic phyllites in the Athens Quadrangle and found the average uranium concentration to be 4.7 ppm as measured by a gamma-ray spectrometer. Graphitic phyllite in the Bill Arp Sheet near Carroll County had uranium concentrations as high as 10.6 and 12.0 ppm, and a single measurement of 75 ppm was recorded from a graphitic phyllite northwest of New Georgia. McConnell and Costello's (1980) analyses of the Palmetto Granite in Fulton, Coweta, and Fayette Counties yielded 2.4-7.6 ppm of uranium. The Lithonia granitic gneiss has 2.8-5.9 ppm uranium. McConnell and Costello (1980) also measured other granites and granitic gneiss in the Piedmont and found uranium concentrations of 2.5-8.0 ppm. Their analyses of aplite dikes in the Austell Gneiss in western Douglas County yielded high values of 117-240 ppm uranium. Glover (1959) analyzed the Chattanooga Shale in Georgia and adjacent states and found that it has an average concentration of 50 ppm U. The highest uranium concentrations in the Chattanooga (80-120 ppm in the Georgia samples) are associated with chert and phosphate nodules. Friddell (1980) conducted a detailed study of the Holocene Penholoway and Talbot shorelines in areas coincident with six aeroradiometric highs (Glynn and McIntosh Counties). He reported uranium concentrations (radium equivalent uranium) varying from 0.3 to 19.5 ppm, with an average of 4.5 ppm.

INDOOR RADON

Indoor radon data from 1534 homes sampled in the State/EPA Residential Radon Survey conducted in Georgia during the winter of 1989 are shown in figure 9 and Table 1. A map of counties is included for reference (fig. 10). Data are shown in figure 9 only for those counties with 5 or more data values. The average for the State was 1.7 pCi/L and the 6.5 percent of the homes tested had indoor radon levels exceeding 4 pCi/L. Indoor radon averages for the counties in the Valley and Ridge, Blue Ridge, and Piedmont are generally in the low (<2 pCi/L) to moderate (2-4 pCi/L) range. Indoor radon averages for counties in the Coastal Plain are generally low. Data are sparse for the southwestern Coastal Plain.

Radon from domestic well water may also contribute to radon in indoor air in certain parts of Georgia. There is considerable debate over the amount of indoor radon that is liberated to indoor air from water use. Several studies indicate that degassing of radon from water can cause spikes in indoor air concentrations, especially during peak water-use periods (Hess and others, 1986; Nazaroff and Nero, 1988). The amount of radon that is contributed to indoor air from water varies substantially and is related to the volume of air in the house and the volume of water used

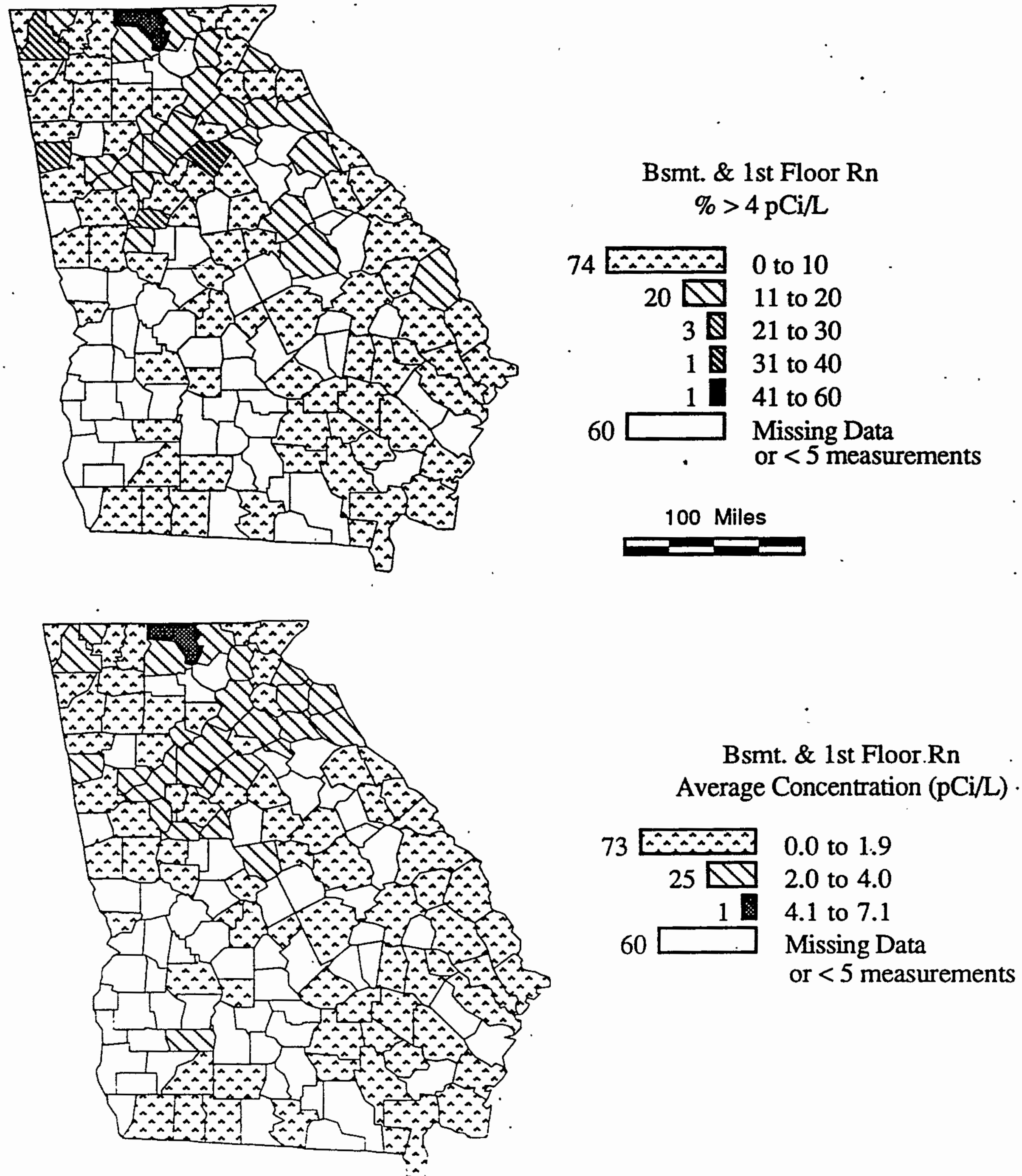


Figure 9. Screening indoor radon data from the EPA/State Residential Radon Survey of Georgia, 1988-89, for counties with 5 or more measurements. Data are from 2-7 day charcoal canister tests. Histograms in map legends show the number of counties in each category. The number of samples in each county (See Table 1) may not be sufficient to statistically characterize the radon levels of the counties, but they do suggest general trends. Unequal category intervals were chosen to provide reference to decision and action levels.

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

COUNTY	NO. OF MEAS.	MEAN	GEOM. MEAN	MEDIAN	STD. DEV.	MAXIMUM	%>4 pCi/L	%>20 pCi/L
APPLING	9	0.6	0.5	0.7	0.4	1.3	0	0
ATKINSON	5	1.0	0.5	0.5	1.4	3.5	0	0
BACON	6	1.3	0.8	1.1	1.1	3.2	0	0
BALDWIN	5	1.0	1.0	0.9	0.3	1.4	0	0
BANKS	6	1.7	1.5	1.6	0.8	2.7	0	0
BARROW	8	1.9	1.8	1.9	0.7	2.9	0	0
BARTOW	9	1.6	1.4	1.5	0.8	2.9	0	0
BEN HILL	4	1.0	0.7	0.9	0.7	1.8	0	0
BERRIEN	4	0.7	0.6	0.8	0.4	1.1	0	0
BIBB	23	1.2	0.9	1.1	0.9	4.2	4	0
BLECKLEY	7	1.5	1.3	1.6	0.5	2.1	0	0
BRANTLEY	4	0.6	0.6	0.6	0.3	0.9	0	0
BROOKS	2	0.9	0.7	0.9	0.6	1.3	0	0
BRYAN	9	0.8	0.6	1.0	0.5	1.3	0	0
BULLOCH	20	1.0	0.8	0.8	0.7	2.5	0	0
BURKE	5	0.9	0.9	0.9	0.4	1.5	0	0
BUTTS	6	2.0	1.7	1.9	1.2	4.0	0	0
CALHOUN	1	1.7	1.7	1.7	0.0	1.7	0	0
CAMDEN	15	0.3	0.2	0.2	0.3	0.9	0	0
CANDLER	2	0.8	0.7	0.8	0.1	0.8	0	0
CARROLL	25	1.4	1.0	1.0	1.2	5.1	4	0
CATOOSA	5	2.4	1.9	1.3	2.4	6.7	20	0
CHARLTON	5	0.4	0.3	0.4	0.4	1.0	0	0
CHATHAM	20	0.9	0.7	0.7	0.7	3.4	0	0
CHATTOOGA	5	1.0	0.7	1.1	0.6	1.8	0	0
CHEROKEE	10	1.5	1.3	1.2	1.0	3.6	0	0
CLARKE	8	2.7	2.3	2.9	1.4	5.1	13	0
CLAY	1	0.4	0.4	0.4	0.0	0.4	0	0
CLAYTON	30	1.8	1.4	1.4	1.4	5.6	13	0
CLINCH	4	0.3	0.2	0.2	0.3	0.7	0	0
COBB	83	1.8	1.3	1.5	1.4	6.7	8	0
COFFEE	22	0.8	0.7	0.7	0.4	2.1	0	0
COLQUITT	17	0.8	0.7	0.8	0.5	1.6	0	0
COLUMBIA	24	1.4	1.0	1.0	1.2	6.1	4	0
COOK	1	1.4	1.4	1.4	0.0	1.4	0	0
COWETA	13	1.2	0.9	0.7	1.2	4.9	8	0
CRAWFORD	3	1.4	1.2	0.8	1.0	2.6	0	0
CRISP	8	0.6	0.4	0.7	0.4	1.1	0	0
DADE	7	1.5	1.1	0.9	1.2	3.8	0	0
DAWSON	2	1.5	1.3	1.5	1.0	2.2	0	0
DE KALB	76	2.6	1.8	1.8	2.7	15.4	11	0

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

COUNTY	NO. OF MEAS.	MEAN	GEOM. MEAN	MEDIAN	STD. DEV.	MAXIMUM	%>4 pCi/L	%>20 pCi/L
DECATUR	9	0.8	0.6	0.7	0.6	2.0	0	0
DODGE	4	0.6	0.4	0.6	0.5	1.2	0	0
DOOLY	2	1.7	1.6	1.7	0.2	1.8	0	0
DOUGHERTY	11	2.1	1.7	1.8	1.7	6.8	9	0
DOUGLAS	26	2.9	2.3	2.4	2.0	9.4	15	0
EARLY	3	2.0	1.1	0.8	2.5	4.9	33	0
ECHOLS	1	0.6	0.6	0.6	0.0	0.6	0	0
EFFINGHAM	12	0.5	0.4	0.5	0.2	1.0	0	0
ELBERT	5	2.5	1.6	1.9	2.2	5.7	20	0
EMANUEL	9	0.5	0.5	0.5	0.2	1.0	0	0
EVANS	5	0.6	0.5	0.4	0.4	1.1	0	0
FANNIN	5	7.1	4.8	4.4	7.0	18.7	60	0
FAYETTE	31	2.0	1.5	1.3	1.9	10.1	6	0
FLOYD	18	1.6	1.2	1.2	1.2	4.3	6	0
FORSYTH	11	1.1	0.9	0.9	0.8	3.3	0	0
FRANKLIN	7	2.0	1.7	1.2	1.2	3.5	0	0
FULTON	75	2.1	1.6	1.5	1.8	8.8	12	0
GILMER	5	4.0	3.2	2.7	3.5	10.3	20	0
GLASCOCK	2	1.4	1.1	1.4	1.1	2.2	0	0
GLYNN	6	0.3	0.2	0.3	0.1	0.5	0	0
GORDON	7	0.7	0.5	0.8	0.5	1.3	0	0
GRADY	6	0.9	0.8	1.0	0.3	1.3	0	0
GREENE	3	3.2	2.1	2.7	3.0	6.5	33	0
GWINNETT	73	2.6	1.9	1.8	2.6	15.0	11	0
HABERSHAM	12	1.6	1.2	1.4	1.1	3.4	0	0
HALL	37	2.9	2.0	1.8	2.7	9.8	19	0
HANCOCK	6	1.5	0.9	1.0	1.5	4.2	17	0
HARALSON	9	2.1	1.6	1.2	1.7	5.5	22	0
HARRIS	2	3.7	2.8	3.7	3.4	6.1	50	0
HART	11	2.0	1.6	2.0	1.3	5.0	9	0
HEARD	1	0.1	0.1	0.1	0.0	0.1	0	0
HENRY	17	1.9	1.6	1.9	0.9	3.8	0	0
HOUSTON	18	1.6	1.3	1.3	1.1	4.7	6	0
IRWIN	1	0.9	0.9	0.9	0.0	0.9	0	0
JACKSON	6	2.5	1.9	1.6	2.2	6.8	17	0
JASPER	3	3.0	2.3	2.6	2.3	5.4	33	0
JEFF DAVIS	5	0.4	0.3	0.4	0.4	0.9	0	0
JEFFERSON	2	1.0	1.0	1.0	0.1	1.1	0	0
JENKINS	5	1.6	1.3	0.8	1.3	3.6	0	0
JOHNSON	4	0.7	0.5	0.9	0.5	1.1	0	0
JONES	6	2.3	2.1	2.4	0.8	3.5	0	0
LAMAR	3	0.7	0.6	0.8	0.3	0.9	0	0
LANIER	2	0.6	0.5	0.6	0.4	0.8	0	0

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

COUNTY	NO. OF MEAS.	MEAN	GEOM. MEAN	MEDIAN	STD. DEV.	MAXIMUM	%>4 pCi/L	%>20 pCi/L
LAURENS	13	1.3	1.1	1.2	0.8	2.5	0	0
LIBERTY	12	0.6	0.5	0.4	0.4	1.5	0	0
LINCOLN	8	1.1	0.8	0.8	1.0	2.9	0	0
LONG	3	1.1	1.1	1.0	0.3	1.5	0	0
LOWNDES	10	0.9	0.7	1.1	0.5	1.6	0	0
LUMPKIN	1	1.8	1.8	1.8	0.0	1.8	0	0
MACON	1	0.8	0.8	0.8	0.0	0.8	0	0
MADISON	8	3.5	1.8	1.5	5.5	16.9	13	0
MCDUFFIE	18	1.1	0.8	0.7	1.0	3.4	0	0
MCINTOSH	2	0.8	0.7	0.8	0.5	1.1	0	0
MERIWETHER	9	1.3	1.1	1.1	0.7	2.8	0	0
MILLER	2	2.2	2.1	2.2	0.5	2.5	0	0
MITCHELL	8	0.7	0.5	0.6	0.5	1.8	0	0
MONROE	3	0.7	0.6	0.5	0.5	1.2	0	0
MONTGOMERY	3	0.8	0.8	0.7	0.3	1.2	0	0
MORGAN	6	1.4	1.1	1.5	0.9	2.5	0	0
MURRAY	9	1.1	0.9	0.9	1.0	3.4	0	0
MUSCOGEE	22	1.1	0.9	0.9	0.8	3.8	0	0
NEWTON	8	1.3	1.1	1.2	0.7	2.8	0	0
OCONEE	1	1.9	1.9	1.9	0.0	1.9	0	0
OGLETHORPE	4	2.9	2.6	2.7	1.5	4.7	25	0
PAULDING	4	1.0	0.6	0.7	1.0	2.5	0	0
PEACH	5	1.6	1.3	1.6	0.8	2.3	0	0
PICKENS	4	2.1	1.5	1.3	2.2	5.3	25	0
PIERCE	13	1.5	1.1	1.0	1.8	7.1	8	0
PIKE	6	1.7	0.5	0.8	2.2	5.3	17	0
POLK	8	1.2	0.9	1.3	0.8	2.6	0	0
PULASKI	3	1.9	1.6	1.5	1.2	3.2	0	0
PUTNAM	11	1.4	1.2	1.1	0.8	3.1	0	0
RABUN	6	1.5	1.3	1.4	0.9	3.1	0	0
RANDOLPH	2	1.3	1.2	1.3	0.7	1.8	0	0
RICHMOND	26	1.0	0.8	0.9	0.5	2.4	0	0
ROCKDALE	24	2.1	1.4	1.4	3.2	16.5	8	0
SCHLEY	2	0.9	0.9	0.9	0.3	1.1	0	0
SCREVEN	5	1.5	0.8	0.6	2.2	5.4	20	0
SEMINOLE	1	1.1	1.1	1.1	0.0	1.1	0	0
SPALDING	19	2.3	1.5	1.3	2.4	8.9	21	0
STEPHENS	12	2.1	1.9	1.9	1.1	4.6	17	0
STEWART	1	1.6	1.6	1.6	0.0	1.6	0	0
SUMTER	12	1.7	1.5	1.6	0.9	3.8	0	0
TALBOT	3	1.4	1.4	1.2	0.3	1.8	0	0
TALIAFERRO	3	1.0	0.9	1.3	0.6	1.4	0	0
TATTNALL	7	0.8	0.6	0.7	0.6	1.7	0	0

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

COUNTY	NO. OF MEAS.	MEAN	GEOM. MEAN	MEDIAN	STD. DEV.	MAXIMUM	%>4 pCi/L	%>20 pCi/L
TAYLOR	1	2.4	2.4	2.4	0.0	2.4	0	0
TELFAIR	5	0.4	0.3	0.5	0.2	0.5	0	0
TERRELL	2	1.1	1.0	1.1	0.7	1.6	0	0
THOMAS	11	1.7	1.3	1.4	1.3	4.9	9	0
TIFT	3	1.1	0.5	1.5	1.0	1.8	0	0
TOOMBS	20	0.9	0.6	1.0	0.6	2.4	0	0
TOWNS	5	1.5	1.3	1.8	0.7	2.2	0	0
TREUTLEN	3	0.9	0.9	0.8	0.2	1.1	0	0
TROUP	19	1.3	1.1	1.2	0.7	3.4	0	0
TURNER	3	0.8	0.8	0.8	0.2	1.0	0	0
TWIGGS	2	1.5	1.2	1.5	1.2	2.3	0	0
UNION	8	2.7	1.9	2.3	2.5	8.5	13	0
UPSON	11	1.2	0.9	1.1	0.6	2.6	0	0
WALKER	16	2.5	1.6	1.4	2.6	8.3	25	0
WALTON	13	2.7	1.6	1.1	2.9	10.1	31	0
WARE	22	0.6	0.5	0.6	0.3	1.0	0	0
WARREN	3	0.6	0.5	0.7	0.2	0.7	0	0
WASHINGTON	6	1.6	1.0	1.4	1.6	4.5	17	0
WAYNE	11	1.1	0.8	0.8	1.0	3.8	0	0
WEBSTER	3	0.8	0.6	0.8	0.6	1.4	0	0
WHEELER	1	1.3	1.3	1.3	0.0	1.3	0	0
WHITE	8	2.5	1.2	1.4	3.9	12.1	13	0
WHITFIELD	8	1.9	1.1	2.1	1.4	3.6	0	0
WILCOX	3	0.2	0.2	0.1	0.2	0.4	0	0
WILKES	9	1.8	1.4	1.3	1.4	4.8	11	0
WILKINSON	4	1.0	1.0	1.0	0.3	1.5	0	0
WORTH	1	2.5	2.5	2.5	0.0	2.5	0	0

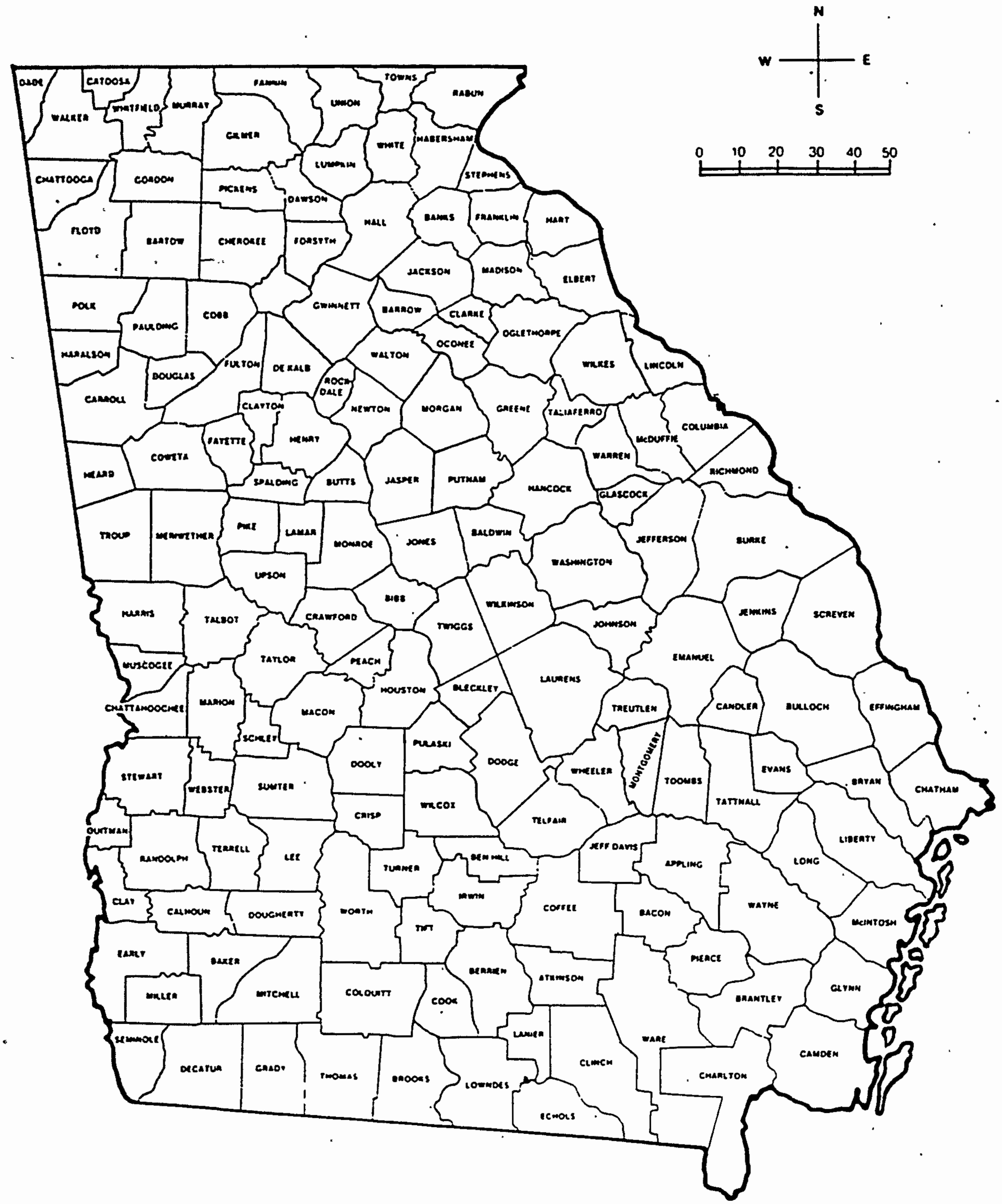


Figure 10. Counties in Georgia (from Facts on File, 1984).

over a given period of time. Selected aquifers in Georgia have been tested for their radon concentrations by the U.S. Environmental Protection Agency (Coker and Olive, 1989). Ten wells were tested in each of nine aquifers within four major geologic provinces, for a total of 90 samples. The results of this study are summarized in Table 2.

TABLE 2. Radon in water for selected aquifers in Georgia (from Coker and Olive, 1989).

Geologic Province	Counties	Avg. Radon in Water	Rock Type
Piedmont	Gwinnett/Barrow	81,180 pCi/L	Granite Gneiss
Piedmont	Greene	18,562 pCi/L	Porphyritic Granite
Piedmont	Elbert/Oglethorpe	11, 760 pCi/L	Non-porphyritic Granite
Piedmont	Spaulding/Pike	4,676 pCi/L	Granite
Blue Ridge	Lumpkin	2,929 pCi/L	Mica Schist/Gneiss
Blue Ridge	Towns	2,229 pCi/L	Biotite Gneiss
Valley and Ridge	Bartow	614 pCi/L	Dolomitic Limestone
Coastal Plain	Marion	293 pCi/L	Sand and Gravel
Coastal Plain	Tift/Berrien	778 pCi/L	Phosphatic Limestone

Granite and granite gneiss aquifers in the Piedmont of Georgia had the highest radon concentrations in water. Schist and gneiss from the Blue Ridge also had high radon concentrations in water, but the concentrations were significantly less than in Piedmont aquifers. In general, the aquifers tested in the Valley and Ridge and Coastal Plain had consistently lower radon in water. The Environmental Protection Agency has not yet set a maximum contaminant level for radon in water but is expected to set one soon.

GEOLOGIC RADON POTENTIAL SUMMARY

For the purpose of this assessment, Georgia has been divided into seven geologic radon potential areas and each area assigned a Radon Index (RI) and a Confidence Index (CI) score (Table 3). These areas are shown in figure 11 and correspond to tectonic/geologic areas shown in figures 2 and 5. The RI is a relative measure of radon potential based on geology, soils, radioactivity, architecture, and indoor radon, as outlined in the preceding sections. The CI is a measure of the relative confidence of the RI assessment based on the quality and quantity of the data used to assess geologic radon potential (please refer to the introduction to this regional book for a detailed discussion of the indexes).

The radon potential of rocks and soils in Georgia is predominately low to moderate, with areas of locally high radon potential. Gregg and Coker (1989, 1990) have examined the geologic controls on radon in Georgia and concluded that granites, granitic gneiss, pegmatites, and mylonites in the Blue Ridge and Piedmont; carbonaceous shales in the Appalachian Plateau and Valley and Ridge; phosphatic sediments in the Coastal Plain; and monazite bearing rocks and heavy mineral placers in the Coastal Plain, Blue Ridge, and Piedmont are likely sources of high indoor radon levels in Georgia. In the following discussion, the factors for each of the rankings in this report are briefly discussed and local variations within each province or subdivision are indicated.

The Georgiabama Thrust Stack, north of the Allatoona Fault

The igneous and metamorphic rocks in the Georgiabama Thrust Stack north of the Altoona Fault have been ranked moderate overall in radon potential, but the radon potential of the area is actually variable. Mafic rocks probably 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 indoor radon averages 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 by metagraywacke, slate, phyllite, and mica schists. Equivalent uranium concentrations from the NURE data (fig. 7) are moderate to high.

The Georgiabama Thrust Stack, south of the Allatoona Fault

The Georgiabama Thrust Stack south of the Alatoona Fault is moderate to locally high in geologic radon potential. The majority of this part of the Georgiabama Thrust Sheet is underlain by schist and amphibolite of the Zebulon sheet, which have generally low radioactivity where they are not intruded by granites or not highly sheared, particularly south of the Towaliga Fault. An area with a distinctly low aeroradiometric signature and which is underlain by mafic metamorphic rocks lies between the Brevard and Allatoona Faults in the northwestern Georgiabama Thrust Stack. All of the soils developed on 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 (Lee, 1980; McConnell and Costello, 1980) and high equivalent uranium (>2.5 ppm) on the NURE map (fig. 7). Soil permeability is generally slow to locally moderate. Indoor radon levels are generally moderate. Recent, unpublished soil-gas radon studies by A.E. Gates and L.C.S. Gundersen in the Brevard zone and surrounding rocks (unpublished data, 1990) 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 4-17 ppm over granite and granitic biotite gneiss (Lithonia gneiss). Soil-gas radon concentrations commonly exceeded 2000 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-gas radon of more than 2000 pCi/L. Mica schist averaged less than 1000 pCi/L where it is undeformed. The Stone Mountain granite and mafic rocks yielded low soil-gas radon. Gregg and Costello (1992) have also measured very high soil-gas radon concentrations associated with the Brevard zone–up to 13,000 pCi/L. 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

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 radioactivity and moderate radon potential. 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.

The Rome-Kingston Thrust Stack

The Rome-Kingston Thrust Stack in the Valley and Ridge Province has been 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 concentrations are variable but generally low to moderate. Permeability of the soils is low to moderate. Equivalent uranium (fig. 7) is moderate to locally high, especially along the Carter's Dam and Emerson faults. Carbonate soils of the Valley and Ridge Province cause indoor radon problems in northern Alabama, eastern Tennessee, western New Jersey, western Virginia, eastern West Virginia (Schultz and others, 1992) and central and eastern Pennsylvania. The Devonian Chattanooga Shale, which crops out locally in parts of the Valley and Ridge, 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). The NURE report for the Rome Quadrangle (Texas Instruments Inc., 1980) describes numerous radioactivity anomalies associated with the Pennington Formation, Bangor Limestone, Fort Paine Chert, Chattanooga Shale, Floyd Shale, the Knox Group, and the Rome Formation.

The 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 (fig. 7) is low to moderate. Permeability of the soils is moderate and indoor radon levels are low.

The 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 radon potential. Gundersen and Peake (1992) examined soil radon in the Coastal Plain in Alabama. The highest soil-gas radon concentrations (>1000 pCi/L) and equivalent uranium (>2 ppm) 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 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 uranium (fig. 7) 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 levels in the Coastal Plain are generally low.

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

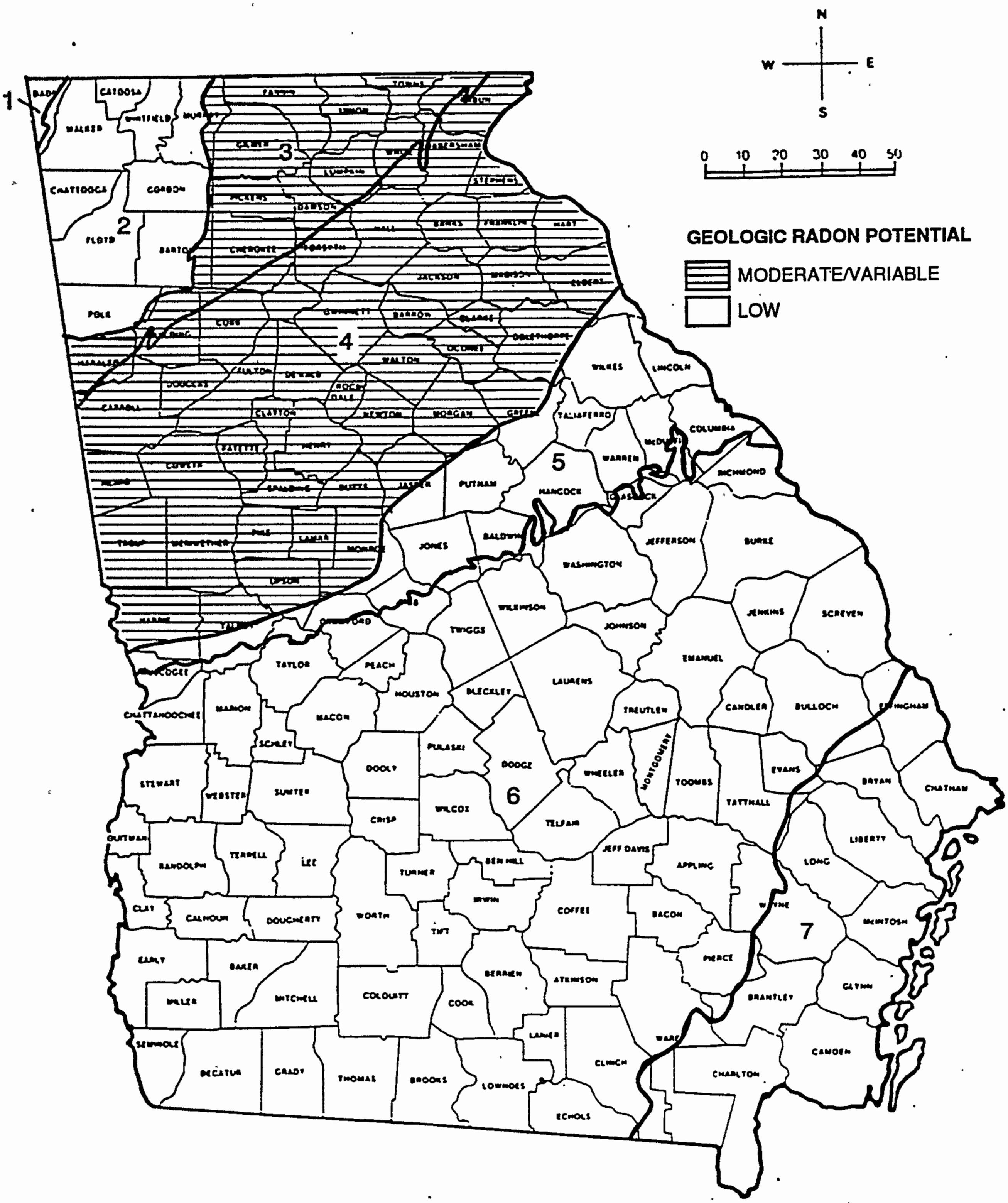


Figure 11. Geologic radon potential areas of Georgia. Refer to Table 3 for RI and CI scores of numbered areas.

TABLE 3. RI and CI scores for geologic radon potential areas of Georgia.

FACTOR	(3)Georgiabama Thrust Stack North of Allatoona Fault RI	CI	(4)Georgiabama Thrust Stack South of Alatoona Fault RI	CI	(5)Little River Thrust Stack RI	CI
INDOOR RADON	2	2	2	2	1	2
RADIOACTIVITY	2	2	3	2	2	2
GEOLOGY	2	2	2	2	2	2
SOIL PERM.	2	2	1	3	1	3
ARCHITECTURE	1	-	1	-	1	-
GFE POINTS	0	-	0	-	0	-
TOTAL	9	8	9	9	7	9
	Mod	Mod	Mod	Mod	Low	Mod

FACTOR	(2)Rome-Kingston Thrust Stack RI	CI	(1)Appalachian Plateau RI	CI	(6) Coastal Plain Cretaceous/Tertiary RI	CI
INDOOR RADON	2	2	1	2	1	2
RADIOACTIVITY	2	2	2	2	2	2
GEOLOGY	2	2	2	2	2	2
SOIL PERM.	1	3	2	2	2	3
ARCHITECTURE	1	-	1	-	1	-
GFE POINTS	0	-	0	-	0	-
TOTAL	8	9	8	8	8	9
	Low	Mod	Low	Mod	Low	Mod

FACTOR	(7) Coastal Plain Quaternary/Pleistocene-Pliocene gravels RI	CI
INDOOR RADON	1	2
RADIOACTIVITY	1	2
GEOLOGY	2	2
SOIL PERM.	2	3
ARCHITECTURE	1	-
GFE POINTS	0	-
TOTAL	7	9
	Low	Mod

RADON INDEX SCORING:

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

Possible range of points = 3 to 17

CONFIDENCE INDEX SCORING:

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

Possible range of points = 4 to 12

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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.)

GEORGIA MAP OF RADON ZONES

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

Ten county designations do not strictly follow the methodology for adapting the geologic provinces to county boundaries. EPA, the Georgia Department of Human Resources have designated Fulton, Cobb, Dekalb, and Gwinnett as Zone 1 counties and Richmond, Walker, Catoosa, Whitfield, Floyd, and Bartow as Zone 2 counties. These zone changes are the result of input from the Georgia Department of Human Resources concerning the potential numbers of homes above 4 pCi/L is these areas based on the available indoor radon measurements.

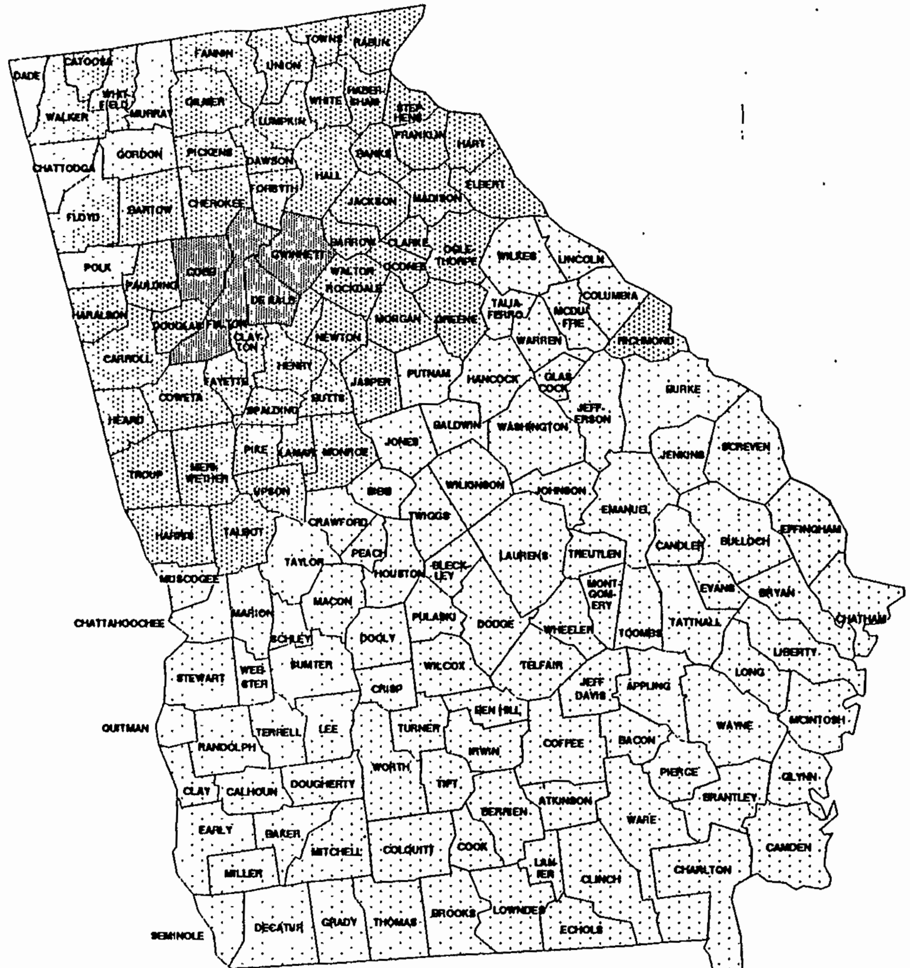
Although the information provided in Part IV of this report -- the State chapter entitled "Preliminary Geologic Radon Potential Assessment of Georgia" -- may appear to be quite specific, it cannot be applied to determine the radon levels of a neighborhood, housing tract, individual house, etc. **THE ONLY WAY TO DETERMINE IF A HOUSE HAS ELEVATED INDOOR RADON IS TO TEST.** Contact the Region 10 EPA office or the Alaska radon program for information on testing and fixing homes. Telephone numbers and addresses can be found in Part II of this report.

The State of Georgia Radon Program is compiling data for a series of population-weighted radon potential maps for Georgia. These maps will provide information on the estimated percentage of radon screening tests by zip code that can be expected to have values over 4 pCi/L. This information will be used to target home builders and realtors in order to promote expanded use of radon- resistant building techniques and increased radon screening of real estate transactions. Data from the development of the radon potential map presented herein will be combined with an expanded radon testing data base and mapping data from the 1990 census to develop target populations for high radon risk. These target populations will be used in the radon risk outreach programs funded by the Environmental Protection Agency State Indoor Radon Grant for Georgia. Information on the Georgia Population Risk Potential Maps may be obtained from the Georgia Radon Program at (404) 894-6644.

GEORGIA - EPA Map of Radon Zones

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

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



Zone 1 Zone 2 Zone 3

IMPORTANT: Consult the publication entitled "Preliminary Geologic Radon Potential Assessment of Georgia" 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.

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