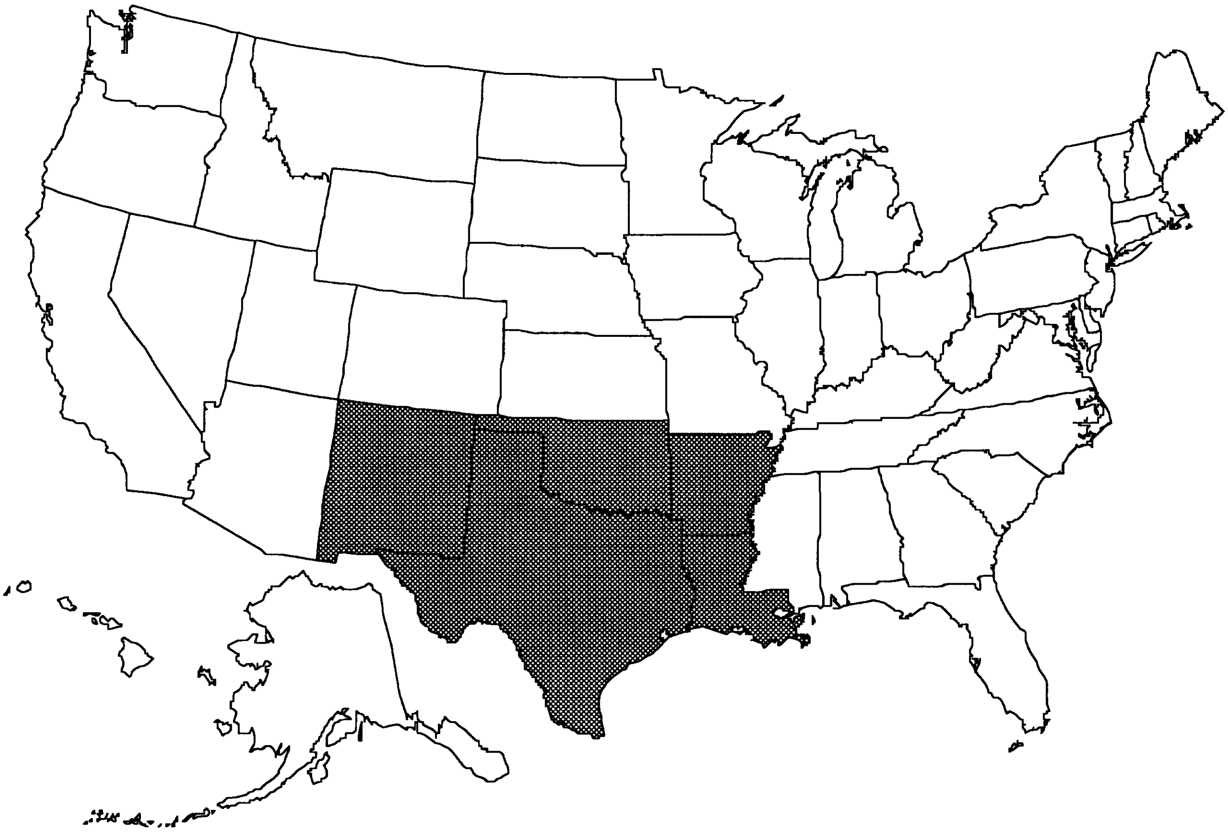
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

GEOLOGIC RADON POTENTIAL OF EPA REGION 6

Arkansas Louisiana New Mexico Oklahoma Texas



OPEN-FILE REPORT 93-292-F

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

1993

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Arkansas, Louisiana, New Mexico, Oklahoma, and Texas

R. Randall Schumann
EDITOR

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

CONTENTS

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THE USGS/EPA RADON POTENTIAL ASSESSMENTS: AN INTRODUCTION

by
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BACKGROUND

The Indoor Radon Abatement Act of 1988 (Public Law 100-551) directed the U.S. Environmental Protection Agency (EPA) to identify areas of the United States that have the potential to produce harmful levels of indoor radon. These characterizations were to be based on both geological data and on indoor radon levels in homes and other structures. The EPA also was directed to develop model standards and techniques for new building construction that would provide adequate prevention or mitigation of radon entry. As part of an Interagency Agreement between the EPA and the U.S. Geological Survey (USGS), the USGS has prepared radon potential estimates for the United States. This report is one of ten booklets that document this effort. The purpose and intended use of these reports is to help identify areas where states can target their radon program resources, to provide guidance in selecting the most appropriate building code options for areas, and to provide general information on radon and geology for each state for federal, state, and municipal officials dealing with radon issues. *These reports are not intended to be used as a substitute for indoor radon testing, and they cannot and should not be used to estimate or predict the indoor radon concentrations of individual homes, building sites, or housing tracts. Elevated levels of indoor radon have been found in every State, and EPA recommends that all homes be tested for indoor radon.*

USGS geologists are the authors of the booklets. The booklets are organized by EPA Federal boundaries (Regions). Each Regional booklet consists of several components, the first being this introduction to the project, including a general discussion of radon (occurrence, transport, etc.), and details concerning the types of data used. The second component is a summary chapter outlining the general geology and geologic radon potential of the EPA Region. The third component is an individual chapter for each state in the Region. Each state chapter discusses the state's specific geographic setting, soils, geologic setting, geologic radon potential, indoor radon data, and a summary outlining the radon potential rankings of geologic areas in the state. A variety of maps are presented in each chapter—geologic, geographic, population, soils, aerial radioactivity, and indoor radon data by county.

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

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

RADON GENERATION AND TRANSPORT IN SOILS

Radon (^{222}Rn) is produced from the radioactive decay of radium (^{226}Ra), which is, in turn, a product of the decay of uranium (^{238}U) (fig. 1). The half-life of ^{222}Rn is 3.825 days. Other isotopes of radon occur naturally, but, with the exception of thoron (^{220}Rn), which occurs in concentrations high enough to be of concern in a few localized areas, they are less important in terms of indoor radon risk because of their extremely short half-lives and less common occurrence. In general, the concentration and mobility of radon in soil are dependent on several factors, the most important of which are the soil's radium content and distribution, porosity, permeability to gas movement, and moisture content. These characteristics are, in turn, determined by the soil's parent-material composition, climate, and the soil's age or maturity. If parent-material composition, climate, vegetation, age of the soil, and topography are known, the physical and chemical properties of a soil in a given area can be predicted.

As soils form, they develop distinct layers, or horizons, that are cumulatively called the soil profile. The A horizon is a surface or near-surface horizon containing a relative abundance of organic matter but dominated by mineral matter. Some soils contain an E horizon, directly below the A horizon, that is generally characterized by loss of clays, iron, or aluminum, and has a characteristically lighter color than the A horizon. The B horizon underlies the A or E horizon. Important characteristics of B horizons include accumulation of clays, iron oxides, calcium carbonate or other soluble salts, and organic matter complexes. In drier environments, a horizon may exist within or below the B horizon that is dominated by calcium carbonate, often called caliche or calcrete. This carbonate-cemented horizon is designated the K horizon in modern soil classification schemes. The C horizon underlies the B (or K) and is a zone of weathered parent material that does not exhibit characteristics of A or B horizons; that is, it is generally not a zone of leaching or accumulation. In soils formed in place from the underlying bedrock, the C horizon is a zone of unconsolidated, weathered bedrock overlying the unweathered bedrock.

The shape and orientation of soil particles (soil structure) control permeability and affect water movement in the soil. Soils with blocky or granular structure have roughly equivalent permeabilities in the horizontal and vertical directions, and air and water can infiltrate the soil relatively easily. However, in soils with platy structure, horizontal permeability is much greater than vertical permeability, and air and moisture infiltration is generally slow. Soils with prismatic or columnar structure have dominantly vertical permeability. Platy and prismatic structures form in soils with high clay contents. In soils with shrink-swell clays, air and moisture infiltration rates and depth of wetting may be limited when the cracks in the surface soil layers swell shut. Clay-rich B horizons, particularly those with massive or platy structure, can form a capping layer that impedes the escape of soil gas to the surface (Schumann and others, 1992). However, the shrinkage of clays can act to open or widen cracks upon drying, thus increasing the soil's permeability to gas flow during drier periods.

Radon transport in soils occurs by two processes: (1) diffusion and (2) flow (Tanner, 1964). Diffusion is the process whereby radon atoms move from areas of higher concentration to

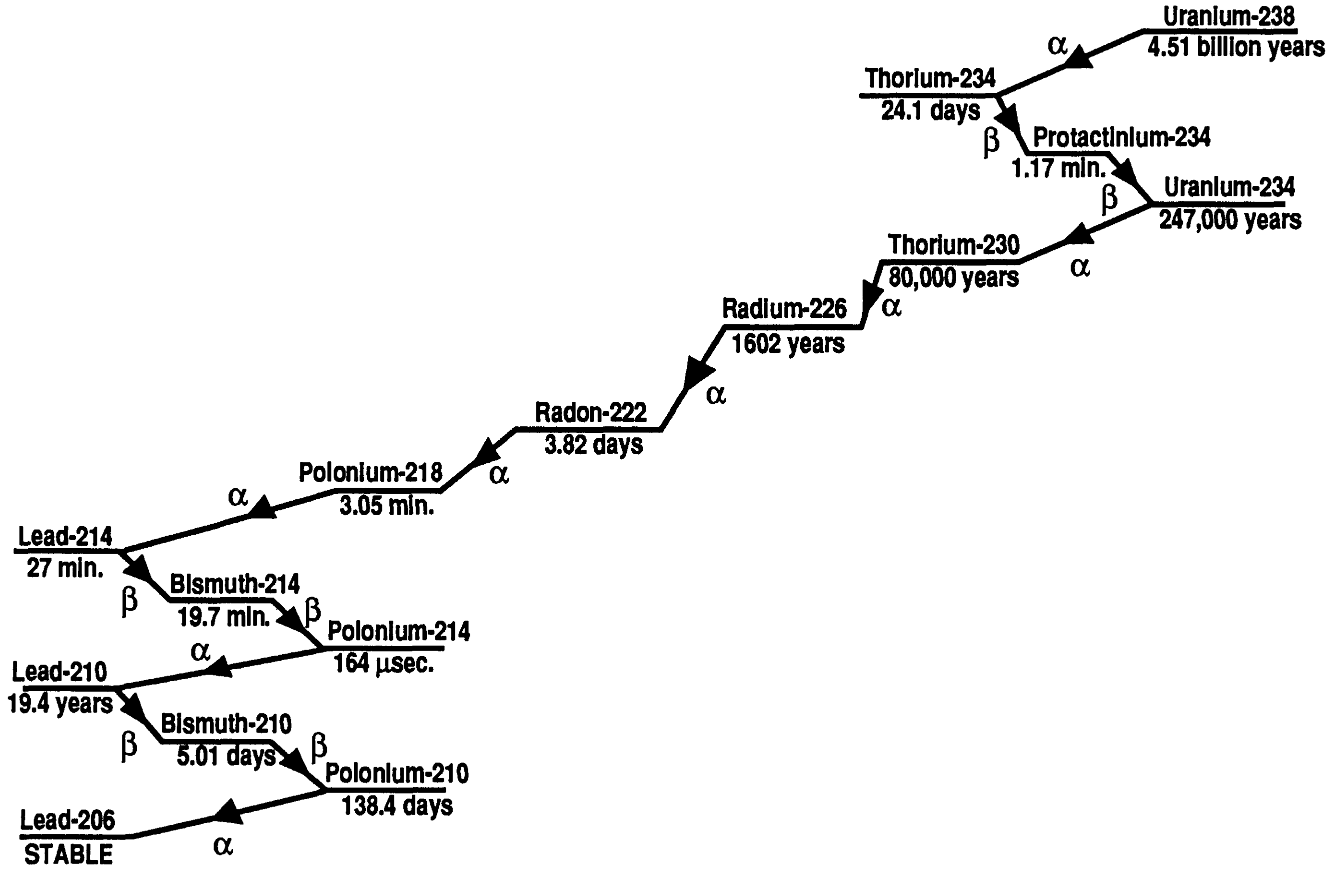


Figure 1. The uranium-238 decay series, showing the half-lives of elements and their modes of decay (after Wanty and Schoen, 1991). α denotes alpha decay, β denotes beta decay.

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

Not all radium contained in soil grains and grain coatings will result in mobile radon when the radium decays. Depending on where the radium is distributed in the soil, many of the radon atoms may remain imbedded in the soil grain containing the parent radium atom, or become imbedded in adjacent soil grains. The portion of radium that releases radon into the pores and fractures of rocks and soils is called the emanating fraction. When a radium atom decays to radon, the energy generated is strong enough to send the radon atom a distance of about 40 nanometers (1 nm = 10^{-9} meters), or about $2x10^{-6}$ inches—this is known as alpha recoil (Tanner, 1980). Moisture in the soil lessens the chance of a recoiling radon atom becoming imbedded in an adjacent grain. Because water is more dense than air, a radon atom will travel a shorter distance in a water-filled pore than in an air-filled pore, thus increasing the likelihood that the radon atom will remain in the pore space. Intermediate moisture levels enhance radon emanation but do not significantly affect permeability. However, high moisture levels can significantly decrease the gas permeability of the soil and impede radon movement through the soil.

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

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

RADON ENTRY INTO BUILDINGS

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

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

METHODS AND SOURCES OF DATA

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

GEOLOGIC DATA

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

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

NURE AERIAL RADIOMETRIC DATA

Aerial radiometric data are used to quantify the radioactivity of rocks and soils. Equivalent uranium (eU) data provide an estimate of the surficial concentrations of radon parent materials (uranium, radium) in rocks and soils. Equivalent uranium is calculated from the counts received by a gamma-ray detector from the 1.76 MeV (mega-electron volts) emission energy corresponding to bismuth-214 (^{214}Bi), with the assumption that uranium and its decay products are in secular equilibrium. Equivalent uranium is expressed in units of parts per million (ppm). Gamma radioactivity also may be expressed in terms of a radium activity; 3 ppm eU corresponds to approximately 1 picocurie per gram (pCi/g) of radium-226. Although radon is highly mobile in soil and its concentration is affected by meteorological conditions (Kovach, 1945; Klusman and Jaacks, 1987; Schery and others, 1984; Schumann and others, 1992), statistical correlations between average soil-gas radon concentrations and average eU values for a wide variety of soils have been documented (Gundersen and others, 1988a, 1988b; Schumann and Owen, 1988). Aerial radiometric data can provide an estimate of radon source strength over a region, but the amount of radon that is able to enter a home from the soil is dependent on several local factors, including soil structure, grain size distribution, moisture content, and permeability, as well as type of house construction and its structural condition.

The aerial radiometric data used for these characterizations were collected as part of the Department of Energy National Uranium Resource Evaluation (NURE) program of the 1970s and early 1980s. The purpose of the NURE program was to identify and describe areas in the United States having potential uranium resources (U.S. Department of Energy, 1976). The NURE aerial radiometric data were collected by aircraft in which a gamma-ray spectrometer was mounted, flying approximately 122 m (400 ft) above the ground surface. The equivalent uranium maps presented in the state chapters were generated from reprocessed NURE data in which smoothing, filtering, recalibrating, and matching of adjacent quadrangle data sets were performed to compensate for background, altitude, calibration, and other types of errors and inconsistencies in the original data set (Duval and others, 1989). The data were then gridded and contoured to produce maps of eU with a pixel size corresponding to approximately 2.5 x 2.5 km (1.6 x 1.6 mi).

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

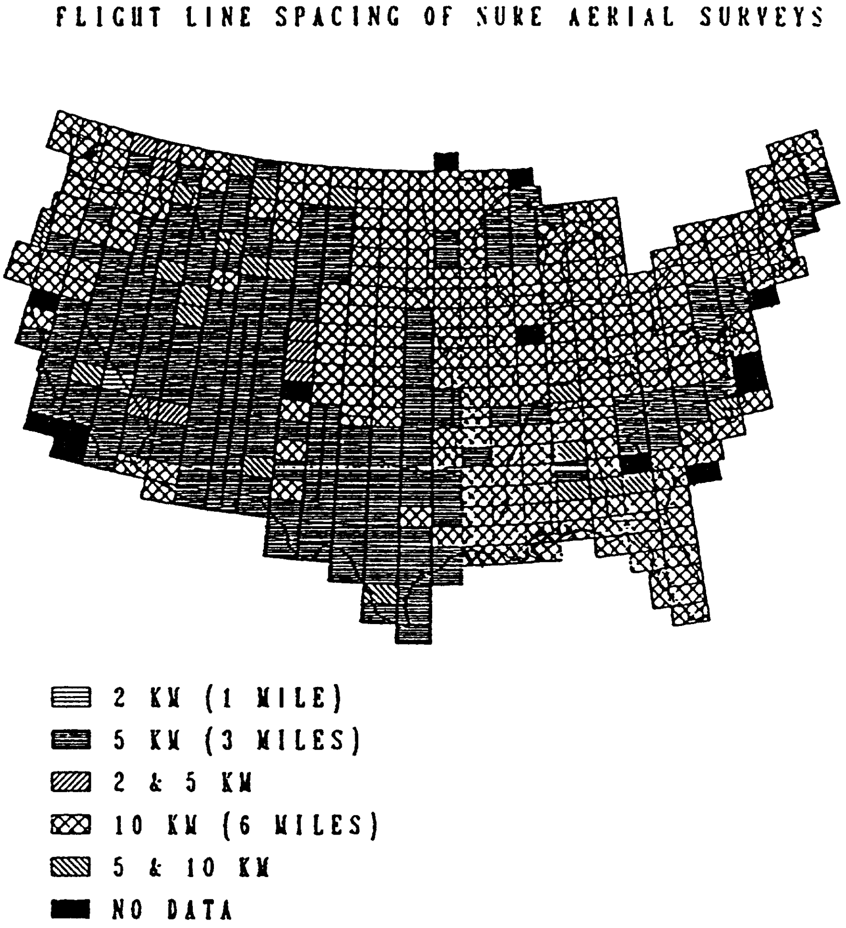


Figure 2. Nominal flightline spacings for NURE aerial gamma-ray surveys covering the contiguous United States (from Duval and others, 1990). Rectangles represent 1°x2° quadrangles.

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

SOIL SURVEY DATA

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

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

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

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

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

INDOOR RADON DATA

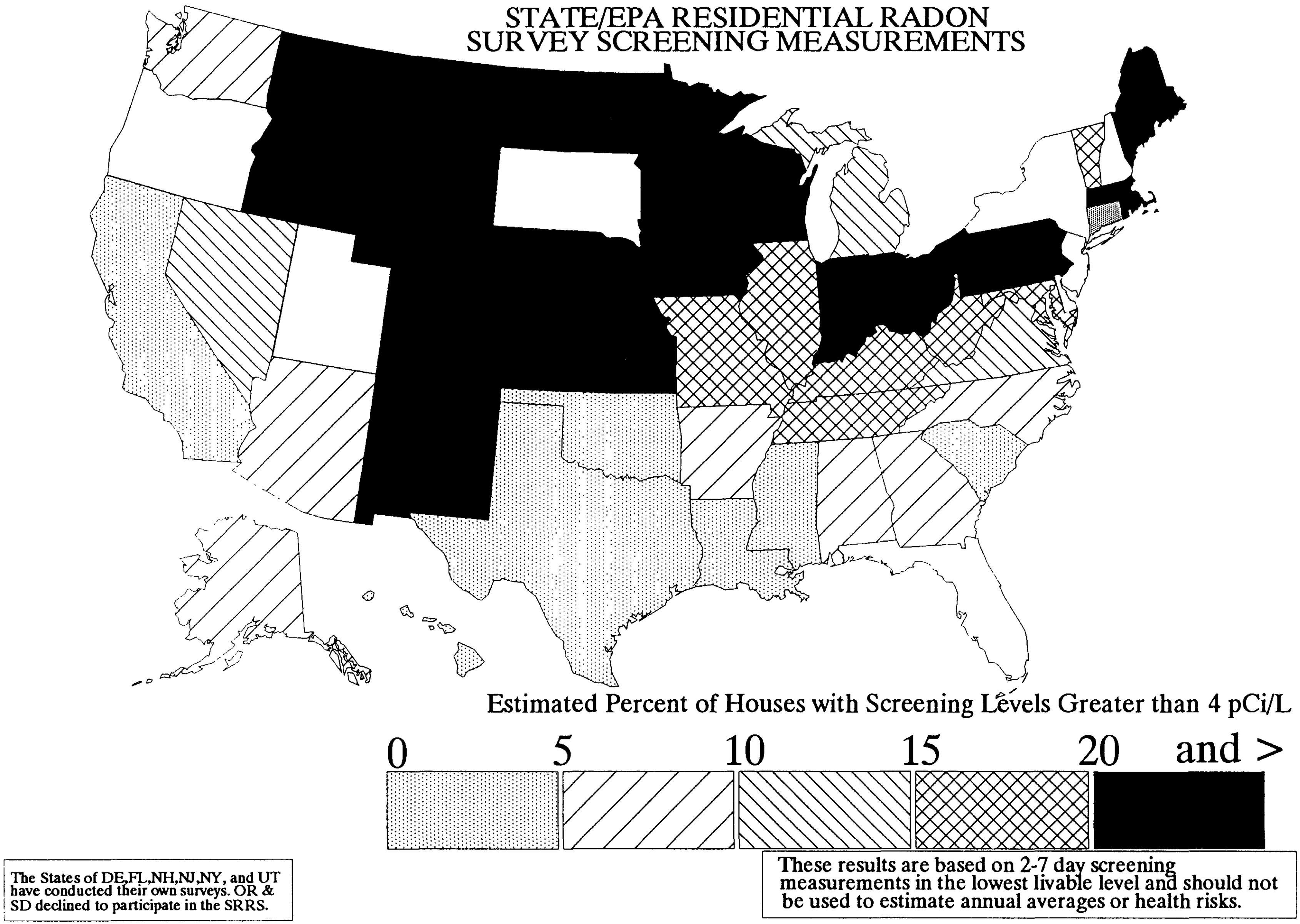
Two major sources of indoor radon data were used. The first and largest source of data is from the State/EPA Residential Radon Survey (Ronca-Battista and others, 1988; Dziuban and others, 1990). Forty-two states completed EPA-sponsored indoor radon surveys between 1986 and 1992 (fig. 3). The State/EPA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

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

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

RADON INDEX AND CONFIDENCE INDEX

Many of the geologic methods used to evaluate an area for radon potential require subjective opinions based on the professional judgment and experience of the individual geologist. The evaluations are nevertheless based on established scientific principles that are universally applicable to any geographic area or geologic setting. This section describes the methods and conceptual framework used by the U.S. Geological Survey to evaluate areas for radon potential



These results are based on 2-7 day screening measurements in the lowest livable level and should not be used to estimate annual averages or health risks.

The States of DE,FL,NH,NJ,NY, and UT have conducted their own surveys. OR & SD declined to participate in the SRRS.

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

based on the five factors discussed in the previous sections. The scheme is divided into two basic parts, a Radon Index (RI), used to rank the general radon potential of the area, and the Confidence Index (CI), used to express the level of confidence in the prediction based on the quantity and quality of the data used to make the determination. This scheme works best if the areas to be evaluated are delineated by geologically-based boundaries (geologic provinces) rather than political ones (state/county boundaries) in which the geology may vary across the area.

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

Indoor radon was evaluated using unweighted arithmetic means of the indoor radon data for each geologic area to be assessed. Other expressions of indoor radon levels in an area also could have been used, such as weighted averages or annual averages, but these types of data were not consistently available for the entire United States at the time of this writing, or the schemes were not considered sufficient to provide a means of consistent comparison across all areas. For this report, charcoal-canister screening measurement data from the State/EPA Residential Radon Surveys and other carefully selected sources were used, as described in the preceding section. To maintain consistency, other indoor radon data sets (vendor, state, or other data) were not considered in scoring the indoor radon factor of the Radon Index if they were not randomly sampled or could not be statistically combined with the primary indoor radon data sets. However, these additional radon data sets can provide a means to further refine correlations between geologic factors and radon potential, so they are included as supplementary information and are discussed in the individual State chapters. If the average screening indoor radon level for an area was less than 2 pCi/L, the indoor radon factor was assigned 1 point, if it was between 2 and 4 pCi/L, it was scored 2 points, and if the average screening indoor radon level for an area was greater than 4 pCi/L, the indoor radon factor was assigned 3 RI points.

Aerial radioactivity data used in this report are from the equivalent uranium map of the conterminous United States compiled from NURE aerial gamma-ray surveys (Duval and others, 1989). These data indicate the gamma radioactivity from approximately the upper 30 cm of rock and soil, expressed in units of ppm equivalent uranium. An approximate average value of eU was determined visually for each area and point values assigned based on whether the overall eU for the area falls below 1.5 ppm (1 point), between 1.5 and 2.5 ppm (2 points), or greater than 2.5 ppm (3 points).

The geology factor is complex and actually incorporates many geologic characteristics. In the matrix, "positive" and "negative" refer to the presence or absence and distribution of rock types known to have high uranium contents and to generate elevated radon in soils or indoors. Examples of "positive" rock types include granites, black shales, phosphatic rocks, and other rock types described in the preceding "geologic data" section. Examples of "negative" rock types include marine quartz sands and some clays. The term "variable" indicates that the geology within the region is variable or that the rock types in the area are known or suspected to generate elevated radon in some areas but not in others due to compositional differences, climatic effects, localized

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

INCREASING RADON POTENTIAL →

FACTOR	POINT VALUE		
	1	2	3
INDOOR RADON (average)	< 2 pCi/L	2 - 4 pCi/L	> 4 pCi/L
AERIAL RADIOACTIVITY	< 1.5 ppm eU	1.5 - 2.5 ppm eU	> 2.5 ppm eU
GEOLOGY*	negative	variable	positive
SOIL PERMEABILITY	low	moderate	high
ARCHITECTURE TYPE	mostly slab	mixed	mostly basement

*GEOLOGIC FIELD EVIDENCE (GFE) POINTS: GFE points are assigned in addition to points for the "Geology" factor for specific, relevant geologic field studies. See text for details.

Geologic evidence supporting:	HIGH radon	+2 points
	MODERATE	+1 point
	LOW	-2 points
	No relevant geologic field studies	0 points

SCORING:

Radon potential category	Point range	Probable average screening indoor radon for area
LOW	3-8 points	< 2 pCi/L
MODERATE/VARIABLE	9-11 points	2 - 4 pCi/L
HIGH	12-17 points	> 4 pCi/L

POSSIBLE RANGE OF POINTS = 3 to 17

TABLE 2. CONFIDENCE INDEX MATRIX

INCREASING CONFIDENCE →

FACTOR	POINT VALUE		
	1	2	3
INDOOR RADON DATA	sparse/no data	fair coverage/quality	good coverage/quality
AERIAL RADIOACTIVITY	questionable/no data	glacial cover	no glacial cover
GEOLOGIC DATA	questionable	variable	proven geol. model
SOIL PERMEABILITY	questionable/no data	variable	reliable, abundant

SCORING:

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

POSSIBLE RANGE OF POINTS = 4 to 12

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

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

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

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

The overall RI for an area is calculated by adding the individual RI scores for the 5 factors, plus or minus GFE points, if any. The total RI for an area falls in one of three categories—low, moderate or variable, or high. The point ranges for the three categories were determined by examining the possible combinations of points for the 5 factors and setting rules such that a majority (3 of 5 factors) would determine the final score for the low and high categories, with allowances for possible deviation from an ideal score by the other two factors. The moderate/variable category lies between these two ranges. A total deviation of 3 points from the "ideal" score was considered reasonable to allow for natural variability of factors—if two of the five factors are allowed to vary from the "ideal" for a category, they can differ by a minimum of 2

(1 point different each) and a maximum of 4 points (2 points different each). With "ideal" scores of 5, 10, and 15 points describing low, moderate, and high geologic radon potential, respectively, an ideal low score of 5 points plus 3 points for possible variability allows a maximum of 8 points in the low category. Similarly, an ideal high score of 15 points minus 3 points gives a minimum of 12 points for the high category. Note, however, that if both other factors differ by two points from the "ideal", indicating considerable variability in the system, the total point score would lie in the adjacent (i.e., moderate/variable) category.

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

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

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

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

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

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

EPA COUNTY RADON POTENTIAL MAPS

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

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APPENDIX A
GEOLOGIC TIME SCALE

Subdivisions (and their symbols): 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 (Pɇ)	Oligocene		38 (34–38)
				Eocene		55 (54–56)
				Paleocene		66 (63–66)
	Mesozoic[2] (Mz)	Cretaceous (K)		Late	Upper	96 (95–97)
				Early	Lower	138 (135–141)
		Jurassic (J)		Late	Upper	
				Middle	Middle	
				Early	Lower	205 (200–215)
		Triassic (T̄R)		Late	Upper	
				Middle	Middle	
				Early	Lower	~240
	Paleozoic[2] (Pz)	Permian (P)		Late	Upper	
				Early	Lower	290 (290–305)
		Carboniferous Systems (C)	Pennsylvanian (ℙ)	Late	Upper	
				Middle	Middle	
				Early	Lower	~330
			Mississippian (M)	Late	Upper	
				Early	Lower	360 (360–365)
		Devonian (D)		Late	Upper	
				Middle	Middle	
				Early	Lower	410 (405–415)
		Silurian (S)		Late	Upper	
				Middle	Middle	
				Early	Lower	435 (435–440)
		Ordovician (O)		Late	Upper	
				Middle	Middle	
				Early	Lower	500 (495–510)
		Cambrian (Є)		Late	Upper	
				Middle	Middle	
				Early	Lower	~570[3]
Proterozoic (Ᵽ)	Late Proterozoic (Z)	None defined				900
	Middle Proterozoic (Y)	None defined				1600
	Early Proterozoic (X)	None defined				2500
Archean (A)	Late Archean (W)	None defined				3000
	Middle Archean (V)	None defined				3400
	Early Archean (U)	None defined				3800 ?
pre-Archean (pA)[4]						

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

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

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

[4] Informal time term without specific rank.

APPENDIX B
GLOSSARY OF TERMS

Units of measure

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

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

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

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

Geologic terms and terms related to the study of radon

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

eolian Pertaining to sediments deposited by the wind.

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

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

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

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

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

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

formation A mappable body of rock having similar characteristics.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

placer deposit See heavy minerals

residual Formed by weathering of a material in place.

residuum Deposit of residual material.

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

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

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

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

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

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

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

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

shrink-swell clay See clay mineral.

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

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

slope An inclined part of the earth's surface.

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

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

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

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

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

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

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

uraniferous Containing uranium, usually more than 2 ppm.

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

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

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

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

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

by

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EPA Region 6 includes the states Arkansas, Louisiana, New Mexico, Oklahoma, and Texas. For each state, geologic radon potential areas were delineated and ranked on the basis of geology, soils, housing construction, indoor radon, 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 6 is given in the individual state chapters. The individual chapters describing the geology and radon potential of the states in Region 6, 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 likely will be found.

Figure 1 shows a generalized map of the physiographic/geologic provinces in Region 6. The following summary of radon potential in Region 6 is based on these provinces. Figure 2 shows average screening indoor radon levels by county calculated from the State/EPA Residential Radon Survey. Figure 3 shows the geologic radon potential areas in Region 6, combined and summarized from the individual state chapters.

ARKANSAS

The geologic radon potential of Arkansas is generally low to moderate. Paleozoic marine limestones, dolomites, and uraniferous black shales appear to be associated with most of the indoor radon levels greater than 4 pCi/L in the State.

Ordovician through Mississippian-age sedimentary rocks, including limestone, dolomite, shale, and sandstone, underlie most of the Springfield and Salem Plateaus. Black shales and residual soils developed from carbonate rocks in the Springfield and Salem Plateaus are moderate to locally high in geologic radon potential. The Ordovician limestones, dolomites, black shales, and sandstones have moderate (1.5-2.5 ppm) to high (>2.5 ppm) equivalent uranium (eU, from aeroradioactivity surveys) and some of the highest indoor radon in the State is associated with them. The Mississippian limestones and shales, however, have low (<1.5 ppm) equivalent uranium with very localized areas of high eU, but also have moderate to high levels of indoor radon associated with them. Black shales and carbonaceous sandstones within the Mississippian, Devonian, and Ordovician units of the plateaus are the likely cause of the local areas of high eU. The Chattanooga Shale and shale units within the Mississippian limestones may be responsible for some of the high indoor radon levels found in Benton County. Limestones are usually low in radionuclide elements but residual soils developed from limestones may be elevated in uranium and radium. Karst and cave features are also thought to accumulate radon.

The Boston Mountains, Arkansas Valley, Fourche Mountains, and Athens Plateau are underlain predominantly by Mississippian and Pennsylvanian sandstones and shales with low to

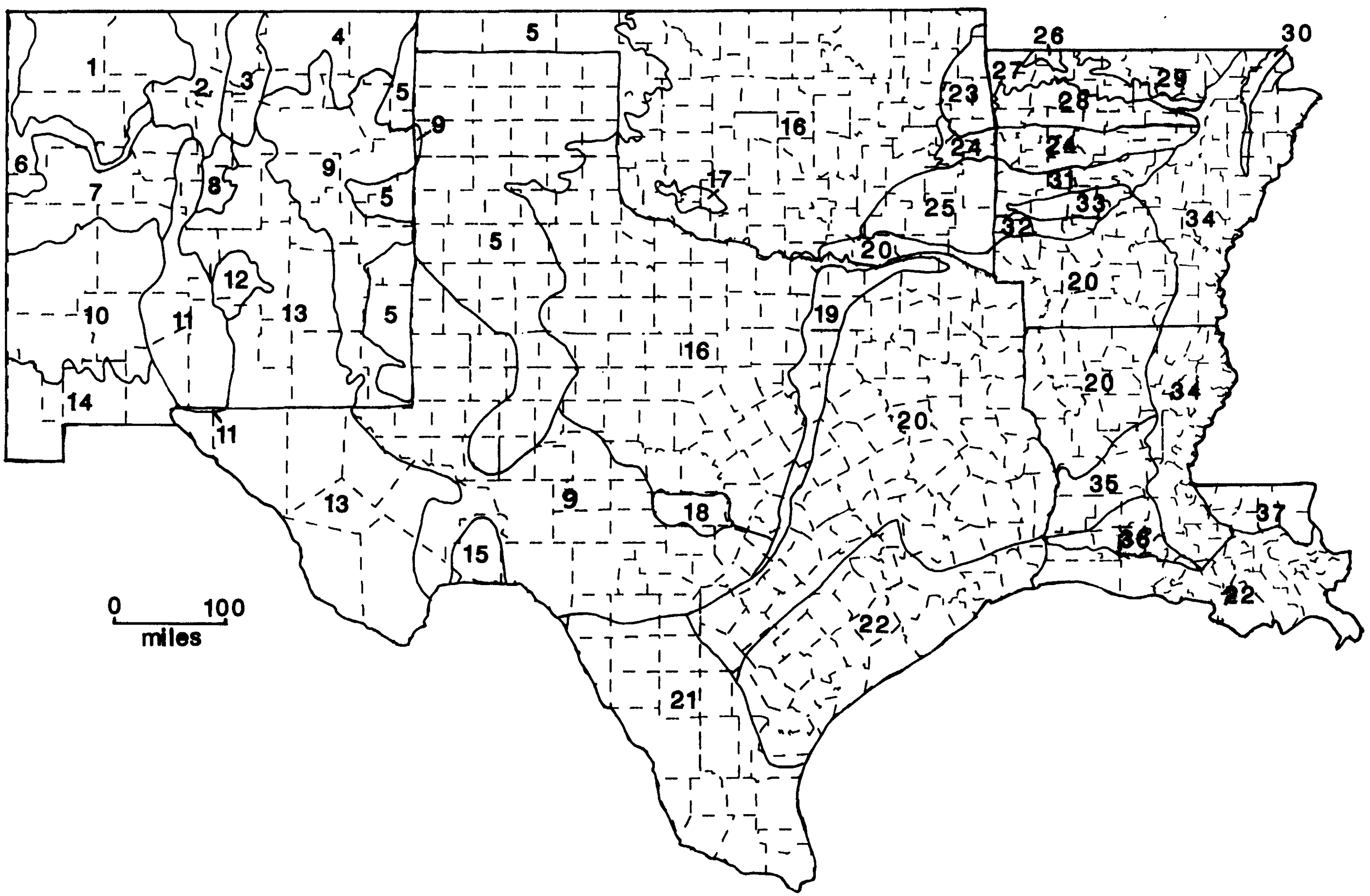

Figure 1. Geologic radon potential areas of EPA Region 6. 1, 4, 7–Cretaceous marine rocks; 2–Jemez Mountains; 3, 11–Southern Rocky Mountains; 5, 15–Tertiary Ogallala Formation (High Plains); 6–Grants uranium belt; 8, 9–Plains and Plateaus (Triassic, Cretaceous and Quaternary deposits; 10–Datil-Mogollon volcanic field; 12–Tertiary volcanic and Cretaceous sedimentary rocks; 13–Late Paleozoic marine limestones; 14–Eastward extension of the Basin and Range Province; 16–Central Oklahoma and Texas (Paleozoic marine sediments); 17–Wichita Mountains; 18, 19–Cretaceous Central Texas and Llano Uplift; 20–Northern Coastal Plains (Old Uplands (LA)); 21–Southern Texas Plain; 22–Coastal Plain (TX)/Old Uplands (LA); 23–Ozark Plateau; 24–Lower Arkansas River Valley; 25–Ouachita Mountains; 26, 29–Salem Plateau; 27–Springfield Plateau; 28–Boston Mountains; 30–Crowley's Ridge; 31–Fourche Mountains; 32–Athens Plateau; 33–Central Ouchita Mountains; 34–Mississippi Alluvial Plain; 35, 37–Terraces; 36–Prairies.

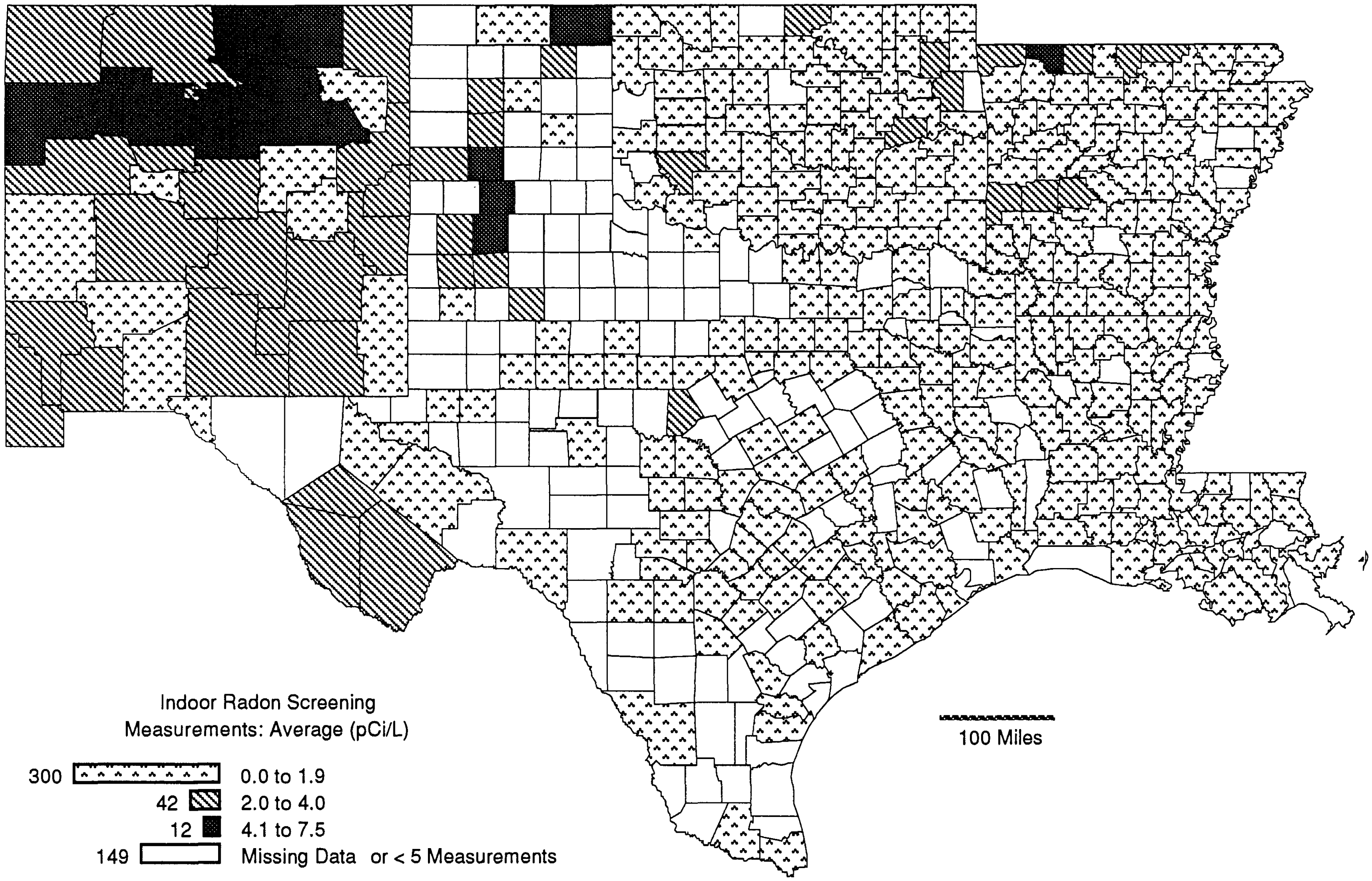

Figure 2. Screening indoor radon average for counties with 5 or more measurements in EPA Region 6. Data are from 2-7 day charcoal canister tests. Data for all states are from the EPA/State Residential Radon Survey. Histograms in map legends show the number of counties in each category.

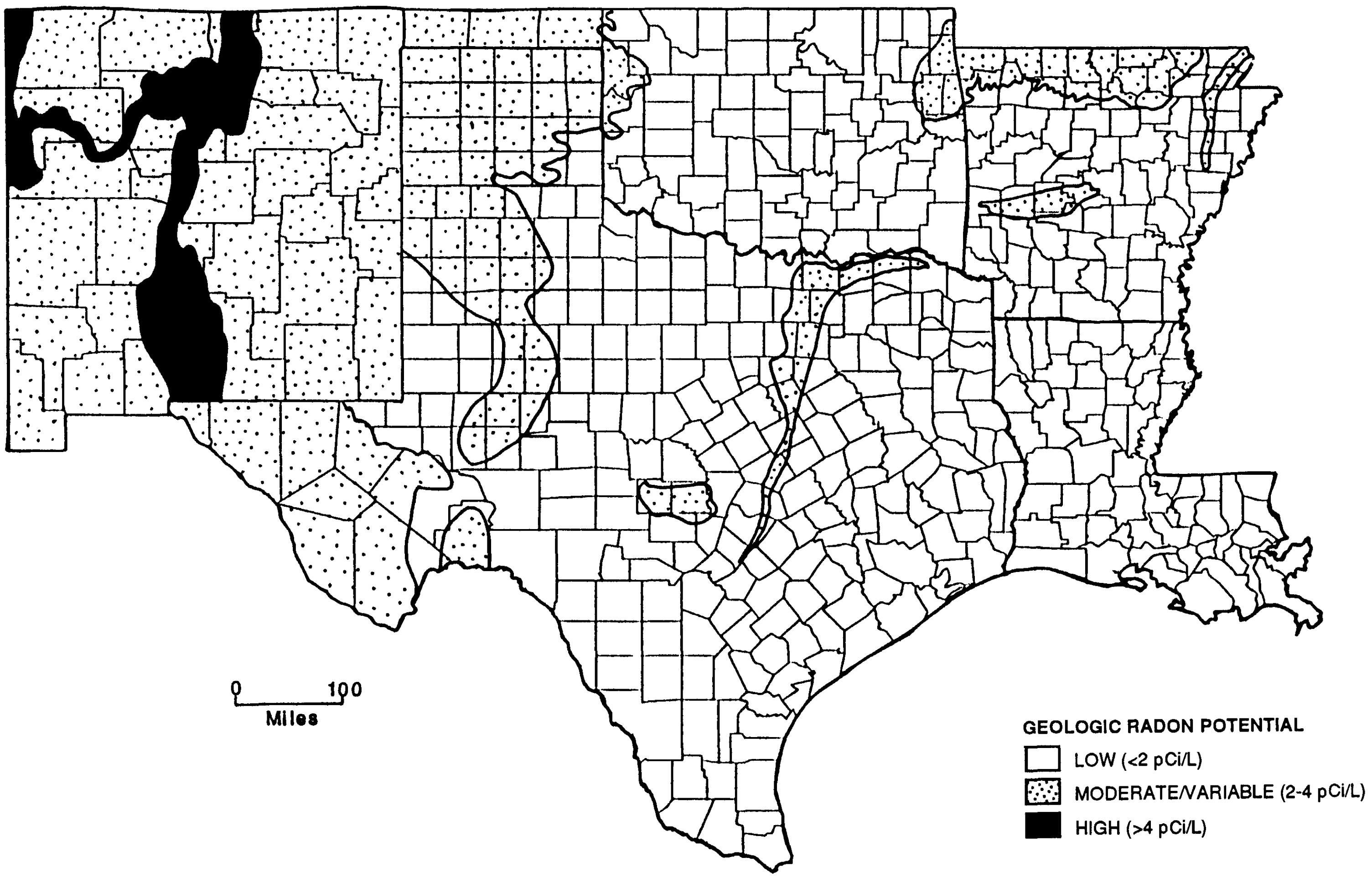

Figure 3. Geologic radon potential areas of EPA Region 6. For more detail, refer to individual state radon potential chapters.

moderate radon potential. Although the indoor radon average for these provinces is low, there are a number of counties in these provinces with screening indoor radon averages slightly higher than 1 pCi/L and maximum readings greater than 4 pCi/L. The marine black shales are probably uranium-bearing. Further, carbonaceous sandstones of the Upper Atoka Formation and Savanna Formation have high (>2.5 ppm) eU associated with them. Uranium also occurs in the Jackfork Sandstone in Montgomery County and in the Atoka Formation in Crawford County. These rocks are the most likely sources for the indoor radon levels. Radon from a hydrocarbon source in these rocks should not be ruled out. The presence of radon and uranium in some natural gas, petroleum, and asphaltite is well known and could contribute radon to indoor air in some locations.

The Central Ouachita Mountains are underlain by intensely-deformed Ordovician and Silurian shales and sandstones with minor chert and limestone. These rocks generally have low to moderate radon potential. Aeroradiometric signatures of 2.5 ppm eU or more are associated with the Ordovician black shales and possibly with some syenite intrusions. Indoor radon in the Central Ouachita Mountains is low to moderate and permeability of the soils is low to moderate.

The West Gulf Coastal Plain is generally low in radon potential. Some of the Cretaceous and Tertiary sediments have moderate eU (1.5-2.5 ppm). Recent studies in the Coastal Plain of Texas, Alabama, and New Jersey show that glauconite and phosphate in sandstones, chalks, marls, and limestones, as well as black organic clays, shales, and muds, are often associated with high concentrations of uranium and radon in the sediments, and could be sources for elevated indoor radon levels. Several formations within the Gulf Coastal Plain of Arkansas contain these types of sediments, especially parts of the upper Cretaceous and lower Tertiary section, but average indoor radon levels in this area are not elevated. The Quaternary sediments of the Coastal Plain have low eU and the indoor radon average is low for the Gulf Coastal Plain overall.

The Mississippi Alluvial Plain and Crowley's Ridge have low to locally moderate radon potential. The southern half of the Mississippi Alluvial Plain is made up predominantly of quartzose sediments, has generally low eU, and has low indoor radon. The northern half of the alluvial plain, however, includes the loess of Crowley's Ridge, which appears to have high equivalent uranium associated with it, and possibly a high loess content in the surrounding sediments in general. The northeastern corner of Arkansas appears to be crossed by the large belt of loess that continues into Kentucky and Tennessee and shows as a distinct area of high eU on the aeroradiometric map of the United States. Some areas of high eU may also be due to uranium in phosphate-rich fertilizers used in agricultural areas. Several of the counties in the northern part of the alluvial plain have maximum indoor radon values greater than 4 pCi/L and indoor radon averages between 1 and 2 pCi/L, which are generally higher than those in surrounding counties.

LOUISIANA

The geology of Louisiana is dominated by ancient marine sediments of the Gulf Coastal Plain and modern river deposits from the Mississippi River and its tributaries. Louisiana is generally an area of low geologic radon potential. The climate, soil, and lifestyle of the inhabitants of Louisiana have influenced building construction styles and building ventilation which, in general, do not allow high concentrations of radon to accumulate. Many homes in Louisiana are built on piers or are slab-on-grade. Overall indoor radon is low; however, several parishes had individual homes with radon levels greater than 4 pCi/L. Parishes with indoor radon levels greater than 4 pCi/L are found in different parts of the State, in parishes underlain by coastal plain sediments, terrace deposits, and loess.

In the Coastal Plain of Louisiana the glauconitic, carbonaceous, and phosphatic sediments have some geologic potential to produce radon, particularly the Cretaceous and lower Tertiary-age geologic units located in the northern portion (Old Uplands) of the State. Soils from clays, shales, and marls in the Coastal Plain commonly have low permeability, so even though these sediments may be a possible source of radon, low permeability probably inhibits radon availability. Some of the glauconitic sands and silts with moderate permeability may be the source of locally high indoor radon. Moderate levels of radioactivity (1.5-2.5 ppm eU) are associated with areas underlain by the Eocene through lower Oligocene-age Coastal Plain sediments, but do not follow formation boundaries or strike belts in a systematic manner. The pattern of moderate radioactivity in this area does appear to follow river drainages and the aeroradioactivity pattern may be associated with northwest- and northeast-trending joints and or faults which, in turn, may control drainage patterns. Part of the pattern of low aeroradioactivity in the Coastal Plain may be influenced by ground saturation with water. This area receives high precipitation and contains an extensive system of bayous and rivers. Besides damping gamma radioactivity, ground saturation can also inhibit radon movement.

The youngest Coastal Plain sediments, particularly Oligocene and younger, have decreasing amounts of glauconite and phosphate and become increasingly siliceous (silica-rich), and thus, are less likely to be significant sources of radon. However, the possibility of roll-front uranium deposits in sedimentary rocks and sediments of Oligocene-Miocene age, analogous to the roll-front uranium deposits in Texas, has been proposed. Anomalous gamma-ray activity has been measured in the lower Catahoula sandstone, but no uranium deposits have yet been identified.

The fluvial and deltaic sediments in the Mississippi Alluvial Plain are low in geologic radon potential. They are not likely to have elevated amounts of uranium and the saturated to seasonally wet conditions of the soils, as well as the high water tables, do not facilitate radon availability. Coarse gravels in the terraces of the Mississippi Alluvial Plain have locally very high permeability and may be a source of radon.

Loess units in the northern portion of the Mississippi floodplain can easily be identified by their radiometric signature on the aeroradioactivity map of Louisiana. Loess is associated with high radiometric anomalies throughout the United States. Radiometric anomalies also seem to be associated with exposures of loess in Iberia, Lafayette, eastern Acadia, and northern Vermilion Parishes, in the southeastern part of the Prairies. Loess tends to have low permeability, so even though these sediments may be a possible source of high radon, the lack of permeability, particularly in wet soils, may inhibit radon availability.

NEW MEXICO

An overriding factor in the geologic evaluation of New Mexico is the abundance and widespread outcrops in local areas of known uranium-producing and uranium-bearing rocks in the State. Rocks known to contain significant uranium deposits, occurrences, or reserves, and rocks such as marine shales or phosphatic limestones that are known to contain low but uniform concentrations of uranium, all have the potential to contribute to elevated levels of indoor radon. In New Mexico, these rocks include Precambrian granites, pegmatites, and small hydrothermal veins; the Pennsylvanian and Permian Cutler Formation, Sangre de Cristo Formation, and San Andres Limestone; the Triassic Chinle Formation; the Jurassic Morrison Formation and Todilto Limestone Member (Wanakah Formation); the Cretaceous Dakota Sandstone, Kirtland Shale, Fruitland Formation, and Crevasse Canyon Formation; the Cretaceous and Tertiary Ojo Alamo Sandstone;

Tertiary Ogallala Formation and Popotosa Formation (Santa Fe Group); Tertiary alkalic intrusive rocks and rhyolitic and andesitic volcanic rocks such as the Alum Mountain andesite; and the Quaternary Bandelier Tuff and Valles Rhyolite.

Several areas in New Mexico contain outcrops of one or more of these rock units that may contribute to elevated radon levels. The southern and western rims of the San Juan Basin expose a Paleozoic to Tertiary sedimentary section that contains the Jurassic, Cretaceous, and Tertiary sedimentary rocks having a high radiometric signature and that are known to host uranium deposits in the Grants uranium district, as well as in the Chuska and Carrizo Mountains. In north-central New Mexico, the Jemez Mountains are formed in part by volcanic rocks that include the Bandelier Tuff and the Valles Rhyolite; this area also has an associated high radiometric signature. In northeastern New Mexico, Precambrian crystalline rocks and Paleozoic sedimentary rocks of the southern Rocky Mountains and Tertiary volcanic rocks and Cretaceous sedimentary rocks are associated with radiometric highs. In southwestern New Mexico, middle Tertiary volcanic rocks of the Datil-Mogollon region are also associated with high radiometric signatures. Remaining areas of the Colorado Plateau, the Basin and Range, and the Great Plains are associated with only moderate to low radiometric signatures on the aeroradiometric map; these areas generally contain Paleozoic to Mesozoic sedimentary rocks, scattered Tertiary and Quaternary volcanic rocks, and locally, Tertiary sedimentary rocks.

The southern extension of the Rocky Mountains and uplifted Paleozoic sedimentary rocks in central New Mexico; Upper Cretaceous marine shales and uranium-bearing Jurassic fluvial sandstones of the Grants uranium belt in the northeastern part of the State; and Tertiary volcanic rocks in the Jemez Mountains, just west of the southern Rocky Mountains, have high radon potential. Average screening indoor radon levels are greater than 4 pCi/L and aeroradioactivity signatures are generally greater than 2.5 ppm eU. Rocks such as Precambrian granites and uplifted Paleozoic strata, Jurassic sandstones and limestones, or Cretaceous to Tertiary shales and volcanic rocks that are known to contain or produce uranium are the most likely sources of elevated indoor radon levels in these areas. The remainder of the State has generally moderate radioactivity, average screening indoor radon levels less than 4 pCi/L, and overall moderate geologic radon potential.

OKLAHOMA

The geology of Oklahoma is dominated by sedimentary rocks and unconsolidated sediments that vary in age from Cambrian to Holocene. Precambrian and Cambrian igneous rocks are exposed in the core of the Arbuckle and Wichita Mountains and crop out in about 1 percent of the State. The western, northern, and central part of the State is underlain by very gently west-dipping sedimentary rocks of the northern shelf areas. A series of uplifts and basins flank the central shelf area. The Gulf Coastal Plain forms the southeastern edge of the State.

Most of the rocks that crop out in the central and eastern part of the State are marine in origin; they include limestone, dolomite, shale, sandstone, chert, and coal of Cambrian through Permian age. Nonmarine rocks of Permian and Tertiary age, including shale, sandstone, and conglomerate, are present in the western part of the central Oklahoma Hills and Plains area; sand, clay, gravel, and caliche dominate in the High Plains in the western part of the State. The Gulf Coastal Plain is underlain by Cretaceous nonmarine sand and clay and marine limestone and clay. Some of these units locally are moderately uranium-bearing.

Surface radioactivity across the State varies from less than 0.5 ppm to 5.0 ppm eU. Higher levels of equivalent uranium (>2.5 ppm) are consistently associated with black shales in the southeastern and westernmost Ouachita Mountains, the Arbuckle Mountains, and the Ozark Plateau; with Permian shale in Roger Mills, Custer, Washita, and Beckham Counties; with granites and related rocks in the Wichita Mountains; and with Cretaceous shale and associated limestone in the Coastal Plain. Low eU values (<1.5 ppm) are associated with large areas of dune sand adjacent to rivers in western Oklahoma; with eolian sands in the High Plains in Cimarron and Ellis Counties; and with Mississippian and Pennsylvanian rocks in the Ouachita Mountains, the Ozark Plateau, and the eastern part of the central Oklahoma plains and hills.

Areas of Oklahoma ranked as locally moderate to high are underlain by black, phosphatic shales and associated limestones in the northeastern part of the State and near the Arbuckle Mountains; the Upper Permian Rush Springs Formation in Caddo County; and granites, rhyolites, and related dikes in the Wichita Mountains in the southwestern part of the State. Areas ranked as generally low are underlain by Paleozoic marine sedimentary rocks in central and northwestern Oklahoma and by Tertiary continental sedimentary rocks on the High Plains.

Well-drained alluvial terraces along some rivers (for example, along the Arkansas River west of Tulsa); steep, thin, sandy to gravelly soils developed on sandstone on river bluffs (for example, bluffs in the southeastern suburbs of Tulsa); and clayey loams on uraniferous shales (in the northeastern corner of the State) are responsible for a significant percentage of elevated indoor radon levels in those areas. Thus, in addition to soils derived from rocks with elevated uranium content, soils in selected parts of counties where river terraces and sandstone bluffs occur might also have elevated radon potential.

Soil moisture may have an additional effect on radon potential across the State. Indoor radon values tend to be higher west of Oklahoma City where rainfall is less than 32 inches per year and lowest in the southeastern corner of the State, where rainfall ranges from 32 to 64 inches per year. Indoor radon values in northeastern Oklahoma, where rainfall is also high, include many readings greater than 4 pCi/L, but the effects of uraniferous black shales and weathered limestone soils on indoor radon may increase the levels overall and counter the effects of regional variation in soil moisture. High permeability, dry soils, and moderate uranium content may be responsible for elevated indoor radon readings in Beaver County.

TEXAS

The geologic radon potential of Texas is relatively low to moderate overall. The relatively mild climate throughout much of the State, especially in the most populous areas, and the predominance of slab-on-grade housing seems to have influenced the overall potential. Significant percentages of houses with radon levels exceeding 4 pCi/L are restricted primarily to the High Plains and the Western Mountains and Basins provinces. However, no physiographic province in Texas is completely free from indoor radon levels greater than 4 pCi/L.

Elevated indoor radon can be expected in several geologic settings in Texas. Granites and metamorphic rocks in central Texas, Tertiary silicic volcanic and tuffaceous sedimentary rocks in western Texas, dark marine shales in east-central Texas and the Big Bend area, sand and caliche associated with the Ogallala Formation and overlying units in the High Plains of Texas, sediments of Late Cretaceous age along the eastern edge of central Texas, and residual soils and alluvium derived from these units are likely to have significant percentages of homes over 4 pCi/L. Except for the High Plains and the Western Mountains and Basins Provinces, these rocks generally make up only a relatively small percentage of the surface area of the various physiographic provinces. However, the outcrop belt of Upper Cretaceous sedimentary rocks of the East Texas Province passes near some substantial population centers. Extreme indoor radon levels (greater than 100 pCi/L) may be expected where structures are inadvertently sited on uranium occurrences. This is more likely to occur in more populated areas along the outcrop belt of the Ogallala Formation at the edge of the Llano Estacada in the northern and central parts of the High Plains and Plateaus Province. In this outcrop area, sedimentary rocks with more than 10 ppm uranium are relatively common.

The northern part of the High Plains and Plateau Province has moderate radon potential. Uranium occurrences, uranium-bearing calcrete and silcrete, and uranium-bearing lacustrine rocks along the outcrop belt of the Ogallala Formation and in small upper Tertiary lacustrine basins within the northern High Plains may locally cause very high indoor radon levels. Indoor radon data are elevated in many counties in this area . Equivalent uranium values in this area range from 1.0 to 4.0 ppm. An area of elevated eU along the Rio Grande River is included in this radon potential province. The southern part of the High Plains and Plateaus Province has low radon potential overall as suggested by generally low eU values and low indoor radon. This area is sparsely populated and existing indoor radon measurements may not adequately reflect the geologic radon potential. An area of low eU covered by the sandy facies of the Blackwater Draw Formation in the northeastern corner of the Western Mountains and Basins Province is included in this radon potential area. Some parts of this province that may have locally elevated indoor radon levels include areas of thin soils over limestone and dolomite in the Edwards Plateau of the southern part of this province, and areas of carbonaceous sediments in the southeastern part of this province.

The Western Mountains and Basins Province has moderate indoor radon potential overall. Although average indoor radon levels are mixed (low in El Paso County, but high in three southern counties), areas of elevated eU are widespread. Uranium-bearing Precambrian rocks, silicic volcanic rocks, and alluvium derived from them may locally cause average indoor radon levels in some communities to exceed 4 pCi/L. Some indoor radon levels exceeding 20 pCi/L may also be expected. Exceptionally dry soils in this province may tend to lower radon potential. In very dry soils, the emanating fraction of radon from mineral matter is lowered somewhat.

The Central Texas Province has low radon potential overall; however, areas along the outcrop belt of the Woodbine and Eagle Ford Formations and the Austin Chalk along the east edge of this province, and areas of Precambrian metamorphic and undifferentiated igneous rocks in the Llano Uplift in the southern part of this province have moderate geologic radon potential. Structures sited on uranium occurrences in the Triassic Dockum Group in the western part of this province may locally have very high indoor radon levels.

The East Texas Province has low radon potential overall. Soil moisture levels are typically high; soil permeability is typically low to moderate; and eU levels are low to moderate. A few areas of well-drained soils and elevated eU may be associated with local areas of moderately elevated indoor radon levels.

The South Texas Plain has low radon potential due to generally low eU and low to moderate soil permeability. Some structures sited on soils with slightly elevated uranium contents in this province may locally have elevated indoor radon levels, but such soils are generally also clay rich and this may mitigate radon movement. The Texas Coastal Plain has low radon potential. Low aeroradioactivity, low to moderate soil permeability, and locally high water tables contribute to the low radon potential of the region.

PRELIMINARY GEOLOGIC RADON POTENTIAL ASSESSMENT OF ARKANSAS

by

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U.S. Geological Survey

INTRODUCTION

Indoor radon data from 1535 homes in Arkansas were collected during the winter of 1990-91 as part of the State/EPA Residential Radon Survey. The maximum value recorded in the survey was 24.2 pCi/L in Benton County. The average indoor radon for the state was 1.2 pCi/L and 5.3 percent of the homes tested had screening indoor radon levels exceeding 4 pCi/L. The geologic radon potential of Arkansas is generally low to moderate. Paleozoic marine limestones, dolomites, and uraniferous black shales appear to be associated with most of the indoor radon levels greater than 4 pCi/L in the State.

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

PHYSIOGRAPHIC AND GEOGRAPHIC SETTING

Arkansas has considerable diversity in its three major physiographic regions: the Ozark Plateaus, the Ouachita Mountains, and the Gulf Coastal Plain. Each of the major provinces is subdivided into sections (fig. 1). The physiographic provinces of Arkansas are a reflection of the underlying bedrock geology (fig. 2). The northern part of the State is characterized by the relatively flat-lying sedimentary rocks of the Salem and Springfield Plateaus and Boston Mountains. The Salem Plateau is generally 200 to 1,250 feet above sea level and is characterized by undulating to hilly terrain, with relief seldom exceeding 200 feet. The Springfield Plateau ranges from 1000 to 1500 feet above sea level and is characterized by broad to hilly terrain with relief of 200-300 feet. The Boston Mountains are flat-topped ridges representing the original erosion surface of the plateaus. Extensive stream dissection has created steep-sided mountains and deep, narrow valleys. Elevations generally range from 1500 to over 2500 feet with 500 to 1300 feet of relief.

The sedimentary rocks of the Ouachita Mountains underwent folding and faulting, creating parallel ridges and valleys with an east-west orientation. Mountain ridges are narrow and have steep slopes and broad valleys. Within the Ouachita Mountains, the Arkansas Valley is 30-40 miles wide and it is traversed by the Arkansas River, which has developed a distinct alluvial plain. Elevation is generally about 500 feet, but several isolated mountains rise from the valley floor to as high as 2753 feet at the top of Magazine Mountain. The Fourche Mountains contain several major

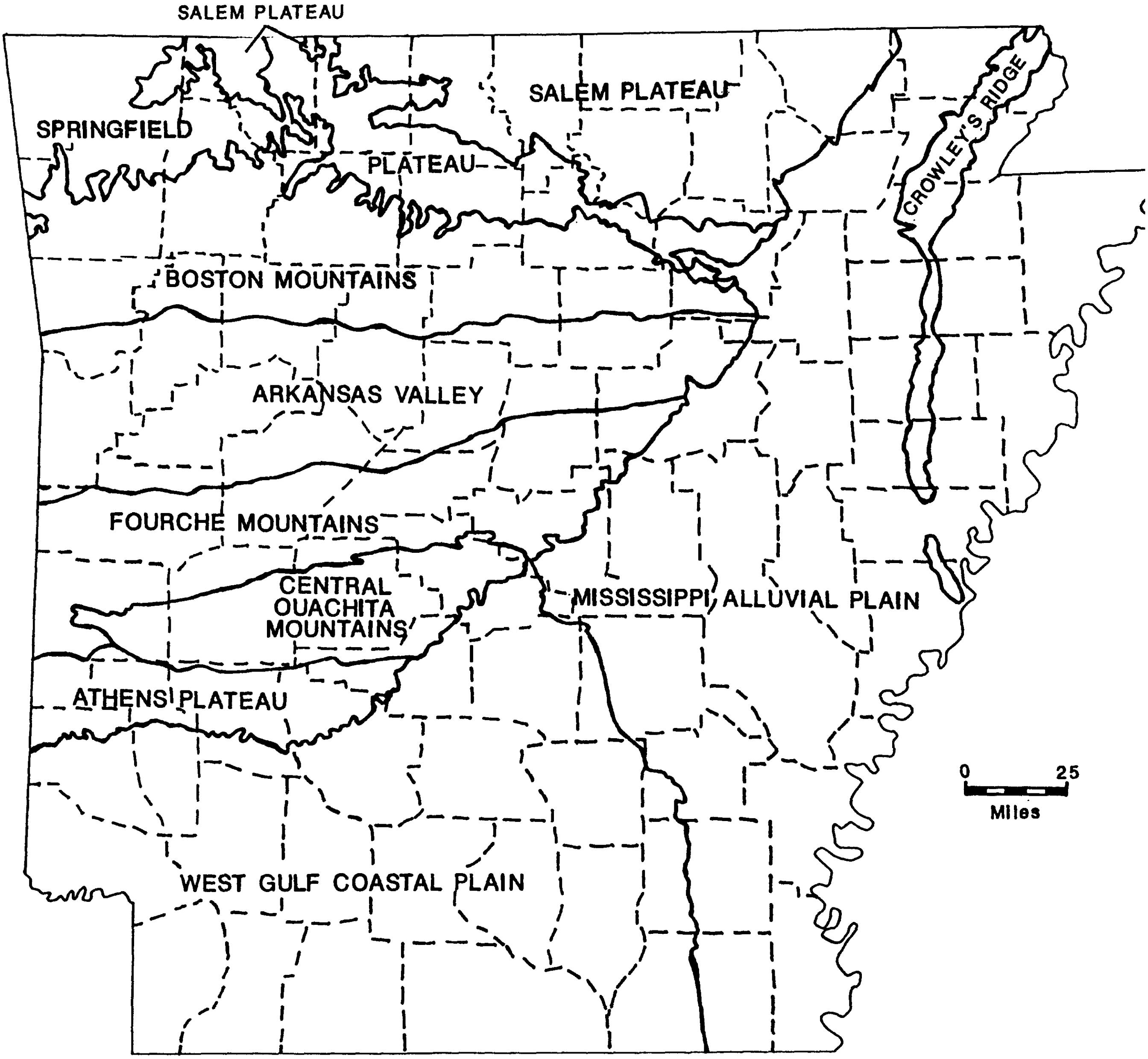

Figure 1. Physiographic regions of Arkansas (redrawn from Yates and Cullom, 1973).

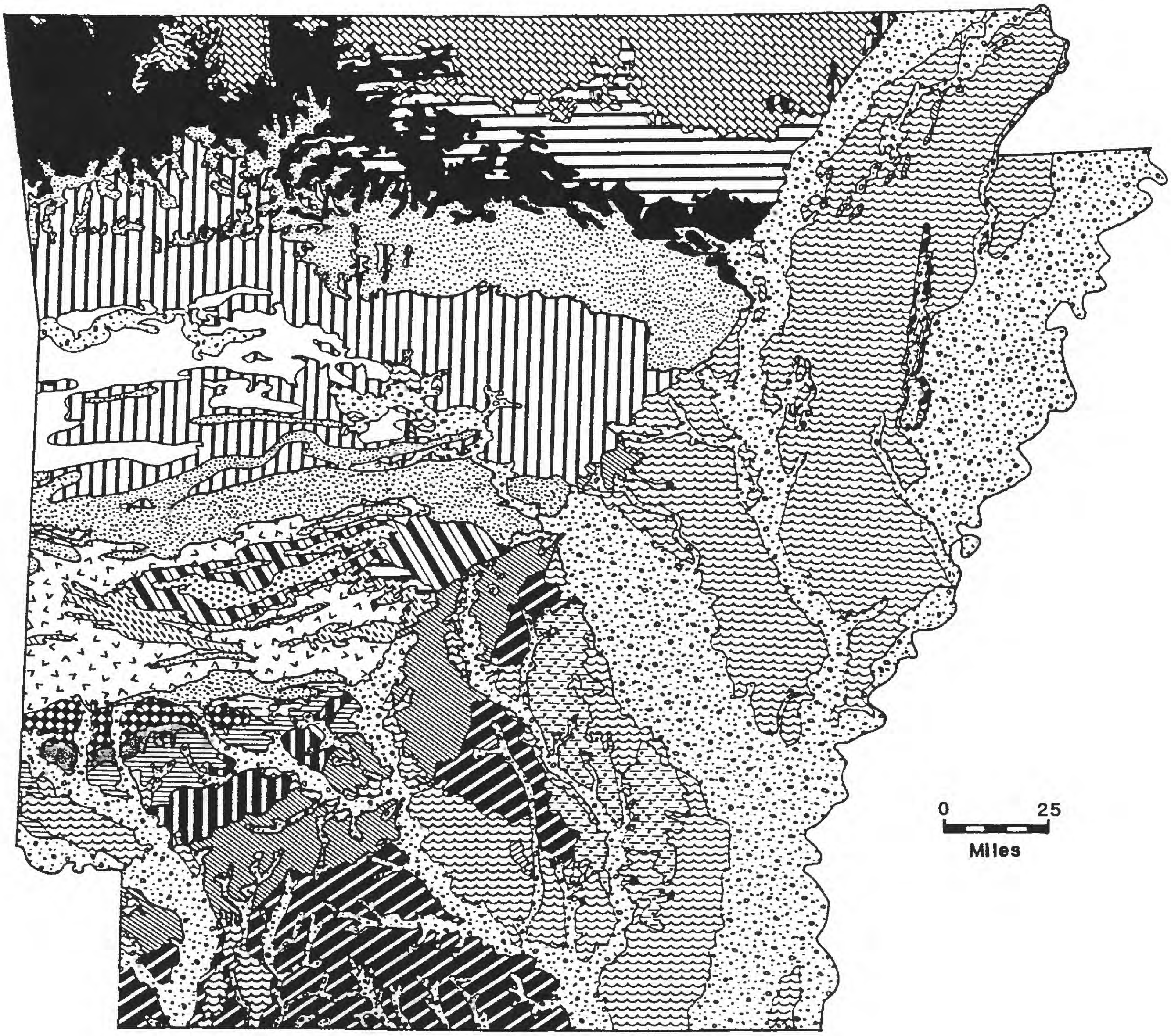

Figure 2. Generalized geologic map of Arkansas (after Haley and others, 1976).

EXPLANATION FOR THE GEOLOGIC MAP OF ARKANSAS

Quaternary

⁘	Alluvium
▒	Loess
≋	Terrace deposits

Tertiary

░	Jackson Group
▨	Claiborne Group
▧	Wilcox Group and Midway Group

Cretaceous

▥	Nacotoch Sand, Arkadelphia Marl, Ozan Formation, Annona Chalk, Marlbrook Marl, and Saratoga Chalk
▤	Tokio Formation and Brownstone Marl
▓	Woodbine Formation
◆	Kiamichi Formation, Goodland Limestone, and Trinity Group
+	Igneous intrusives, includes undifferentiated rocks of Paleozoic age

Pennsylvanian

□	Boggy Formation, Savanna Formation, McAlester Formation, and Hartshorne Sandstone
▥	Atoka Formation
░	Bloyd Shale, Hale Formation, Johns Valley Shale, and Jackfork Sandstone

Mississippian

■	Pitkin Limestone, Fayetteville Shale, Batesville Sandstone, Hindsville Limestone, Ruddell Shale, Moorefield Formation, and Boone Formation
▢	Stanley Shale and Arkansas Novaculite (upper part)

Mississippian - Devonian

▧ Arkansas Novaculite (middle and lower parts), Chattanooga Shale, Clifty Limestone, and Penters Chert

Silurian - Ordovician

▤ Lafferty Limestone, St. Clair Limestone, Brassfield Limestone, Missouri Mountain Slate, Blaylock Sandstone, Polk Creek Shale, Cason Shale, Fernvale Limestone, Kimmswick Limestone, Plattin Limestone, Joachim Dolomite, St. Peter Sandstone, and Everton Formation

Ordovician

▚ Big Fork Chert and Womble Shale

▩ Powell Dolomite, Cotter Dolomite, and Jefferson City Dolomite

░ Blakely Sandstone, Mazarn Shale, Crystal Mountain Sandstone, and Collier Shale ridges with broad valleys. Elevation varies from 1000 to 2500 feet. The Central Ouachita Mountains are closely folded sedimentary rocks with elevations of over 2000 feet; local relief is 300-900 feet. The Athens Plateau is a narrow belt in the southern part of the Ouachita Province underlain by sedimentary rocks. The terrain is undulating with elevation around 500 feet.

The southern and eastern parts of the State are low plains and gently rolling hills, with the exception of Crowley's Ridge, which rises as high as 200 feet above the surrounding plain and is 3-12 miles wide. The West Gulf Coastal Plain stands between 100 and 500 feet above sea level and consists of gently rolling hills covered by unconsolidated sediments, mostly sands. The Mississippi Alluvial Plain is flat with local relief of less than 100 feet and elevations between 100 and 500 feet above sea level.

The highlands are covered mainly by pine, hardwood forests, and pasture while the lowlands are mainly pasture, cropland, and prairie with pine forest in part of the Coastal Plain and hardwood forest in some of the bottomlands.

In 1990, the population of Arkansas was approximately 2,350,725, with 51 percent of the population living in urban areas (fig. 3). The climate in Arkansas is generally mild in winter and hot in summer. Average annual precipitation ranges from 44 to 56 inches (fig. 4). Arkansas is divided into 75 counties (fig. 5).

GEOLOGY AND SOILS

The following discussion of geology and soils is based on Haley and others (1976); Bennison (1986); Lowe (1989); Morris (1989); and Yates and Cullom (1973). A map of soil associations is given in figure 6.

The oldest rocks of the Ozark Plateaus are Ordovician in age and underlie the Arkansas portion of the Salem Plateau. The Lower Ordovician Jefferson City, Cotter, and Powell Dolomites cover most of the northern part of the Salem Plateau and are composed of dolostone and minor amounts of shale, siltstone, and sandstone. Moving south across the plateau, the rocks become younger and are dominated by limestones and sandstones of the Middle Ordovician Everton Formation and St. Peter Sandstone. The youngest Ordovician rocks are a series of limestones and minor dolostones capped locally by the Cason Shale. Silurian and Devonian sedimentary rocks crop out along the southeastern edge of the Salem Plateau and include limestone, marine black shales, cherts, and minor sandstones. The black shales are notably uraniferous and are correlative with the Chattanooga Shale. The carbonate rocks and shales weather to form silty and clayey loams that are deep in valleys but thin on the hillsides and are slowly to moderately permeable. Sandstones form sandy loams of moderate permeability.

Mississippian-age sedimentary rocks of the Boone Formation underlie most of the Springfield Plateau. These rocks are largely cherty limestones with minor shaly limestone and sandstone. Soils are clayey to cherty loams of slow to moderate permeability. Below the Boone, lenses of the Chattanooga Shale within a thin sandstone have been found (Swanson and Landis, 1962). Isolated outcrops of uranium-bearing Chattanooga Shale are found throughout the Springfield Plateau, but constitute only a small percentage of the total. The easternmost part of the Springfield Plateau contains the Moorefield Shale as well as younger Mississippian sandstones, black shales, and limestones which are also found in the Boston Mountains. The base of the northernmost Boston Mountains are formed from limestone and black shale of Late Mississippian age. The eastern half of the Boston Mountains are also underlain by the Early Pennsylvanian-age Bloyd Shale and sandy limestones and silty shales of the Hale Formation. The western half of the

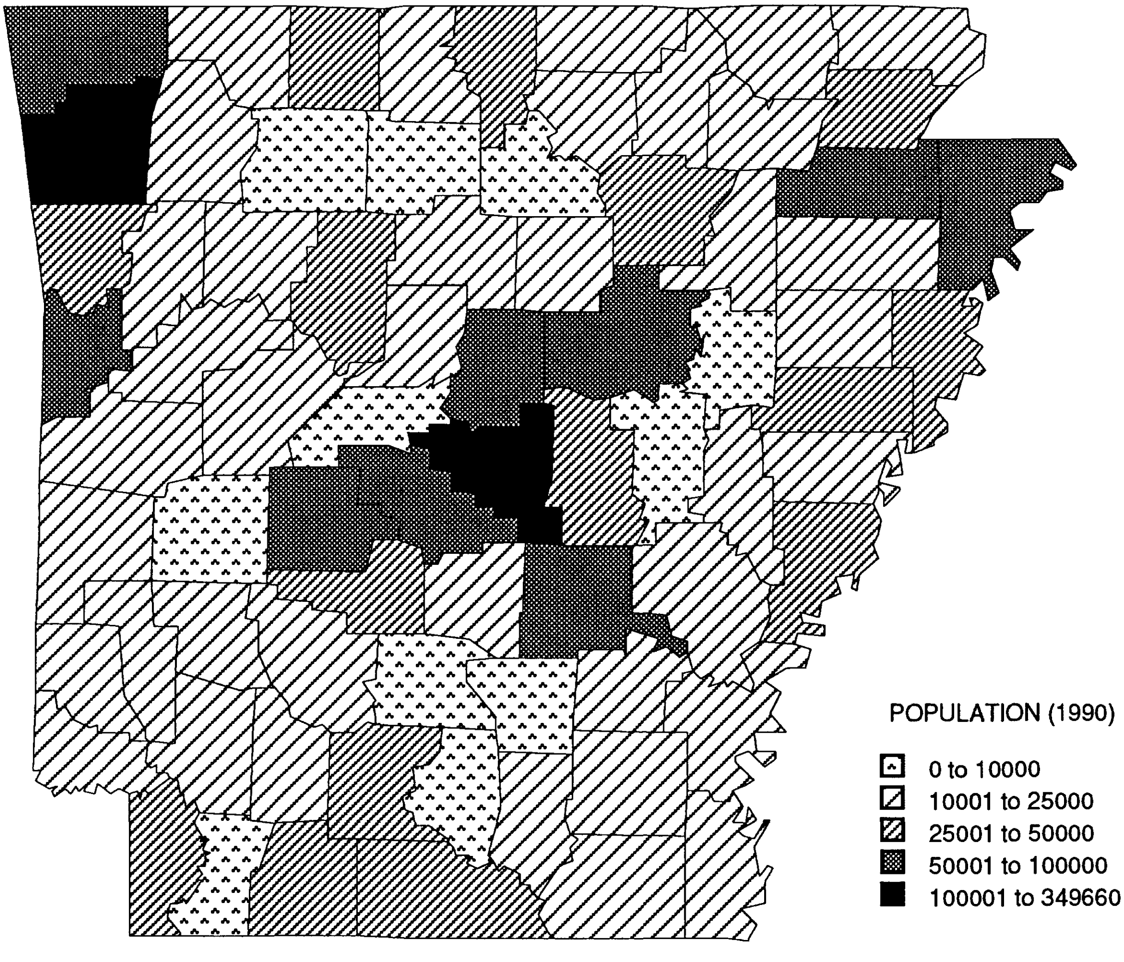

Figure 3. Population of counties in Arkansas (1990 U.S. Census data).

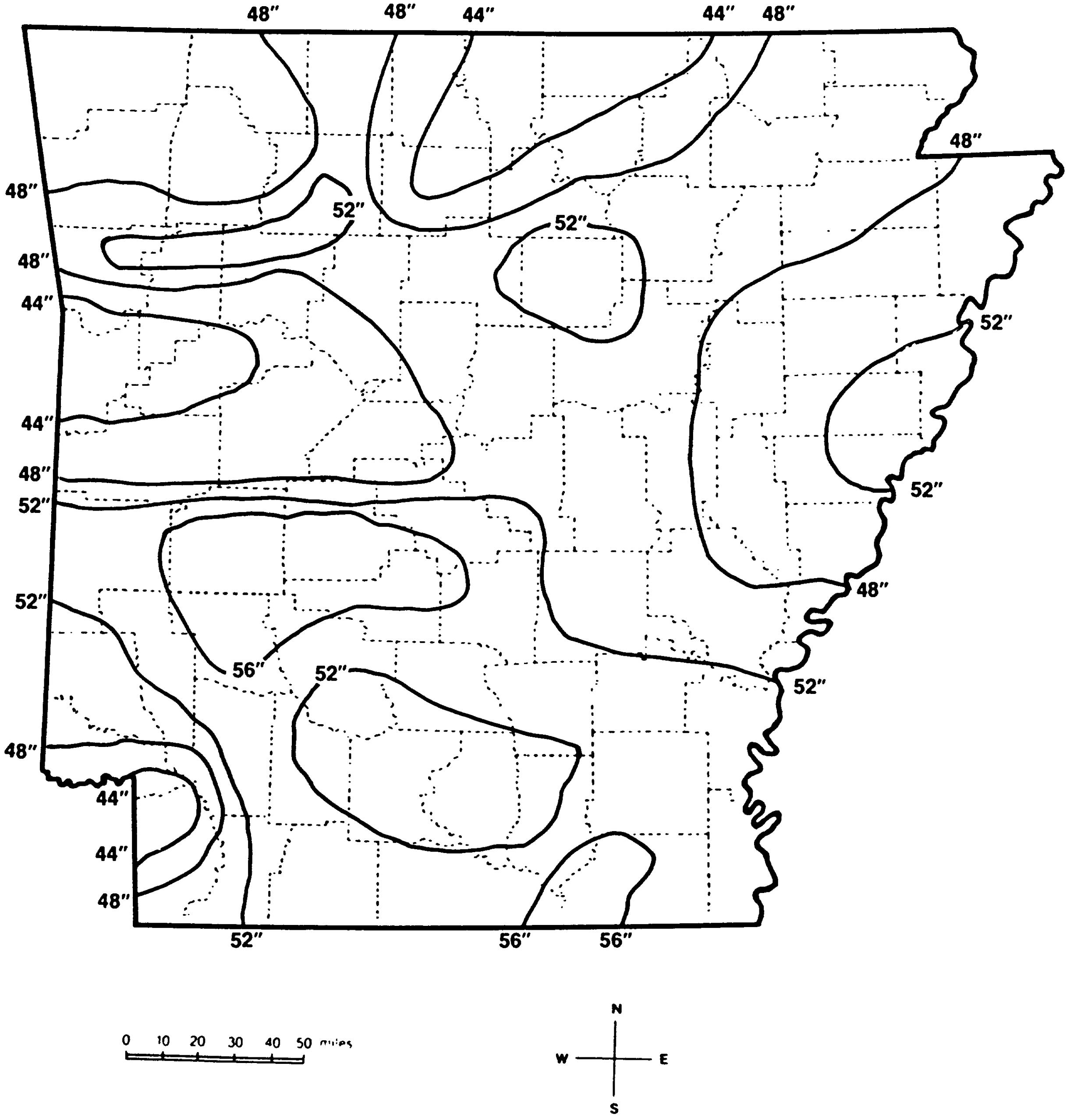

Figure 4. Average annual precipitation in Arkansas (from Facts on File, 1984).

Figure 5. Counties and county seats in Arkansas (from Facts on File, 1984).

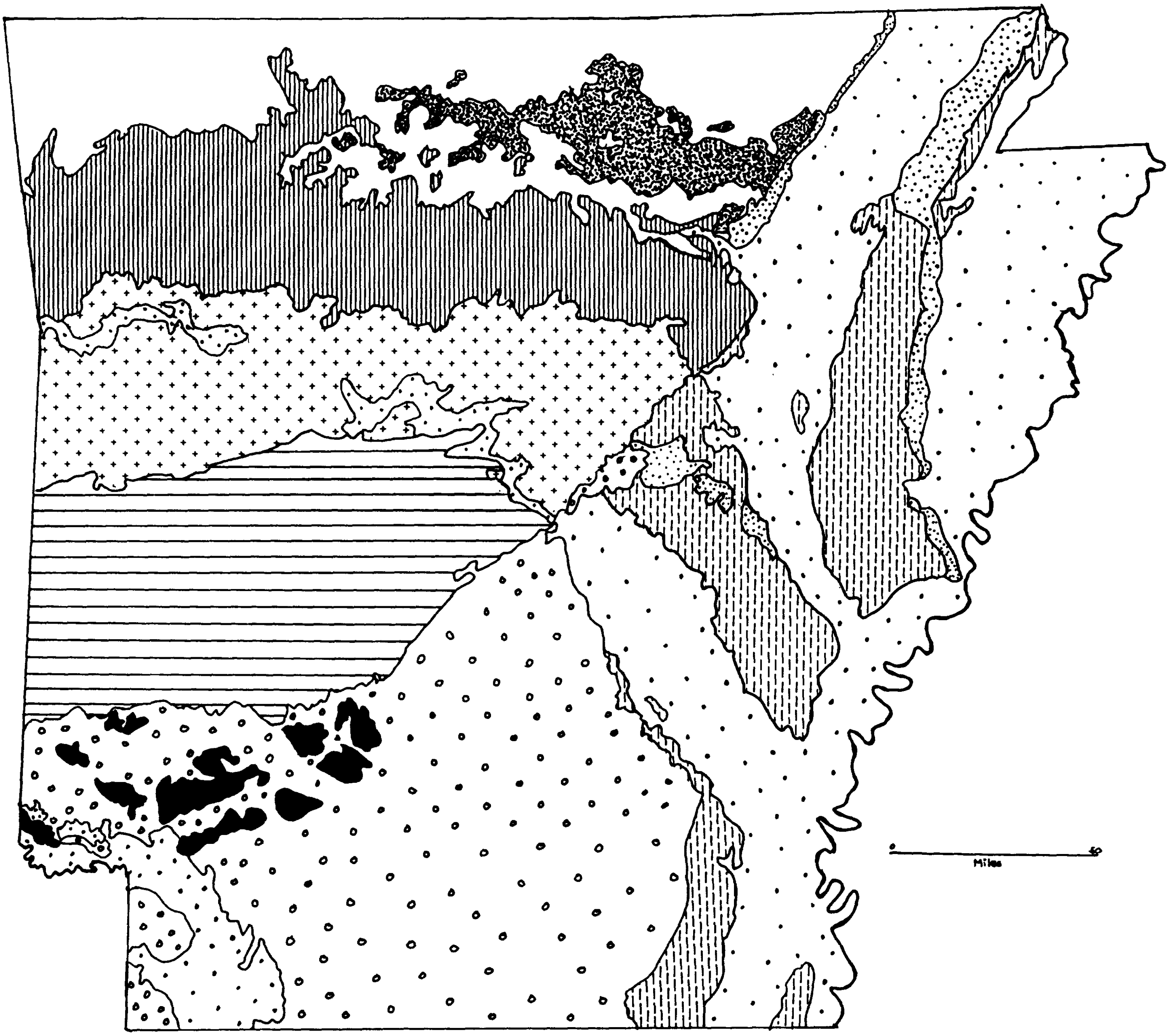

Figure 6. Generalized map of soil associations in Arkansas (after U.S. Soil Conservation Service, 1982).

Description of General Soil Map Units in Arkansas

□

Ozark Highlands

Cherty limestone and dolomite

Developed on cherty limestone, dolomite and minor calcareous shale and have slopes that are level to gently sloping on plateaus and stream valleys and moderate to very steep slopes in mountain areas. Soils are variable cherty silt loams to clay loams with very slow to moderate permeability and are generally excessively to moderately well drained.

▩

Sandstone and limestone

Developed on sandstone, limestone and dolomite and are gently sloping to very steep on uplands. Soils are stony, sandy to clay loams, with slow to moderate permeability, and are well drained.

▥

Boston Mountains

Developed on sandstone, siltstone and shale and are nearly level to moderately sloping in valleys and on ridgetops and steep on hills and mountainsides. Soils are sandy clay loam, gravelly or stony, with very slow to moderately rapid permeability, and are well drained.

⊞

Arkansas Valley and Ridges

Developed on sandstone, siltstone and shale and are level to gently sloping in valleys and on ridgetops and moderately sloping to very steep on hills and mountainsides. Soils vary from silty or sandy clay loam to silt clay with some gravelly and stony areas, very slow to moderately rapid permeability, and poorly to well drained.

▤

Ouachita Mountains

Developed on shale, slate, quartzite, novaculite, and sandstone and are level to gently sloping in valleys and moderately sloping to steep on mountainsides. Soils are sand or silt clay loam to silt clay, gravelly or shaly with very slow to rapid permeability, and are well to excessively drained.

⁘

Bottom Lands and Terraces

Developed in clayey, loamy, or sandy alluvium and are generally level to gently sloping with some escarpments being moderately steep. Soils are silt or sand loam to silt clay, poorly to excessively drained, and have slow permeability, some sandy loams have moderate to rapid permeability.

○

Coastal Plain

Developed on clayey, loamy, or sandy marine sediments and are generally level to nearly level on flood plains and terraces and nearly level to moderately steep on uplands. Soils are silt to sand loam and silt clay with moderate to slow permeability, and are moderately well drained to well drained with locally poor drainage.

▥

Loessial Plains and Hills

Loessial Plains

Developed on loess and are level to nearly level with a few areas moderately sloping. Soils are silt loam and silt clay loam with very slow to slow permeability, and are poorly to moderately well drained.

⁙

Loessial Hills

Developed on loess and have slopes that are nearly level to steep. Soils are silt loam and silt clay loam, with moderately to moderately slow permeability, and are moderately to well drained.

■

Blackland Prairies

Soils are developed from clayey sediments overlying beds of marly clay or chalk and have slopes that are nearly level to moderately steep. Soils are silt loam to clay with very slow permeability and are moderately to well drained.

Boston Mountains is capped by the sandstones and shales of the Atoka Formation. Soils are sand and clay loams that are generally well drained and slowly to moderately permeable.

The Ouachita Mountains Province includes the Arkansas Valley, the Fourche Mountains, the Central Ouachita Mountains, and the Athens Plateau. Most of the Arkansas Valley is also underlain by the Atoka Formation, which is divided into lower, middle, and upper parts on the State geologic map (Haley and others, 1976) in this area. The western Arkansas Valley is underlain by upper Pennsylvanian sedimentary rocks that include sandstones, black shales, and commercial-grade coal. Soils are variable but are generally slowly to moderately permeable and classified as sandy, silty, or clayey loams.

The northern Fourche Mountains are underlain by shales and sandstones of the Lower Atoka Formation. The southern Fourche Mountains are underlain by the Lower Pennsylvanian Johns Valley Shale and Jackfork Sandstone as well as the extensive Mississippian-age Stanley Shale. The Lower Pennsylvanian rocks include sandstones, black shales, and minor limestones and cherty limestones. Soils are generally clayey to sandy loams of moderate permeability. The Stanley Shale surrounds the Central Ouachita Mountains and underlies most of the Athens Plateau. It is made up of siliceous to micaceous shales, sandstones, and a tuff near the base of the group. Soils are silty clays and silty loams of moderate permeability. The Jackfork Sandstone and lower part of the Atoka Formation are also exposed in the south-central Athens Plateau.

The ridges of the Central Ouachita Mountains consist of highly folded and intensely deformed Ordovician and Silurian shales and sandstones with minor chert and limestone. Soils are silty clays and silty loams of low to moderate permeability. The Arkansas Novaculite, of Mississippian-Devonian age, is exposed along the outer edge of the Central Ouachita Mountains. The Arkansas Novaculite is chert that is rarely calcareous, may include silt -and sand-size quartz grains, and contains black shale in the middle part of the formation.

Igneous rocks, predominantly syenite, make up a small portion of the Ouachita Province and also intrude the Tertiary sediments of the Coastal Plain. The main mass of intrusions occurs on the southeastern side of the Ouachita, although dikes are scattered throughout the uplift. Principal exposures of igneous rocks are found in Pulaski, Garland, Saline, and Hot Spring County. Rare-earth elements are associated with the syenite in Garland and Hot Springs Counties and may also be a source of uranium and thorium, especially where they are hosted in carbonatite.

The Coastal Plain Province consists of the West Gulf Coastal Plain and the Mississippi Alluvial Plain, including the loess hills of Crowley's Ridge. Except for a few small areas, much of the Mississippi Alluvial Plain consists of recent alluvium and terraces deposited by the flood waters of the Mississippi River and its tributaries. These recent sediments vary from coarse to fine material having from rapid to slow permeability. Tertiary-age marine sediments form the base of Crowley's Ridge and cover large areas of the West Gulf Coastal Plain. The Tertiary sediments are composed of coarse-grained quartzose and glauconitic sand, clay, and gravel, as well as bauxite, lignite, phosphate, and marl deposits. Most soils are sandy loams and minor silt and clay loams with moderate to moderately rapid permeability. Nepheline syenite intrudes sediments of the Midway and Wilcox Groups, which contain commercial deposits of bauxite. Diamond-bearing lamproite intrudes the Lower Cretaceous Trinity Group near Murfreesboro. The West Gulf Coastal Plain is also cut by several major rivers that deposited river alluvium and terraces similar to those in the Mississippi Alluvial Plain. The loess soils of Crowley's Ridge are composed of wind-blown silt that forms silt loam with moderate permeability.

INDOOR RADON DATA

Indoor radon data from 1535 homes sampled in the State/EPA Residential Radon Survey conducted in Arkansas during the winter of 1990-91 are shown in Table 1 and illustrated in figure 7. Figure 5 is a map of the counties for reference. The maximum value recorded in the survey was 24.2 pCi/L in Benton County. The average screening indoor radon level for the state was 1.2 pCi/L and 5.3 percent of the homes tested had indoor radon levels exceeding 4 pCi/L. The most notable counties include Benton and Boone, with indoor radon county averages greater than 3 pCi/L, and Baxter, Fulton, Garland, Montgomery, and Polk, with indoor radon county averages between 2-3 pCi/L. The map patterns in figure 7 show that the southern third of Arkansas has the lowest radon, while the west-central and northernmost parts of the State have higher indoor radon. With reference to physiographic regions, it appears that the Salem and Springfield Plateaus are the areas of moderate to locally high indoor radon, whereas Crowley's Ridge, the Arkansas Valley, the Ouachita, Fourche, and Boston Mountains, and possibly parts of the Mississippi Alluvial Plain, are mixtures of low to moderate indoor radon. The Gulf Coastal Plain is an area of low indoor radon. Indoor radon data in this area are sparse, and few homes have basements.

RADIOMETRIC DATA

An aeroradiometric map of Arkansas (fig. 8) 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) shows two belts of relatively higher equivalent uranium (eU) than the rest of the Sstate: one in the northeast corner of the State, and one running from east to west in the north-central part of the State. For the purposes of this report, low (eU) is defined as less than 1.5 parts per million (ppm), moderate eU is defined as 1.5-2.5 ppm, and high eU is defined as greater than 2.5 ppm. Low eU is associated with Mississippian limestones and shales in the Springfield Plateau, the Gulf Coastal Plain sediments, and parts of the Central Ouachita and Athens Plateau. Moderate eU is found throughout the Sstate associated with the Upper Cretaceous and lower Tertiary Gulf Coastal Plain sediments, parts of the Mississippi Alluvial Plain, Crowley's Ridge, the shales, dolostones, and limestones of the Salem Plateau, and much of the Central Ouachitas, especially the Devonian-Silurian sedimentary rocks and, possibly, the syenite intrusive rocks. Small areas of high eU appear to be associated with loess on Crowley's Ridge, some of the Quaternary sediments in the northern Mississippi Alluvial Plain, the Atoka Formation in the Arkansas Valley, the Cotter and Jefferson City Dolomites, and the shales in the Salem Plateau. The high equivalent uranium in the Mississippi Alluvial Plain may be associated with the loess content of the plain or may be cultural, possibly the result of uranium in phosphate fertilizers, a common occurrence in heavy agricultural areas. High to moderate eU in the Arkansas Valley may also be associated with the use of fertilizers in this area.

GEOLOGIC RADON POTENTIAL

A comparison of the aerial radioactivity map for Arkansas with the State geologic and soils maps and the indoor radon data allows us to make some observations about the geologic radon potential of the State.

The carbonate soils and black shales in the Springfield and Salem Plateaus are considered moderate to locally high in geologic radon potential. The Ordovician limestones, dolomites,

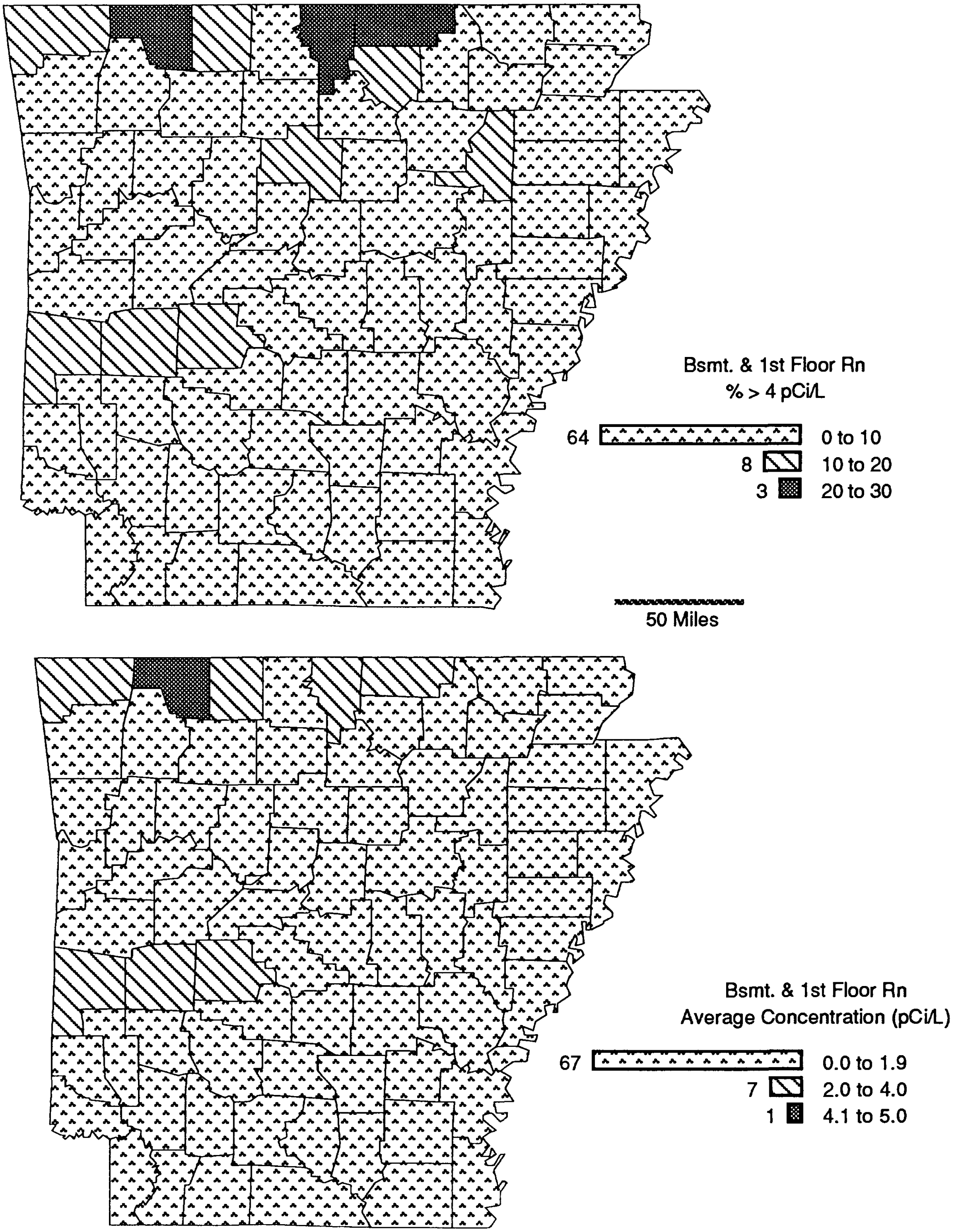

Figure 7. Screening indoor radon data from the State/EPA Residential Radon Survey of Arkansas, 1990-91, for counties with 5 or more measurements. Data are from 2-7 day charcoal canister tests. Histograms in map legends show the number of counties in each category. The number of samples in each county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

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

COUNTY	NO. OF MEAS.	MEAN	GEOM. MEAN	MEDIAN	STD. DEV.	MAXIMUM	%>4 pCi/L	%>20 pCi/L
ARKANSAS	11	0.9	0.5	0.7	0.8	2.8	0	0
ASHLEY	6	0.8	0.3	0.6	0.8	2.0	0	0
BAXTER	33	2.9	1.4	1.2	3.7	15.7	27	0
BENTON	80	3.0	1.6	1.4	4.5	24.2	20	4
BOONE	18	3.2	2.3	2.2	3.3	12.6	17	0
BRADLEY	9	0.6	0.4	0.4	0.5	1.8	0	0
CALHOUN	6	0.3	0.2	0.2	0.3	0.8	0	0
CARROLL	7	5.0	1.4	0.7	7.9	20.8	29	14
CHICOT	12	0.6	0.3	0.4	0.8	2.0	0	0
CLARK	11	0.5	0.3	0.4	0.5	1.8	0	0
CLAY	17	1.1	0.5	0.7	1.9	8.0	6	0
CLEBURNE	13	1.5	0.9	0.8	1.7	6.6	8	0
CLEVELAND	5	0.4	0.2	0.2	0.4	0.8	0	0
COLUMBIA	16	0.5	0.3	0.3	0.5	1.8	0	0
CONWAY	24	0.6	0.4	0.4	0.5	1.7	0	0
CRAIGHEAD	31	1.1	0.8	0.7	1.2	6.6	3	0
CRAWFORD	25	0.8	0.5	0.8	0.8	2.3	0	0
CRITTENDEN	18	0.5	0.4	0.4	0.4	1.5	0	0
CROSS	4	1.0	0.7	1.0	0.8	2.0	0	0
DALLAS	2	0.1	0.1	0.1	0.1	0.2	0	0
DESHA	7	0.2	0.1	0.2	0.1	0.3	0	0
DREW	14	0.8	0.5	0.8	0.6	1.8	0	0
FAULKNER	71	0.9	0.6	0.7	0.9	4.5	1	0
FRANKLIN	10	0.9	0.5	0.6	1.0	3.3	0	0
FULTON	7	2.6	2.1	2.0	1.6	5.1	29	0
GARLAND	65	2.3	1.5	1.5	2.2	11.1	15	0
GRANT	9	0.7	0.6	0.5	0.3	1.2	0	0
GREENE	9	0.6	0.3	0.6	0.8	2.5	0	0
HEMPSTEAD	10	0.3	0.2	0.3	0.3	0.9	0	0
HOT SPRING	17	0.6	0.4	0.5	0.6	2.2	0	0
HOWARD	7	1.0	0.6	0.5	1.2	3.5	0	0
INDEPENDENCE	22	1.4	0.8	1.1	1.5	5.9	9	0
IZARD	18	1.9	1.0	1.3	2.0	7.9	11	0
JACKSON	9	1.8	0.6	0.5	3.3	10.5	11	0
JEFFERSON	33	0.5	0.3	0.3	0.5	2.3	0	0
JOHNSON	16	1.0	0.7	0.6	0.8	2.5	0	0
LAFAYETTE	13	0.6	0.4	0.4	0.6	1.6	0	0
LAWRENCE	12	1.3	1.0	1.0	0.9	3.2	0	0
LEE	4	1.3	1.2	1.3	0.6	2.0	0	0
LINCOLN	6	0.5	0.3	0.3	0.5	1.2	0	0
LITTLE RIVER	8	0.3	0.2	0.3	0.2	0.7	0	0

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

COUNTY	NO. OF MEAS.	MEAN	GEOM. MEAN	MEDIAN	STD. DEV.	MAXIMUM	%>4 pCi/L	%>20 pCi/L
LOGAN	31	1.0	0.7	0.8	0.8	3.1	0	0
LONOKE	51	0.7	0.5	0.5	0.5	2.7	0	0
MADISON	8	1.5	1.1	1.1	1.1	3.8	0	0
MARION	11	1.1	0.7	1.2	0.8	2.3	0	0
MILLER	10	0.1	0.1	0.1	0.3	0.6	0	0
MISSISSIPPI	14	1.2	0.6	0.8	1.4	4.9	7	0
MONROE	6	0.7	0.5	0.7	0.4	1.2	0	0
MONTGOMERY	20	2.3	1.2	1.7	2.1	7.9	20	0
NEVADA	8	0.5	0.3	0.3	0.6	1.7	0	0
NEWTON	12	1.7	0.9	1.6	1.2	3.7	0	0
OUACHITA	21	0.4	0.3	0.5	0.3	0.8	0	0
PERRY	10	1.0	0.6	0.8	0.8	2.5	0	0
PHILLIPS	5	0.6	0.5	0.4	0.4	1.1	0	0
PIKE	13	1.0	0.7	0.8	0.7	2.1	0	0
POINSETT	10	0.9	0.5	0.6	0.9	2.9	0	0
POLK	16	2.0	1.0	1.0	2.7	10.1	13	0
POPE	57	1.3	0.7	0.7	1.7	8.3	7	0
PRAIRIE	8	0.7	0.3	0.5	0.8	2.2	0	0
PULASKI	127	0.9	0.6	0.6	1.4	15.2	2	0
RANDOLPH	5	1.3	1.1	1.3	0.6	1.9	0	0
SALINE	36	1.6	0.9	0.9	2.4	14.2	6	0
SCOTT	20	0.7	0.5	0.5	0.6	2.1	0	0
SEARCY	10	0.8	0.5	0.7	0.9	3.0	0	0
SEBASTIAN	68	0.7	0.5	0.5	0.8	3.7	0	0
SEVIER	11	1.2	0.6	0.8	1.4	4.8	9	0
SHARP	12	1.6	1.2	1.2	1.2	4.2	8	0
ST. FRANCIS	9	0.7	0.5	0.7	0.6	2.0	0	0
STONE	21	1.0	0.8	0.9	0.9	4.3	5	0
UNION	42	0.5	0.3	0.4	0.4	1.8	0	0
VAN BUREN	14	1.6	0.9	0.9	1.7	5.9	14	0
WASHINGTON	63	1.6	1.1	1.1	1.8	12.8	3	0
WHITE	48	1.2	0.6	0.7	1.9	11.5	4	0
WOODRUFF	1	1.2	1.2	1.2	0.0	1.2	0	0
YELL	22	0.9	0.6	0.8	0.8	2.7	0	0

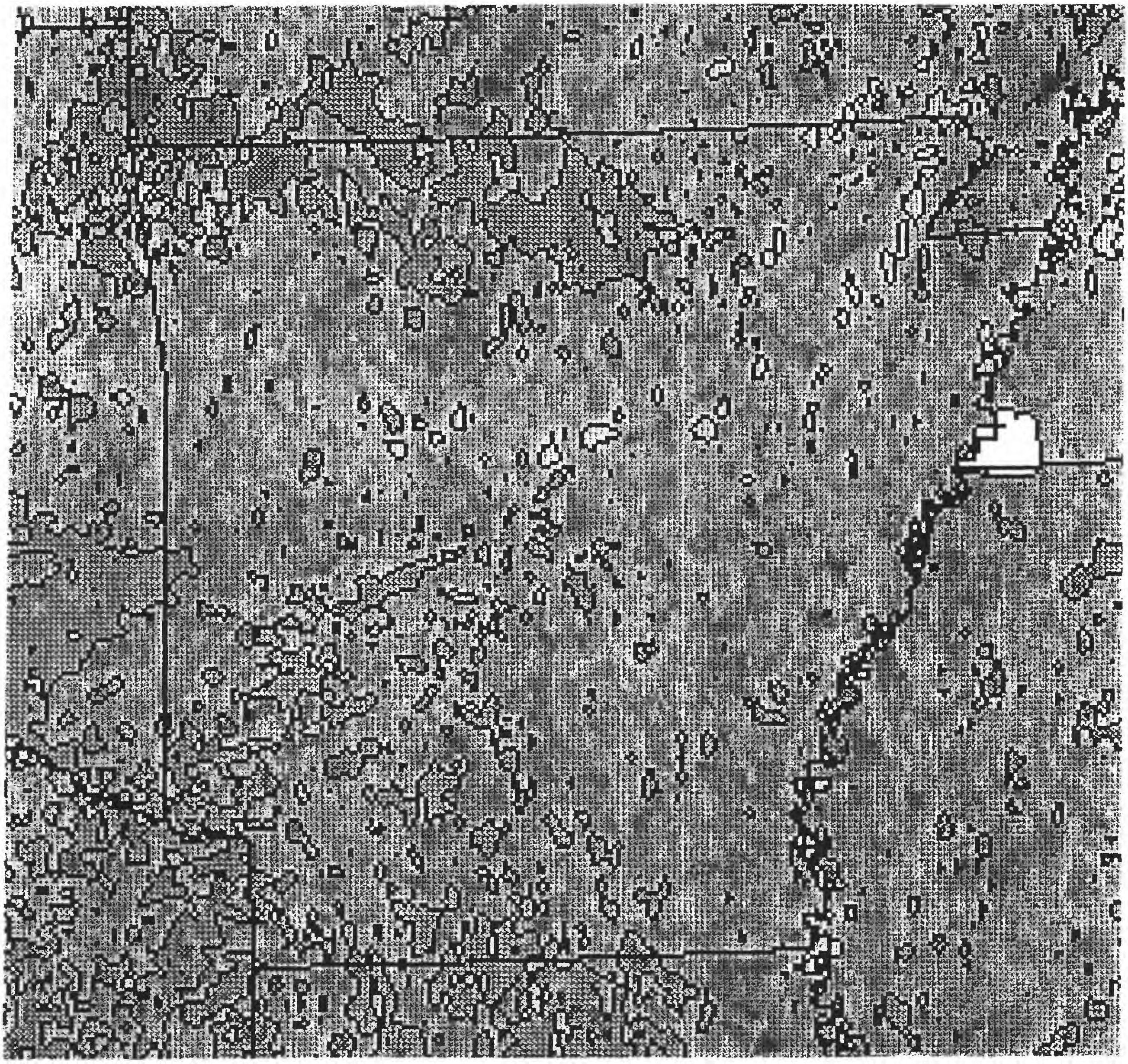

Figure 8. Aerial radiometric map of Arkansas (after Duval and others, 1989). Contour lines at 1.5 and 2.5 ppm equivalent uranium (eU). Pixels shaded at 0.5 ppm eU increments.

black shales, and sandstones have moderate to high equivalent uranium associated with them and some of the highest radon in the State is associated with them. The Mississippian limestones and shales, however, have low equivalent uranium associated with them but also have moderate to high levels of indoor radon associated with them, including the highest indoor radon level recorded in the State/EPA Residential Radon Survey in the State in Benton County. Black shales and carbonaceous sandstones within the Mississippian, Devonian, and Ordovician units are the likely cause of the local areas of high eU (fig. 8). The Chattanooga Shale is particularly well known for containing uranium in above-average amounts (Glover, 1959), and most marine black shales have elevated levels of uranium (> 5 ppm) concentrated with organics or in phosphate. Strata of the Chattanooga below the Mississippian limestones and shales, and the shale units within the Mississippian limestones may be responsible for some of the high indoor radon levels found in Benton County. Carbonate rocks are usually low in radionuclide elements but the soils developed from carbonate rocks may be elevated in uranium and radium. Carbonate soils are derived from the dissolution of the calcium carbonate ($CaCO_3$) that makes up the majority of the rock. When the $CaCO_3$ has been dissolved away, the soils are enriched in the remaining impurities, predominantly base metals, including radionuclides. Rinds containing high concentrations of uranium and uranium minerals can be formed on the surfaces of rocks involved with $CaCO_3$ dissolution and karstification. Karst and cave morphology is also thought to accumulate radon. Carbonate soils derived from Cambrian-Ordovician rock units of the Valley and Ridge Province cause indoor radon problems in eastern Tennessee, western New Jersey, western Virginia, eastern West Virginia (Schultz and others, 1992) and central and eastern Pennsylvania.

The Boston Mountains, Arkansas Valley, Fourche Mountains, and Athens Plateau are underlain predominantly by Mississippian and Pennsylvanian sandstones and shales with low to moderate radon potential. The marine black shales are most likely uraniferous and the Upper Atoka Formation and Savanna Formation have high (>2.5 ppm) eU associated with them. Finch (1967) has reported uranium occurrences in carbonaceous sandstone in the Jackfork Sandstone in Montgomery County and in the Atoka Formation in Crawford County. Greater than 5 ppm uranium is also reported for shales in the Atoka Formation by Vine (1962). The presence of radon and uranium in some natural gas, petroleum and asphaltite is well known (for a short review see Tanner, 1980). Rare asphaltite is reported in the Jackfork sandstone and in some of the Cretaceous sandstones in Arkansas (Chenoweth, 1989). Oil and gas is also known to occur with the upper Pennsylvanian sediments in the Arkansas Valley. Many of these units are similar to units in Oklahoma that contain uranium associated with coaly and petroliferous rocks (Bell, 1960; Vine, 1962). Although the indoor radon average for these provinces is low, there are a number of counties in these provinces with averages slightly higher than 1 pCi/L and maximum readings greater than 4 pCi/L. The marine black shales and carbonaceous sandstones are the likely source for the locally elevated indoor radon. However, radon from a hydrocarbon source should not be ruled out.

The Central Ouachita Mountains are underlain by intensely deformed Ordovician and Silurian shales and sandstones with minor chert and limestone. These rocks generally have low to moderate radon potential. Aerial radiometric signatures of 2.5 ppm eU or more are associated with the Ordovician black shales and possibly with some of the syenite intrusions. Uranium was also reported to occur in carbonaceous material from one of the Ordovician sandstones in western Montgomery County by Finch (1967). Indoor radon in the Central Ouachita Mountains is low to moderate and permeability of the soils is low to moderate.

The West Gulf Coastal Plain is generally low in radon potential. Parts of the Cretaceous and Tertiary sediments have moderate eU in the 1.5-2.5 ppm range. Recent studies in the Coastal Plain of Texas, Alabama, and New Jersey show that glauconite and phosphate in sandstones, chalks, marls, and limestones, as well as black organic clays, shales, and muds are often associated with high concentrations of uranium and radon in the sediment (Gundersen and others, 1991). Several formations within the Gulf Coastal Plain contain these types of sediments, especially parts of the upper Cretaceous and lower Tertiary sedimentary section; however, average indoor radon levels in this area are not elevated. The Quaternary sediments of the Coastal Plain have low eU and the indoor radon average is low for the Gulf Coastal Plain overall.

The Mississippi Alluvial Plain and Crowley's Ridge have low to locally moderate radon potential. The southern half of the Mississippi Alluvial Plain is made up predominantly of quartzose sediments, has generally low eU, and has low indoor radon. The northern half of the alluvial plain, however, includes the loess of Crowley's Ridge, which appears to have high equivalent uranium associated with it (fig. 8), and possibly a high loess content in the surrounding sediments in general. The northeastern corner of Arkansas appears to be crossed by the large belt of loess that continues into Kentucky and Tennessee and shows as a distinct area of high eU on the radiometric map of the United States (Duval and others, 1989). Soil radon concentrations greater than 1000 pCi/L have been measured in the loess in Tennessee (Peake and Gundersen, 1989). Several of the counties in the northern part of the alluvial plain have maximum indoor radon values greater than 4 pCi/L and averages between 1 and 2 pCi/L, which are generally higher than surrounding counties. As mentioned before, the high eU may also be due to uranium in phosphatic fertilizers in agricultural areas.

SUMMARY

For the purpose of this assessment, Arkansas has been divided into nine geologic radon potential areas and each area assigned a Radon Index (RI) and a Confidence Index (CI) score (Table 2). These areas correspond to the areas delineated in figure 1. 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 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 at the beginning of this regional book for a detailed explanation of the indexes.

Areas of moderate to locally high geologic radon potential include the Springfield Plateau and the Salem Plateau. Low to moderate geologic radon potential has been assigned to the northern Mississippi Alluvial Plain, Crowley's Ridge, the Boston and Fourche Mountains, the Arkansas Valley, the Central Ouachita Mountains, and the Athens Plateau. The southern Mississippi River Alluvial Plain and the West Gulf Coastal Plain have low geologic radon potential.

Uraniferous marine black shales, carbonaceous sandstone, and soils derived from dolomite and limestone appear to be the principal sources for radon in the State. Other possible local sources of radon include areas of uranium mineralization associated with the syenite intrusives in the Central Ouachita Mountains and Gulf Coastal Plain; loess on Crowley's Ridge; glauconitic, phosphatic, and carbonaceous sediments in the Gulf Coastal Plain; and coaly or petroleum-rich sediments in central Arkansas.

Climate and architecture probably play a significant role in the overall low to moderate radon potential of the State. Most of the housing in Arkansas is slab-on- grade, crawl space, or without basements which contributes to the overall low indoor radon average. The warm climate of Arkansas, lifestyle of the inhabitants, and home ventilation practices also contribute significantly to lower indoor radon.

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

TABLE 2. Radon Index and Confidence Index scores for areas in Arkansas.

	Springfield Plateau		Salem Plateau		Arkansas Valley	
FACTOR	RI	CI	RI	CI	RI	CI
INDOOR RADON	2	3	2	3	1	3
RADIOACTIVITY	2	3	2	3	2	3
GEOLOGY	2	2	2	2	2	2
SOIL PERM.	2	3	2	3	2	2
ARCHITECTURE	1	-	1	-	1	-
GFE POINTS	0	-	0	-	0	-
TOTAL	9	11	9	11	8	10
	Mod	High	Mod	High	Low	High

	Fourche Mountains and Boston Mountains		Central Ouachita		Athens Plateau	
FACTOR	RI	CI	RI	CI	RI	CI
INDOOR RADON	1	3	2	3	1	2
RADIOACTIVITY	2	3	2	3	2	3
GEOLOGY	2	2	2	2	2	2
SOIL PERM.	2	2	2	2	2	2
ARCHITECTURE	1	-	1	-	1	-
GFE POINTS	0	-	0	-	0	-
TOTAL	8	10	9	10	8	9
	Low	High	Mod	High	Low	Mod

	West Gulf Coastal Plain		Mississippi Alluvial Plain		Crowley's Ridge	
FACTOR	RI	CI	RI	CI	RI	CI
INDOOR RADON	1	2	1	1	1	1
RADIOACTIVITY	1	3	2	3	3	3
GEOLOGY	2	2	2	2	2	2
SOIL PERM.	2	2	2	2	2	2
ARCHITECTURE	1	-	1	-	1	-
GFE POINTS	0	-	0	-	0	-
TOTAL	7	9	8	8	9	8
	Low	Mod	Low	Mod	Mod	Mod

RADON INDEX SCORING:

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

Possible range of points = 3 to 17

CONFIDENCE INDEX SCORING:

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

Possible range of points = 4 to 12

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PRELIMINARY GEOLOGIC RADON POTENTIAL ASSESSMENT OF LOUISIANA

by

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U.S. Geological Survey

INTRODUCTION

Louisiana has an overall low indoor radon potential. Only a few rock types in the State have uranium and radium concentrations that might produce elevated indoor radon. Further, the climate, soil, and lifestyle of the inhabitants have influenced building construction styles and building ventilation which, in general, do not allow high concentrations of radon to accumulate. Indoor radon data from 1314 homes sampled in the State/EPA Residential Radon Survey conducted in Louisiana during the winter of 1990-91 had an average of 0.5 pCi/L and 0.8 percent of the homes tested had indoor radon levels exceeding 4 pCi/L.

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

PHYSIOGRAPHIC AND GEOGRAPHIC SETTING

The physiography of Louisiana is in part a reflection of the underlying geology (fig. 1). Louisiana is divided into two major physiographic regions: The Coastal Plain and the Mississippi Alluvial Plain. For the purposes of this report, however, we will refer to the major topographic areas of the State of which there are six (fig. 2). The Old Uplands area is equivalent to the Coastal Plain, whereas the other areas refer to specific morphologic areas formed by the Mississippi River and its tributaries, which include: the Floodplain, the Terraces, the Prairies, and the Delta. The area of the Cheniers is influenced both by the river and ocean. The Cheniers is characterized by beach and dune ridges of sand overlying clay and mud marsh deposits. Elevation is at or near sea level and the landscape is flat-lying except for the beach ridges (called cheniers). The Delta is a complex coastal area in which the Mississippi River deposits sediment and has systems of levees designed to maintain the river in its current channel. Elevation is at or near sea level and the delta plain is flat. The Floodplain consists of the meandering channels of the Mississippi River, including recent alluvial deposits and natural levees. Elevation is from sea level up to several tens of feet, and the topography is gently rolling. The Prairies and Terraces are characterized by older alluvial, terrace, and deltaic deposits which vary in elevation from 5 to 400 feet and consist of flat-lying to hilly terrain. The Old Uplands contains low hills of ancient marine sediments and the

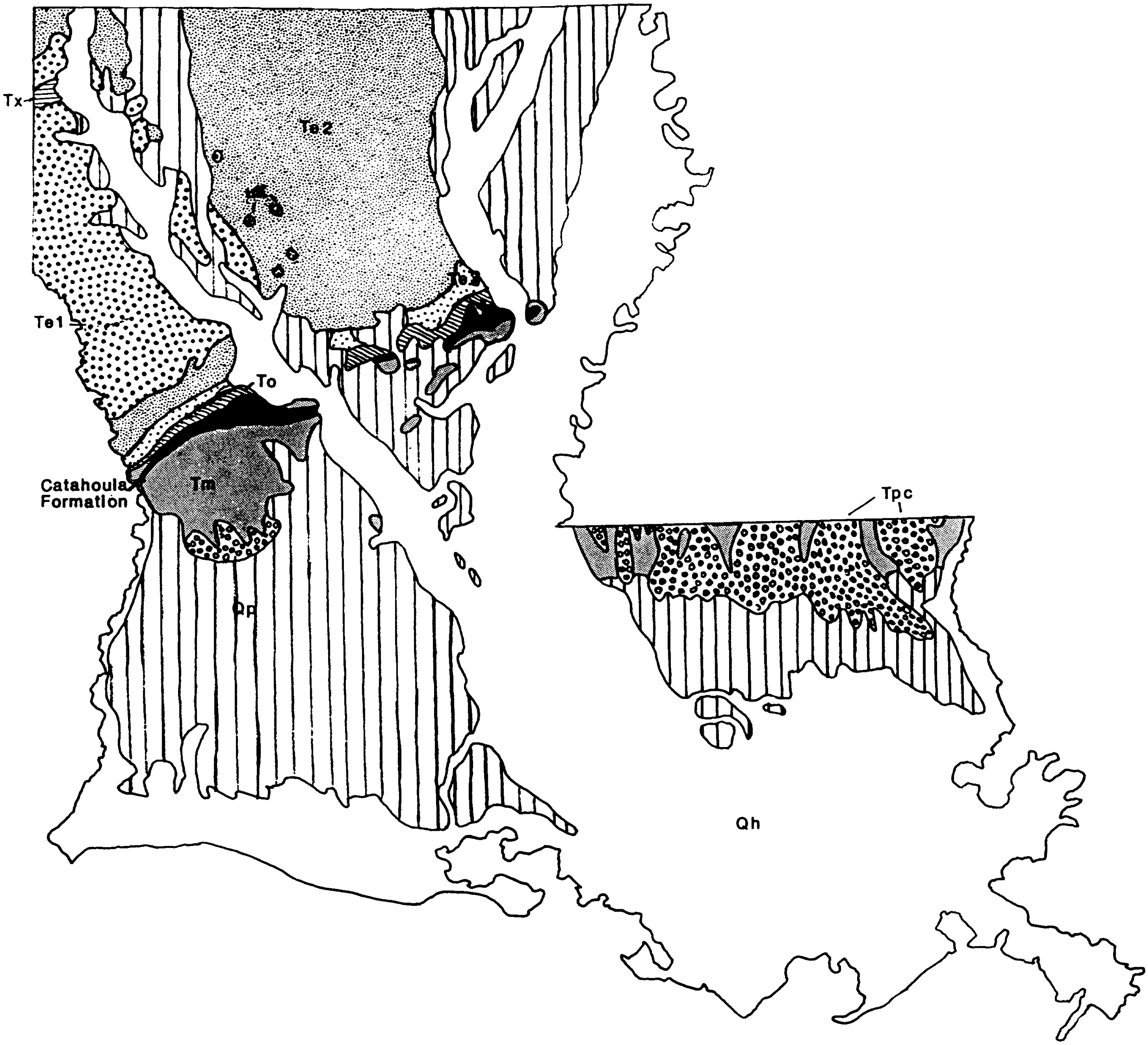

Figure 1. General geologic map of Louisiana (after Snead and McCulloh 1984; King and Beikman, 1974).

Lousiana General Geology Map
Description of Units

CODE	LITHOLOGY
☐	**Qh:** *Alluvium*: gray to brown clay and silty clay, some sand and gravel. *Natural levees*: gray and brown silt, silty clay, and very fine sand. *Delta plain, fresh marsh:* gray to black clay of very high organic content, some peat. *Delta plain, saline marsh* of gray to black clay of high organic content and some peat. *Chenier plain, fresh marsh* : gray to brown to black clay and silt of high organic content. *Chenier plain, saline marsh*: gray to brown to black clay and silt of moderate organic content. *Cheniers:* white to light gray fine sand and shell fragments. *Deweyville Terrace:* gray mixed with brown to red clay and silty clay, some sand and gravel locally.
▥	**Qp** : *Prairie terraces*: light gray to light brown clay, sandy clay, silt, sand and some gravel. *Braided stream terraces*: light gray, tan, and brown fine to coarse sand, some clay, silt, and gravel (west side of Mississippi Valley in northeastern Louisiana. *Intermediate terraces:* light gray to orange-brown clay, sandy clay, and silt, much sand and gravel locally.
○ ○ ○	**Tpc** : *High terraces*: thin sheets of tan to orange sandy clay, silt, and clayey sand with a large amount of basal , sandy gravel.
▒	**Tm** : *Blounts Creek Member*: gray to green silty clays, siltstones, and silts with abundant sand beds, some lignite and lenses of black chert gravel. *Castor Creek Member*: gray to dark gray calcareous clays which may weather to black soil, lignitic clays and noncalcareous clayey silts. *Williamson Creek Member*: white to gray silts, siltstones, silty clays, and sand beds, some lenses of black chert gravel. *Dough Hills Member*: gray to yellow silty clays, light gray calcareous clays which may weather to black soil, some siliceous silt and volcanic ash beds. *Carnahan Bayou Member*: yellow to gray siltstone, sandstone, and clays with thin tuffaceous beds, some lenses of black chert gravel and petrified wood locally. *Lena Member*: gray calcareous clays which may weather to black soils, siltstones, tuffaceous clays and some volcanic ash beds.
■	**Catahoula Formation**: gray to white sandstone, loose quartz sand, tuffaceous sandstone, volcanic ash, and brown sandy clays, petrified wood locally.
▧	**To: Vicksburg Group:** (Undifferentiated) brown to gray lignitic clays with thin interbeds of lignite or micaceous sands, calcareous , dark shale, petrified wood, and bluish fossiliferous clay locally.
░	**Te3: Jackson Group:** (Undifferentiated) light gray to brown lignitic, clays with interbeds of limonitic, glauconitic sands or lignite, at base, calcareous, glauconitic, shaley and fossiliferous beds may weather to black soil.
▓	**Te2: Claiborne Group**: *Cockfield Formation*: brown lignitic clays, silts, and sands, some sideritic glauconite may weather to brown ironstone in lower part. *Cook Mountain Formation*: greenish gray sideritic, glauconitic clay in upper part may weather to brown ironstone, yellow to brown clays and fossiliferous marl in lower part may weather to black soil. Ironstone concretions near base. *Sparta Formation*: white to light gray massive sands with interbedded clays, some thin interbeds of lignite or lignitic sands and shales. *Cane River Formation:* brown silty clay with basal glauconitic, fossiliferous silts which may weather to ironstone locally.
⁘	**Te1 : Wilcox Group:** gray to brown lignitic sands and silty to sandy lignitic clays, many seams of lignite, some limestone and glauconite, underlain by fossiliferous marine units.
▤	**Tx : Midway Group:** (Undifferentiated), dark gray to black shale, glauconitic sands and silty clays with several lenses of coquinic limestone.
⊗ ⊗	**uK**: Fossiliferous limestone and marl.

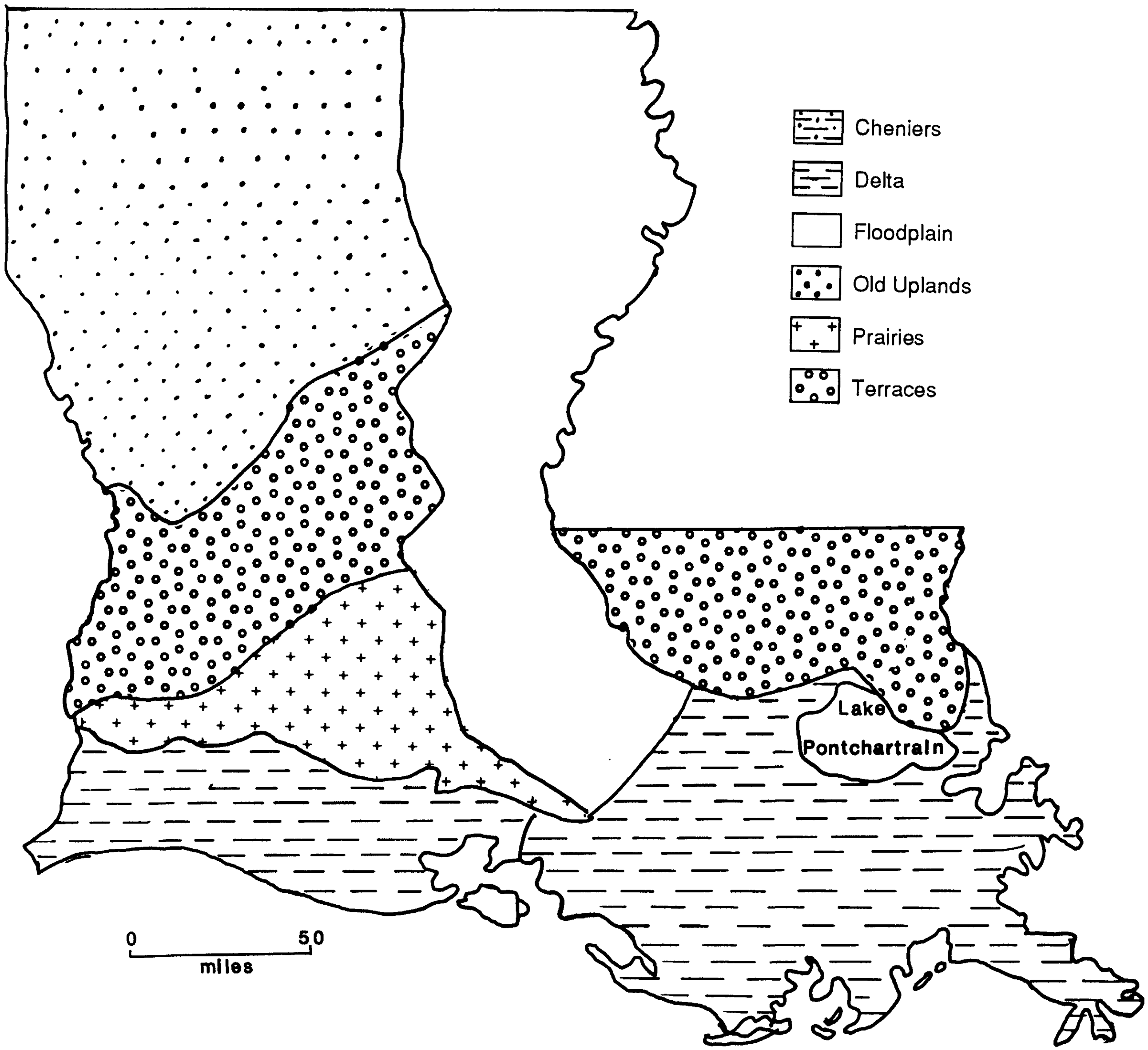

Figure 2. Topographic areas of Louisiana (modified from Newton, 1972).

highest elevation in Louisiana at 535 feet. Elevation is generally above 200 feet and the terrain is hilly to gently rolling.

Population distribution and land use in Louisiana reflects in part the geology, topography, and climate of the State. The 1990 population is approximately 4,219,973, with a population density of 92 per square mile; 69 percent of the population is urban (fig. 3). The climate of Louisiana is subtropical with some influence by continental weather patterns. The summers are hot and humid and the winters are mild, with occasional influxes of Arctic air. From June through November, Louisiana is prone to tropical storms and hurricanes. Average temperature ranges from 64°F in the north to 71°F in the southern portion of the State. Precipitation ranges from 48 to 64 inches per year (fig. 4).

GEOLOGY AND SOILS

The geology of Louisiana is dominated by the ancient marine sediments of the Gulf Coastal Plain and the recent river deposits from the Mississippi River and its tributaries. The following discussion of geology and soils is derived from Snead and McCulloh (1984); Soil Conservation Service (1987) and selected Parish reports; and Richmond and others (1990). A map of general soil areas is given in figure 5.

The Coastal Plain

The area known as the Old Uplands is underlain predominantly by Coastal Plain deposits of Cretaceous to Tertiary age. The majority of these rocks and sediments are marine sandstone, siltstone, shale, sand, silt, clay, limestone, and marl. The soils of the Old Uplands consist of decomposition residuum of the ancient Coastal Plain sediments and rocks. They are usually moist, gently to moderately sloping, with well developed clay horizons and low organic matter content in the subsurface. Permeability is generally controlled by grain size and clay content.

The oldest rocks exposed in Louisiana are Upper Cretaceous limestone and marl exposed in two interior salt domes of the Old Uplands. The oldest Tertiary rocks exposed are the Midway Group, which consists of gray to black carbonaceous shales and glauconitic sands. These rocks are also exposed in the same two salt domes. Both of these units cover only a minor surface area in Louisiana.

The Midway Group is succeeded by the sediments of the Wilcox Group, consisting of gray to brown lignitic sand and silty to sandy lignitic clay, lignite, minor limestone, and glauconite. This group underlies northwestern Louisiana west of the Red River. Soils are generally clayey, fine to medium sands and sandy clays that are slowly to moderately permeable.

The Claiborne Group underlies a large area between the Red River and the Mississippi Alluvial Plain. It consists of several distinct formations, many of which weather to ironstone or have ironstone concretions. The Cane River Formation is a brown silty clay with basal glauconitic, fossiliferous silts. Soils are silty clay and clayey silt with slow permeability. Massive white sands interbedded with clays, lignite, and shales make up the Sparta Formation. Soils are medium-grained sand, clayey sand, and minor sandy clays of slow to moderate permeability. The Cook Mountain Formation consists of sideritic, glauconitic clay and fossiliferous marl. Soils are dominated by clay and are slowly permeable. The top of the Claiborne Group is the Cockfield Formation, which includes lignitic clays, silts, and sands with some glauconite. Soils are sandy loams and silty, sandy clays of slow to moderate permeability.

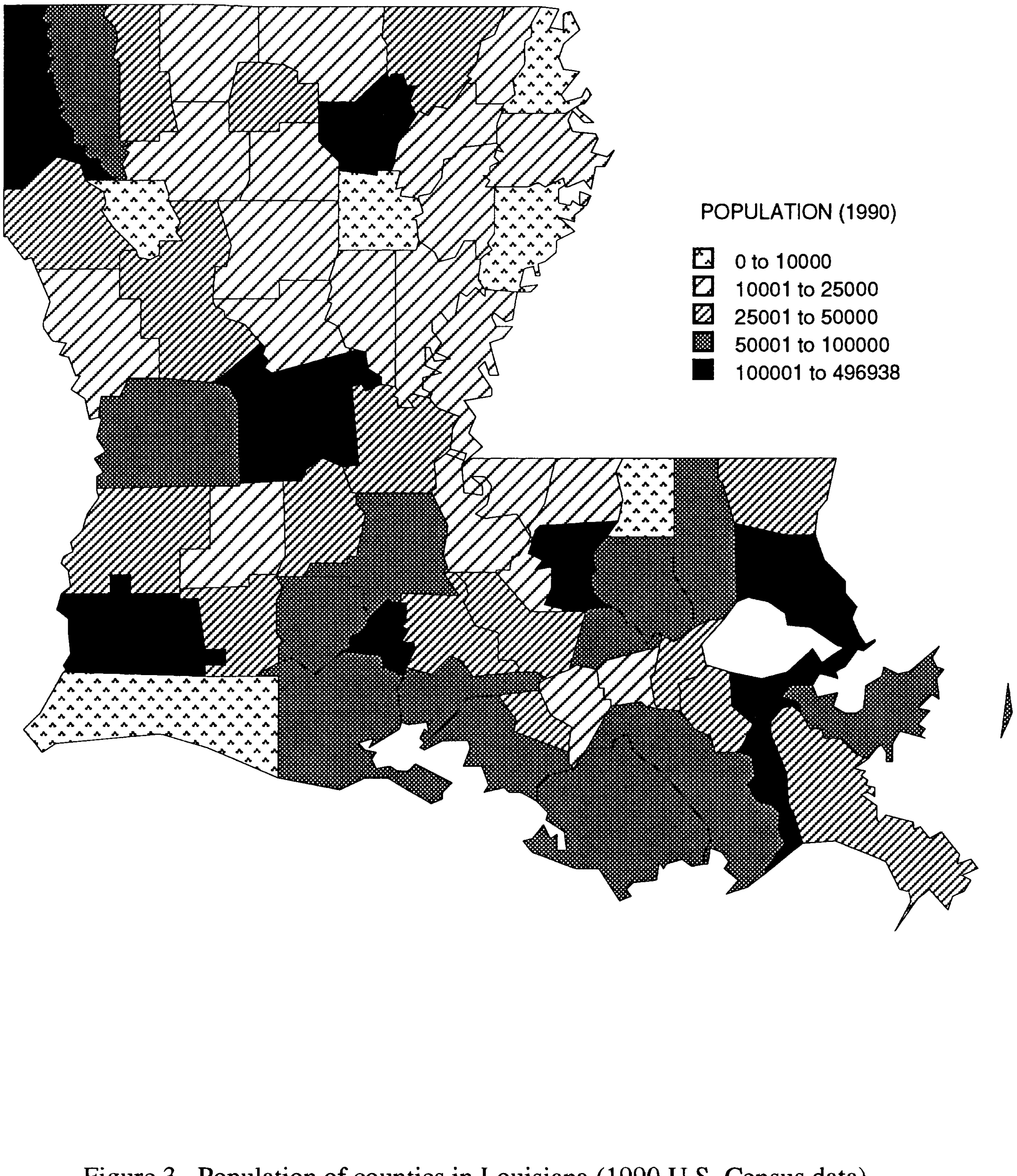

Figure 3. Population of counties in Louisiana (1990 U.S. Census data).

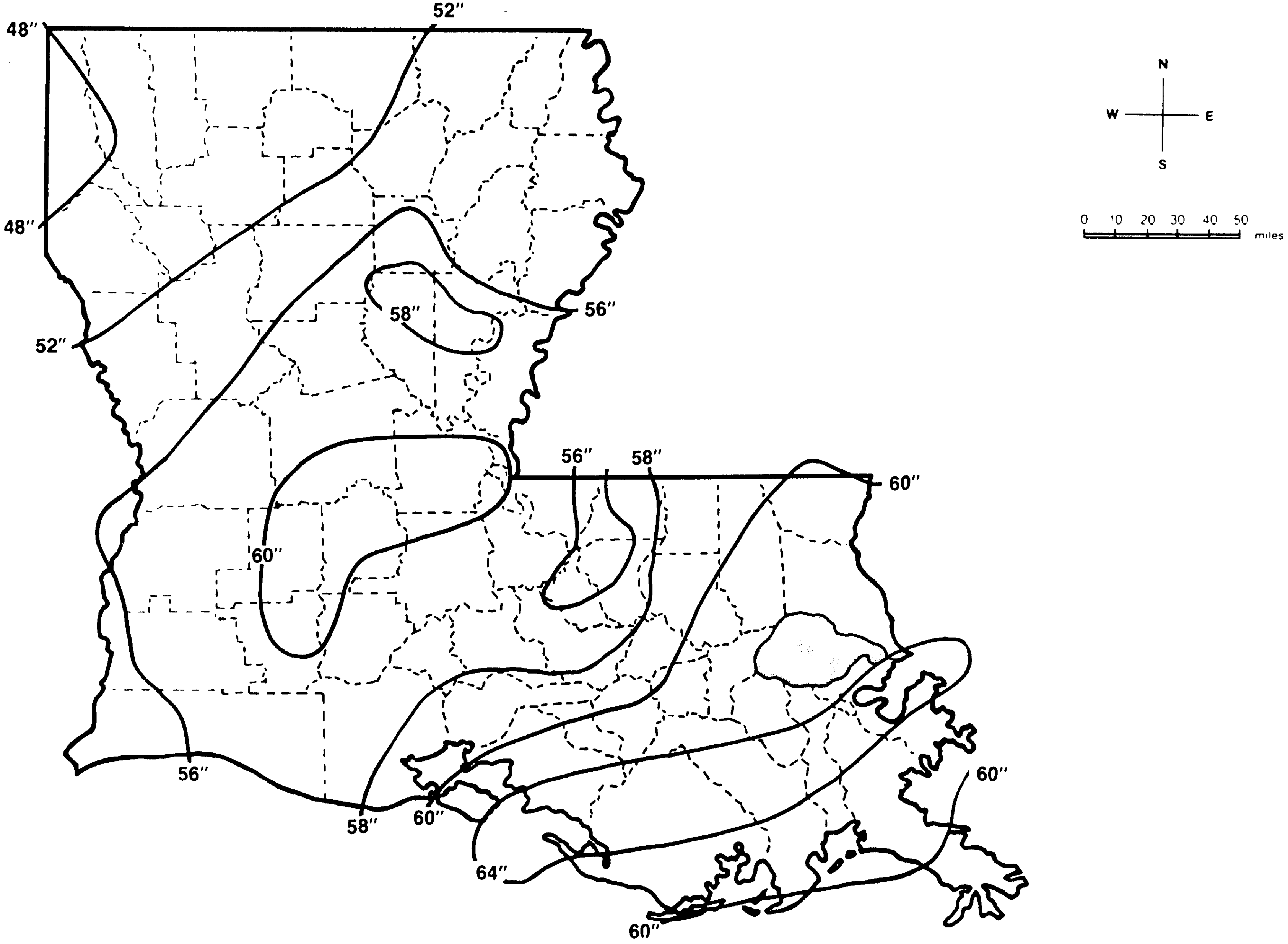

Figure 4. Annual precipitation in Louisiana (Facts on File, 1984).

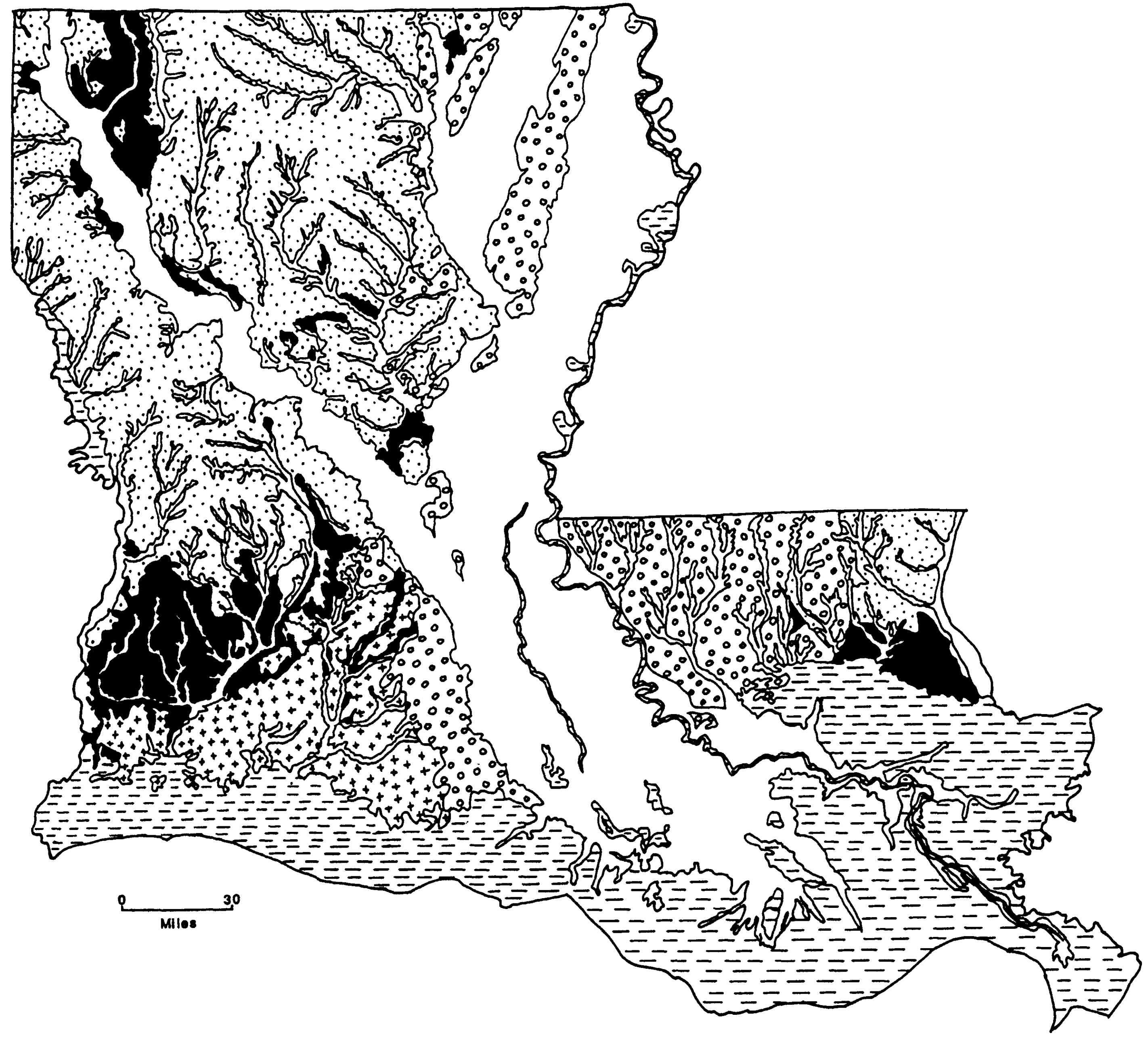

Figure 5. Generalized map showing soil areas of Louisiana (redrawn from map supplied by the Louisiana State University Remote Sensing and Image Processing Lab, 1992, from U.S. Soil Conservation Service soil survey data).

GENERALIZED SOIL MAP OF LOUISIANA
EXPLANATION

⁙ COASTAL PLAIN–gently to moderately sloping, usually moist, clay, clay loam, silty clay loam, silt loam, silt, and fine sand, slowly to locally moderately permeable.

■ GULF COAST FLATWOODS–poorly drained silty and clayey loams, frequently saturated.

⊞ GULF COAST PRAIRIES–loamy soils with clayey subsoils, slowly permeable.

° SOUTHERN MISSISSIPPI VALLEY SILTY UPLANDS–loess and loessal soils: silt and silty loams with very minor sand and clay, somewhat poorly drained, seasonally wet in the northern part of the State to typically wet in the southern part, generally slowly permeable.

□ RECENT ALLUVIUM–poorly to moderately drained, slowly to moderately permeable, loam, silt, and sand in floodplains. On levees, poorly drained, slowly permeable, loams, silt loams and silty clay loams in the south; well drained, highly permeable, loams and sands in the north.

☰ MARSH–Fresh water and salt water marshes containing clay, silt, and peat, usually saturated.

The Jackson Group consists of light gray to brown lignitic clays with interbeds of limonitic, glauconitic sands or lignite. Near the base of the unit are calcareous, glauconitic, shaly and fossiliferous sediments that typically weather to a black soil. Soils are silty clays and micaceous fine sandy clays that are slowly permeable. The Jackson Group is exposed in a narrow band which crosses central Louisiana south of the Claiborne Group.

The Vicksburg Group and Catahoula Formation also form narrow bands of outcrop just south of the Jackson Group. The Vicksburg Group consists of brown to gray lignitic clays with thin interbeds of lignite or micaceous sands, calcareous, dark shale, petrified wood, and local blue fossiliferous clay. Soils are silty clay and micaceous fine sandy clay that are slowly permeable. The Catahoula Formation is characterized by gray to white sandstone, unconsolidated quartz sand, tuffaceous sandstone, volcanic ash, and brown sandy clays, with petrified wood locally. Soils are clayey, fine to medium sand and fine sandy, silty clay that are slowly to moderately permeable.

On the geologic map of Louisiana included in this report (fig. 1), the Miocene-age Coastal Plain sediments have been placed in one group and form a discontinuous line of exposures in Central Louisiana across the southern part of the Coastal Plain and the easternmost Terraces. The Lena Member is composed of gray calcareous clays (which may weather to black soils), siltstones, tuffaceous clays and some volcanic ash beds. The Carnahan Bayou Member consists of yellow to gray siltstone, sandstone, and clays with thin tuffaceous beds and local lenses of black chert gravel and petrified wood. The Dough Hills Member has gray to yellow silty clays, light gray calcareous clays which may weather to black soil, and some siliceous silt and volcanic ash beds. The Williamson Creek Member consists of white to gray silts, siltstones, silty clays, and sand beds with some lenses of black chert gravel. These units are succeeded by the Castor Creek Member which consists of gray to dark gray calcareous clays (which may weather to black soil), lignitic clays, and noncalcareous clayey silts. The Blounts Creek Member consists of gray to green silty clays, siltstones, and silts with abundant sand beds, minor lignite, and lenses of black chert gravel. Soils are clays, smectitic clays with high shrink-swell potential, sandy clays, fine sands, and clayey sands. Permeability is generally slow.

The Mississippi Alluvial Plain

The soils underlying the Mississippi Alluvial Plain are characterized by high organic contents, reflect the grain size of the particular environment of deposition, and generally are moist to seasonally wet and have high water tables. Permeability expressed in the Soil Conservation Service parish reports is water permeability and is not applicable to gas permeability in water-saturated sediments.

The two areas known as the Terraces on the physiographic map consist of several different terrace deposits formed by the progressive change in relative sea level and aggradation of the Mississippi Delta. The High Terraces are tan to orange clay, silt, and sand with a large amount of basal gravel. The Intermediate Terraces are light gray to brown clay, sandy clay, silt , and locally extensive deposits of sand and gravel. Soils in the terraces are silty and clayey loams that are frequently saturated and poorly drained. The Prairie Terraces underlie most of the areas known as the Prairie and the Terraces on the topographic areas map (fig. 2). They show little dissection in contrast to the other terrace deposits, are generally finer grained, and are composed of gray to brown clay, sandy clay, silt, sand, and some gravel. Soils in the Prairies are generally loamy in surface layers and have clayey subsoils of slow permeability.

Two major alluvial plains, the Mississippi and the Red River, cover a significant portion of Louisiana and are made up of approximately equal amounts of alluvial and natural levee deposits at the surface. Alluvial sediments are predominantly gray to brown clay and silty clay, with some sand and gravel. They are poorly drained, frequently flooded, and have slow permeability. They are deposited in the overbank flood areas adjacent to natural levees and, in the lower valleys of the Mississippi, are predominantly backswamp organic clay and silt. Sandy channel and point bar deposits of the river also occur but tend to be covered by levee deposits. Natural levees of gray and brown silt, silty clay, and very fine sand form along the present and former courses and distributaries of the rivers. The levee deposits slope away from the river channel and merge with the alluvial deposits. In the south, levee soils are silt loams and silty clay loams of slow permeability. To the north in both the Red River and Mississippi Floodplains, levee soils are well drained loams and sands with high permeability. In the northern part of the Mississippi Alluvial Plain, braided stream terraces of light gray, tan, and brown, fine to coarse sand, some clay, silt, and gravel cover extensive areas and are considered glacial outwash of the ancestral Arkansas River. Along streams of intermediate size, including the northwestern edge of the Mississippi Alluvial Plain and along the Sabine River, a Quaternary unit known as the Deweyville Terrace is found. It consists of gray, brown, and red clay and silty clay, with some sand and gravel locally.

The Delta Plain forms the southeastern extension of Louisiana into the Gulf Coastal waters. It consists of freshwater marsh with gray to black clay of very high organic content and some peat. This is rimmed with saline marsh of gray to black clay with high organic content and some peat.

The northern part of the Cheniers is freshwater marsh of gray to brown and black clays and silts of high organic content. Saline marsh with gray, brown, and black clay and silt of moderate organic content is found in the southern part. The cheniers themselves are white to light gray, fine sand and shell fragments that form linear ridges, especially along the coast.

Loess

Loess is a windblown silt deposit and it is exposed in three principal areas in Louisiana: the northern Mississippi Alluvial Plain, the eastern part of the Prairies, and the eastern Terraces. Loess is the main component of the Southern Mississippi Valley Silty Uplands soil area (fig. 5). Loess is tan to reddish brown massive silt with some clay and minor amounts of very fine sand. Soils derived from loess are silt loams, somewhat poorly drained, and are typically wet in the southern part of the State and seasonally wet in the north. They have generally low permeability.

RADIOMETRIC DATA

An aeroradiometric map of Louisiana (fig. 6) was compiled from spectral gamma-ray data acquired during the U.S. Department of Energy National Uranium Resource Evaluation (NURE) program (Duval and others, 1989). For the purposes of this report, low equivalent uranium (eU) on the map is defined as less than 1.5 parts per million (ppm), moderate eU is defined as 1.5-2.5 ppm, and high eU is defined as greater than 2.5 ppm. In figure 6, low eU appears to be associated with Coastal Plain sediments in the north-central and northwestern parts of the State and in the coastal marshes that border the southern part of the State. Moderate eU is found throughout the Mississippi Alluvial Plain and the coastal prairies and some parts of the Coastal Plain. Moderate eU also appears to correlate well with the loess deposits found in the northern Floodplain and in the southeastern part of the Prairies. Very small, local areas of high eU (fig. 6) are found in the Prairies and the Mississippi Alluvial Plain. In the Prairies, these local areas of high eU seem to be associated with distinct exposures of loess. Some of the moderate to high equivalent uranium may be cultural and the result of uranium in phosphate fertilizers, a common occurrence in heavy

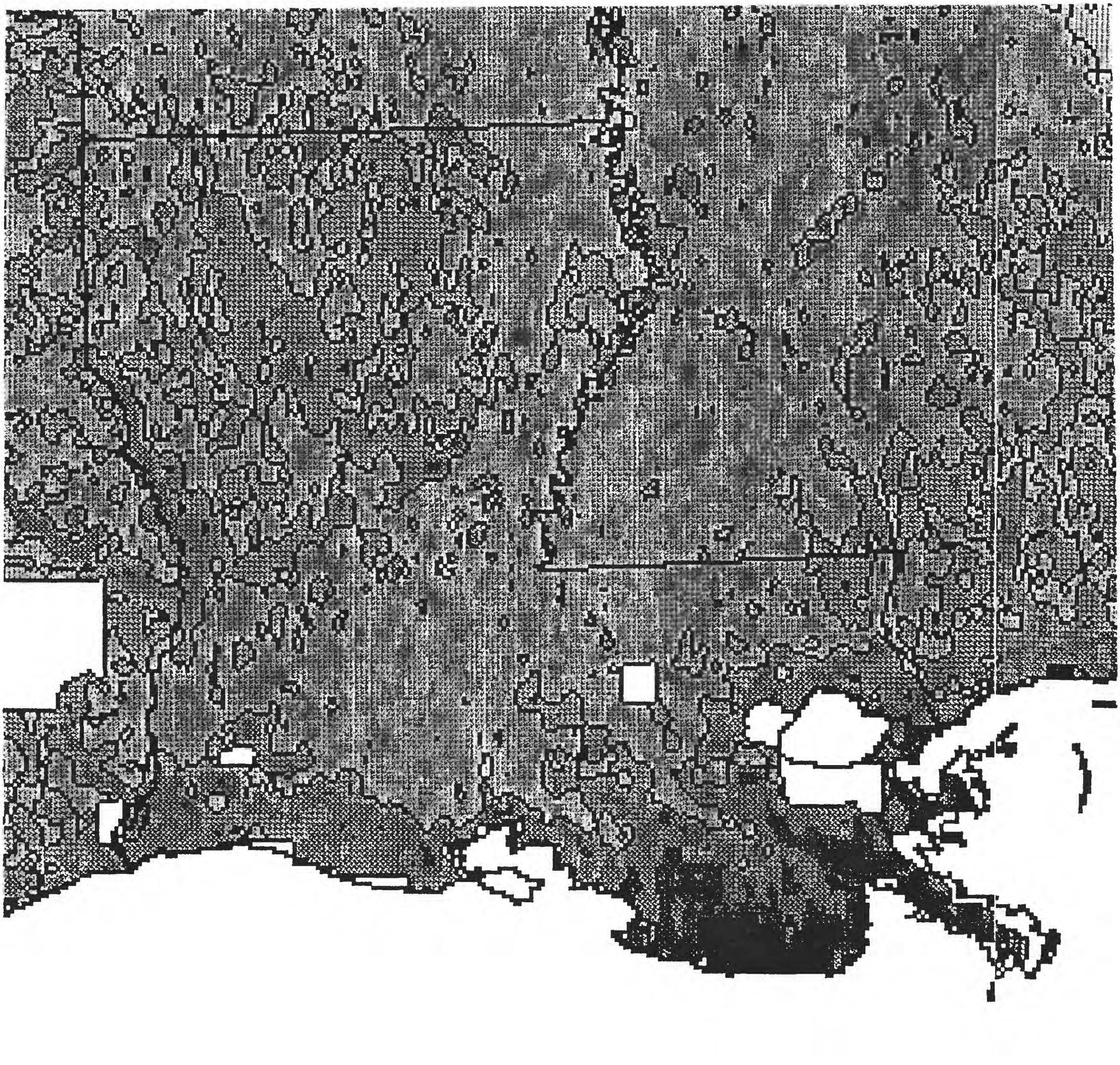

Figure 6. Aerial radiometric map of Louisiana (after Duval and others, 1989). Contour lines at 1.5 and 2.5 ppm equivalent uranium (eU). Pixels shaded at 0.5 ppm eU increments.

agricultural areas, or associated with cities, such as the radiometric anomaly over Alexandria. Naturally-occurring radioactive materials in the form of pipe scale, which can be concentrated in active and abandoned oil-industry pipe yards, may also be a local source of some of the anomalies.

INDOOR RADON DATA

Indoor radon data from 1314 homes sampled in the State/EPA Residential Radon Survey conducted in Louisiana during the winter of 1990-91 are shown in figure 7 and presented in Table 1. A map of parishes is included for reference (fig. 8). Data are shown on the maps only for those parishes with 5 or more data values. The maximum value recorded in the survey was 8 pCi/L in Rapides Parish. The average for the State was 0.5 pCi/L and 0.8 percent of the homes tested had indoor radon levels exceeding 4 pCi/L. The most notable parishes include West Carrol and Union, which have indoor radon averages greater than 1 pCi/L. Seven parishes have maximum indoor radon levels greater than 4 pCi/L; they are West Carrol, Union, Ouachita, Caddo, Rapides, Lafayette, and St. Tammany. The majority of these parishes are underlain by alluvium and deltaic sediments. Overall, Louisiana ranks as the second lowest state in the State/EPA Residential Radon Survey; only Hawaii had a lower state radon average.

GEOLOGIC RADON POTENTIAL

An examination of the aerial radioactivity map for Louisiana, its State geologic map, and the indoor radon map allows us to make some observations about the geologic radon potential of the State. Overall indoor radon is low; however, several parishes had individual homes with radon levels greater than 4 pCi/L (fig. 7). Parishes with maximum indoor radon levels exceeding 4 pCi/L are found in areas of the State underlain by coastal plain sediments, terrace deposits, and loess.

A study of the radon in the Coastal Plain of Texas, Tennessee, and Alabama (Peake and Gundersen, 1989; Gundersen and others, 1991) suggests that glauconitic, phosphatic, and carbonaceous sediments, and sedimentary rocks equivalent to those, in Louisiana can cause elevated levels of indoor radon. Ground surveys of radioactivity and radon surveys of soil in the above-mentioned study indicate that the upper Cretaceous through lower Tertiary Coastal Plain sediments are sources of high radon (> 1000 pCi/L) and uranium. Soils from clays, shales, and marls commonly have low permeability, so even though these sediments may be a possible source of radon, slow permeability probably inhibits radon availability. Some of the glauconitic sands and silts with moderate permeability may be the source of locally high indoor radon. Moderate levels of radioactivity are found on the NURE radiometric map (fig. 6) in areas underlain by the Eocene through lower Oligocene-age Coastal Plain sediments, but do not follow formation boundaries or strike belts in a systematic manner. The pattern of moderate radioactivity in this area does appear to follow river drainages and according to R.P. McCulloh (Louisiana Geological Survey, pers. comm., 1992) the aerial radioactivity pattern may be associated with northwest- and northeast-trending joints and(or) faults which in turn may control drainage patterns. Part of the pattern of low radioactivity in the Coastal Plain may be influenced by ground saturation with water. This area receives high precipitation and contains an extensive system of bayous and rivers. Besides damping gamma radioactivity, ground saturation can also inhibit radon movement.

Loess deposits in Tennessee were also examined by Peake and Gundersen (1989) and high levels of radon were extracted from both dry and moist loess soils. On the radioactivity map of Louisiana, the loess units can easily be traced, following the highest of the moderate uranium

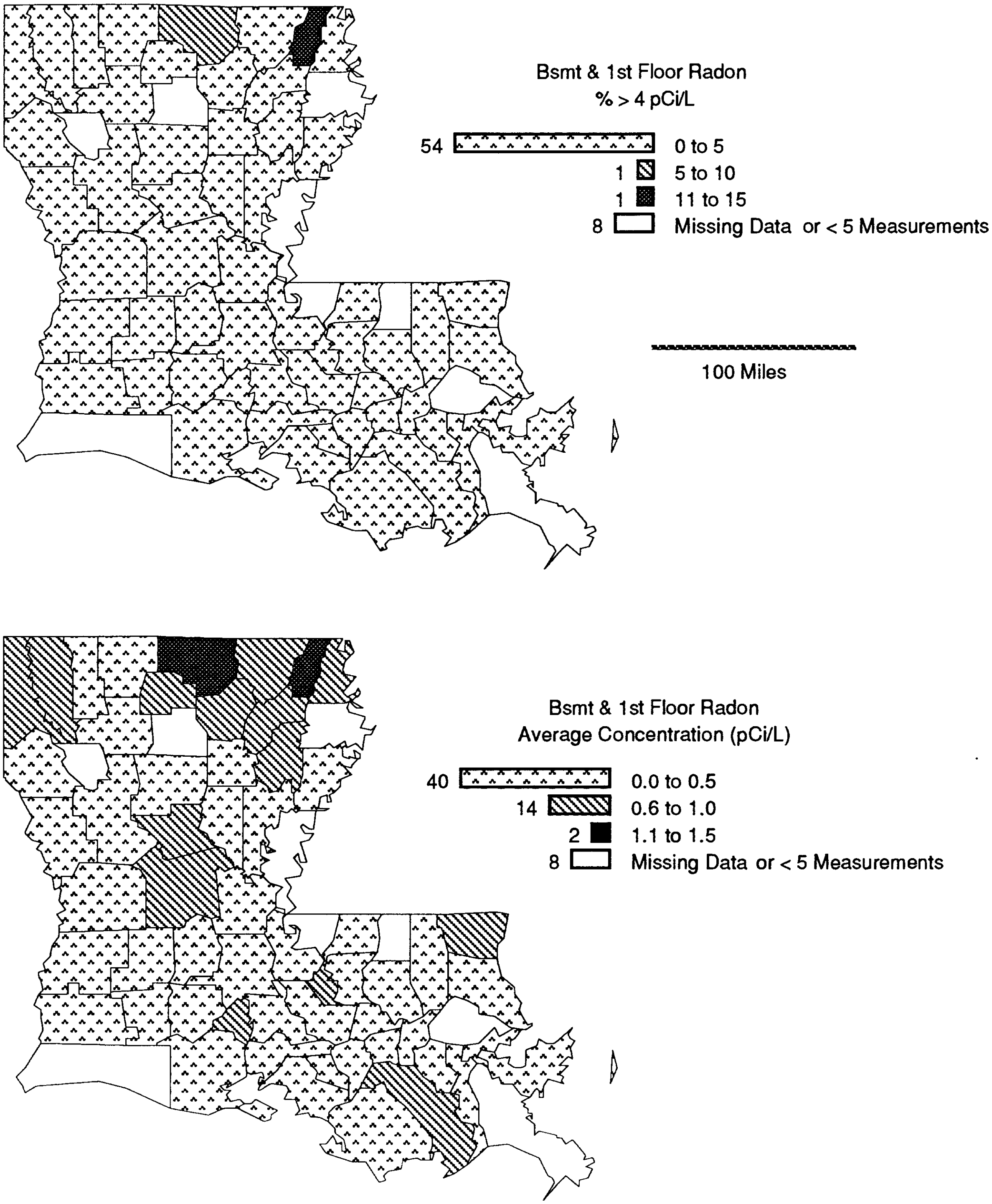

Figure 7. Screening indoor radon data from the EPA/State Residential Radon Survey of Louisiana, 1990-91, for parishes with 5 or more measurements. Data are from 2-7 day charcoal canister tests. Histograms in map legends show the number of parishes in each category. The number of samples in each parish (see Table 1) may not be sufficient to statistically characterize the radon levels of the parishes, 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 Louisiana conducted during 1989-90. Data represent 2-7 day charcoal canister measurements from the lowest level of each home tested.

PARISH	NO. OF MEAS.	MEAN	GEOM. MEAN	MEDIAN	STD. DEV.	MAXIMUM	%>4 pCi/L	%>20 pCi/L
ACADIA	13	0.5	0.2	0.4	0.6	1.6	0	0
ALLEN	5	0.2	0.1	0.1	0.4	0.8	0	0
ASCENSION	23	0.4	0.3	0.4	0.5	1.5	0	0
ASSUMPTION	5	0.3	0.1	0.0	0.6	1.3	0	0
AVOYELLES	6	0.2	0.2	0.2	0.2	0.4	0	0
BEAUREGARD	8	0.4	0.3	0.4	0.6	1.7	0	0
BIENVILLE	15	0.2	0.2	0.2	0.5	1.5	0	0
BOSSIER	35	0.6	0.3	0.4	0.5	1.8	0	0
CADDO	83	0.7	0.4	0.5	1.1	7.6	2	0
CALCASIEU	60	0.3	0.2	0.2	0.7	2.3	0	0
CALDWELL	13	0.3	0.2	0.1	0.5	1.6	0	0
CAMERON	2	0.3	0.2	0.3	0.5	0.6	0	0
CATAHOULA	7	0.3	0.2	0.5	0.5	0.8	0	0
CLAIBORNE	16	0.5	0.3	0.4	0.7	2.1	0	0
CONCORDIA	7	0.4	0.3	0.4	0.6	1.4	0	0
DE SOTO	6	0.4	0.3	0.5	0.5	1.1	0	0
EAST BATON ROUGE	170	0.4	0.3	0.4	0.5	2.4	0	0
EAST CARROLL	9	0.9	0.3	0.3	1.1	2.8	0	0
EAST FELICIANA	5	0.2	0.2	0.2	0.4	0.6	0	0
EVANGELINE	6	0.3	0.2	0.2	0.4	1.0	0	0
FRANKLIN	9	0.8	0.5	0.7	0.9	2.9	0	0
GRANT	9	0.6	0.5	0.4	0.6	1.5	0	0
IBERIA	12	0.4	0.2	0.4	0.6	1.5	0	0
IBERVILLE	7	0.5	0.3	0.3	0.6	1.3	0	0
JACKSON	2	0.8	0.7	0.8	0.2	0.9	0	0
JEFFERSON	104	0.3	0.2	0.3	0.5	2.4	0	0
JEFFERSON DAVIS	8	0.4	0.3	0.5	0.3	0.9	0	0
LA SALLE	10	0.3	0.2	0.2	0.7	2.0	0	0
LAFAYETTE	71	0.8	0.4	0.5	1.0	5.0	3	0
LAFOURCHE	12	0.6	0.4	0.5	0.8	2.4	0	0
LINCOLN	11	0.6	0.5	0.6	0.4	1.3	0	0
LIVINGSTON	29	0.5	0.3	0.3	0.7	3.0	0	0
MADISON	2	1.4	0.7	1.4	1.6	2.5	0	0
MOREHOUSE	12	0.8	0.4	0.8	0.9	2.7	0	0
NATCHITOCHES	27	0.6	0.3	0.4	0.6	2.3	0	0
ORLEANS	51	0.3	0.2	0.3	0.5	1.4	0	0
OUACHITA	44	0.6	0.3	0.4	0.8	4.1	2	0
PLAQUEMINES	3	0.4	0.2	0.0	0.9	1.4	0	0
POINTE COUPEE	6	0.1	0.1	0.1	0.1	0.3	0	0
RAPIDES	47	0.6	0.3	0.5	1.2	8.0	2	0
RED RIVER	4	0.8	0.7	0.9	0.4	1.3	0	0

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

PARISH	NO. OF MEAS.	MEAN	GEOM. MEAN	MEDIAN	STD. DEV.	MAXIMUM	%>4 pCi/L	%>20 pCi/L
RICHLAND	8	0.6	0.3	0.3	0.8	2.4	0	0
SABINE	8	0.2	0.1	0.1	0.3	0.7	0	0
ST. BERNARD	18	0.2	0.2	0.3	0.3	0.7	0	0
ST. CHARLES	15	0.2	0.2	0.2	0.3	0.7	0	0
ST. JAMES	12	0.4	0.3	0.4	0.4	1.1	0	0
ST. JOHN	11	0.2	0.2	0.3	0.5	0.9	0	0
ST. LANDRY	28	0.3	0.2	0.3	0.5	1.5	0	0
ST. MARTIN	8	0.3	0.2	0.3	0.3	0.8	0	0
ST. MARY	17	0.2	0.2	0.2	0.3	1.0	0	0
ST. TAMMANY	73	0.5	0.3	0.4	1.0	5.2	3	0
TANGIPAHOA	18	0.3	0.2	0.1	0.6	2.2	0	0
TENSAS	6	0.1	0.1	0.0	0.4	0.8	0	0
TERREBONNE	35	0.4	0.3	0.5	0.4	1.5	0	0
UNION	12	1.1	0.6	0.6	1.4	4.5	8	0
VERMILION	13	0.5	0.3	0.4	0.9	3.0	0	0
VERNON	15	0.3	0.2	0.3	0.4	1.2	0	0
WASHINGTON	7	0.7	0.5	0.7	0.4	1.0	0	0
WEBSTER	14	0.4	0.3	0.2	0.5	1.1	0	0
WEST BATON ROUGE	7	0.6	0.4	0.6	0.3	0.9	0	0
WEST CARROLL	7	1.4	0.6	0.5	1.9	5.3	14	0
WEST FELICIANA	3	1.5	1.4	1.7	0.6	1.9	0	0
WINN	5	0.3	0.2	0.3	0.4	0.7	0	0

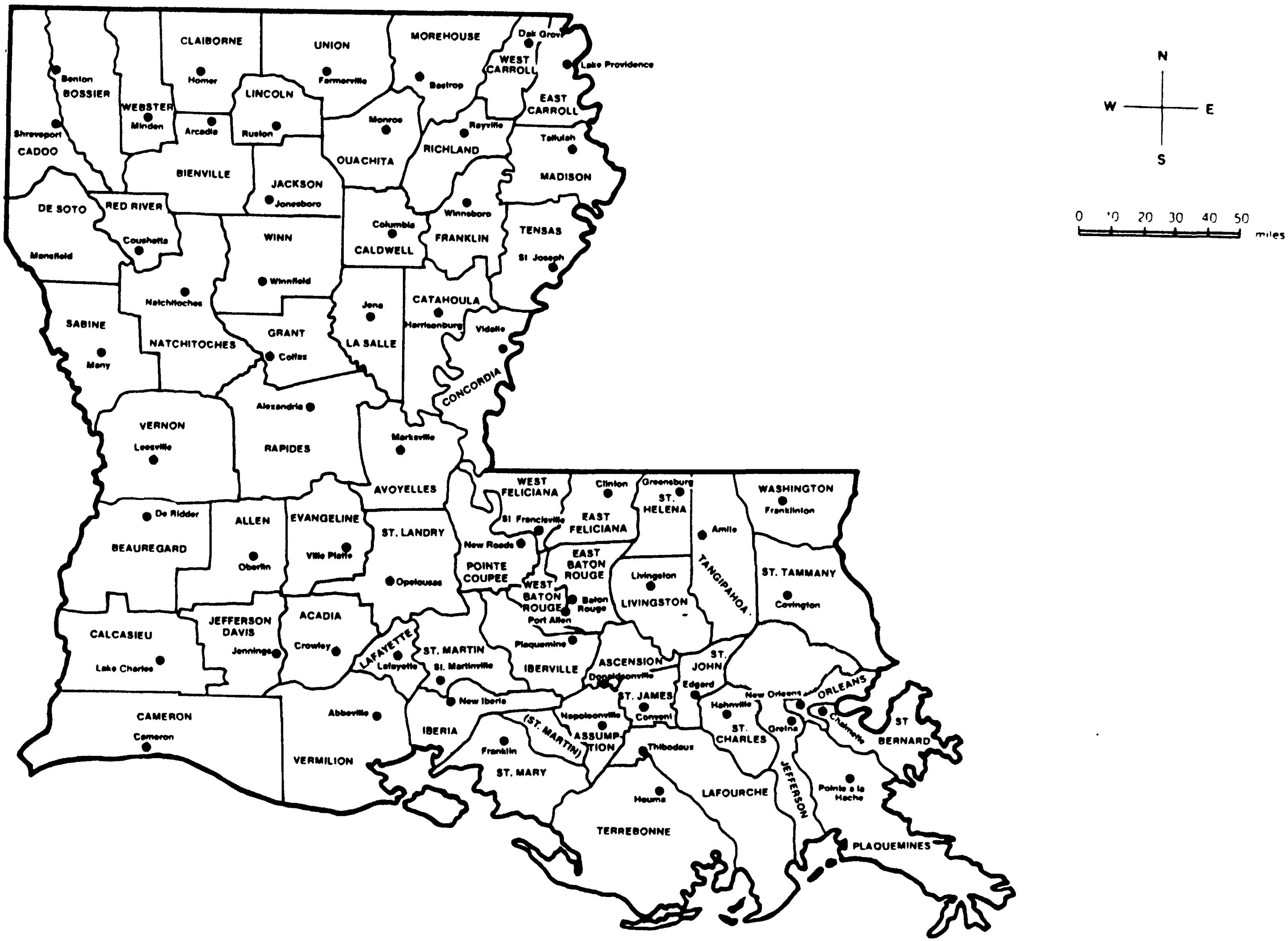

Figure 8. Parishes of Louisiana (Facts on File, 1984).

anomalies in the northern portion of the Mississippi Floodplain. On the National Radiometric Map of the United States (Duval and others, 1989) loess throughout the United States is associated with high radiometric anomalies. Radiometric anomalies in the southeastern part of the Prairies also seem to be associated with the exposure of loess as mapped on the Louisiana State Geologic Map (Snead and McCulloh, 1984) in Iberia, Lafayette, eastern Acadia, and northern Vermilion Parishes. Loess tends to have low permeability, so even though these sediments may be a possible source of high radon, the permeability may inhibit radon availability.

The youngest Coastal Plain sediments, particularly Oligocene and younger, have decreasing amounts of glauconite and phosphate and become increasingly siliceous and less likely to be significant sources of radon. However, the possibility of roll-front uranium deposits in sedimentary rocks and sediments of Oligocene-Miocene-age, analogous to the roll-front uranium deposits in Texas, has been proposed by McCulloh (1982). McCulloh (1982) also reports surface gamma anomalies from the lower Catahoula sandstone measured by private industry. Thus far, uranium deposits have not been reported.

The fluvial and deltaic sediments in the Mississippi Alluvial Plain are low in geologic radon potential. They are not likely to have elevated amounts of uranium and the saturated to seasonally wet conditions of the soils, as well as the high water tables, do not facilitate radon availability.

SUMMARY

For the purposes of this assessment, Louisiana has been divided into six geologic radon potential areas based on physiography and geology. Each area has been assigned a Radon Index (RI) and a Confidence Index (CI) score (Table 2). The RI is a semi-quantitative measure of radon potential based on geology, soils, radioactivity, architecture, and indoor radon. The CI is a measure of the relative confidence of the RI assessment based on the quality and quantity of the data used to assess geologic radon potential (see the Introduction chapter to this regional booklet for more information on the methods and data used).

Examination of the indoor radon and geologic data reveals that Louisiana is generally an area of low radon potential. The climate, soil, and lifestyle of the inhabitants of Louisiana have influenced building construction styles and building ventilation which, in general, do not allow high concentrations of radon to accumulate. Many homes in Louisiana are built on piers or are slab-on-grade. Glauconitic, carbonaceous, and phosphatic sediments of the Coastal Plain, particularly the Cretaceous and lower Tertiary-age geologic units located in the northern portion of the State, have some geologic potential to produce radon. Other areas to consider as possible sources of radon include Oligocene-Miocene age units that may host roll-front uranium deposits, and loess deposits. Several areas of moderate to high equivalent uranium occur in the Mississippi Alluvial Plain and the Prairies, and appear to be associated with loess.

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

TABLE 2. RI and CI for major physiographic and geologic areas of Louisiana.

	Cheniers		Delta		Floodplain	
FACTOR	RI	CI	RI	CI	RI	CI
INDOOR RADON	1	2	1	2	1	2
RADIOACTIVITY	1	3	2	3	2	3
GEOLOGY	1	2	1	2	1	2
SOIL PERM.	2	2	1	2	2	2
ARCHITECTURE	1	-	1	-	1	-
GFE POINTS	0	-	0	-	0	-
TOTAL	6	9	6	9	7	9
	LOW	MOD	LOW	MOD	LOW	MOD

	Old Uplands		Prairies		Terraces	
FACTOR	RI	CI	RI	CI	RI	CI
INDOOR RADON	1	2	1	2	1	2
RADIOACTIVITY	1	3	2	3	2	3
GEOLOGY	2	2	1	2	2	2
SOIL PERM.	2	2	2	2	2	2
ARCHITECTURE	1	-	1	-	1	-
GFE POINTS	0	-	0	-	0	-
TOTAL	7	9	7	9	8	9
	LOW	MOD	LOW	MOD	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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PRELIMINARY GEOLOGIC RADON POTENTIAL ASSESSMENT OF NEW MEXICO

by

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U.S. Geological Survey

INTRODUCTION

Several areas of New Mexico have the potential to generate and transport radon in sufficient concentrations to be of concern in indoor air, because radon is a radioactive decay product of uranium, and because the uranium- and radium-bearing bedrock and the soils and alluvium derived from those rocks are locally abundant in the State. Uranium deposits in New Mexico occur in numerous rock units of varying age and lithology, and New Mexico has ranked first in domestic uranium production since 1956 (McLemore, 1983; McLemore and Chenoweth, 1989). In addition to uranium-bearing bedrock, other factors such as shears and fractures in bedrock, soil permeability, and the nature and occurrence of groundwater and geothermal areas have the potential to affect the generation of radon in local areas.

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

PHYSIOGRAPHIC AND GEOGRAPHIC SETTING

Four major physiographic provinces (fig. 1A) extend into New Mexico: the Southern Rocky Mountains, the Colorado Plateau, the Basin and Range, and the Great Plains (Mallory, 1972). The Southern Rocky Mountains extend only into the north-central part of New Mexico, whereas the Colorado Plateau covers the northwestern quarter of the State. The Basin and Range accounts for one third in southwestern and central New Mexico, and the Great Plains cover about the eastern third of the State.

Each of the major physiographic provinces in New Mexico can be subdivided into several smaller sections and subsections (fig. 1B; Hawley, 1986). The Southern Rocky Mountains extend south from Colorado into the north-central part of New Mexico. The province consists of two north-south trending ranges separated by the San Luis Valley, a deep structural basin of the northern part of the Rio Grande rift. The valley grades southward into the Española Valley of the Basin and Range Province. Numerous glaciated peaks and valleys are present in the mountain ranges, including Wheeler Peak, which at 13,161 ft is the highest point in New Mexico.

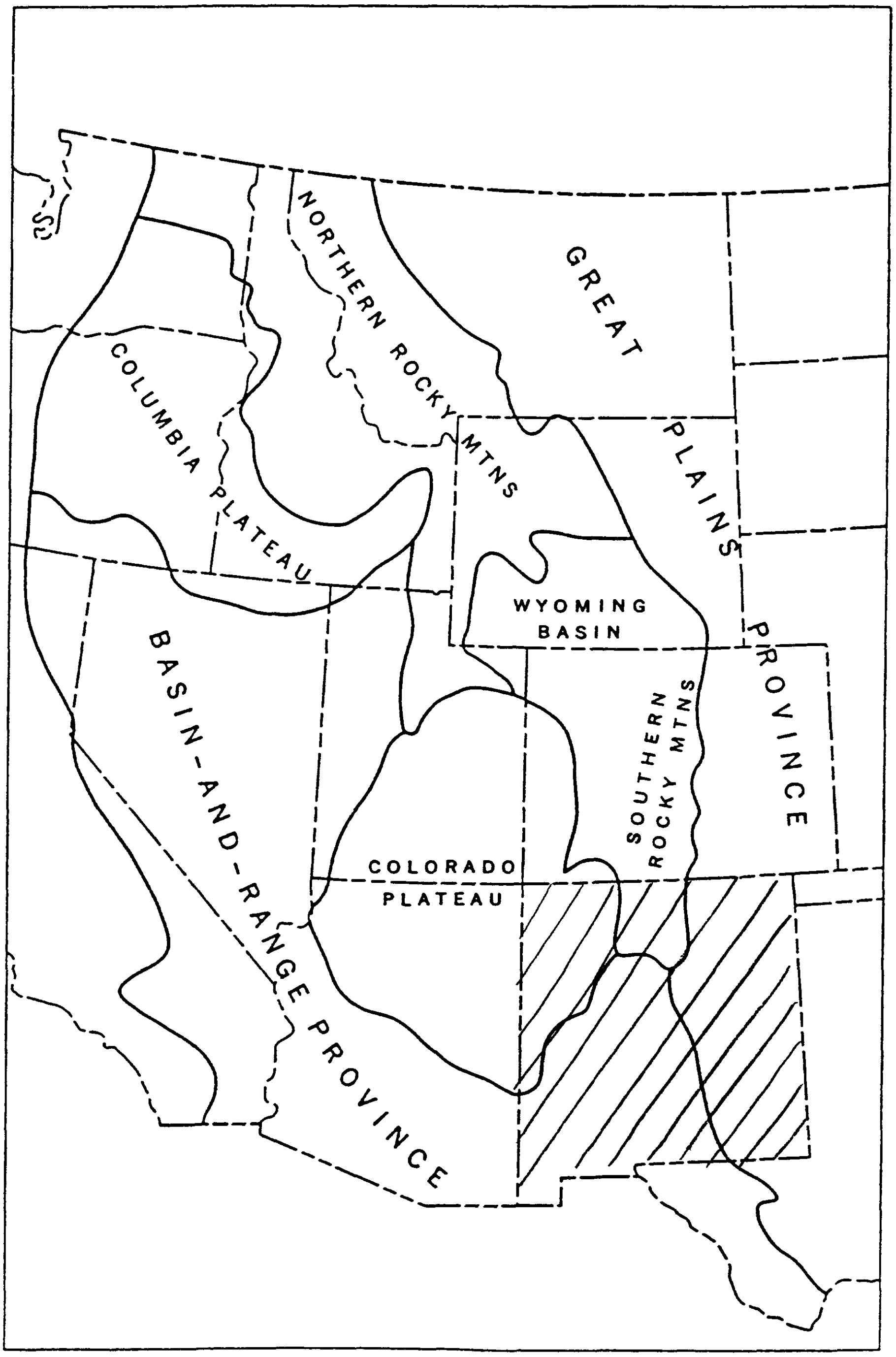
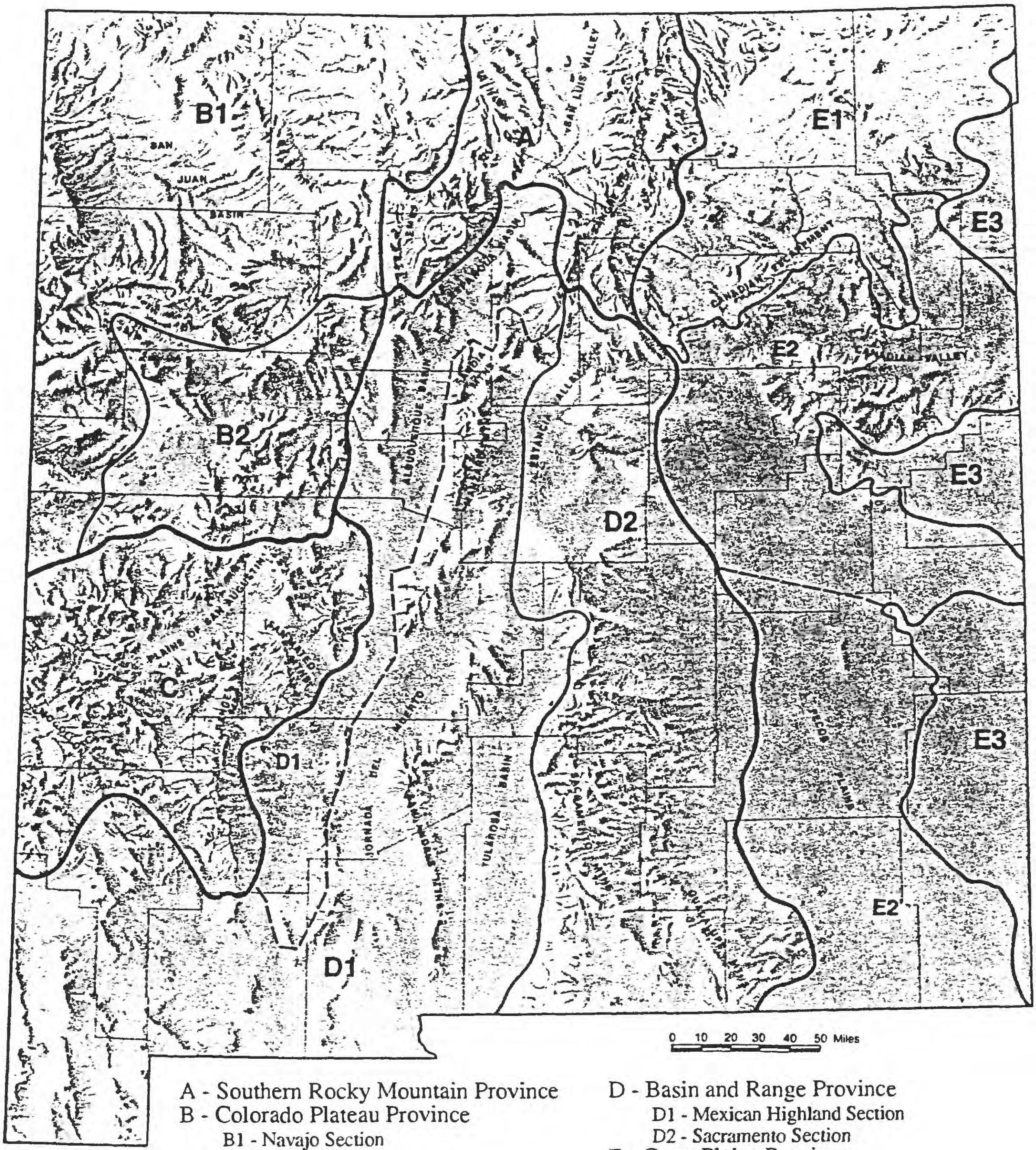


Figure 1A. Major physiographic provinces of the western United States (modified from Mallory, 1972).



A - Southern Rocky Mountain Province
B - Colorado Plateau Province
  B1 - Navajo Section
  B2 - Acoma-Zuni Section
C - Datil-Mogollon Section

D - Basin and Range Province
  D1 - Mexican Highland Section
  D2 - Sacramento Section
E - Great Plains Province
  E1 - Raton Section
  E2 - Pecos Valley Section
  E3 - High Plains

Figure 1B. Physiographic provinces in New Mexico (modified from Hawley, 1986).

The Colorado Plateau, a roughly circular area centered about the Four Corners region of Utah, Colorado, Arizona, and New Mexico, covers about the northwestern quarter of New Mexico. The Colorado Plateau consists of highly dissected plateaus and mesas ranging in elevation from about 5,000 ft to over 11,000 ft. The summit of Mount Taylor at 11,301 ft is the highest point on the Colorado Plateau in New Mexico. The Navajo section of the Colorado Plateau is dominated by two large structural basins: the San Juan Basin and the Gallup-Zuni basin. The Acoma-Zuni section of the Colorado Plateau, a newly defined physiographic unit (Hawley, 1986), is characterized by volcanic rocks and basalt flows and is dominated by Mount Taylor, an ancient volcano.

The Basin and Range Province covers about one third of southwestern and central New Mexico and is characterized by block-faulted, generally north-south trending mountain ranges and flat-floored basins. The Basin and Range includes several subsections. The Datil-Mogollon section, a newly defined physiographic subdivision that is transitional between the Basin and Range and the Colorado Plateau, includes structural basins and block-faulted mountain ranges along with large volcanic calderas and volcanoes. The Mexican Highland section in the western part of the Basin and Range Province of New Mexico includes two large areas of Basin and Range structures and the broad valley of the Rio Grande. The Sacramento section in the eastern part contains high mesas and rolling plains interspersed with broad basins.

The Great Plains Province in the eastern third of New Mexico includes parts of three sections: the Raton , Pecos Valley, and High Plains sections. The Raton section is characterized by high piedmont plains, basalt flows, and deep canyons eroded by the Canadian and Cimarron Rivers. The Pecos Valley section includes piedmont plains and the valleys of the Canadian and Pecos Rivers. The High Plains section occurs as three separate areas extending west into New Mexico from the Panhandle region of Texas and Oklahoma. The High Plains are characterized by a flat to undulating surface with elevations ranging from about 3,500 ft to 5,000 ft.

Population density and distribution (fig. 2A, B) and land use in New Mexico reflect the geology, topography, climate, and early exploration and settlement in the State. New Mexico is a sparsely populated state, having a statewide population density of slightly over 10 persons per square mile (fig. 2A; Williams, 1986) with much of the population concentrated in a few urban areas and along rivers and groundwater sources or major transportation routes (fig. 2B). Minor concentrations of people are localized by proximity to recent economic development related to energy and mineral resources.

Major industries in New Mexico include grazing, agriculture, manufacturing, forestry, military installations, mining, and recreation. Ranchland is the most widespread land use in the State. Agricultural activities include irrigated and non-irrigated cropland and rangeland. Military installations provide a small and local contribution to the State's economy. Manufacturing is restricted to small urban areas, and forestry is locally concentrated in mountainous regions. Mineral and energy resource production have a diverse history in New Mexico, and they are significant industries in the State. New Mexico has been a leading producer of uranium, potash, and perlite in the United States and is a major producer of many other base and precious metals. Recreation is a major industry in New Mexico and is shared by both winter activities at ski areas and by summer recreation and tourism.

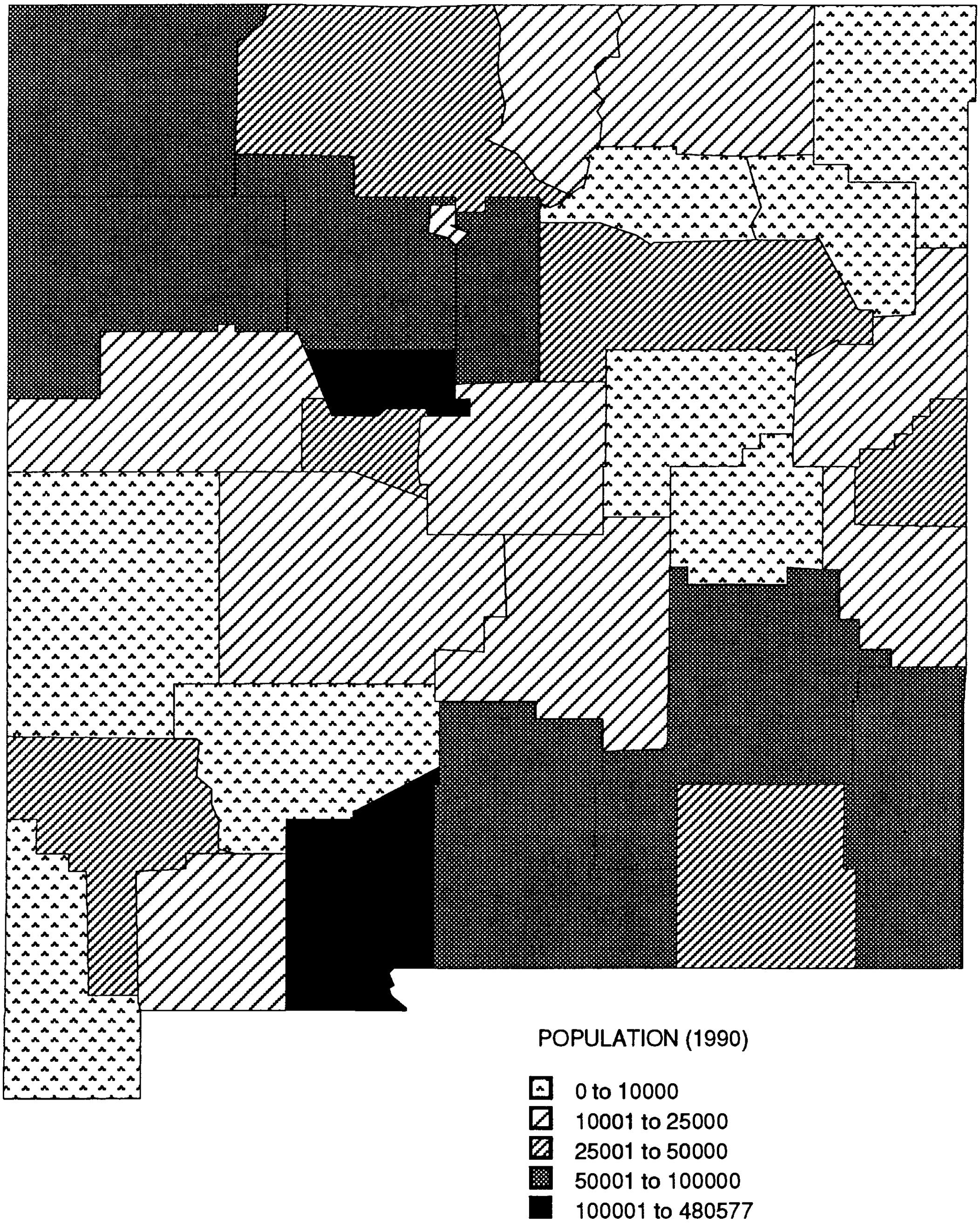


Figure 2A. Population of counties in New Mexico (1990 U.S. Census data).

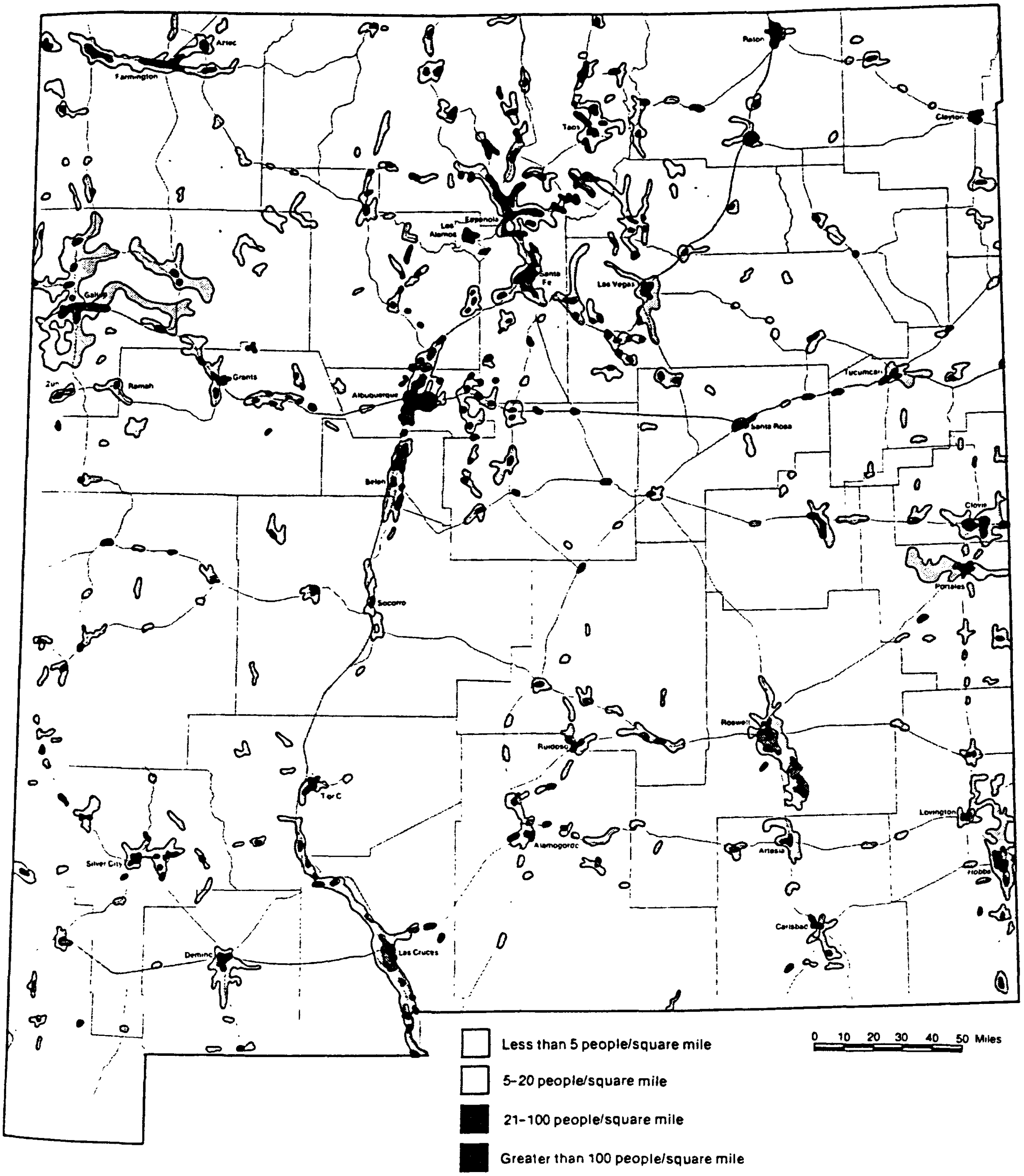


Figure 2B. Map showing population distribution in New Mexico in 1986 (modified from Williams, 1986).

GEOLOGY

New Mexico's geology is complex and a wide variety of bedrock geology (fig. 3) is exposed in each of the major physiographic provinces. The following discussion of the geology of New Mexico is condensed from Dane and Bachman (1965), Mallory (1972), New Mexico Geological Society (1982), and Kues and Callender (1986). A detailed geologic map of New Mexico is presented by Dane and Bachman (1965); the reader is urged to consult this or other publications for more detailed information.

Rocks ranging in age from Precambrian to Quaternary are exposed throughout New Mexico. Precambrian rocks in New Mexico are exposed predominantly in the cores of mountain ranges in the Southern Rocky Mountains and in the Basin and Range. Minor exposures of Precambrian rocks occur along the Rio Grande rift in the Basin and Range and in the Zuni uplift near the southern margin of the Colorado Plateau. Precambrian rocks include both metamorphic rocks, including phyllite, schist, quarzite, felsite, and amphibolite, and igneous rocks, comprising granite and pegmatite. The intervening basins in the mountain ranges and the major portion of both the Colorado Plateau and the Great Plains in New Mexico are characterized both by relatively undeformed Paleozoic to Cenozoic sedimentary rocks and by Cretaceous through Quaternary volcanic and volcaniclastic rocks.

Paleozoic rocks in New Mexico include strata from each period: Cambrian, Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, and Permian. Paleozoic sedimentary rocks are exposed on the flanks of the Southern Rocky Mountains, which were uplifted during the Laramide orogeny in the Late Cretaceous to Eocene, and in scattered outcrops in mountains of the Basin and Range, in the Zuni uplift and the Rio Grande rift, and in extensive flat-lying outcrops in the Great Plains. Paleozoic rocks are predominantly marine limestones, sandstones, and shales deposited in shallow seas, but they also include locally significant conglomerates, sandstones, and mudstones deposited in non-marine settings on alluvial fans, within rivers and floodplains, and as wind-blown eolian sand dunes.

Mesozoic sedimentary rocks crop out over a wide area in New Mexico, with extensive exposures on the Colorado Plateau and in the northern part of the Great Plains, and with minor outcrops in the mountains of the Basin and Range, along the Rio Grande rift, and in the Southern Rocky Mountains. Mesozoic strata include Triassic, Jurassic, and Cretaceous rocks. Triassic strata comprise marginal-marine sandstones and shales and extensive continental fluvial and lacustrine sandstones, mudstones, and limestones. Jurassic rocks consist of marine limestones and shales, eolian sandstones, and continental lacustrine and fluvial sandstones and mudstones. Cretaceous rocks form a thick sedimentary section in New Mexico and consist of marine shales, sandstones, and limestones that are interspersed with non-marine sandstones, shales, and coals.

The Cenozoic Era in New Mexico was characterized by abundant volcanic activity that began in the latest Cretaceous and continued into the Holocene. Extensive Cretaceous through mid-Teriary volcanic rocks are present in southwestern New Mexico in the Basin and Range Province. Upper Tertiary to Quaternary volcanic rocks crop out in scattered localities in the Basin and Range, on the Colorado Plateau, in the Southern Rocky Mountains, and in the Great Plains. Tertiary and Quaternary sedimentary rocks consisting of conglomerate, sandstone, and shale were deposited in the San Juan Basin on the Colorado Plateau, and throughout the Great Plains and the valleys of the Basin and Range by non-marine proceses and include extensive alluvial, colluvial, lacustrine, and eolian deposits.

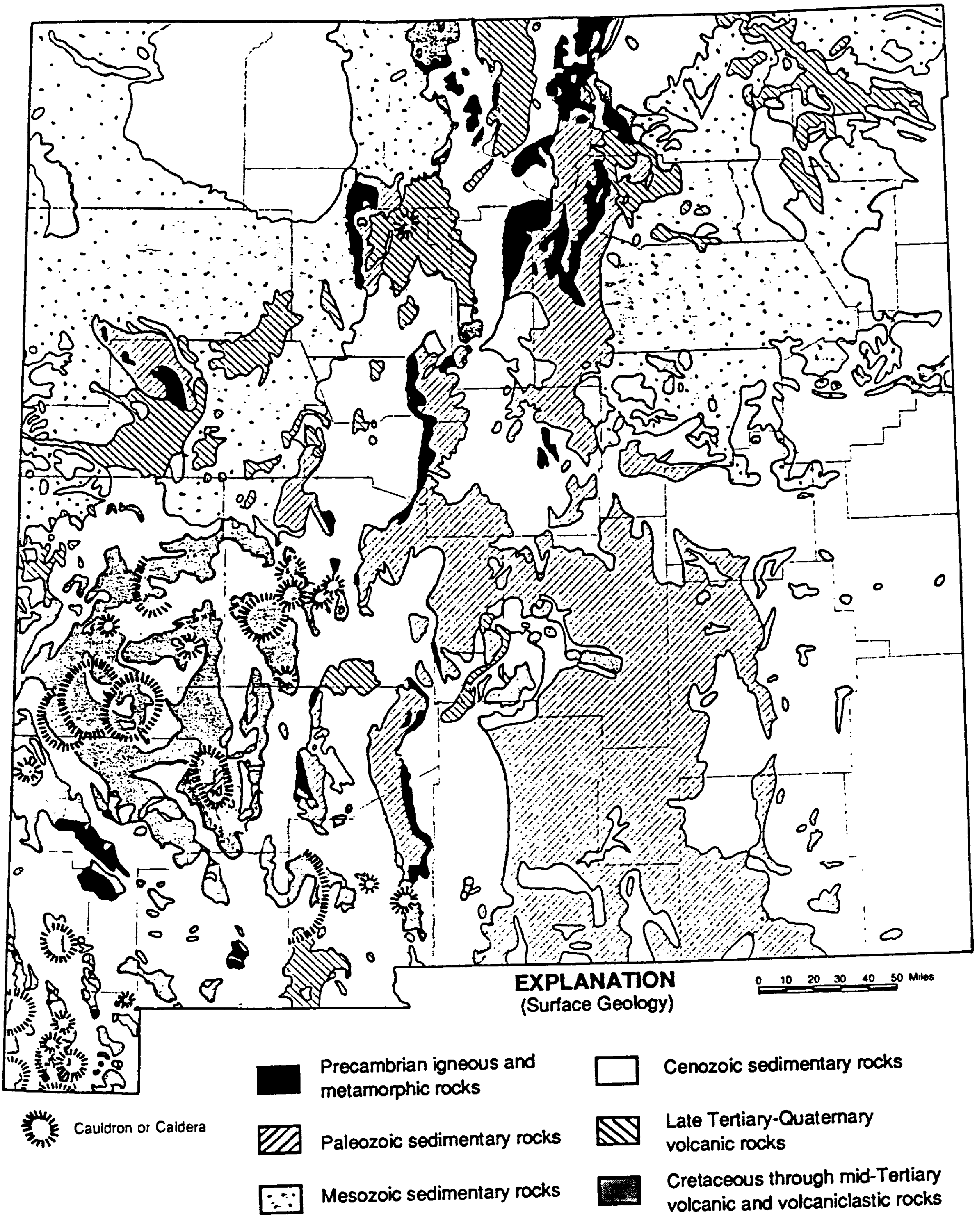


Figure 3. Map showing generalized geology of New Mexico (modified from Kues and Calender, 1986).

Historically New Mexico has ranked first in uranium production in the United States since 1956 (McLemore, 1983; McLemore and Chenoweth, 1989). Many areas of the State contain uranium deposits or occurrences (fig. 4A) or potential uranium resources (fig. 4B) (Chenoweth, 1976; McLemore, 1983; McLemore and Chenoweth, 1989). Major uranium production was centered in the Grants uranium district at the southern margin of the San Juan Basin on the Colorado Plateau (Rautman, 1980). Prior to 1989, the Grants uranium district constituted the largest uranium-producing area in the United States. Minor sporadic uranium production from western San Juan County, where uranium was first discovered in New Mexico in 1918 (Hatchell, 1986), lasted until about 1980. Jurassic sandstones are the most common host to uranium ore in New Mexico, but rocks of all ages and lithologies, ranging from Precambrian granites to recent travertines, contain uranium (McLemore, 1983; McLemore and Chenoweth, 1989). Uranium occurs in sandstones, coals, limestones, shales, igneous and metamorphic rocks, pegmatites, veins, volcanic rocks, and breccia pipes. Much of the following discussion of uranium-bearing rocks in New Mexico is summarized from Chenoweth (1976), McLemore (1983), and McLemore and Chenoweth (1989); the latter report contains detailed discussions and references on the uranium resources of New Mexico.

Uranium deposits in New Mexico occur in three general settings: deposits in sedimentary rocks, fracture-controlled or vein-type deposits, and disseminated uranium deposits in igneous and metamorphic rocks (McLemore and Chenoweth, 1989). Uranium in sedimentary rocks occurs primarily in sandstones of the Upper Jurassic Morrison Formation, and to a lesser extent in other sandstones, in limestone-bearing formations, and other sedimentary rocks.

The Upper Jurassic Morrison Formation hosts the majority of New Mexico's uranium deposits in fluvial sandstone beds. The major uranium deposits of the Morrison Formation occur in the Grants uranium district along the southern flank of the San Juan Basin and in the Shiprock district in northwestern New Mexico. Uranium deposits also occur in the Morrison Formation of northeastern New Mexico, but they are generally small and low grade deposits.

Sandstone uranium deposits also occur in Pennsylvanian, Permian, Triassic, Cretaceous, Tertiary, and Quaternary rocks (Hilpert, 1969; Chenoweth, 1976; McLemore, 1983; McLemore and Chenoweth, 1989), but they are generally smaller in size and lower in grade than deposits in the Morrison Formation. Subsidiary to only the Morrison Formation deposits are the uranium deposits in the Upper Cretaceous Dakota Sandstone in the Grants uranium district. Other low-grade roll-front type uranium deposits occur in the Lower Cretaceous Burro Canyon Formation in the Chama Basin near Abiquiu, in the Upper Cretaceous Crevasse Canyon Formation in the area around Hook Ranch-Riley and Red Basin-Pietown, in the Eocene and Oligocene Galisteo Formation in the Hagan Basin, and in the Upper Cretaceous and Paleocene Ojo Alamo Sandstone near Mesa Portales.

Small sandstone-hosted uranium deposits occur at scattered localities throughout the State in rocks ranging in age from Pennsylvanian to Quaternary. These rocks include the Middle Pennsylvanian to Lower Permian Sangre de Cristo Formation; the Lower Permian Cutler, Abo, and Yeso Formations; the Upper Triassic Chinle Formation; the Upper Cretaceous Gallup Sandstone, Point Lookout Formation, Kirtland Shale, and Fruitland Formation; the Upper Cretaceous and lower Tertiary McRae Formation; the Eocene San Jose and Baca Formations; and the Oligocene to Pleistocne Santa Fe Group, which includes the Oligocene and Miocene Popotosa Formation.

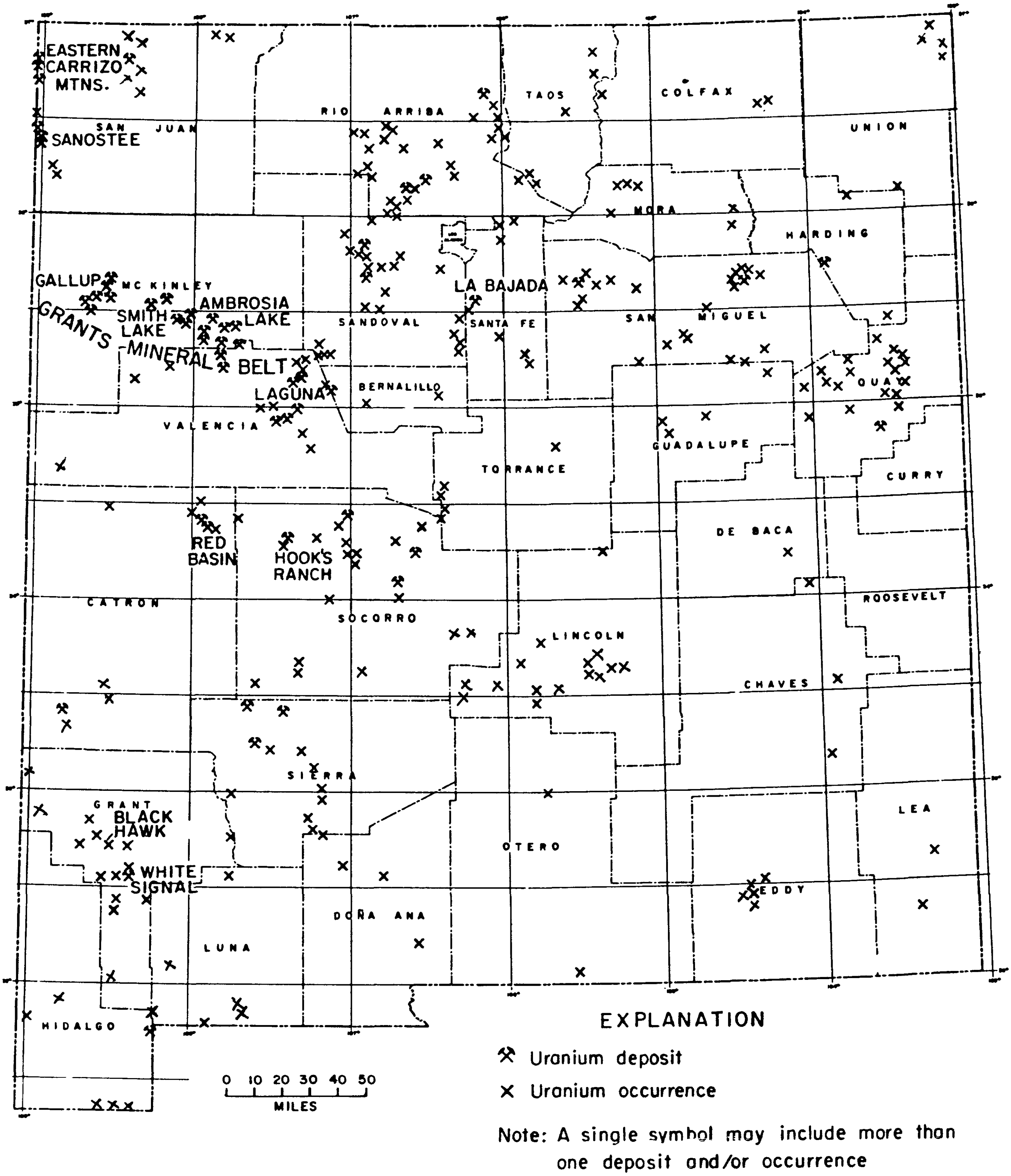


Figure 4A. Map showing uranium deposits and occurrences in New Mexico (modified from Chenoweth, 1976).

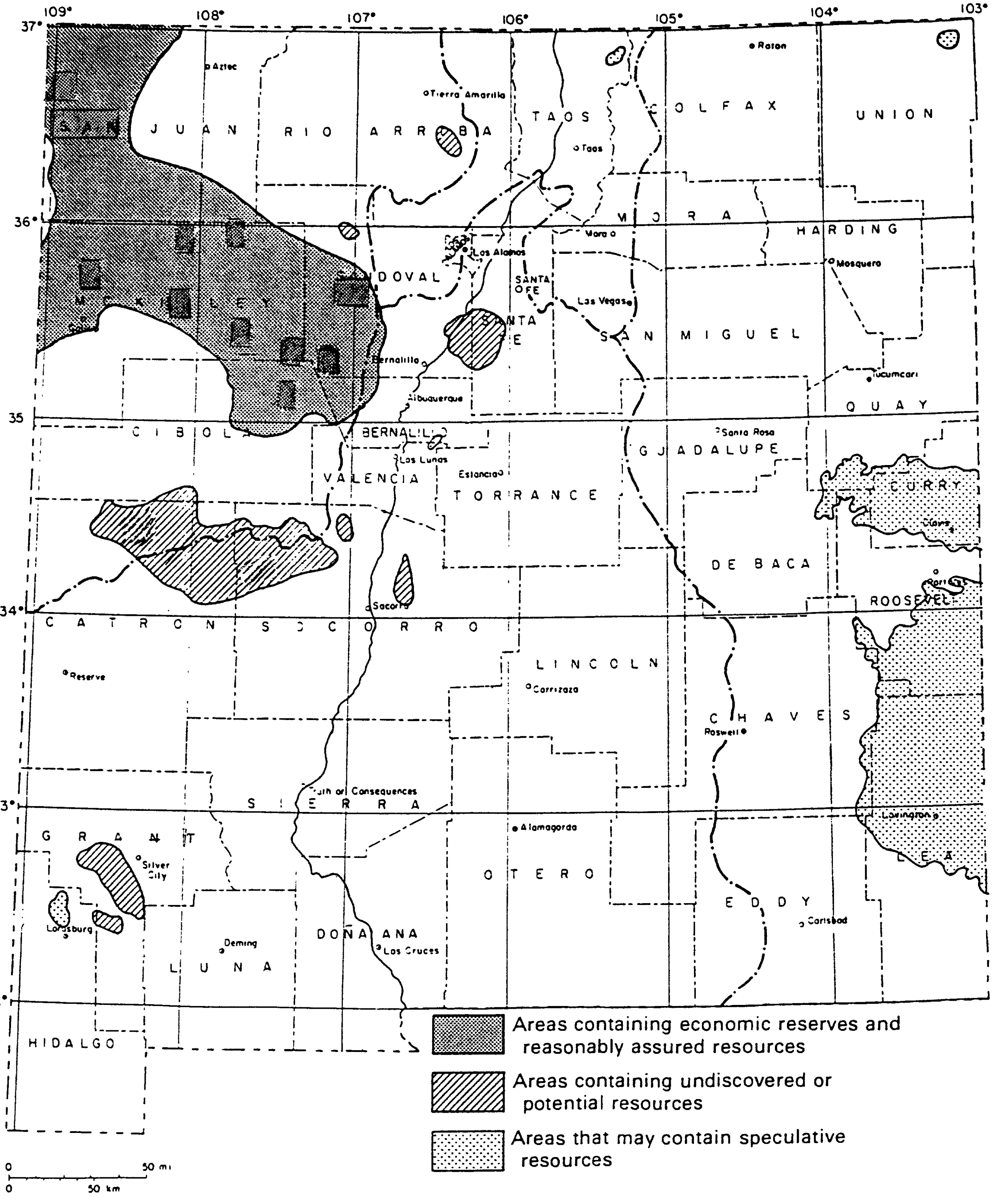


Figure 4B. Map showing areas of uranium resources and resource potential in New Mexico (modified from McLemore and Chenoweth, 1989).

Additional significant uranium deposits in New Mexico occur in rocks other than sandstone. Important uranium deposits occur in limestones of the Middle Jurassic Todilto Limestone Member of the Wanakah Formation in the Grants uranium district along the southern San Juan Basin, and minor uranium occurrences are known from the Permian Yates, Seven Rivers, and Queen Formations in Eddy County near Carlsbad. Significant uranium has been produced from vein-type deposits within the conglomerates of the Santa Fe Group and Precambrian granite in the Ladron Mountains, and other minor vein-type occurrences are along the Rio Grande valley in Socorro and Sierra Counties and at the La Bajada deposit in the Oligocene Espinaso Volcanics. Mineralized collapse-breccia pipes constitute minor uranium occurrences in the southern San Juan Basin and in the Black Mesa area.

Igneous and metamorphic rocks are known to contain small and scattered uranium deposits or occurrences in New Mexico (McLemore and Chenoweth, 1989). Many scattered localities contain small uraniferous epithermal veins, but they are generally thin and discontinuous or have sporadically distributed uranium minerals. Minor uranium ore and small uranium occurrences have been noted as disseminated uranium minerals from igneous and metamorphic rocks, including pegmatites, alkalic rocks, granites, carbonatite dikes, diatremes, volcanogenic strata, and contact metamorphosed rocks. Uranium is locally found in volcanogenic deposits near Tertiary calderas, such as in Socorro and Sierra Counties.

Groundwater in northeastern and east-central New Mexico may contain uranium (McLemore and Chenoweth, 1989) and thus may contribute to elevated levels of indoor radon when the radon dissolved in the water degasses into the indoor air. Anomalous concentrations of uranium in groundwater occur north of the outcrop of the Morrison Formation in southern Union County and eastern Harding County (McLemore and North, 1985). The Miocene Ogallala Formation in southeastern New Mexico may contain small surficial uranium deposits in calcrete and may contribute to anomalous uranium in groundwater where the Ogallala serves as an aquifer.

SOILS

A generalized soil map of New Mexico (fig. 5) compiled from Maker and Daugherty (1986) shows that the southern half of New Mexico is dominated by Aridisols, and to a lesser extent by Mollisols, with minor areas of Alfisols, Entisols, and small areas of gypsum sands and basaltic lavas. In the northern half of New Mexico, the northwestern quarter of the State is dominated by Entisols. The remaining part contains primarily Aridisols and Mollisols, with minor regions of Alfisols and basaltic lavas. Data on soil permeability and clay content was not readily available at the scale of the map used in figure 5, and for the purposes of estimating the radon potential of areas in the State later in this report, each area was considered to have moderate soil permeability. County and district soil surveys (U.S. Soil Conservation Service and U.S. Forest Service) are available for most of the State. They should be consulted for more detailed information on soil texture, structure, permeability, and seasonal moisture content for specific localities.

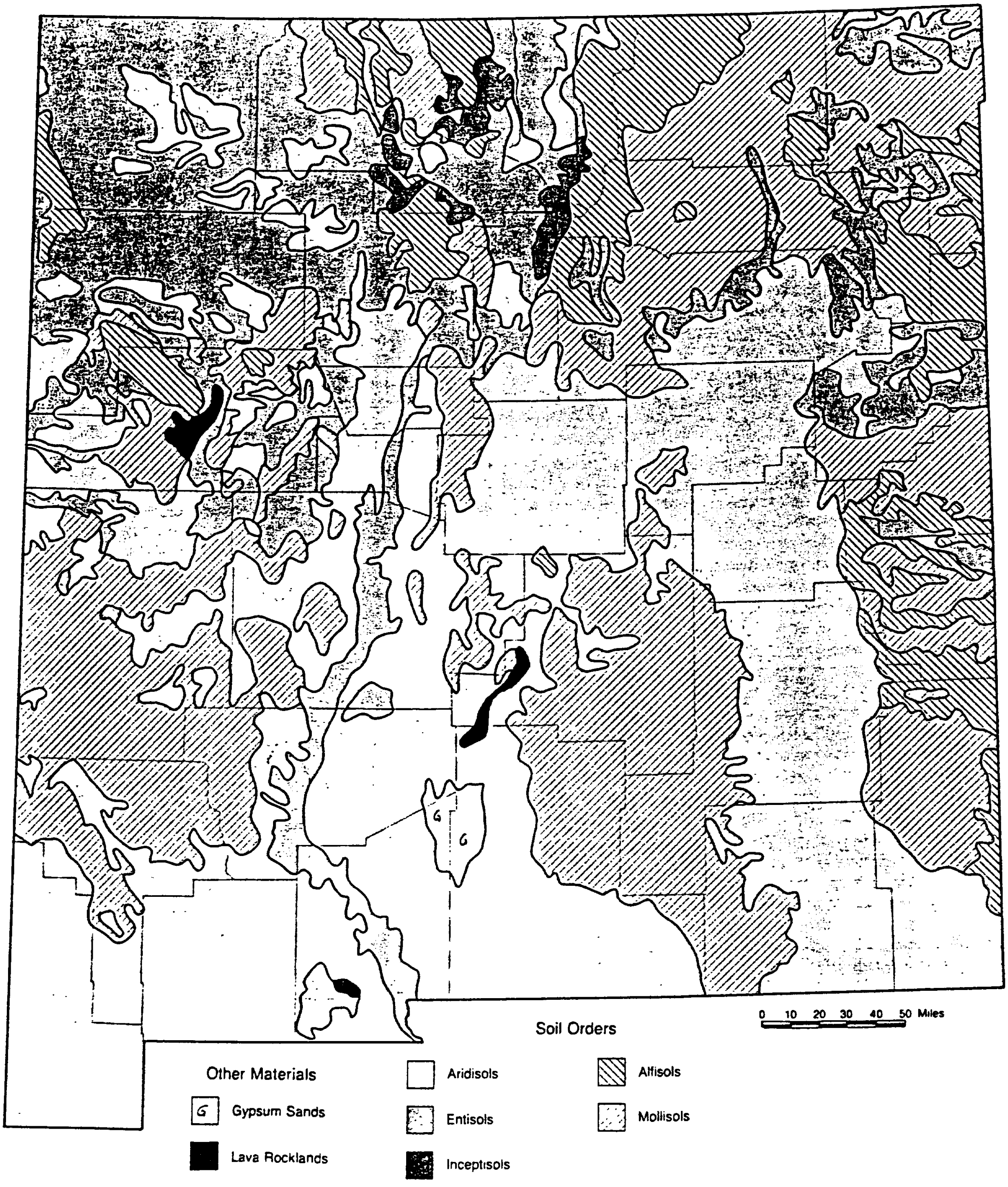


Figure 5. Map showing generalized soils of New Mexico (modified slightly from Maker and Daugherty, 1986).

INDOOR RADON DATA

Screening indoor radon data for New Mexico from the State/EPA Residential Radon Survey (fig. 6, Table 1) was collected during the winter of 1988-89. Data is shown in figure 6 only for those counties in which five or more measurements were made. A map showing the counties in New Mexico (fig. 7) is provided to facilitate discussion of correlations among indoor radon data (fig. 6), geology (fig. 3), aerial radiometric data (fig. 8), and soils (fig. 5). In this discussion, "elevated" indoor radon levels refers to average indoor radon levels greater than 4.0 pCi/L. Seven counties—Colfax, McKinley, Mora, San Miguel, Sandoval, Santa Fe, and Taos—had screening indoor radon averages greater than 4 pCi/L. The other counties had screening indoor radon averages less than 4 pCi/L. Eighteen counties throughout the State (fig. 6, Table 1) had screening indoor radon averages between 2 and 4 pCi/L, and the remaining 8 counties had indoor radon averages less than 2 pCi/L (fig. 6; Table 1).

Elevated indoor radon levels appear to correlate with the geology and physiography of several areas. Counties with the highest indoor radon averages coincide with outcrops of Jurassic to Cretaceous fluvial sandstones and marine shales along the western and southern margins of the San Juan Basin in northwestern New Mexico; with the Tertiary and Quaternary volcanic rocks of the Jemez Mountains in north-central New Mexico; and with Precambrian gneiss, Cretaceous and Tertiary marine shale, and Tertiary and Quaternary volcanic and intrusive rocks in northeastern New Mexico. Each of these areas has a corresponding high radiometric signature on the aerial radiometric map (fig. 8).

GEOLOGIC RADON POTENTIAL

A comparison of geology (fig. 3) with aerial radiometric data (fig. 8) and indoor radon data (fig. 6) provides preliminary indications of rock types and geologic features suspected of producing elevated indoor radon levels. This evaluation parallels the study of radon availability in New Mexico by McLemore and Hawley (1988), but the present study identifies areas based on geologic terranes and does not identify specific counties with potential radon availability as they did. As pointed out by McLemore and Hawley (1988), counties in New Mexico are very large, and major geologic features cut across county boundaries, thus creating problems in ranking counties for radon availability. They also point out that New Mexico's population is sparse and is concentrated in cities and towns. This population distribution must also be considered in evaluating the indoor radon data (fig. 6), which are grouped by county.

An overriding factor in the geologic evaluation is the abundance and widespread outcrops in local areas of known uranium-producing and uranium-bearing rocks in the State (fig. 3; McLemore, 1983). Rocks known to contain significant uranium deposits, occurrences, or reserves (McLemore, 1983, 1988; McLemore and Chenoweth, 1989), and rocks such as marine shales or phosphatic limestones that are known to typically contain low but uniform concentrations of uranium, all have the potential to contribute to elevated levels of indoor radon. In New Mexico, these rocks include Precambrian granites, pegmatites, and small hydrothermal veins; the Pennsylvsanian and Permian Cutler Formation, Sangre de Cristo Formation, and San Andres Limestone; the Triassic Chinle Formation; the Jurassic Morrison Formation and Todilto Limestone Member (Wanakah Formation); the Cretaceous Dakota Sandstone, Kirtland Shale, Fruitland Formation, and Crevasse Canyon Formation; the Cretaceous and Tertiary Ojo Alamo Sandstone; Tertiary Ogallala Formation and Popotosa Formation (Santa Fe Group); Tertiary alkalic intrusives

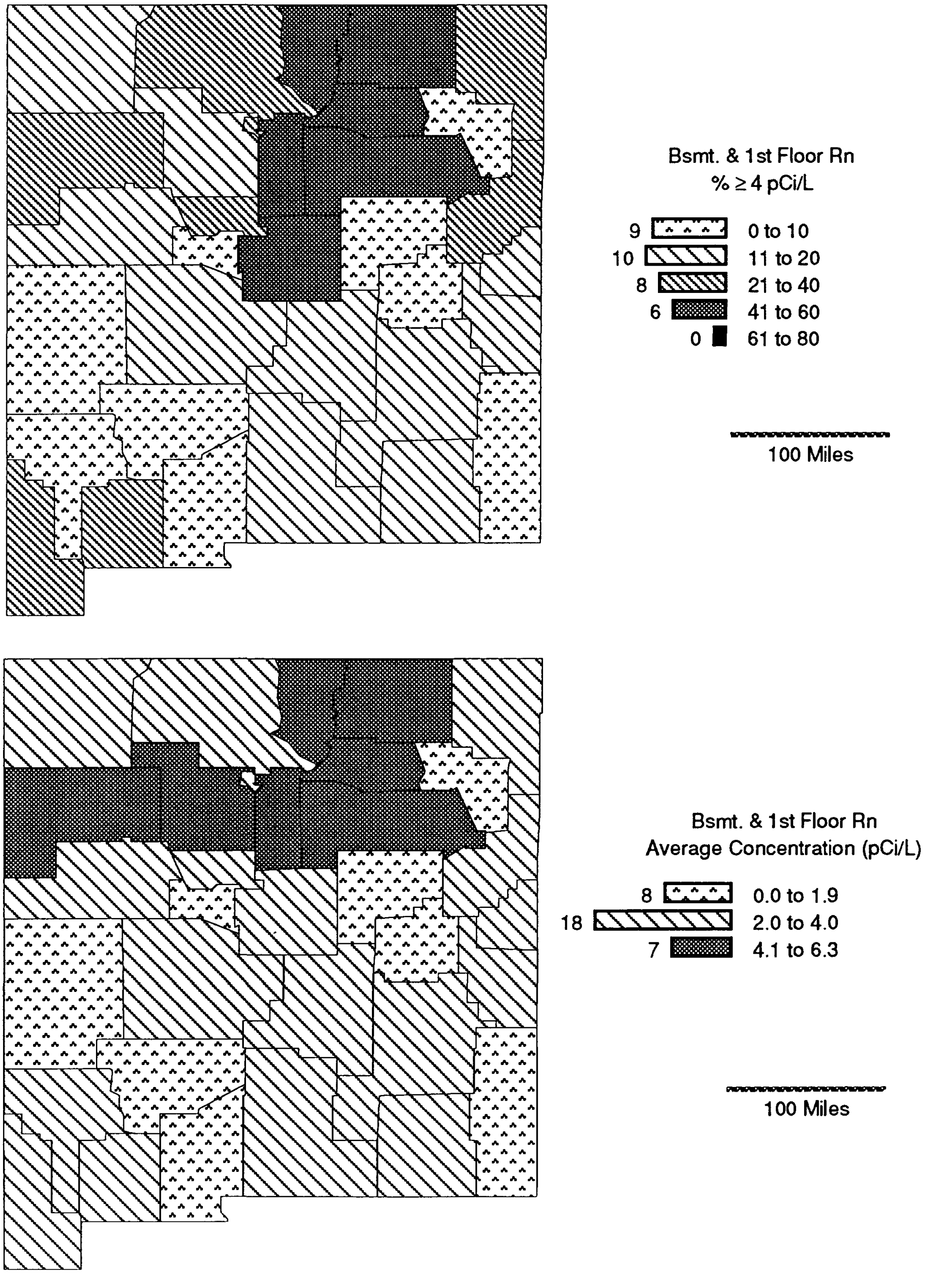


Figure 6. Screening indoor radon data from the EPA/State Residential Radon Survey of New Mexico, 1988-89, for counties with 5 or more measurements. Data are from 2-7 day charcoal canister tests. Histograms in map legends show the number of counties in each category. The number of samples in each county (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 New Mexico 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
BERNALILLO	406	3.7	2.7	2.6	3.5	27.0	28	1
CATRON	16	1.4	1.0	1.0	1.2	4.2	6	0
CHAVES	52	2.7	2.2	2.3	1.7	6.6	17	0
CIBOLA	6	2.3	1.8	2.3	1.5	4.7	17	0
COLFAX	91	6.0	3.8	3.9	11.5	105.4	49	3
CURRY	47	2.6	1.9	2.1	2.1	11.3	13	0
DE BACA	12	1.3	1.1	1.0	1.0	4.2	8	0
DONA ANA	86	1.8	1.4	1.3	1.4	9.0	7	0
EDDY	51	2.0	1.2	1.3	1.9	7.5	16	0
GRANT	60	2.1	1.3	1.5	2.1	13.4	10	0
GUADALUPE	8	1.3	1.0	1.1	0.8	2.7	0	0
HARDING	12	1.9	1.2	1.1	1.9	6.9	8	0
HIDALGO	18	3.7	2.8	3.4	2.8	12.5	39	0
LEA	50	1.6	1.1	1.1	1.4	7.6	6	0
LINCOLN	18	2.6	1.9	1.7	2.5	10.1	11	0
LOS ALAMOS	42	3.0	2.4	2.7	2.2	13.0	24	0
LUNA	49	3.8	2.5	2.4	4.6	27.7	22	2
MCKINLEY	53	6.0	2.8	3.2	13.0	87.3	34	6
MORA	17	4.6	3.5	3.9	3.2	11.5	41	0
OTERO	46	2.7	1.6	1.9	3.4	21.6	17	2
QUAY	10	3.2	2.7	2.6	1.8	6.0	30	0
RIO ARRIBA	72	3.4	2.3	2.2	4.0	24.7	21	1
ROOSEVELT	44	2.2	1.7	1.7	1.7	7.4	11	0
SAN JUAN	196	2.4	2.0	1.9	2.2	24.8	11	1
SAN MIGUEL	78	4.9	3.1	3.2	5.9	36.2	45	4
SANDOVAL	76	4.6	2.3	2.0	10.2	76.7	20	3
SANTA FE	73	4.6	3.2	3.5	3.8	21.6	41	1
SIERRA	41	1.3	1.0	1.0	0.9	3.9	0	0
SOCORRO	41	2.5	1.9	2.0	1.7	7.2	17	0
TAOS	47	6.3	3.8	4.7	6.6	31.4	57	4
TORRANCE	10	3.9	2.4	2.8	3.6	9.4	50	0
UNION	32	3.4	2.5	2.1	3.1	15.1	31	0
VALENCIA	25	1.9	1.8	1.7	0.8	3.6	0	0

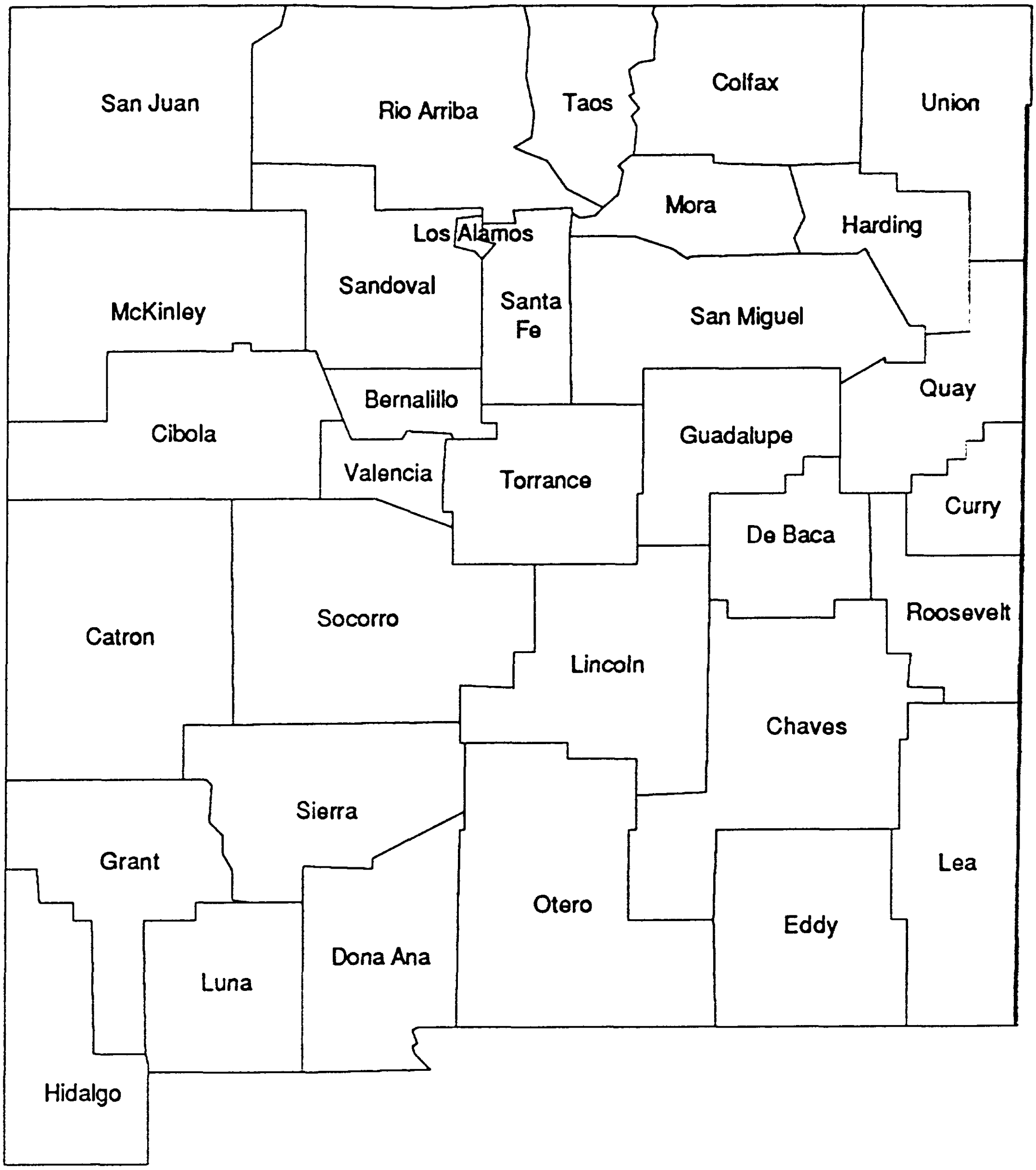


Figure 7. Map showing counties in New Mexico.

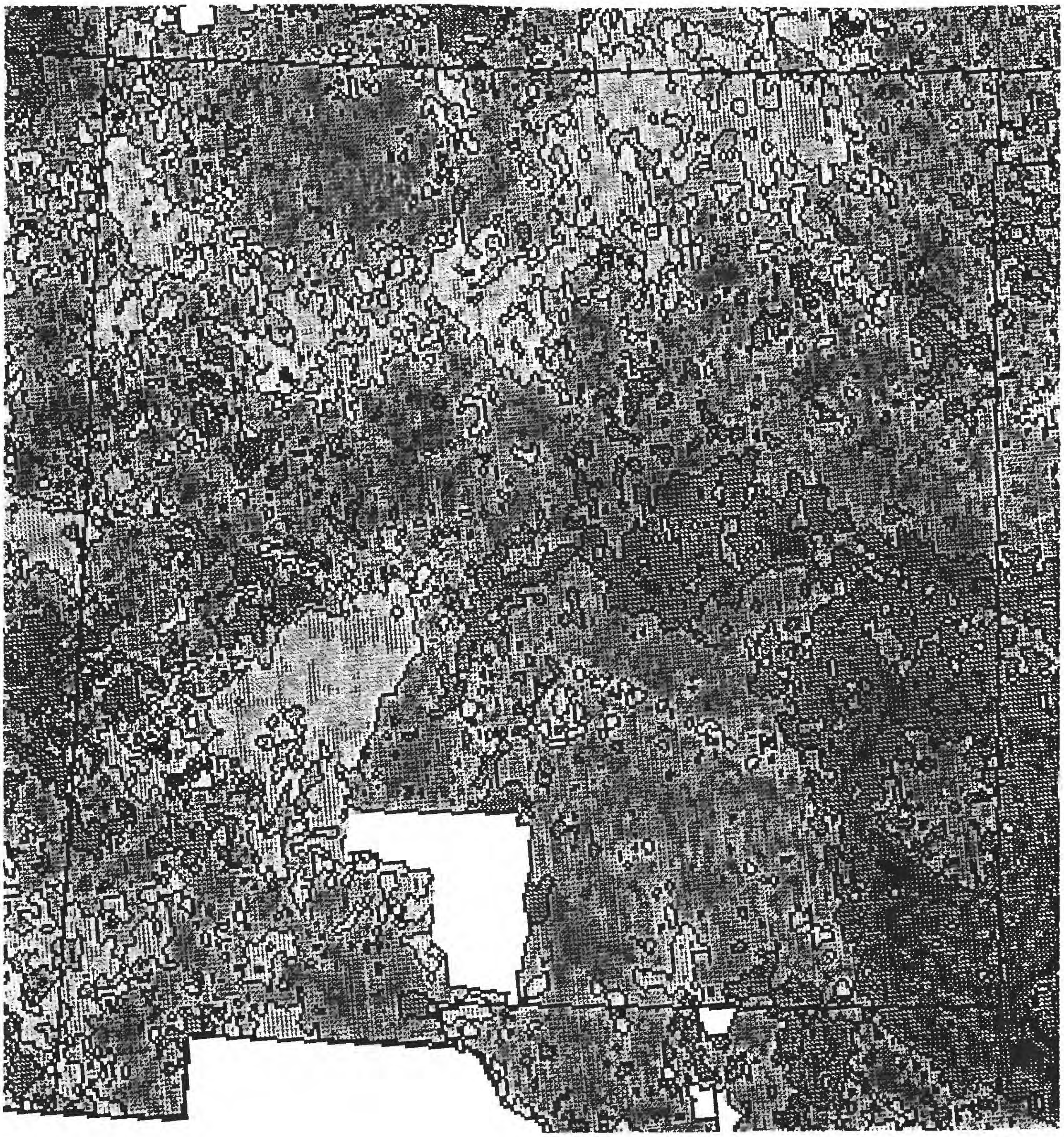


Figure 8. Aerial radiometric map of New Mexico (after Duval and others, 1989). Contour lines at 1.5 and 2.5 ppm equivalent uranium (eU). Pixels shaded from 0 to 6.0 ppm eU at 0.5 ppm eU increments; darker pixels have lower eU values; white indicates no data.

and rhyolitic and andesitic volcanic rocks such as the Alum Mountain andesite; and the Quaternary Bandelier Tuff and Valles Rhyolite.

Several areas in New Mexico contain outcrops of one or more of these rock units (fig. 4) that may contribute to elevated radon levels. The southern and western rims of the San Juan Basin expose a Paleozoic to Tertiary sedimentary section that contains the Jurassic, Cretaceous, and Tertiary sedimentary rocks that have a high radiometric signature (fig. 8) and that are known to host uranium deposits in the Grants uranium district, as well as in the Chuska and Carrizo Mountains. In north-central New Mexico, the Jemez Mountains are formed in part by volcanic rocks that include the Bandelier Tuff and the Valles Rhyolite; this area also has an associated high radiometric signature. In northeastern New Mexico, Precambrian crystalline rocks and Paleozoic sedimentary rocks of the southern Rocky Mountains and Tertiary volcanic rocks and Cretaceous sedimentary rocks are associated with radiometric highs. In southwestern New Mexico, middle Tertiary volcanic rocks of the Datil-Mogollon region are also associated with high radiometric signatures. Remaining areas of the Colorado Plateau, the Basin and Range, and the Great Plains are associated with only moderate to low radiometric signatures on the aerial radiometric map; these areas generally contain Paleozoic to Mesozoic sedimentary rocks, scattered Tertiary and Quaternary volcanic rocks, and locally Tertiary sedimentary rocks.

SUMMARY

For purposes of assessing the geologic radon potential of the State, New Mexico can be divided into 10 general areas (termed Area 1 through Area 10; fig. 9 and Table 2) and scored with a Radon Index (RI), a semi-quantitative measure of radon potential, and an associated Confidence Index (CI), a measure of the relative confidence of the assessment based on the quality and quantity of data used to make the evaluations. For further details on the ranking schemes and the factors used in the evaluations, refer to the Introduction chapter to this regional booklet. Note that in any specified area, smaller areas of either higher or lower radon potential than that assigned to the entire area may exist because of local factors influencing the generation and transport of radon.

Areas 1, 2, and 3 each have high radon potential (RI=12) associated with a high confidence index (CI=10) on the basis of high indoor radon measurements, high surface radioactivity as evidenced by the aerial radiometric data, and the presence of rocks such as Precambrian granites and uplifted Paleozoic strata, Jurassic sandstones and limestones, or Cretaceous to Tertiary shales and volcanic rocks that are known to contain or produce uranium. Area 1 includes the southern extension of the Rocky Mountains and uplifted Paleozoic sedimentary rocks; Area 2 includes Upper Cretaceous marine shales and uranium-bearing Jurassic fluvial sandstones of the Grants uranium belt; and Area 3 includes Tertiary volcanic rocks in the Jemez Mountains. Areas 4 through 10 each have moderate or variable geologic radon potential (RI=11 to 9) associated with a moderate confidence index (CI=9). These areas exhibit moderate indoor radon measurements, have moderate surface radioactivity, and contain rocks that are known to contain minor amounts of uranium or scattered uranium anomalies and occurrences. Area 4 includes Tertiary volcanic rocks of the Datil-Mogollon volcanic field. Area 5 is an eastward extension of the Basin and Range Province. Area 6 contains extensive outcrops of Late Paleozoic marine limestones. Area 7 includes three parts of New Mexico that have variable geology but that are primarily underlain by Cretaceous marine rocks. Area 8 encompasses Tertiary volcanic and Cretaceous sedimentary rocks. Area 9 is predominantly underlain by sedimentary rocks of the Tertiary Ogallala Formation. Area 10 is underlain primarily by Triassic and Quaternary deposits.

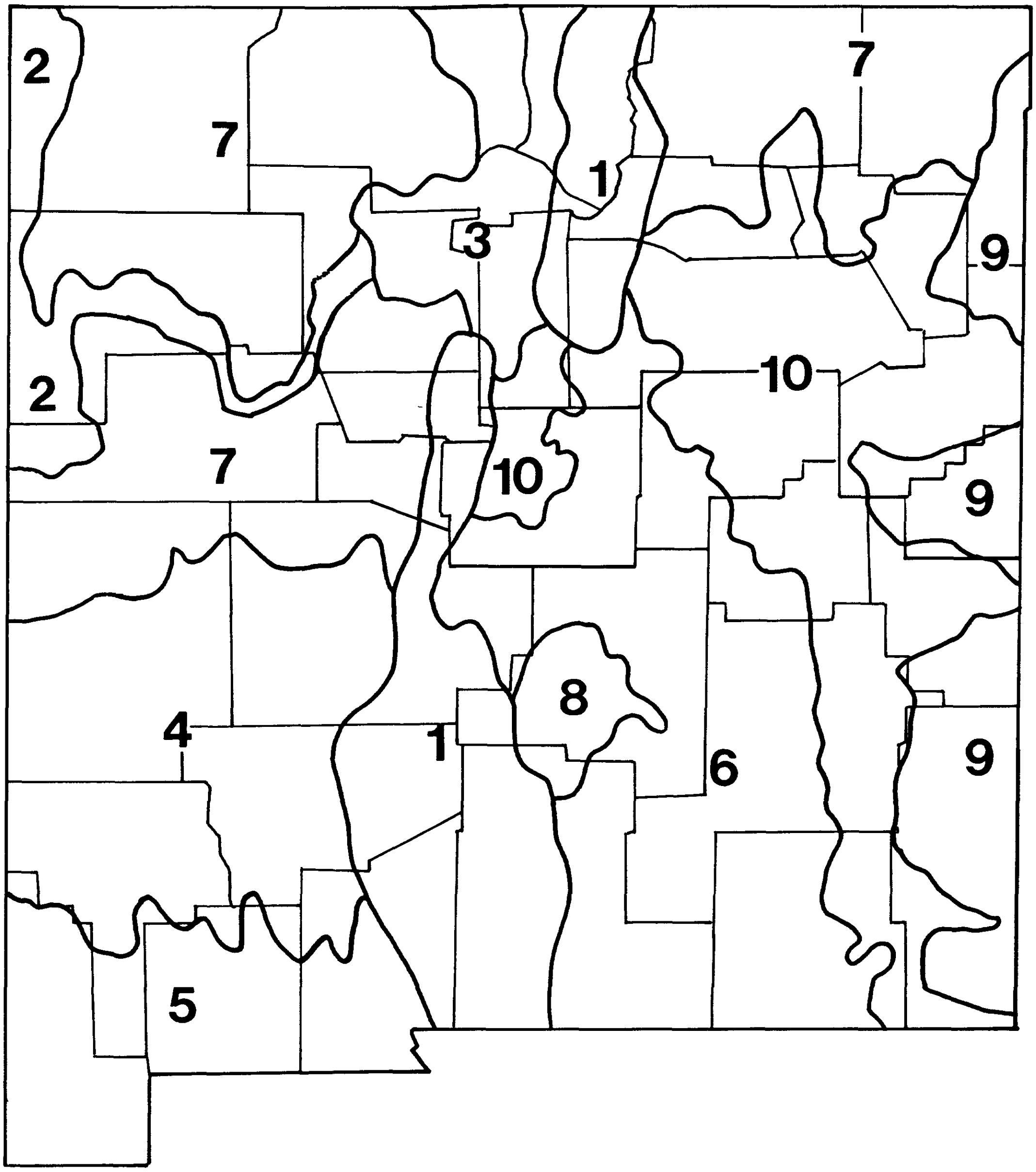


Figure 9. Map showing radon potential areas in New Mexico.

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

TABLE 2. Radon Index (RI) and Confidence Index (CI) scores for geologic radon potential areas of New Mexico. See figure 9 for locations of areas.

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

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

	Area 9		Area 10	
FACTOR	RI	CI	RI	CI
INDOOR RADON	2	3	3	3
RADIOACTIVITY	2	3	1	3
GEOLOGY	2	2	2	2
SOIL PERM.	2	1	2	1
ARCHITECTURE	1	--	1	--
GFE POINTS	0	--	0	--
TOTAL	9	9	9	9
RANKING	MOD	MOD	MOD	MOD

RADON INDEX SCORING:

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

Possible range of points = 3 to 17

CONFIDENCE INDEX SCORING:

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

Possible range of points = 4 to 12

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PRELIMINARY GEOLOGIC RADON POTENTIAL ASSESSMENT OF OKLAHOMA

by

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INTRODUCTION

This assessment of the radon potential of Oklahoma relies heavily on geologic information derived from publications of the Oklahoma Geological Survey, especially Flood and others (1990), from publications of the U.S. Geological Survey, and from an analysis of data gathered by U.S. Environmental Protection Agency (EPA) and the Oklahoma Department of Health during a radon survey in the winter of 1989-1990. Much information on the geographic setting is derived from The National Atlas of the United States of America.

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

Oklahoma lies within the continental interior of the United States and extends from the northern edge of the Gulf Coastal Plain to the western part of the High Plains. Several physiographic subdivisions are recognized, but various sources differ as to nomenclature. A simplified version (fig. 1) of the physiographic map in Johnson and others (1972) has been used in the discussion below. The High Plains of western Oklahoma is characterized by flat upland surfaces that are deeply dissected along rivers and major streams; relief in dissected areas is 50-200 ft in the east and 200-600 ft in the far west. In the western part more than 80 percent of the land surface is gently sloping, whereas in the eastern part 50-80 percent of the land surface is gently sloping.

The Central Oklahoma Plains and Hills are characterized by irregular hills and plains of low relief (100-300 ft) where 50-80 percent of the land is gently sloping. Areas of low hills and smooth plains of low relief occur in the northern, northeastern, and southwestern part of the province. In the areas of low hills and smooth plains, more than 80 percent of the land surface is gently sloping. Low hills (Arbuckle Mountains) occur within this province in southern Oklahoma. Cuestas are common in the eastern third of this province, and low hills are common in the western third of this province. Several belts of sand dunes lie along the major river valleys in the western half of the Central Oklahoma Plains and Hills.

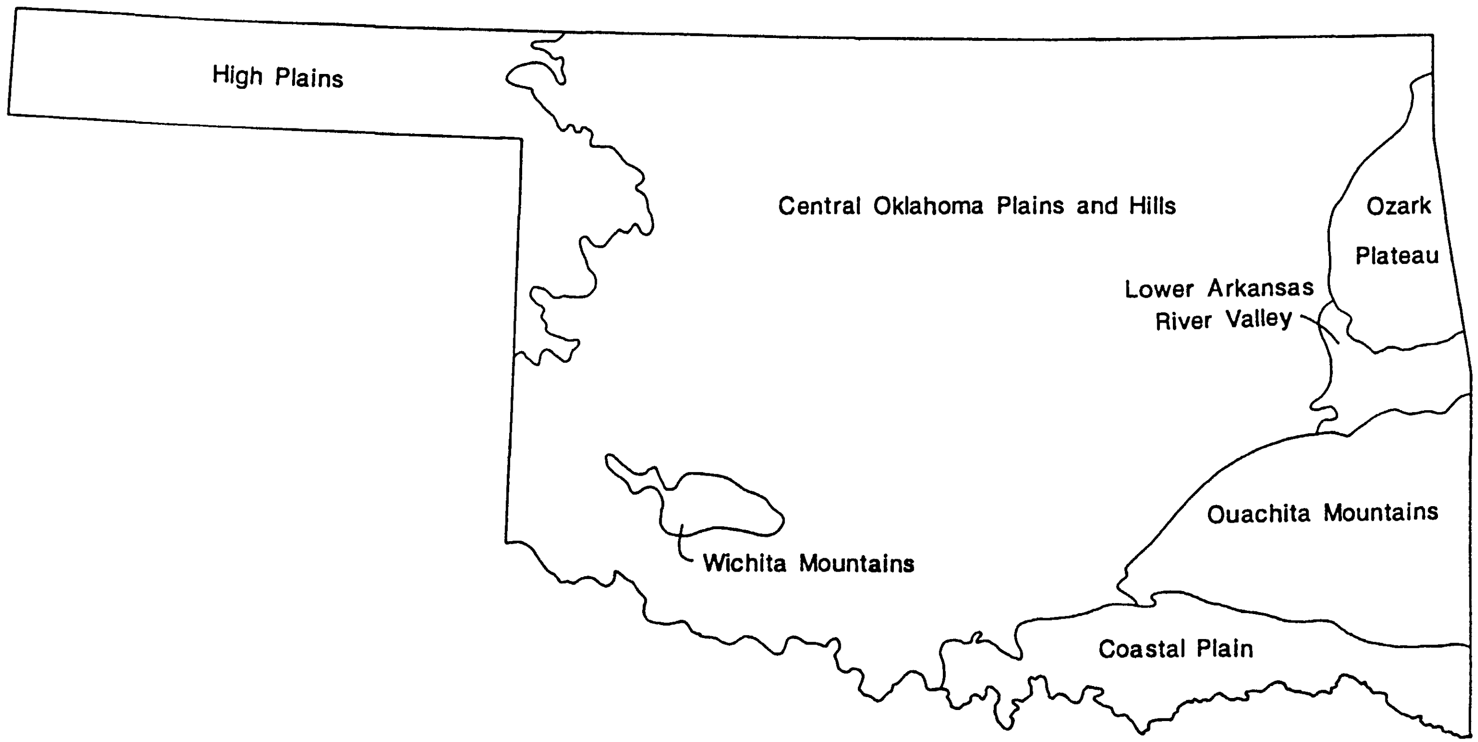


Fig. 1- Map showing physiographic provinces of Oklahoma. Modified from page 3 of Johnson and others (1972).

The Wichita Mountains are low mountains of moderate local relief (300-1,000 ft); 50-80 percent of the surface is gently sloping. The Ouachita Mountains are an area of open high hills (100-500 ft of local relief) to open low mountains (500-1,000 ft of local relief) where 20-50 percent of the land surface is gently sloping. The Ozark Plateau features tablelands of moderate relief (100-300 ft) where 50-80 percent of the land surface is gently sloping and high hills (local relief 300-800 ft) where less than 20 percent of the land surface is gently sloping. Between the Ouachita Mountains and the Ozark Plateau lies the lower Arkansas River Valley, which features broad valleys with intervening flat-topped hills where the local relief is 300-1,500 ft and 50-80 percent of the land surface is gently sloping. The Coastal Plain forms a small area of irregular gently dissected plains where local relief ranges 50-100 ft.

Rainfall in Oklahoma decreases progressively from the southeastern corner of the State, where the mean annual precipitation is as much as 60 inches, to the western part of the Panhandle, where the mean annual precipitation is less than 16 inches. Precipitation in the High Plains is generally 16 to 24 inches, whereas in the Central Oklahoma Plains and Hills it ranges from 24 to 40 inches.

Most of the population of Oklahoma is located in major metropolitan areas, primarily in Cleveland, Tulsa , and Comanche Counties (figs. 2 and 3). The remaining populace is rather evenly distributed in small towns throughout the rural parts of the State, except in the northwestern corner where the population density is somewhat less.

Agriculture varies considerably across the State. The High Plains are used for dryland and irrigated crops, although in some areas semiarid grasslands are used for grazing. The Central Oklahoma Plains and Hills are dominated by dryland crops although substantial areas of pasture, grazed woodland, grazing land, and forest occur east of Oklahoma City. The Wichita Mountains are a mix of open grazed woodlands and semiarid grazing lands. The Ouachita Mountains are dominated by forests and grazed woodlands mixed with croplands and pastures. The Ozark Plateau is comprised mostly of forest and grazed woodland with lesser cropland, pasture, and grazing land. The lower Arkansas River Valley is cropland with pasture, woodland, and forest. The Coastal Plain is a mix of cropland, pasture, and forest.

GEOLOGIC SETTING

The geology of Oklahoma is dominated by sedimentary rocks and unconsolidated sediments which vary in age from Cambrian to Holocene. Precambrian and Cambrian igneous rocks are exposed in the core of the Arbuckle and Wichita Mountains (fig. 4) and they crop out in about 1 percent of the State. Structurally, the western, northern, and central part of the State is underlain by very gently west-dipping sedimentary rocks of the northern shelf areas. A series of uplifts and basins flank the central shelf area (fig. 4). The Gulf Coastal Plain lies along the southeastern edge of the State.

Most of the rocks that crop out in the central and eastern part of the State are marine in origin; they include limestone, dolomite, shale, sandstone, chert, and coal of Cambrian through Permian age (fig. 5). Nonmarine rocks of Permian and Tertiary age, including shale, sandstone, and conglomerate, are present in the western part of the central Oklahoma Hills and Plains area; sand, clay, gravel, and caliche dominate the High Plains in the western part of the State. The Gulf Coastal Plain is underlain by Cretaceous nonmarine sand and clay and marine limestone and clay. Some of these units locally are moderately uraniferous (see discussion in Flood and others, 1990, and Totten and Fay, 1982).

Fig. 2- Map showing counties and county names in Oklahoma.

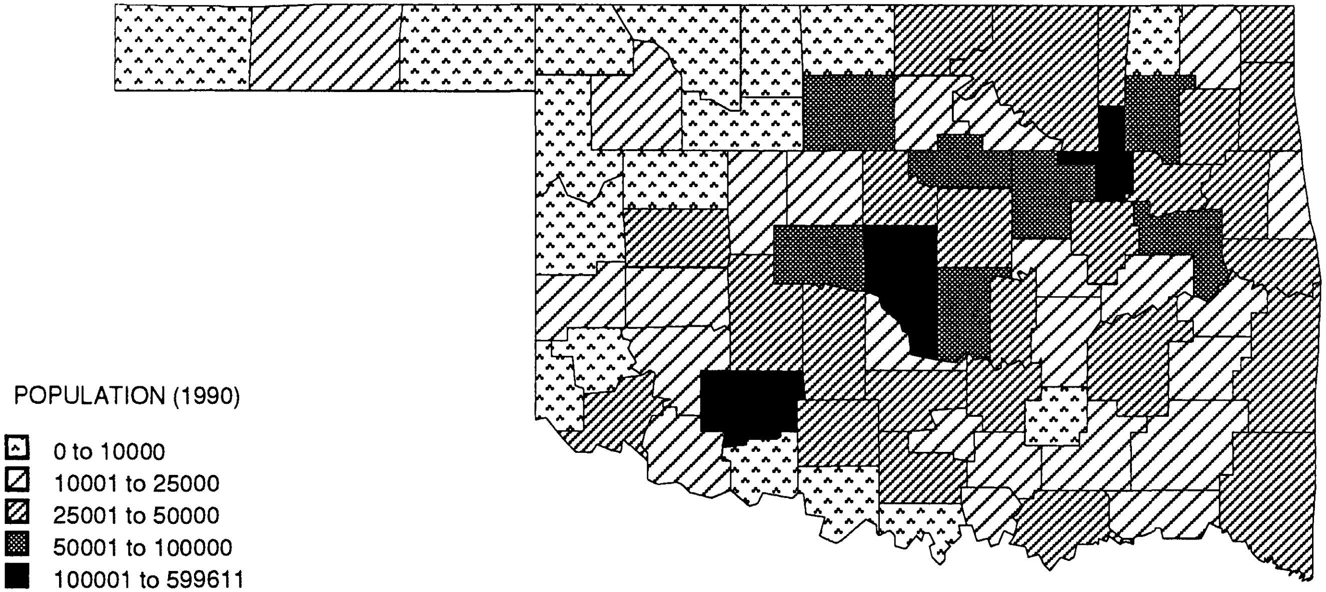


Figure 3. Population of counties in Oklahoma (1990 U.S. Census data).

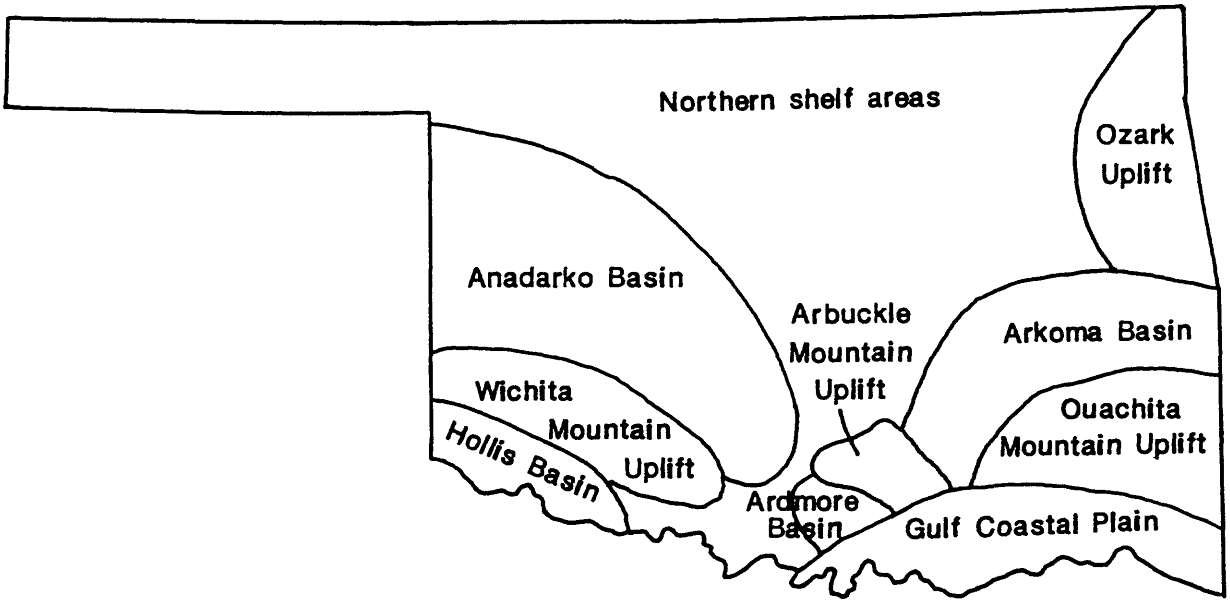
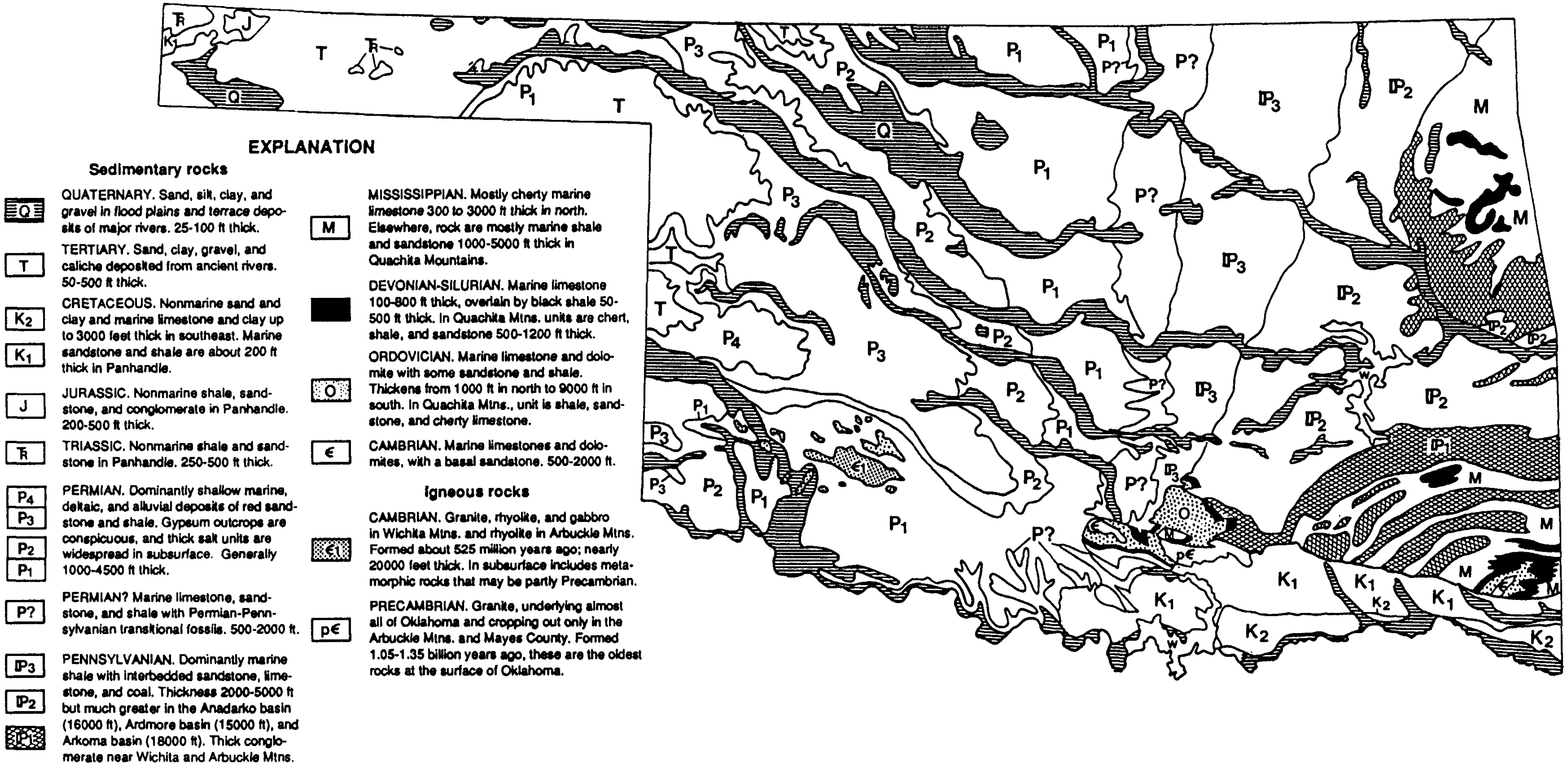


Fig. 4- Major geologic provinces of Oklahoma. From Johnson and others (1972).



EXPLANATION

Sedimentary rocks

Q — QUATERNARY. Sand, silt, clay, and gravel in flood plains and terrace deposits of major rivers. 25-100 ft thick.

T — TERTIARY. Sand, clay, gravel, and caliche deposited from ancient rivers. 50-500 ft thick.

K2 / K1 — CRETACEOUS. Nonmarine sand and clay and marine limestone and clay up to 3000 feet thick in southeast. Marine sandstone and shale are about 200 ft thick in Panhandle.

J — JURASSIC. Nonmarine shale, sandstone, and conglomerate in Panhandle. 200-500 ft thick.

TR — TRIASSIC. Nonmarine shale and sandstone in Panhandle. 250-500 ft thick.

P4 / P3 / P2 / P1 — PERMIAN. Dominantly shallow marine, deltaic, and alluvial deposits of red sandstone and shale. Gypsum outcrops are conspicuous, and thick salt units are widespread in subsurface. Generally 1000-4500 ft thick.

P? — PERMIAN? Marine limestone, sandstone, and shale with Permian-Pennsylvanian transitional fossils. 500-2000 ft.

IP3 / IP2 / IP1 — PENNSYLVANIAN. Dominantly marine shale with interbedded sandstone, limestone, and coal. Thickness 2000-5000 ft but much greater in the Anadarko basin (16000 ft), Ardmore basin (15000 ft), and Arkoma basin (18000 ft). Thick conglomerate near Wichita and Arbuckle Mtns.

M — MISSISSIPPIAN. Mostly cherty marine limestone 300 to 3000 ft thick in north. Elsewhere, rock are mostly marine shale and sandstone 1000-5000 ft thick in Quachita Mountains.

■ — DEVONIAN-SILURIAN. Marine limestone 100-800 ft thick, overlain by black shale 50-500 ft thick. In Quachita Mtns. units are chert, shale, and sandstone 500-1200 ft thick.

O — ORDOVICIAN. Marine limestone and dolomite with some sandstone and shale. Thickens from 1000 ft in north to 9000 ft in south. In Quachita Mtns., unit is shale, sandstone, and cherty limestone.

Є — CAMBRIAN. Marine limestones and dolomites, with a basal sandstone. 500-2000 ft.

Igneous rocks

Є1 — CAMBRIAN. Granite, rhyolite, and gabbro in Wichita Mtns. and rhyolite in Arbuckle Mtns. Formed about 525 million years ago; nearly 20000 feet thick. In subsurface includes metamorphic rocks that may be partly Precambrian.

pЄ — PRECAMBRIAN. Granite, underlying almost all of Oklahoma and cropping out only in the Arbuckle Mtns. and Mayes County. Formed 1.05-1.35 billion years ago, these are the oldest rocks at the surface of Oklahoma.

Fig. 5 - Generalized geologic map of Oklahoma. Modified from page 4 in Johnson and others (1972).

An aeroradiometric map of Oklahoma (fig. 6) shows that the average equivalent uranium (eU) content of materials at the surface is about 1.5-2.0 ppm. Surface materials across the State vary from less than 0.5 ppm to 5.0 ppm eU. Higher levels of uranium (>2.5 ppm) are consistently associated with black shales in the southeastern and westernmost Ouachita Mountains, the Arbuckle Mountains, and the Ozark Plateau; with Permian shale in Roger Mills, Custer, Washita, and Beckham Counties; with granites and related rocks in the Wichita Mountains; and with Cretaceous shale and associated limestone in the Coastal Plain. Low eU values (<1.5 ppm) are associated with large areas of dune sand adjacent to rivers in western Oklahoma; with eolian sands in the High Plains in Cimarron and Ellis Counties; and with Mississippian and Pennsylvanian rocks in the Ouachita Mountains, the Ozark Plateau, and the eastern part of the central Oklahoma plains and hills.

SOILS

Soils of the High Plains lie within the mesic ustic soil temperature and soil moisture regime (Rose and others, 1990) and thus are moderately moist in the wintertime (44-56 percent pore saturation in sandy loams, and 58-74 percent in a silty clay loam) and slightly moist in the summertime (24-44 percent pore saturation in sandy loams, and 39-58 percent pore saturation in silty clay loams). Soils of the western two-thirds of the Central Oklahoma Plains and Hills and the Wichita Mountains are within the thermic ustic regime and are similarly moderately moist in the wintertime (44-56 percent saturation in sandy loams, and 58-74 percent in a silty clay loam) and slightly moist in the summertime (24-44 percent pore saturation in sandy loams, and 39-58 percent pore saturation in silty clay loams). Soils in the eastern part of the Oklahoma Hills and Plains, the Arbuckle and Ouachita Mountains, the Coastal Plain, and Arkansas River Valley are generally thermic udic and are very moist in the wintertime (56-96 percent pore saturation in sandy loams, and 74-99 percent saturation in a silty clay loam) and slightly moist in the summertime (24-44 percent pore saturation in sandy loams, and 39-58 percent pore saturation in silty clay loams). In the Ozark Plateau, soils are mesic udic and thus are very moist in the wintertime (56-96 percent pore saturation in sandy loams, and 74-99 percent saturation in a silty clay loam) and moderately moist in the summertime (44-56 percent saturation in sandy loams, and 58-74 percent in a silty clay loam).

There are few areas in Oklahoma where highly permeable soils occur (>6 inches per hour in a percolation test). Some of the sandy soils developed on eolian deposits in the High Plains and along several rivers are locally rapidly permeable (6-20 inches per hour). Steep, well-drained, sandy to gravelly soils such as those that might develop on sandstone substrate on river bluffs and alluvium on river terraces are also locally rapidly permeable.

INDOOR RADON DATA

The U.S. EPA and the Oklahoma State Department of Health completed a population-weighted survey of indoor radon levels in Oklahoma during the winter of 1989-1990 (Table 1, fig. 7). Sampled houses were randomly selected from existing housing stock, which means that homes sampled tend to cluster in the more populated areas. Interpretations of population-based data must be made with caution, because the measured houses are typically only from a relatively few population centers within a given county or area and do not provide geographic coverage of

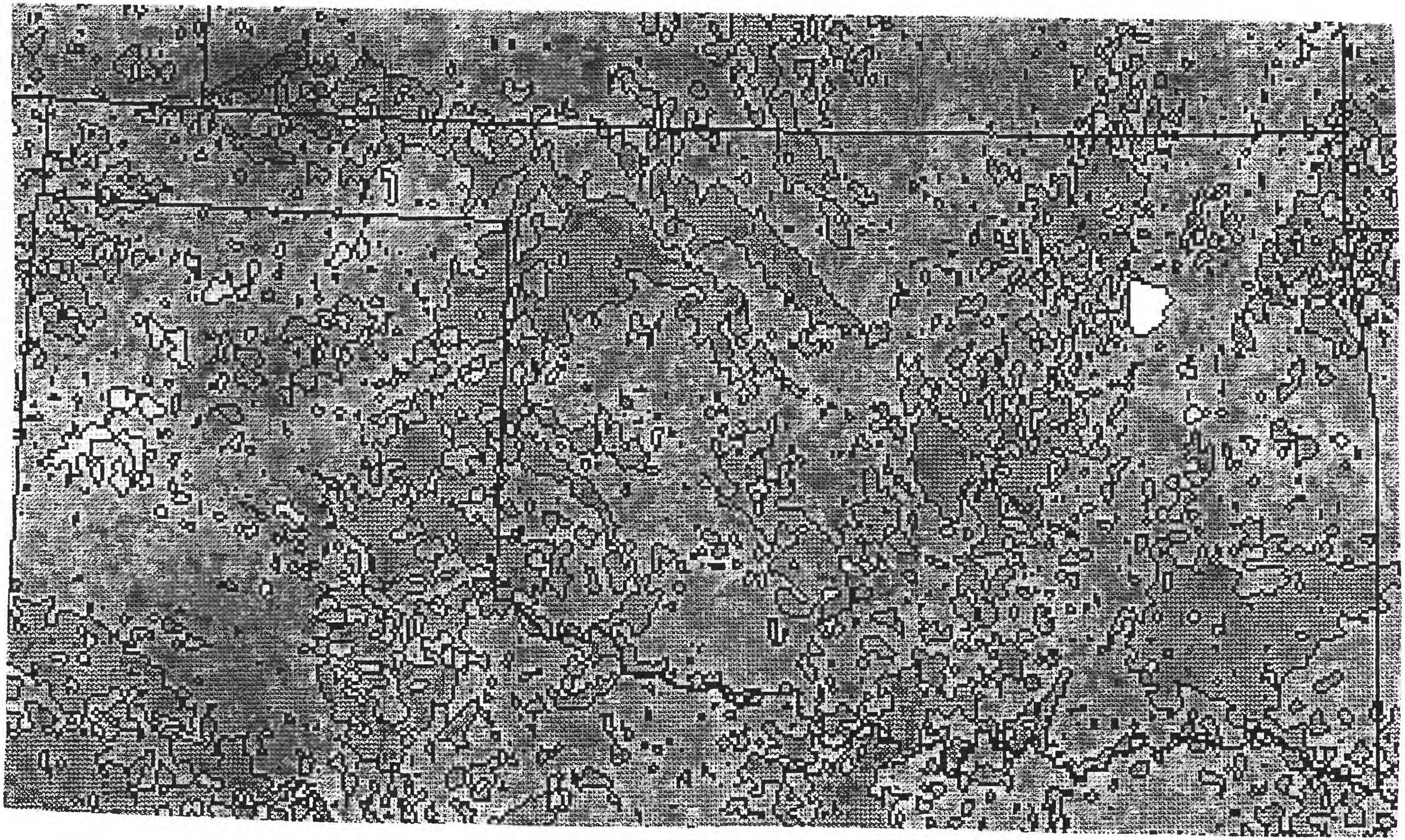


Fig. 6- Aerial radiometric map of Oklahoma (after Duval and others, 1989). Contour lines at 1.5 and 2.5 ppm equivalent uranium (eU). Pixels shaded from 0 to 6.0 ppm eU at 0.5 ppm eU increments; darker pixels have lower eU values; white indicates no data.

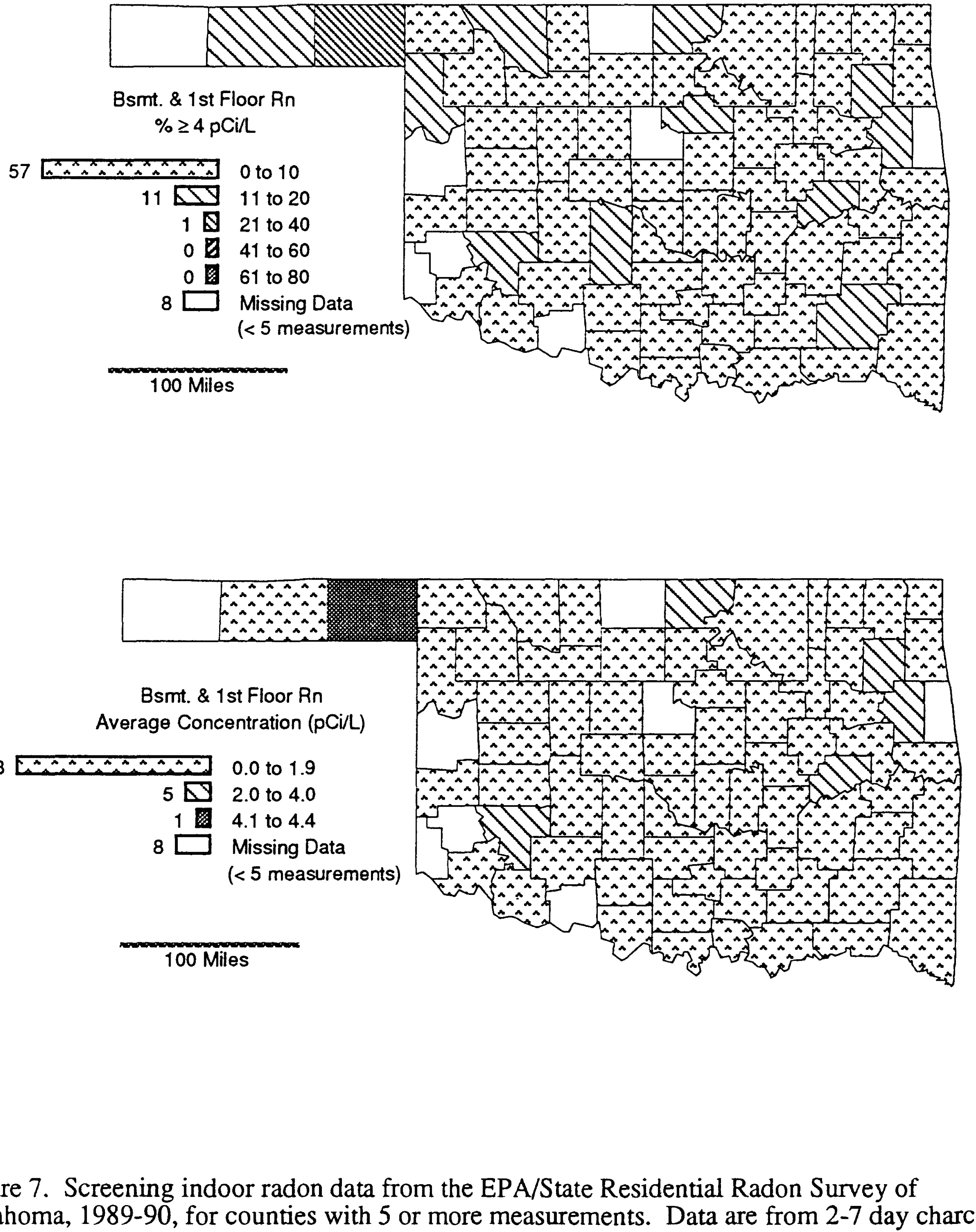


Figure 7. Screening indoor radon data from the EPA/State Residential Radon Survey of Oklahoma, 1989-90, for counties with 5 or more measurements. Data are from 2-7 day charcoal canister tests. Histograms in map legends show the number of counties in each category. The number of samples in each county (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 Oklahoma conducted during 1989-90. 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
ADAIR	4	1.0	0.4	0.4	1.5	3.2	0	0
ALFALFA	6	0.7	0.6	0.7	0.5	1.5	0	0
ATOKA	5	0.4	0.3	0.2	0.5	1.1	0	0
BEAVER	8	4.4	3.7	3.5	2.6	7.6	38	0
BECKHAM	15	0.8	0.4	0.5	1.1	4.2	7	0
BLAINE	13	1.5	0.9	1.1	1.3	3.7	0	0
BRYAN	21	0.4	0.3	0.2	0.9	2.6	0	0
CADDO	26	1.1	0.7	1.0	1.0	3.3	0	0
CANADIAN	23	1.8	1.1	1.4	2.1	10.6	4	0
CARTER	28	0.5	0.3	0.3	0.6	1.8	0	0
CHEROKEE	20	3.0	1.0	1.1	4.5	16.2	20	0
CHOCTAW	13	0.6	0.3	0.5	0.7	2.3	0	0
CIMARRON	3	0.6	0.6	0.7	0.1	0.7	0	0
CLEVELAND	31	1.2	0.7	1.0	1.0	3.7	0	0
COAL	5	0.6	0.3	0.4	0.7	1.9	0	0
COMANCHE	64	1.0	0.7	0.8	1.0	3.9	0	0
COTTON	4	3.3	0.8	0.5	5.9	12.2	25	0
CRAIG	20	1.6	0.9	1.2	2.0	8.4	10	0
CREEK	37	0.4	0.3	0.4	0.6	1.8	0	0
CUSTER	23	1.3	1.0	1.1	0.9	3.3	0	0
DELAWARE	23	1.9	0.9	1.0	3.8	18.5	4	0
DEWEY	6	1.7	1.4	1.6	1.0	3.4	0	0
ELLIS	6	1.9	1.1	0.9	2.3	6.4	17	0
GARFIELD	51	1.5	1.1	1.2	1.3	7.0	6	0
GARVIN	25	0.7	0.3	0.3	1.0	2.8	0	0
GRADY	30	1.9	1.0	1.1	2.4	10.9	13	0
GRANT	2	0.6	0.3	0.6	1.1	1.3	0	0
GREER	1	1.7	1.7	1.7	0.0	1.7	0	0
HARMON	3	2.0	2.0	2.1	0.2	2.2	0	0
HARPER	7	1.8	1.6	1.6	0.7	2.8	0	0
HASKELL	6	0.0	0.1	0.0	0.3	0.5	0	0
HUGHES	12	0.4	0.3	0.5	0.5	1.8	0	0
JACKSON	16	1.6	1.2	1.1	1.2	4.6	6	0
JEFFERSON	5	1.0	0.4	0.7	1.2	2.6	0	0
JOHNSTON	15	0.9	0.6	0.5	0.9	3.0	0	0
KAY	48	2.0	1.1	1.7	1.8	7.2	13	0
KINGFISHER	10	1.0	0.7	1.1	0.8	2.0	0	0
KIOWA	14	2.2	1.7	1.8	1.5	5.6	14	0
LATIMER	8	0.6	0.4	0.4	0.6	1.7	0	0
LE FLORE	25	0.5	0.3	0.4	0.6	1.8	0	0
LINCOLN	20	0.8	0.4	0.5	0.8	2.9	0	0

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

COUNTY	NO. OF MEAS.	MEAN	GEOM. MEAN	MEDIAN	STD. DEV.	MAXIMUM	%>4 pCi/L	%>20 pCi/L
LOGAN	4	0.6	0.5	0.7	0.4	1.0	0	0
LOVE	8	0.7	0.4	0.5	1.0	2.8	0	0
MAJOR	11	1.0	0.6	0.6	1.1	3.5	0	0
MARSHALL	11	0.4	0.2	0.3	0.6	1.5	0	0
MAYES	30	2.6	1.3	1.5	3.4	13.2	17	0
MCCLAIN	23	1.0	0.5	0.7	1.3	5.8	4	0
MCCURTAIN	25	0.6	0.3	0.4	0.9	3.0	0	0
MCINTOSH	6	3.1	1.1	1.8	4.3	11.4	17	0
MURRAY	7	0.9	0.6	0.8	0.7	1.8	0	0
MUSKOGEE	48	0.7	0.3	0.3	1.2	6.2	4	0
NOBLE	12	0.9	0.6	0.9	0.6	1.7	0	0
NOWATA	13	0.6	0.3	0.2	0.7	2.2	0	0
OKFUSKEE	13	0.4	0.3	0.6	0.7	1.1	0	0
OKLAHOMA	155	0.9	0.5	0.6	1.1	7.5	1	0
OKMULGEE	26	0.5	0.3	0.4	0.5	2.0	0	0
OSAGE	27	1.1	0.6	0.9	1.0	3.4	0	0
OTTAWA	28	0.9	0.4	0.6	2.1	11.2	4	0
PAWNEE	10	0.6	0.4	0.5	0.6	1.8	0	0
PAYNE	38	1.8	0.5	0.7	4.1	24.6	13	3
PITTSBURG	38	0.5	0.3	0.4	0.6	2.0	0	0
PONTOTOC	27	0.9	0.4	0.4	1.3	5.9	7	0
POTTAWATOMIE	40	0.5	0.3	0.5	0.7	2.4	0	0
PUSHMATAHA	9	1.2	0.7	0.9	1.5	4.5	11	0
ROGER MILLS	4	0.7	0.6	0.7	0.4	1.2	0	0
ROGERS	27	1.7	0.5	1.0	3.0	15.6	7	0
SEMINOLE	8	0.2	0.1	0.1	0.5	1.2	0	0
SEQUOYAH	10	0.4	0.3	0.5	0.3	0.8	0	0
STEPHENS	24	0.7	0.4	0.7	0.5	1.8	0	0
TEXAS	20	1.9	1.2	1.6	1.8	7.0	15	0
TILLMAN	5	1.2	1.0	1.3	0.8	2.3	0	0
TULSA	127	1.1	0.5	0.7	2.0	17.2	3	0
WAGONER	16	0.8	0.5	0.6	0.8	3.2	0	0
WASHINGTON	51	1.2	0.7	1.0	1.6	11.5	2	0
WASHITA	9	1.2	0.5	1.3	1.1	2.8	0	0
WOODS	8	1.8	1.3	1.2	1.4	4.3	13	0
WOODWARD	17	1.1	0.7	0.9	1.1	4.0	0	0

the county's entire surface area. Of 1834 measurements in the State/EPA Residential Radon Survey dataset for Oklahoma, 84, or 4.5 percent, are greater than 4 pCi/L.

Beaver County (8 measurements in 4 communities, Table 1) has average indoor radon levels that are more than twice statewide levels. With the exception of Cotton County in the southwest part of the State, all individual readings over 10 pCi/L occur in six counties in the northeastern part of the State. This is an area underlain, in part, by black shales and marine limestones and is an area of relatively high rainfall. Studies of black shale terrains elsewhere show consistently elevated indoor radon levels (Hansen, 1986). In spite of the low uranium content of limestones, soils developed from limestones in high-rainfall areas often have high uranium contents. Indoor radon levels in such areas in the northeastern United States are often elevated (Sachs and others, 1982). In Oklahoma, median and average indoor radon levels generally range 0-1 pCi/L for the counties that lie southeast of Oklahoma City (about the southeastern 40 percent of the State) with the exception of three counties–Cleveland, Johnston, and Pushmataha. Average indoor radon levels in counties north and west of Oklahoma City are more variable, but the average and median values are generally between 1 and 2 pCi/L. High levels of rainfall and high soil moisture in the southeastern part of the State may suppress radon migration in soils even where elevated levels of soil uranium occur. Counties in which the maximum levels of indoor radon are between 4 and 10 pCi/L appear to be randomly distributed across the State.

GEOLOGIC RADON POTENTIAL

Flood and others (1990) have evaluated the radon potential of Oklahoma using data on the uranium content of bedrock as the primary criteria. Information on the uranium content of rocks across the State was derived from published analytical data and from the NURE aeroradiometric data. Flood and others (1990) ranked areas across the State in five categories from generally very low to locally moderate to high. Those areas ranked as locally moderate to high are underlain by black, phosphatic shales and associated limestones in the northeastern part of the State and near the Arbuckle Mountains; the Upper Permian Rush Springs Formation in Caddo County; and granites, rhyolites, and related dikes in the Wichita Mountains in the southwestern part of the State. Areas ranked as generally low to generally very low are underlain by Paleozoic marine sedimentary rocks in central and northwestern Oklahoma and by Tertiary continental sedimentary rocks on the High Plains.

The State/EPA Residential Radon Survey data do not permit an in-depth comparison with the map of Flood and others (1990) because many areas are not sampled adequately. The State/EPA data show selected zipcodes in which several values greater than 4 pCi/L occur. A comparison of the State/EPA data in selected zipcodes to the soils mapped in those zipcodes in county soil surveys suggests that well-drained alluvial terraces along some rivers (for example, along the Arkansas River west of Tulsa); steep, thin, sandy to gravelly soils developed on sandstone on river bluffs (for example, bluffs in the southeastern suburbs of Tulsa); and clayey loams on uraniferous shales (throughout the northeastern part of the State) are responsible for a significant percentage of elevated values in those areas. These observations suggest that, in addition to soils derived from rocks with elevated uranium content, soils in selected parts of counties where river terraces and sandstone bluffs occur might also have elevated radon potential.

The regional patterns in the State/EPA data also suggest that soil moisture may have an additional effect on radon potential across the State. Indoor radon values tend to be higher west of Oklahoma City where rainfall is less than 32 inches per year and lowest in the southeastern corner of the State where rainfall ranges from 32 to 64 inches per year. Indoor radon values in the northeast, where rainfall also is high, include many over 4 pCi/L, but the effects of uraniferous black shales and weathered limestone soils on indoor radon may increase the levels overall and counter the effects of regional variation in soil moisture. Otton and Duval (1991) have previously noted an apparent soil moisture-soil permeability effect in the Pacific Northwest. Dry, permeable soils east of the Cascade Mountains are associated with townships in which several houses have indoor radon levels over 4 pCi/L, whereas west of the Cascades, wet soils, even where highly permeable, do not have associated high indoor radon levels unless permeabilities are extreme or slopes are very steep. High permeability, dry soils, and moderate uranium content may be responsible for elevated indoor radon readings in Beaver County.

SUMMARY

There are seven physiographic provinces in Oklahoma for which radon potential may be evaluated (fig. 1). A relative index of radon potential (RI) and an index of the level of confidence in the available data (CI) have been established (see discussion in the introductory chapter of this volume). The seven physiographic provinces in Oklahoma are evaluated in Table 2.

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

TABLE 2. Radon Index (RI) and Confidence Index (CI) for geologic radon potential areas of Oklahoma. See figure 1 for locations of areas. See the introductory chapter for discussion of RI and CI.

	High Plains		Central Oklahoma		Ozark Plateau		Wichita Mountains	
FACTOR	RI	CI	RI	CI	RI	CI	RI	CI
INDOOR RADON	2?	2	1	3	2	3	1	3
RADIOACTIVITY	2	3	1	3	2	3	1	2
GEOLOGY	2	2	2	2	2	2	1	2
SOIL PERM.	2	2	2	2	2	2	2	3
ARCHITECTURE	1	-	1	-	1	-	1	-
GFE POINTS	0	-	0	-	0	-	0	-
TOTAL	9?	9	7	10	9	10	6	10
RANKING	MOD	MOD	LOW	HIGH	MOD	HIGH	LOW	HIGH

	Lower Arkansas		Ouachita Mountians		Coastal Plain	
FACTOR	RI	CI	RI	CI	RI	CI
INDOOR RADON	1	3	1	3	1	3
RADIOACTIVITY	2	3	2	3	2	3
GEOLOGY	2	2	2	2	2	2
SOIL PERM.	2	3	2	3	2	2
ARCHITECTURE	1	-	1	-	1	-
GFE POINTS	0	-	0	-	0	-
TOTAL	8	11	8	11	8	10
RANKING	LOW	HIGH	LOW	HIGH	LOW	HIGH

- Not used in CI.

RADON INDEX SCORING:

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

Possible range of points = 3 to 17

CONFIDENCE INDEX SCORING:

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

Possible range of points = 4 to 12

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PRELIMINARY GEOLOGIC RADON POTENTIAL ASSESSMENT OF TEXAS

by

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INTRODUCTION

This assessment of the radon potential of Texas is based upon geologic information derived from publications of the Texas Bureau of Economic Geology, from publications of the U.S. Geological Survey, and from an analysis of indoor radon data gathered by the State of Texas and the US Environmental Protection Agency (EPA) during the winter of 1990-91 Much information on the geographic setting is derived from The National Atlas of the United States of America.

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

PHYSIOGRAPHIC SETTING

Texas is a large state that extends from the Gulf Coast westward to the southern limits of the Rocky Mountains and northward to the continental interior of the United States. For the purposes of this report, six physiographic subdivisions have been defined (fig. 1). The Western Mountains and Basins province is characterized by plains with intervening mountains and hills. In the western part of this province, high mountains with 3000-5000 feet of relief occur. In the eastern part, relief decreases to 500-1000 feet.

The High Plains and Plateaus Province comprises broad, smooth plains with 100-300 feet of relief in the northern portion, and areas of tablelands, high hills, and plains with moderate relief (300-1000 feet) in the southern portion. The Central Texas Province is an extension of the Great Plains. It is characterized by tablelands and plains with hills of low to moderate relief (100-500 feet) in the west and irregular plains and hills (relief 100-500 feet) to the east. The East Texas Province is an area composed mostly of irregular plains (100-300 feet of relief), except for an area of plains with hills (300-500 feet of relief) in the east-central part. The Coastal Plain Province is an area of smooth plains of low relief (0-100 feet). The South Texas Plain Province includes a large area of irregular plains to the northwest (relief 100-300 feet) and an area of flat plains along the coast (0-100 feet of relief).

Annual precipitation (fig. 2) increases eastward across Texas from less than 10 inches per year to 55-60 inches per year in the southeast corner of the State near the Texas-Louisiana border. In hilly to mountainous areas, precipitation increases with altitude.

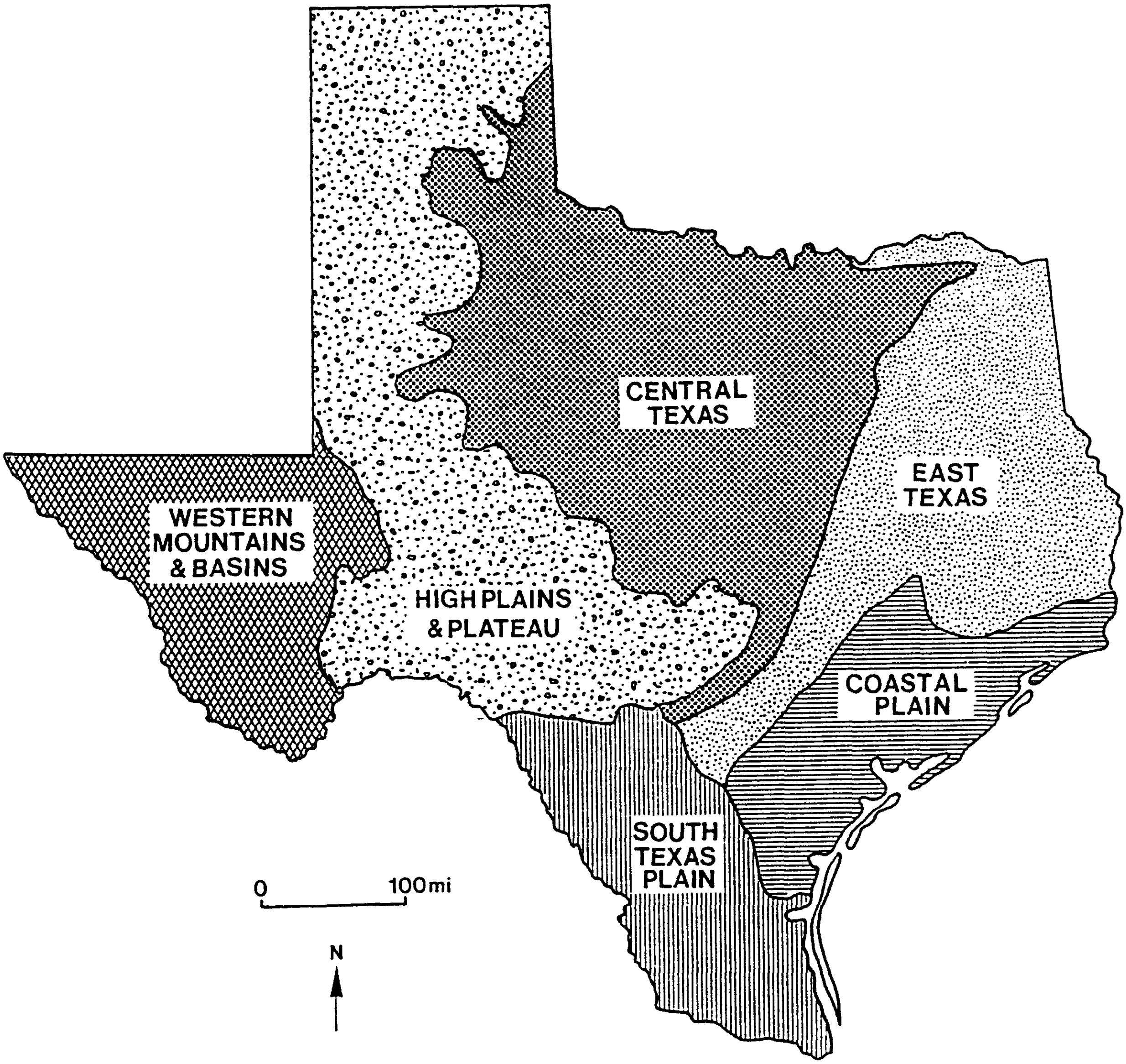

Fig. 1- Map showing physiographic provinces of Texas.
From Facts on File, 1984.

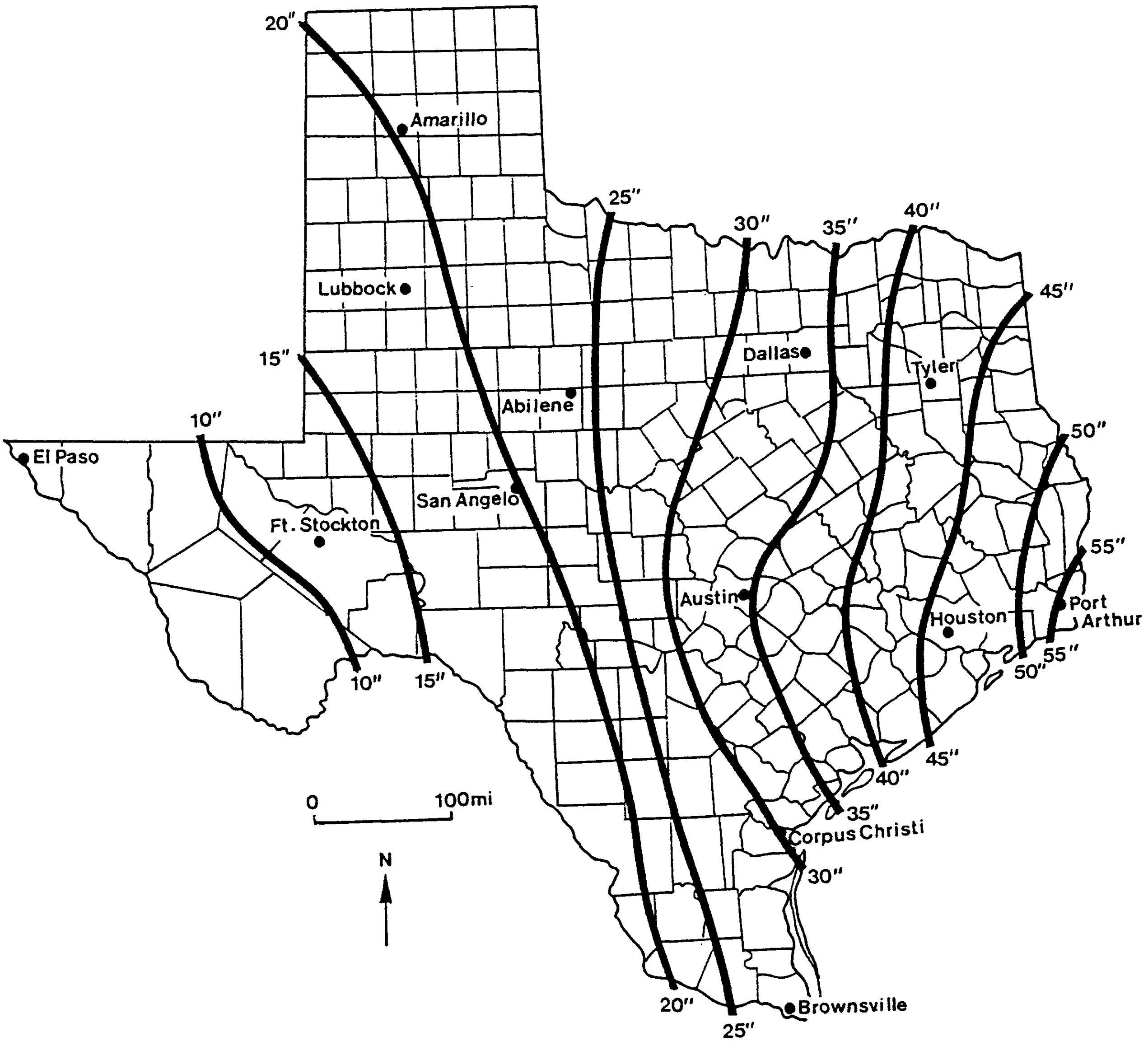

Fig. 2- Map showing annual precipitation in Texas.
From Facts on File, 1984.

About 80 percent of the population of Texas (fig. 3) is concentrated in urban areas of the central and southeast parts of the State. Dallas-Ft. Worth, Houston, and San Antonio are the major urban centers. Rural areas in the Western Mountains and Basins and South Texas Plain Provinces are sparsely populated, whereas rural areas in the East Texas Province and the western part of the Central Texas Province are more heavily populated.

Vegetation and land use vary considerably across the State. Most of the High Plains and Plateaus Province is used principally for dryland and irrigated crops, although in many areas semiarid grasslands are used for grazing. In the southeast part of this province, grazed forest and woodlands predominate. In the Western Mountains and Basins Province, grazed desert shrublands, grasslands, and open woodlands are found. In the Central Texas Province, croplands dominate, with some pasture, woodland, and forest. Grazed grasslands lie at the western edge of this province. The East Texas Province is largely covered by woodland and forest, with lesser cropland and pasture. In the Coastal Plain Province, there is a mixture of cropland, pasture, and grazed forest and woodlands. Extensive marshlands occur along the coast. In the South Texas Plain Province, grazed grassland, open woodland, and desert shrubland occur, plus some areas of dry and irrigated cropland.

GEOLOGIC SETTING

Texas is underlain mostly by sedimentary rocks and unconsolidated sediments that vary in age from Cambrian to Holocene. Precambrian metamorphic and igneous rocks are exposed in the core of the Llano (southern Central Texas Province) and Van Horn uplifts (Western Mountains and Basins Province) (figs. 4 and 5), but they are exposed in less than 1 percent of the State. Tertiary volcanic rocks and related Tertiary volcaniclastic sedimentary rocks occur in volcanic centers and associated small basins in the Western Mountains and Basins Province.

Structurally, the northern, western, and central part of the State is characterized by series of uplifts and basins of pre-Cretaceous age (Figs. 4 and 5). Cretaceous and younger sedimentary rocks of the southeastern 40 percent of the State dip into the Gulf of Mexico basin. Tertiary volcanism and subsequent extension affected the westernmost part of the State, resulting in the formation of extensional basins, intervening mountain ranges, and volcanic centers. During the Miocene, a broad sheet of alluvial fan and related sedimentary rocks (the Ogallalla Formation and overlying units) were deposited on the flank of a broad north-trending uplift in central New Mexico. The erosional remnants of this sheet form the Texas High Plains (the northern part of the High Plains and Plateaus Province).

The sedimentary rocks that crop out in the Western Mountains and Basins, southern High Plains and Plateaus, and most of the East Texas Provinces are marine in origin; they include limestone, dolomite, shale, evaporite deposits, and sandstone of Cambrian through Cretaceous age (fig. 5). Nonmarine rocks of Triassic age, including shale, sandstone, and conglomerate, are present in limited areas in the western part of the Central Texas Province and along the Canadian River valley in the northern part of the High Plains and Plateaus Province. Nonmarine gravel, sand, clay, and caliche (also called calcrete) dominate the northern 60 percent of the High Plains and Plateaus Province. The East Texas, Coastal Plain, South Texas Plain, and the east edge of the Central Texas Provinces are underlain by Cretaceous through Quaternary marine sandstone, shale, chalk, limestone, siltstone, clay, and lignite. Some of the sandstones and shales in this latter area are tuffaceous and some of the shales are carbonaceous.

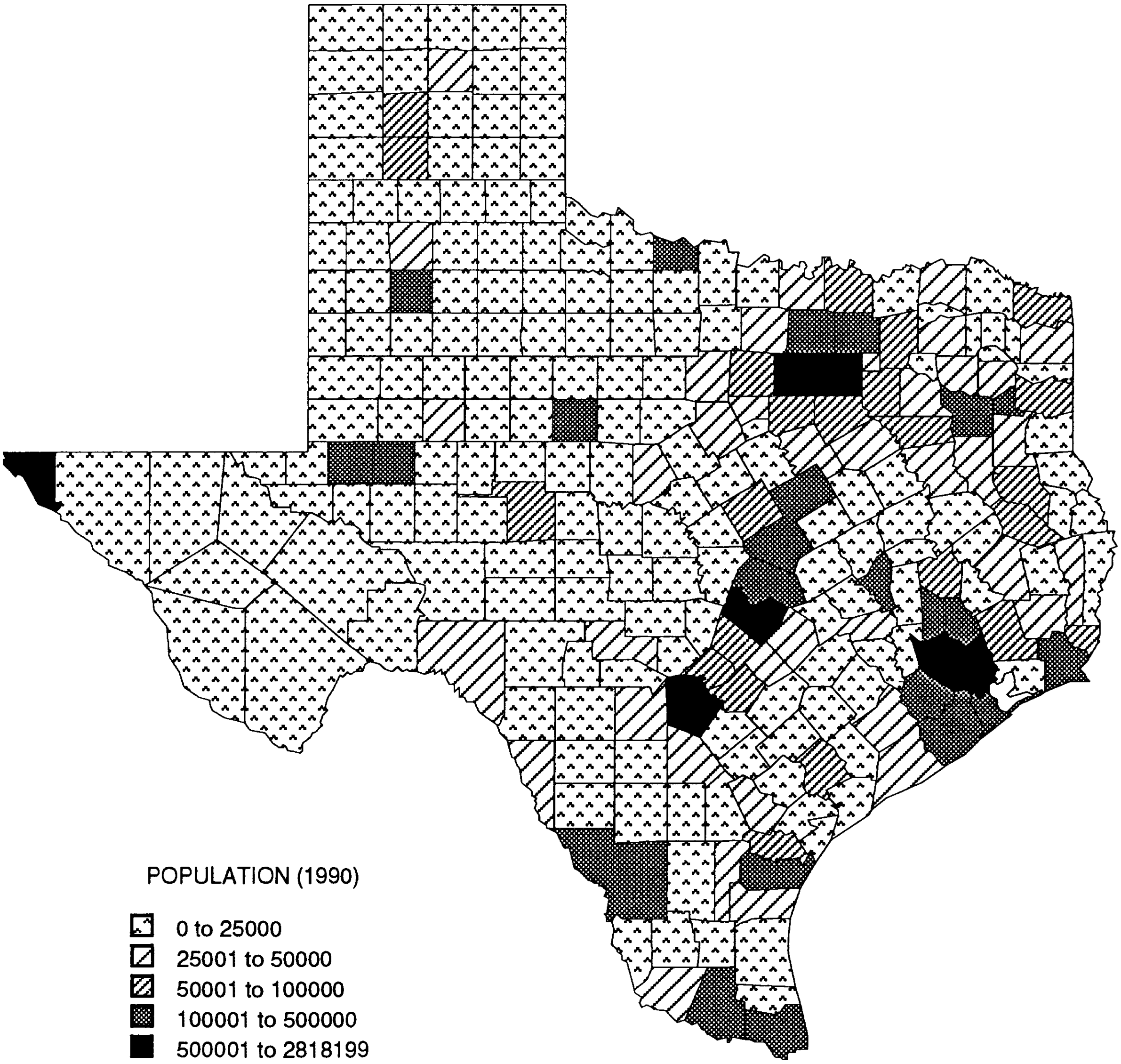

Fig. 3- Population of counties in Texas (1990 U.S. Census data).

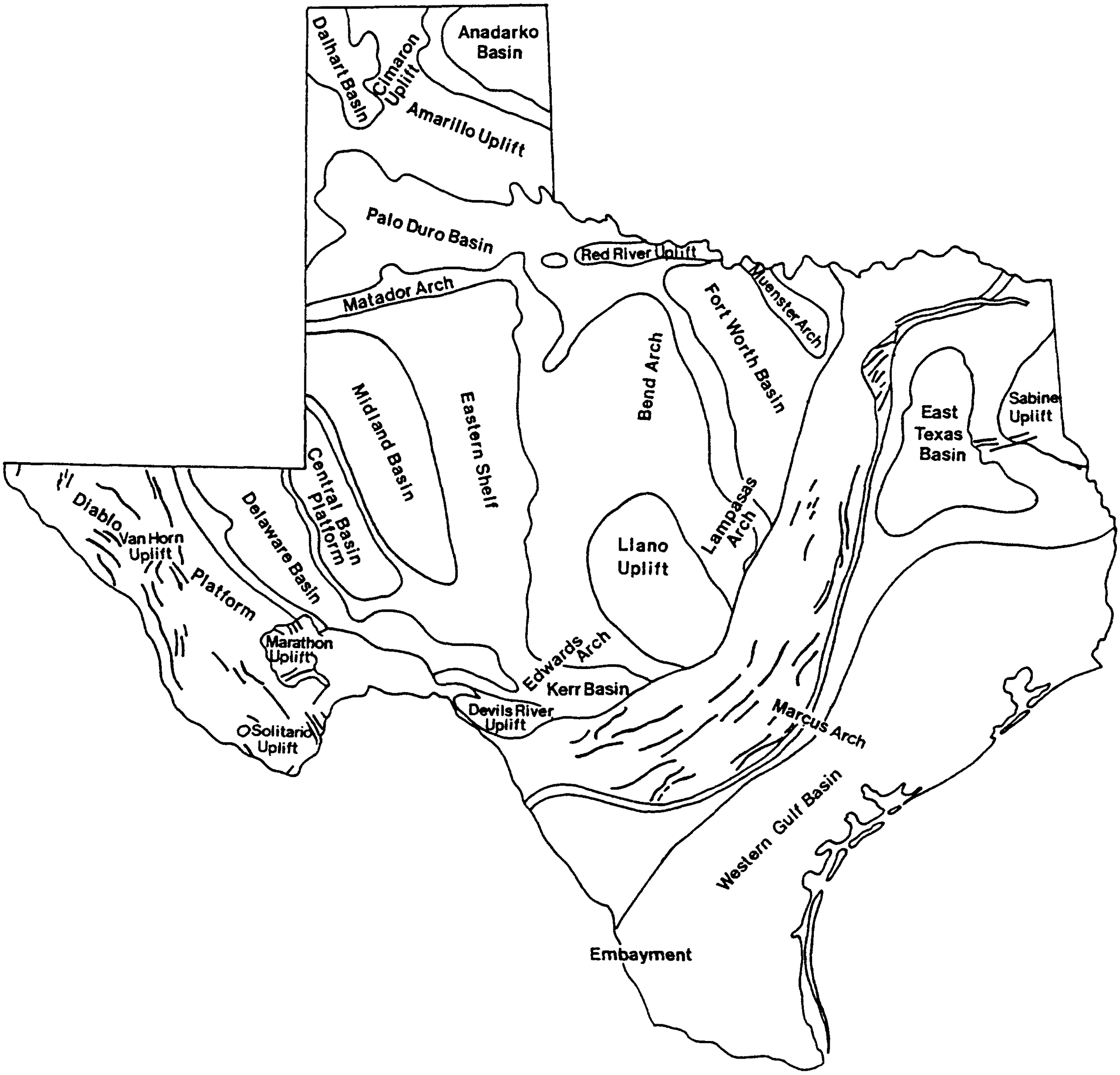

Fig. 4- Major geologic structures in Texas. From Renfro and others, 1973.

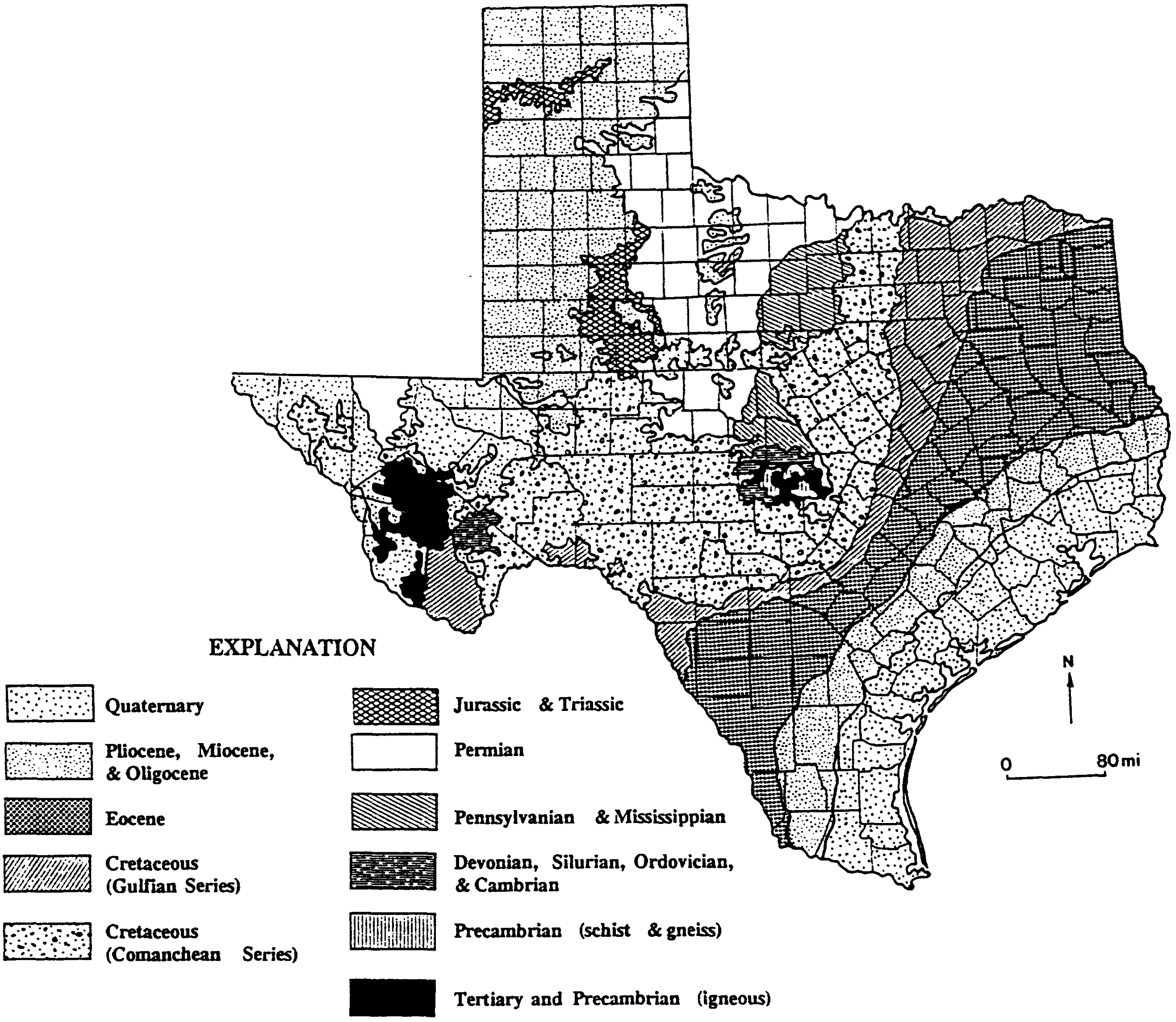

Fig. 5- Generalized geologic map of Texas. From Arbingast (1976).

An aeroradiometric map of Texas (fig. 6) shows that the average equivalent uranium (eU) content of rocks and soils at the surface is about 1.5 ppm. Rocks and soils across the State vary from less than 0.5 ppm to greater than 5.5 ppm eU. Levels of eU less than 1.0 ppm are associated with eolian deposits (especially the sand-rich facies of the Pleistocene Blackwater Draw Formation) of western Texas and with Quaternary marine deposits of the Gulf Coastal area. Higher levels of uranium (>2.5 ppm) are associated with 1) Precambrian metamorphic and igneous rocks in the Llano and Van Horn uplifts, and alluvium derived from them; 2) Tertiary rhyolitic and alkaline volcanic rocks in westernmost Texas; 3) the Miocene Ogallalla Formation and overlying sediments in the Panhandle of Texas (northernmost part of the High Plains and Plateaus Province); 4) Triassic nonmarine sedimentary rocks of the Dockum Group in northwestern Texas; 5) Upper Cretaceous carbonaceous rocks in east-central Texas (the Woodbine and Eagle Ford Formations between the Dallas-Ft. Worth and Austin areas) and in the Big Bend area; and 6) part of the northeast-trending outcrop belt of Tertiary tuffaceous fluvial and marine sedimentary rocks in the northern part of the South Texas Plain and southwest part of the Coastal Plain Provinces. Two small areas of greater than 5.5 ppm eU occur in this latter area; these represent places where the aircraft flew over open-pit uranium mines.

Studies of soil-gas radon and radioactivity along transects crossing Cretaceous and younger rocks from the Central Texas Province to the Coastal Plain Province (Gundersen and others, 1991) show that elevated soil-gas radon (as much as 6500 picocuries per liter, pCi/L) is associated with some Upper Cretaceous sedimentary rocks, principally carbonaceous shale and mudstone of the Woodbine and Eagle Ford Formations and the Austin Chalk, but that most of the Cretaceous, Tertiary and Quaternary units were low to moderate in soil-gas radon and radioactivity.

Uranium occurrences and deposits are found in several areas of Texas. A major uranium mining district is hosted by Tertiary sandstones in South Texas. Small uranium deposits occur in sandstones of the Triassic Dockum Group in the western part of central Texas. Uranium-rich calcrete and silcrete occurs in sandstones and mudstones of the Ogallalla Formation and in overlying Pliocene and Pleistocene sandstones and lacustrine sedimentary rocks in the northern part of the High Plains and Plateaus Province. Uranium occurs in volcanic rocks and volcaniclastic sedimentary rocks near volcanic centers in the Western Mountains and Basins Province.

SOILS

Extensive areas of highly permeable soils (>6 in/hr in a percolation test) are generally not found in Texas, although sandy soils with permeabilities near or locally exceeding this value occur in several areas. In the central part of the High Plains and Plateaus Province, near the southeastern corner of New Mexico, sandy loams and fine sandy loams dominate. These soils may have sufficient permeability to influence indoor radon levels. Substantial areas of sandy soils occur in the central parts of the South Texas Plain Province and the southwestern part of the Coastal Plain Province; however, these often have highly cemented zones of caliche at depth that may hinder the ability of radon to migrate. Alluvial fan deposits in the Western Mountains and Basins Province may also locally be highly permeable, but these are also commonly highly cemented.

Thin soils with bedrock at shallow depths occur over the limestone and dolomite in the southern part of the High Plains and Plateau Province (Edwards Plateau) and thin, sandy soils occur over granitic rocks in the Llano uplift area. Shallow bedrock in these areas typically contains abundant fracture zones that enhance radon migration.

Fig. 6- Aerial radiometric map of Texas (after Duval and others, 1989). Contour lines at 1.5 and 2.5 ppm equivalent uranium (eU). Pixels shaded from 0 to 6.0 ppm eU at 0.5 ppm eU increments; darker pixels have lower eU values; white indicates no data.

Soil temperature and soil moisture vary widely across Texas, with steady increases in soil temperature from north to south and steady increases in soil moisture from west to east (Rose and others, 1991). Soils of the northern 10 percent of the High Plains and Plateaus Province are mesic ustic and thus are moderately moist in the wintertime (44-56 percent pore saturation in sandy loams, and 58-74 percent in a silty clay loam) and slightly moist in the summertime (24-44 percent pore saturation in sandy loams, and 39-58 percent pore saturation in silty clay loams). The soils of the Western Mountains and Basins Province are thermic aridic–slightly moist in the wintertime (24-44 percent pore saturation in sandy loams, and 39-58 percent pore saturation in silty clay loams) and slightly dry in the summertime (4-24 percent pore saturation in sandy loams and 6-39 percent pore saturation in silty clay loam). Soils of the rest of the High Plains and Plateaus Province and all of the central Texas Province are thermic ustic–moderately moist in the wintertime (44-56 percent saturation in sandy loams, and 58-74 percent in a silty clay loam) and slightly moist in the summertime (24-44 percent pore saturation in sandy loams, and 39-58 percent pore saturation in silty clay loams). The soils of the East Texas Province and the eastern part of the Coastal Plain Province are thermic udic and are very moist in the wintertime (56-96 percent pore saturation in sandy loams, and 74-99 percent saturation in a silty clay loam) and slightly moist in the summertime (24-44 percent pore saturation in sandy loams, and 39-58 percent pore saturation in silty clay loams). The South Texas Plain and the western part of the Coastal Plain range from hyperthermic aridic along the Rio Grande River to hyperthermic ustic elsewhere. Hyperthermic aridic soils are slightly dry all year long and hyperthermic ustic soils are slightly moist all year long.

The low soil moisture levels in the dry soils of western and southern Texas may decrease the radon emanation coefficient somewhat, especially during the drier periods of the year. The wet winter soils in the East Texas Province may slow radon migration because pore spaces are filled with water.

INDOOR RADON DATA

The U.S. Environmental Protection Agency (EPA), in cooperation with the Texas Department of Health, completed a random, stratified (geology and population) survey of indoor radon levels in homes across Texas during the winter of 1990-1991 (Table 1, fig. 7). A map of counties is included for reference (fig. 8). About 5 percent of measurements in the State/EPA Residential Radon Survey dataset are equal to or greater than 4 pCi/L. Average measurements for 3 counties in the northern High Plains and Plateaus Province average greater than 4 pCi/L. Hale County averages 7.5 pCi/L. Average measurements range from 2-4 pCi/L for three counties in the Big Bend area of the Western Mountains and Basins Province, for several counties in the northern and central High Plains and Plateaus Province, and for Brown County in the Central Texas Province (fig. 7). Values exceeding 20 pCi/L are restricted to the High Plains and Plateaus Province and the Western Mountains and Basins Province. Indoor radon levels are low in counties in the uranium mining area in south Texas, however only 50 houses were measured in 12 counties where uranium mining occurs and this sampling may not have been sufficient to identify areas of possible elevated indoor radon levels asssociated with uranium deposits in the subsurface.

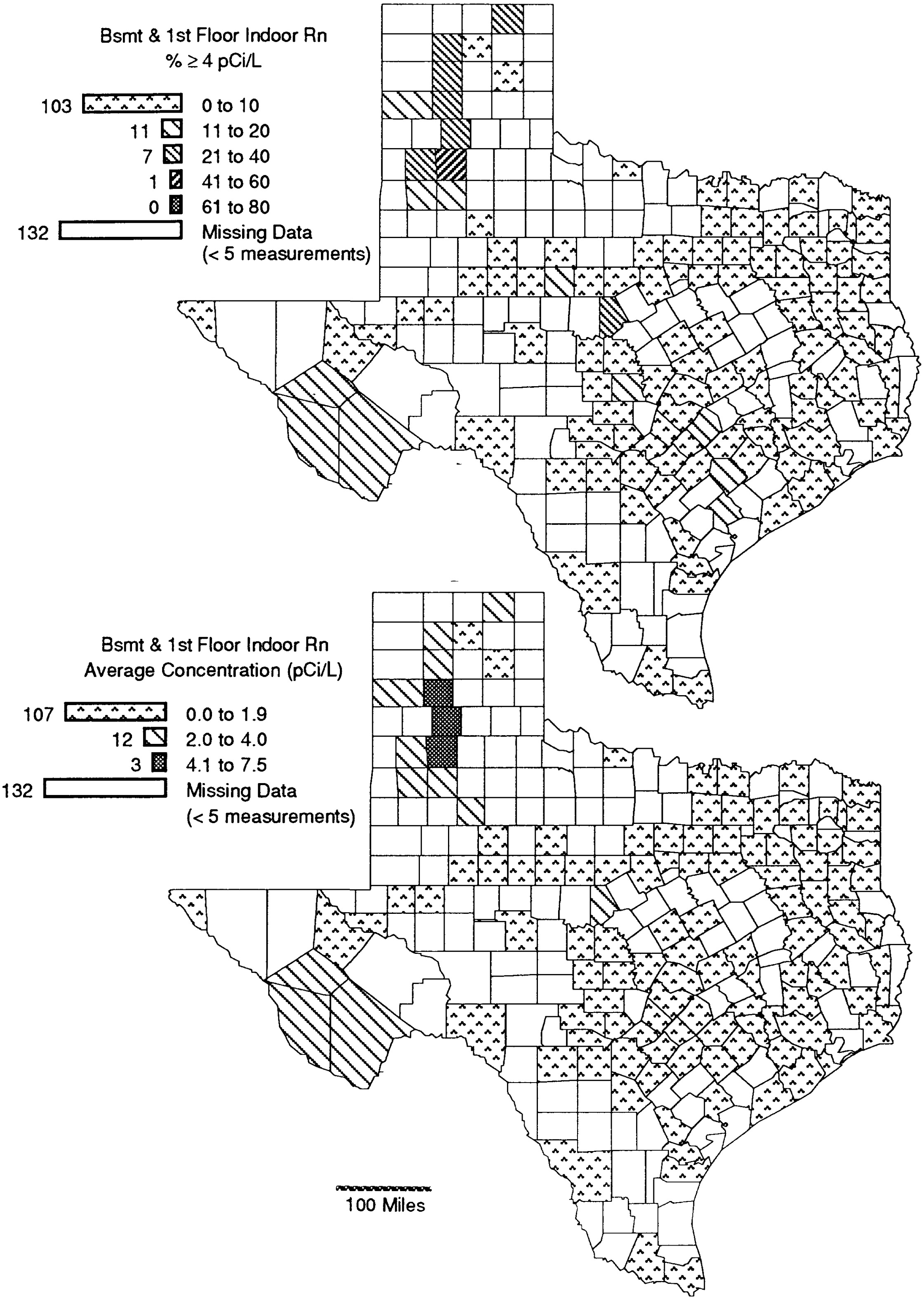

Fig. 7- Screening indoor radon data from the EPA/State Residential Radon Survey of Texas, 1990-91, for counties with 5 or more measurements. Data are from 2-7 day charcoal canister tests. Histograms in map legends show the number of counties in each category. The number of samples in each county (See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

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

COUNTY	NO. OF MEAS.	AVERAGE	MEDIAN	GEOM. MEAN	MAX	%≥4 pCi/L	%≥20 pCi/L
ANDERSON	3	0.0	0.1	0.4	1.4	0	0
ANDREWS	2	1.0	1.0	0.9	1.1	0	0
ANGELINA	12	0.3	0.3	0.3	1.3	0	0
ARANSAS	2	0.0	0.0	0.0	0.0	0	0
ARCHER	2	0.7	0.7	0.5	1.2	0	0
ARMSTRONG	3	2.9	1.5	2.4	5.8	33	0
ATASCOSA	11	0.5	0.5	0.5	1.7	0	0
AUSTIN	8	0.5	0.3	0.4	2.2	0	0
BAILEY	3	3.6	1.6	2.0	8.6	33	0
BANDERA	5	0.6	0.4	0.5	1.0	0	0
BASTROP	9	1.6	0.5	0.9	9.8	11	0
BAYLOR	2	1.0	1.0	0.9	1.4	0	0
BEE	5	0.4	0.3	0.5	0.9	0	0
BELL	18	1.2	1.1	0.9	3.9	0	0
BEXAR	57	1.1	0.8	0.8	6.7	4	0
BLANCO	3	2.0	2.3	1.9	2.7	0	0
BORDEN	2	0.7	0.7	0.6	1.0	0	0
BOSQUE	4	1.2	1.4	1.2	1.5	0	0
BOWIE	22	0.5	0.4	0.5	1.8	0	0
BRAZORIA	25	0.3	0.2	0.4	1.2	0	0
BRAZOS	19	0.8	0.5	0.5	4.2	5	0
BREWSTER	57	2.5	2.3	2.0	8.4	18	0
BRISCOE	2	3.3	3.3	2.8	5.0	50	0
BROWN	6	2.6	0.9	1.3	7.8	33	0
BURNET	97	1.3	1.0	0.9	13.9	5	0
CALDWELL	7	0.2	0.2	0.4	2.2	0	0
CALHOUN	1	1.2	1.2	1.2	1.2	0	0
CALLAHAN	5	0.6	0.6	0.7	1.4	0	0
CAMERON	9	0.5	0.4	0.4	1.4	0	0
CAMP	2	0.8	0.8	0.7	1.0	0	0
CARSON	4	8.8	2.0	3.3	30.1	25	25
CASS	9	0.6	0.8	0.6	1.1	0	0
CASTRO	3	1.6	1.3	1.4	2.7	0	0
CHEROKEE	7	1.0	0.9	0.9	1.6	0	0
CLAY	2	1.4	1.4	1.3	1.4	0	0
COCHRAN	1	1.5	1.5	1.5	1.5	0	0
COKE	1	0.0	0.0	0.0	0.0	0	0
COLEMAN	2	0.6	0.6	0.5	0.9	0	0
COLLIN	36	1.0	0.8	0.8	5.2	3	0
COLORADO	6	0.3	0.4	0.3	0.4	0	0
COMAL	18	1.1	0.8	0.8	3.7	0	0
COMANCHE	4	0.7	0.6	0.6	1.0	0	0
CONCHO	2	0.2	0.2	0.3	0.3	0	0

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

COUNTY	NO. OF MEAS.	AVERAGE	MEDIAN	GEOM. MEAN	MAX	%≥4 pCi/L	%≥20 pCi/L
COOKE	7	1.0	0.9	1.0	1.8	0	0
CORYELL	6	0.9	0.8	0.6	2.2	0	0
CRANE	1	0.1	0.1	0.1	0.1	0	0
CROCKETT	2	1.1	1.1	1.1	1.2	0	0
CROSBY	3	1.2	1.2	1.1	1.8	0	0
DALLAM	1	0.1	0.1	0.1	0.1	0	0
DALLAS	85	1.2	1.0	0.9	6.8	4	0
DAWSON	3	1.8	1.5	1.6	2.7	0	0
DEAF SMITH	6	3.2	3.2	2.3	7.7	17	0
DELTA	1	0.6	0.6	0.6	0.6	0	0
DENTON	30	1.0	0.9	0.8	3.0	0	0
DE WITT	4	0.4	0.4	0.4	0.7	0	0
DICKENS	1	3.1	3.1	3.1	3.1	0	0
DIMMIT	2	0.5	0.5	0.5	0.5	0	0
DONLEY	1	3.2	3.2	3.2	3.2	0	0
DUVAL	3	0.7	0.4	0.9	2.1	0	0
EASTLAND	5	0.6	0.6	0.6	1.2	0	0
ECTOR	39	0.9	0.8	0.7	7.3	3	0
ELLIS	13	0.8	0.7	0.6	2.3	0	0
EL PASO	96	1.0	0.6	0.6	21.6	2	1
ERATH	6	0.4	0.4	0.4	0.7	0	0
FALLS	2	0.4	0.4	0.3	0.7	0	0
FANNIN	2	1.0	1.0	0.4	1.8	0	0
FAYETTE	13	1.1	0.9	0.8	3.2	0	0
FISHER	1	0.0	0.0	0.0	0.0	0	0
FLOYD	2	0.5	0.5	0.4	0.5	0	0
FORT BEND	23	0.3	0.2	0.3	2.2	0	0
FRANKLIN	2	0.2	0.2	0.5	0.5	0	0
FREESTONE	3	0.2	0.2	0.2	0.4	0	0
FRIO	3	0.7	1.0	0.6	1.0	0	0
GAINES	2	0.8	0.8	0.8	1.0	0	0
GALVESTON	35	0.2	0.1	0.3	0.9	0	0
GARZA	20	2.1	1.9	1.7	6.9	10	0
GILLESPIE	12	1.3	0.9	0.8	4.7	8	0
GLASSCOCK	2	1.3	1.3	1.2	1.4	0	0
GOLIAD	4	0.4	0.4	0.3	0.7	0	0
GONZALES	5	1.3	0.6	0.8	3.4	0	0
GRAY	9	1.7	1.7	1.6	2.6	0	0
GRAYSON	14	1.2	0.7	0.7	5.3	7	0
GREGG	21	0.9	0.5	0.6	7.1	5	0
GRIMES	3	0.5	0.1	0.4	1.4	0	0
GUADALUPE	15	1.0	0.9	0.8	3.1	0	0
HALE	15	7.5	3.0	4.2	41.3	47	13
HALL	1	0.4	0.4	0.4	0.4	0	0

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

COUNTY	NO. OF MEAS.	AVERAGE	MEDIAN	GEOM. MEAN	MAX	%≥4 pCi/L	%≥20 pCi/L
HAMILTON	1	0.4	0.4	0.4	0.4	0	0
HANSFORD	3	3.7	3.7	2.5	6.8	33	0
HARDIN	5	0.7	0.8	0.7	1.2	0	0
HARRIS	116	0.4	0.3	0.3	3.8	0	0
HARRISON	21	0.5	0.5	0.5	1.2	0	0
HARTLEY	1	0.6	0.6	0.6	0.6	0	0
HASKELL	1	0.8	0.8	0.8	0.8	0	0
HAYS	15	1.1	0.9	0.9	2.6	0	0
HEMPHILL	1	1.6	1.6	1.6	1.6	0	0
HENDERSON	14	0.7	0.3	0.4	5.1	7	0
HIDALGO	20	0.5	0.4	0.4	1.9	0	0
HILL	2	0.5	0.5	0.5	0.7	0	0
HOCKLEY	7	2.8	1.0	1.8	13.5	14	0
HOOD	7	1.2	1.0	1.0	3.0	0	0
HOPKINS	6	0.3	0.3	0.4	0.6	0	0
HOUSTON	7	0.4	0.2	0.4	1.3	0	0
HOWARD	114	1.7	0.9	0.9	65.9	4	1
HUDSPETH	2	0.6	0.6	0.6	0.8	0	0
HUNT	9	0.6	0.4	0.5	1.8	0	0
HUTCHINSON	14	1.5	1.2	1.3	6.3	7	0
JACK	1	0.3	0.3	0.3	0.3	0	0
JASPER	11	0.5	0.2	0.3	3.1	0	0
JEFF DAVIS	16	3.7	1.7	1.9	13.6	19	0
JEFFERSON	25	0.3	0.2	0.3	0.9	0	0
JIM HOGG	1	1.1	1.1	1.1	1.1	0	0
JOHNSON	7	0.7	0.7	0.7	2.1	0	0
JONES	5	1.0	0.7	0.9	2.8	0	0
KARNES	3	1.7	0.7	0.7	4.4	33	0
KAUFMAN	5	1.1	1.5	0.8	1.6	0	0
KENDALL	5	1.0	1.0	0.9	1.9	0	0
KERR	20	1.4	1.4	1.0	6.0	5	0
KINNEY	3	0.1	0.1	0.2	0.3	0	0
KLEBERG	1	0.5	0.5	0.5	0.5	0	0
KNOX	1	0.9	0.9	0.9	0.9	0	0
LAMAR	5	0.2	0.3	0.4	0.5	0	0
LAMB	10	2.9	2.1	2.2	6.9	30	0
LAMPASAS	2	1.9	1.9	0.8	3.5	0	0
LA SALLE	1	0.1	0.1	0.1	0.1	0	0
LAVACA	10	1.2	0.4	0.7	7.5	10	0
LEE	3	1.2	0.6	0.7	2.9	0	0
LEON	3	0.2	0.2	0.3	0.4	0	0
LIBERTY	2	0.0	0.0	0.0	0.0	0	0
LIMESTONE	4	0.0	0.0	0.2	0.3	0	0
LIPSCOMB	2	1.6	1.6	1.5	1.9	0	0

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

COUNTY	NO. OF MEAS.	AVERAGE	MEDIAN	GEOM. MEAN	MAX	%≥4 pCi/L	%≥20 pCi/L
LIVE OAK	4	0.8	0.4	0.7	2.5	0	0
LLANO	47	1.7	1.3	1.3	5.4	15	0
LUBBOCK	68	2.8	1.9	1.9	23.9	18	1
LYNN	1	1.5	1.5	1.5	1.5	0	0
MCCULLOCH	26	1.2	0.8	0.7	12.5	4	0
MCLENNAN	29	1.2	0.8	0.7	5.9	3	0
MCMULLEN	1	1.5	1.5	1.5	1.5	0	0
MADISON	2	0.4	0.4	0.7	0.7	0	0
MARION	3	0.8	1.0	1.1	1.3	0	0
MARTIN	3	1.8	1.2	1.3	3.8	0	0
MASON	21	1.3	0.9	0.9	7.0	10	0
MATAGORDA	8	0.7	0.5	0.7	2.9	0	0
MAVERICK	3	1.5	1.5	1.4	2.2	0	0
MEDINA	9	0.5	0.4	0.4	1.1	0	0
MENARD	3	1.0	1.1	1.0	1.4	0	0
MIDLAND	48	1.1	1.0	0.9	3.4	0	0
MILAM	7	0.6	0.5	0.7	1.7	0	0
MITCHELL	34	1.4	0.9	0.9	14.0	6	0
MONTAGUE	3	0.7	0.5	0.6	1.3	0	0
MONTGOMERY	27	0.3	0.2	0.4	2.1	0	0
MOORE	6	3.4	3.1	3.3	5.2	33	0
MORRIS	7	0.7	0.9	0.8	1.1	0	0
NACOGDOCHES	9	0.6	0.3	0.5	1.4	0	0
NAVARRO	3	0.1	0.0	0.5	0.5	0	0
NEWTON	2	0.1	0.1	0.3	0.3	0	0
NOLAN	5	0.9	1.1	0.9	1.8	0	0
NUECES	17	0.7	0.5	0.7	2.1	0	0
OCHILTREE	5	3.6	3.1	3.4	5.5	40	0
ORANGE	13	0.5	0.4	0.4	1.2	0	0
PALO PINTO	6	0.7	0.6	0.6	1.9	0	0
PANOLA	9	0.3	0.2	0.3	0.7	0	0
PARKER	5	0.3	0.1	0.3	0.8	0	0
PARMER	4	3.2	3.1	2.1	6.2	50	0
PECOS	6	0.4	0.4	0.3	0.8	0	0
POLK	7	0.5	0.4	0.7	1.3	0	0
POTTER	29	3.4	3.3	2.6	11.1	34	0
PRESIDIO	43	2.6	2.3	2.0	7.2	19	0
RAINS	3	0.3	0.3	0.3	0.3	0	0
RANDALL	20	5.6	3.4	3.3	33.1	35	5
REAL	2	0.2	0.2	0.4	0.4	0	0
RED RIVER	1	0.0	0.0	0.0	0.0	0	0
REEVES	9	1.2	1.2	0.8	2.8	0	0
REFUGIO	1	0.2	0.2	0.2	0.2	0	0
ROBERTSON	5	0.6	0.5	0.4	1.1	0	0

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

COUNTY	NO. OF MEAS.	AVERAGE	MEDIAN	GEOM. MEAN	MAX	%≥4 pCi/L	%≥20 pCi/L
ROCKWALL	3	0.3	0.4	0.4	0.5	0	0
RUNNELS	4	0.8	0.7	0.8	1.1	0	0
RUSK	10	0.2	0.3	0.3	0.7	0	0
SABINE	3	0.5	0.5	0.5	0.8	0	0
SAN AUGUSTINE	5	0.7	0.4	0.7	1.5	0	0
SAN JACINTO	5	0.3	0.3	0.4	0.5	0	0
SAN PATRICIO	7	0.6	0.2	0.3	3.1	0	0
SAN SABA	30	1.2	0.7	0.8	9.6	3	0
SCHLEICHER	1	0.3	0.3	0.3	0.3	0	0
SCURRY	75	1.4	1.1	1.0	7.6	3	0
SHACKELFORD	2	0.4	0.4	0.3	0.4	0	0
SHELBY	3	0.0	0.0	0.4	0.4	0	0
SHERMAN	3	11.7	15.3	10.1	15.6	67	0
SMITH	46	0.5	0.4	0.4	3.7	0	0
STARR	1	0.8	0.8	0.8	0.8	0	0
STEPHENS	3	2.3	2.1	2.2	3.4	0	0
STERLING	1	3.6	3.6	3.6	3.6	0	0
STONEWALL	1	0.7	0.7	0.7	0.7	0	0
SUTTON	1	0.4	0.4	0.4	0.4	0	0
SWISHER	5	6.3	1.9	2.8	15.4	40	0
TARRANT	84	1.1	0.7	0.8	7.4	4	0
TAYLOR	26	1.4	0.9	1.0	5.7	12	0
TERRY	5	1.6	1.5	1.1	3.3	0	0
THROCKMORTON	1	2.0	2.0	2.0	2.0	0	0
TITUS	7	0.4	0.4	0.5	1.0	0	0
TOM GREEN	15	0.9	0.7	0.7	3.3	0	0
TRAVIS	53	1.4	0.8	0.9	7.0	8	0
TRINITY	1	0.6	0.6	0.6	0.6	0	0
TYLER	4	0.5	0.6	0.7	1.0	0	0
UPSHUR	9	0.4	0.1	0.4	1.1	0	0
UPTON	1	2.0	2.0	2.0	2.0	0	0
UVALDE	6	0.8	0.6	0.8	1.9	0	0
VAL VERDE	8	0.5	0.4	0.4	1.0	0	0
VAN ZANDT	8	0.3	0.3	0.3	0.7	0	0
VICTORIA	9	1.4	0.4	0.7	9.5	11	0
WALKER	12	0.6	0.2	0.5	2.8	0	0
WALLER	6	0.2	0.3	0.4	0.6	0	0
WARD	6	0.5	0.7	0.7	1.0	0	0
WASHINGTON	5	0.4	0.3	0.5	1.1	0	0
WEBB	19	0.4	0.4	0.4	1.5	0	0
WHARTON	3	0.6	0.0	1.9	1.9	0	0
WHEELER	4	1.8	2.0	1.2	3.2	0	0
WICHITA	13	1.5	1.3	1.2	4.3	8	0
WILLACY	2	0.5	0.5	0.5	0.6	0	0

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

COUNTY	NO. OF MEAS.	AVERAGE	MEDIAN	GEOM. MEAN	MAX	%≥4 pCi/L	%≥20 pCi/L
WILLIAMSON	38	1.4	1.1	1.0	6.4	3	0
WILSON	6	0.2	0.1	0.3	1.0	0	0
WINKLER	3	0.2	0.0	1.0	1.0	0	0
WISE	3	0.6	0.6	0.9	1.5	0	0
WOOD	16	0.3	0.3	0.3	0.8	0	0
YOAKUM	4	3.2	2.7	1.8	7.3	25	0
YOUNG	2	0.9	0.9	0.9	1.1	0	0
ZAVALA	4	0.6	0.6	0.6	1.1	0	0

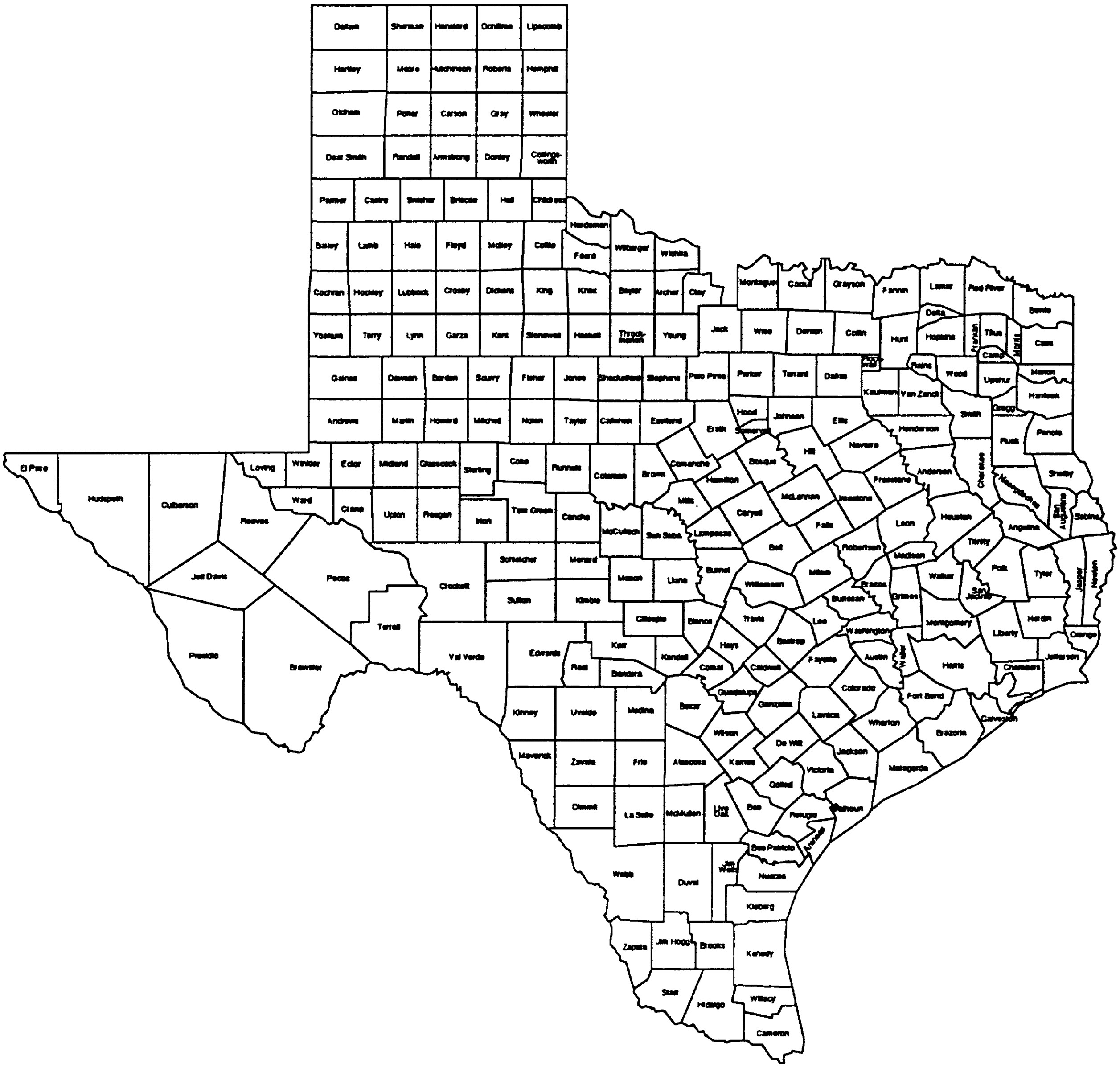

Fig. 8- Map showing counties and county names in Texas.

GEOLOGIC RADON POTENTIAL

The geologic radon potential of Texas is generally low overall. The relatively mild climate throughout much of the State, especially in the most populous areas, and the predominance of slab-on-grade housing seems to have influenced the overall potential. Significant percentages of houses with indoor radon levels exceeding 4 pCi/L are restricted to the High Plains and the Western Mountains and Basins Provinces. However, no physiographic province in Texas is completely free from indoor radon levels above 4 pCi/L.

Elevated indoor radon can be expected in several geologic settings in Texas. Uranium-rich (>2.5 ppm for the purposes of this report) granites and metamorphic rocks in central Texas, uranium-rich Tertiary silicic volcanic and tuffaceous sedimentary rocks in western Texas, uranium-rich dark marine shales in east-central Texas and the Big Bend area, uranium-rich sand and caliche associated with the Ogallalla Formation and overlying units in the High Plains of Texas, uranium-rich sediments of Late Cretaceous age along the eastern edge of central Texas, and residual soils and alluvium derived from these units are likely to have significant percentages of homes with indoor radon levels exceeding 4 pCi/L. Except for the High Plains and the Western Mountains and Basins Provinces, these rocks generally make up only a small percentage of the surface area of the various physiographic provinces. However, the outcrop belt of Upper Cretaceous sedimentary rocks of the East Texas Province passes near substantial population centers. The most likely areas for elevated indoor radon levels to occur are those in which elevated eU values occur in the aeroradiometric data (fig. 6). An exception may be the uranium mining district in south Texas. There, the uranium deposits occur at depth, often below the water table, and the influence of such deposits on the near surface soil-gas radon levels may be subdued.

Extreme indoor radon levels (greater than 100 pCi/L) may be expected where structures are inadvertently sited on uranium occurrences. This is more likely to occur in more populated areas along the outcrop belt of the Ogallalla Formation at the edge of the Llano Estacada in the northern and central parts of the High Plains and Plateaus Province. In this outcrop area, sedimentary rocks with more than 10 ppm uranium are common.

SUMMARY

Eight areas of Texas for which geologic radon potential may be evaluated were delineated (fig. 9). These areas generally follow the physiographic provinces of figure 1 with some modifications based on internal differences in geology, soils, and aeroradiometric signature. A relative index of radon potential (RI) and an index of the level of confidence in the available data (CI) have been established (see discussion in the introductory section of this volume) . The areas are evaluated in Table 2.

The northern part of the High Plains and Plateau Province (N, fig. 9) has moderate radon potential. Uranium occurrences, anomalously uranium-rich calcrete and silcrete, and uranium-rich lacustrine rocks along the outcrop belt of the Ogallalla Formation and in small upper Tertiary lacustrine basins within the northern High Plains may locally cause very high indoor radon levels. Indoor radon data are elevated in many counties in this area . Equivalent uranium values in this area range from 1.0-4.0 ppm. An area of elevated eU along the Rio Grande River (also labeled "N" in fig. 9) is included in this radon potential province.

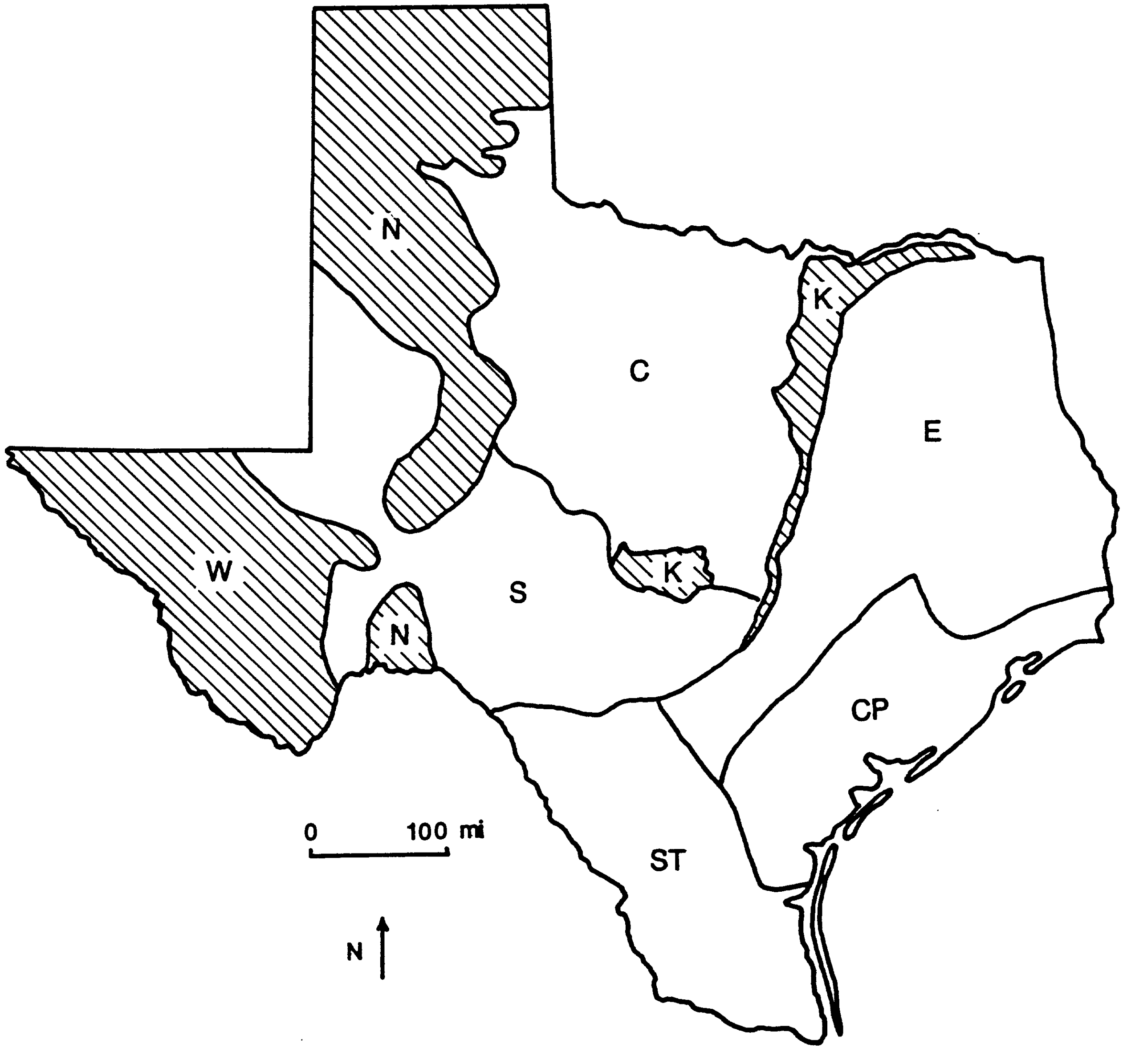

Fig. 9- Map showing radon potential areas of Texas. W- Western mountains and basins; N- Northern High Plains and Plateaus; S- Southern High Plains and Plateaus; C- Central Texas; K- Cretaceous Central Texas and Llano Uplift;; E- East Texas; ST- Southern Texas Plain; CP- Coastal Plain. Cross-hatched areas have moderate potential. The other areas are low.

The southern part of the High Plains and Plateaus Province has low radon potential overall as suggested by generally low eU values and low indoor radon. This area is sparsely populated and indoor radon measurements may not adequately reflect the geologic radon potential. An area of low eU covered by the sandy facies of the Blackwater Draw Formation in the northeast corner of the Western Mountains and Basins Province is included in this radon potential province. Some local areas within this province with potentially high indoor radon levels include areas covered by thin soils over limestone and dolomite in the Edwards Plateau of the southern part of this province and areas underlain by carbonaceous sediments in the southeastern part of this province.

The Western Mountains and Basins Province has moderate indoor radon potential overall. Although average indoor radon levels are mixed (low in El Paso County, but high in three southern counties), areas of elevated eU are widespread (fig. 6). Uranium-rich Precambrian rocks and uranium-rich silicic volcanic rocks and alluvium derived from them may locally cause average indoor radon levels in some communities to exceed 4 pCi/L. Values exceeding 20 pCi/L may also be expected locally. Exceptionally dry soils in this province may tend to lower radon potential. In very dry soils, the emanating fraction of radon from mineral matter is lowered.

The Central Texas Province has low radon potential overall; however, areas along the outcrop belt of the Woodbine and Eagle Ford Formations and the Austin Chalk (part of the Upper Cretaceous Gulfian Series, fig. 5) along the eastern edge of this province and areas of Precambrian metamorphic and undifferentiated igneous rocks in the Llano Uplift (fig. 5) in the southern part of this province have moderate geologic radon potential and are separated out as a distinctive radon potential area. Structures sited on uranium occurrences in the Triassic Dockum Group in the western part of this province may locally have very high indoor radon levels.

The East Texas Province has low radon potential overall. Soil moistures are typically high; soil permeability is typically low to moderate; and eU levels are low to moderate. A few areas of well-drained soils and elevated eU (fig. 6) may be localized areas of moderate radon potential.

The Texas Coastal Plain has low geologic radon potential. Low aeroradioactivity, low to moderate soil permeability, and locally high water tables contribute to low radon potential.

The South Texas Plain has low radon potential due to generally low eU and low to moderate soil permeability. Some structures sited on the more uranium-rich soils in this province (fig. 6) may locally have elevated indoor radon levels, but such soils are generally also clay-rich and this may mitigate against radon movement.

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

TABLE 2. Radon Index (RI) and Confidence Index (CI) scores for geologic radon potential areas of Texas. See figure 9 for locations of areas.

	Northern High P/P		Southern High P/P		Western Mtns/Basins		Central Texas	
FACTOR	RI	CI	RI	CI	RI	CI	RI	CI
INDOOR RADON	2	2	1?	1	2?	1	1	2
RADIOACTIVITY	2	2	1	2	2	3	1	3
GEOLOGY	2	2	2	2	2	2	2	2
SOIL PERM.	2	3	2	3	2	3	2	3
ARCHITECTURE	2	-	1	-	1	-	1	-
GFE POINTS	0	-	0	-	0	-	0	-
TOTAL	10	9	7	8	9	9	7	10
RANKING	MOD	MOD	LOW	MOD	MOD	MOD	LOW	HIGH

	Cretaceous Cent. Texas		East Texas		Coastal Plain		South Texas Plain	
FACTOR	RI	CI	RI	CI	RI	CI	RI	CI
INDOOR RADON	2?	1	1	2	1	2	1?	1
RADIOACTIVITY	2	2	1	3	1	3	1	3
GEOLOGY	2	2	2	2	2	2	2	2
SOIL PERM.	2	3	1	3	2	3	2	3
ARCHITECTURE	1	-	1	-	1	-	1	-
GFE POINTS	1	-	0	-	0	-	0	-
TOTAL	10	8	6	10	7	10	7	9
RANKING	MOD	MOD	LOW	HIGH	LOW	HIGH	LOW	MOD

- Not used in CI.

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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