Airborne Radon in Homes in Summit County, Ohio: A Geographic Analysis[1]

VERN R. HARNAPP, H. A. DOLLWET, AND SHIYING RONG, Department of Geography/Planning and Department of Biology, The University of Akron, Akron, OH 44325

ABSTRACT. The purpose of this study was to: 1) create a GIS data base with 546 radon readings from mainly single-family homes in Summit County, OH; and 2) to describe the geographic pattern of indoor radon in the county. The average radon level was 4.01 pCi/L, just at the Environmental Protection Agency's (EPA) recommended action level. Thirty-two percent of the homes in the county exceeded that level. Geologic factors that influence indoor radon concentrations are areas where the Ohio shale and soils combined with high uranium content underlie the surface. Soils with high permeabilities also yield high radon levels. Positive correlations exist, albeit not all are statistically significant, between radon activity and air temperature, soil permeability, surface uranium concentration, and proximity to underground mines. A negative correlation was found to exist between radon reading and barometric pressure. Houses with basements also have higher radon readings than those built on slabs. No significant difference was found in seasonal indoor-radon concentrations.

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INTRODUCTION

Within the past decade concern has increased about the health hazard posed by radon gas in homes in the United States. The relationship of high radon levels and a high rate of lung cancer in uranium miners has been known for decades (Holaday et al. 1957; Colorado Bureau of Mines 1967). Only recently, however, has the general public become aware of the more subtle health risk posed by radon which can accumulate under normal living conditions in dwellings. Radon, emanating from soil and bedrock, from building materials, and even from water, is a major cause of lung cancer fatalities (Brookins 1990). The United States Environmental Protection Agency (EPA) estimates that indoor radon contaminates one in fifteen U.S. homes and may be responsible for as many as 20,000 lung cancer deaths each year (U.S. EPA 1993). The figure may actually be higher, but cases of combined smoking and indoor radon-caused lung cancer are often recorded as deaths related to smoking.

Given the increased availability of information regarding radon gas, the federal EPA has placed the state of Ohio in Tier 1, its highest category of radon risk. Because of this high risk and an increase in the public's awareness of health hazards related to radon gas in homes, many people have had their homes tested. Additionally, some public agencies, like local health departments, have also sponsored limited testing. In this study tests mainly from individual homes form the data base for gaining insight into the local situation regarding levels of radon gas in homes.

MATERIALS AND METHODS

The test protocol for radon testing was that set forth by the EPA. Prior to starting the test, homeowners were instructed via telephone to close all exterior windows 12 hours prior to the start of the test, and that these windows had to remain closed for the 2-day test period. Exterior doors could be opened and closed for normal ingress and egress, but could not be left open for more than a few seconds. Fireplaces were not to be used unless they were the only source of heat. High volume attic fans could not be used.

For the test itself, the 4-inch open-faced activated charcoal canister was used, manufactured by F & J Specialty Company of Miami, FL. At the end of the test, the canisters were evaluated by an EPA-listed and State of Ohio licensed laboratory. The canisters were counted for 10 minutes for gamma emission of the radon daughter products Lead-214 (Pb-214) and Bismuth-214 (Bi-214), using a 3-inch sodium iodide crystal and a multi-channel analyzer made by Nucleus Corporation, Oak Ridge, TN.

This study of airborne indoor radon is based on 546 readings taken at individual sites in Summit County, OH, between 1987 and 1994 (Fig. 1). The data are not aggregated, therefore, a particular site can be identified with a particular set of environmental conditions (i.e., soil type, soil permeability, uranium content of soil, etc.), which is useful in establishing possible relationships between radon and contributing factors. Each site is identified in a Geographic Information System (GIS) by its latitude and longitude coordinate rather that by name and address which preserves the privacy of the resident. The Kumar et al. study (1990) lists 817 radon readings in Summit County collected between 1985 and 1989 which have a mean of 4.4 pCi/L. The 546 readings in our study from Summit County are not included in the statewide survey, and hence are a new and independent data set.

More than 95% of the buildings in the Summit County data set were single detached homes. As shown in Fig. 1, the northwest and southeast parts of the county had relatively few sampling sites because they are lightly populated in comparison with the rest of the county.

Data came from homes tested at the request and expense of individual owners who were interested in

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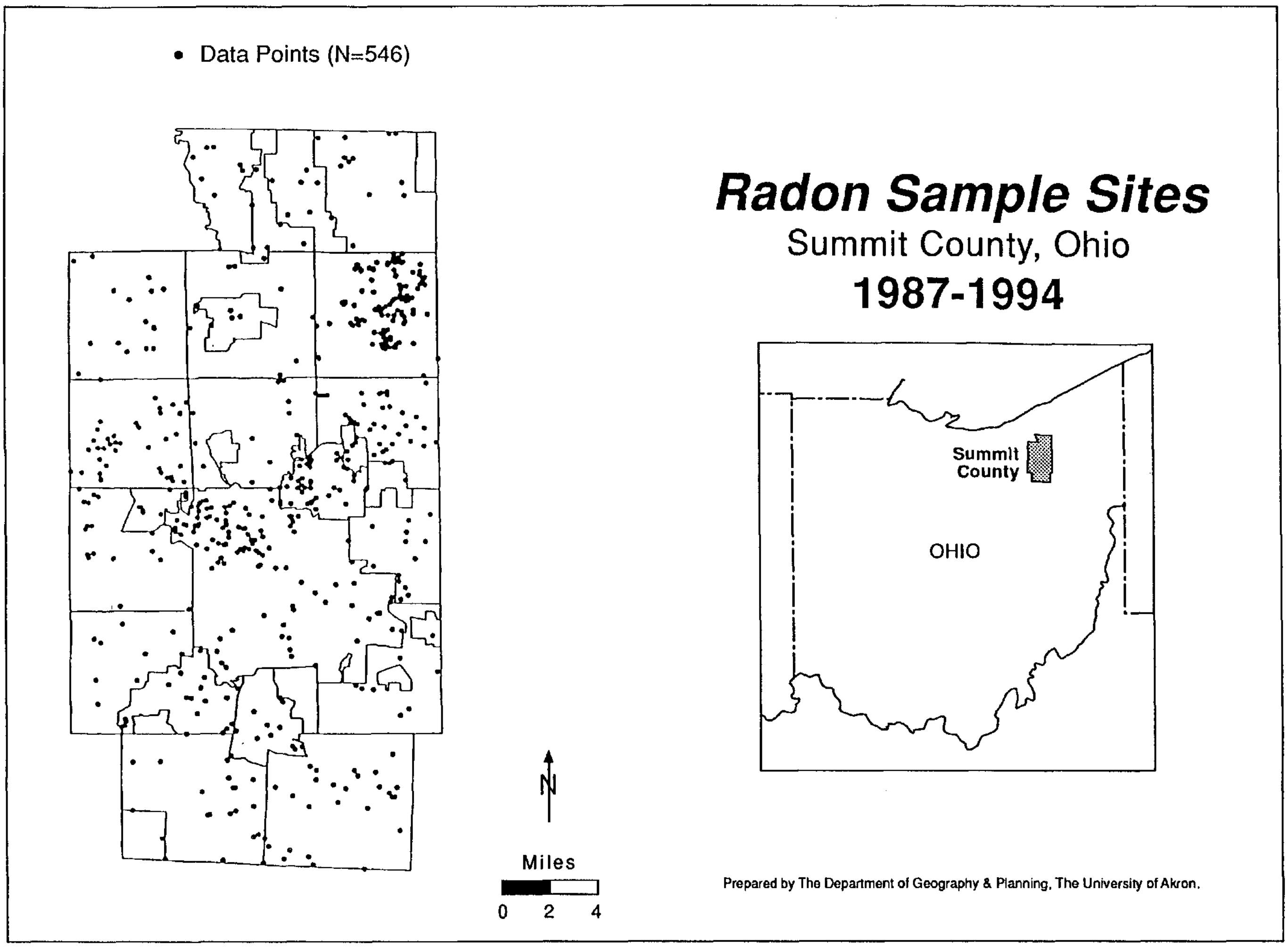

FIGURE 1. Radon sample sites in Summit County, OH, between 1987 and 1994.

finding if their buildings had high levels of radon gas. The bias of high income and high education level may be present in the data as most of the single-family dwellings were valued in excess of $100,000 (Dollwet 1992) and it is postulated that high education level also relates to concern for radon as a health threat. Nonetheless, value in the data set rests in its large size, extensive geographic coverage, and individual site characteristics.

The purpose of this study is two-fold: 1) to provide a baseline GIS data base for continued monitoring of radon in Summit County; 2) to identify and attempt to explain the geographic pattern of radon pollution in the county.

The first step in the study involved designing and creating the data base to which the variables from the radon testing were added. Demographic information in the data base included: latitude, longitude, address, city, and zip code. Each record in the data base contained the date of the radon testing as well as the reading (in pCi/L) and indicated whether or not the house had a basement. Geographic information in the data base included: soil type, soil permeability, depth to bedrock, depth to groundwater, uranium content of soil, and proximity to underground mining areas. The data base also included the ambient factors present on the day of the reading such as season, temperature, precipitation, and barometric pressure.

Five hundred and forty-six test sites were entered into the data base. All sites were then address-matched using the address-matching capabilities of Atlas*GIS and the Topologically Integrated Geographic Encoding Referencing (TIGER) line file of Summit County, OH, which contains address ranges for all roads in the county. The address matching procedure was based on latitude and longitude coordinates of each address to which the 546 addresses were matched and kept for the study.

Unfortunately, upon closer scrutiny it was found that a significant number of locations could not be matched exactly using these two programs. Subsequently, no-match addresses were manually located on soil maps provided by the Summit Soil and Water Conservation District. An exact location is critical to locating a site on its particular soil type if reasonable relationships are to be made.

The second step was to determine the soil type for each site. Using twelve raster-based soil maps from the Ohio Capability Analysis Program (OCAP), each map was calibrated (establishing the digitizing tablet-real coordinates relationship) to the TIGER file. Each grid cell from the raster soil map represents an area of 1.15 acres. Where a particular address was located along the edge of two grid cells (about one per cent of the cases) that address was manually verified on the Summit County Soil map. Using digitizing and manual verification methods of address is more accurate for analyzing the radon situation than lumping areas by postal zip codes, a practice common in other research.

For each site, the soil type was digitized and the corresponding soil code from the OCAP recorded as well as the other geographic information for each site in the data base.

After all variables and associated values were entered, the data base was verified to insure that each site did not contain erroneous or missing values. A series of maps and tables were produced showing potential relationships between the radon activity and the variables within the data base. Additionally, the sample sites with readings greater than 4 pCi/L were correlated with the 40 local soil types represented in this study (Fig. 2). Other "themes" were also mapped. These included: all sites with readings greater that 10 pCi/L; sites within 0.5 mi radius of underground mines; sites with a soil permeability of less that 1"/hr, between 1" and 6"/hr, and those greater than 6"/hr; sites with readings greater than 4 pCi/L, with basement, and particular soil types.

Those sites with readings greater than 4 pCi/L were of special interest since that is the recommended action level set by the EPA. Homes containing radon activities above this level should be considered for mitigation procedures.

The last stage of the study involved the application of statistical techniques of regression analysis, *t*-test, and ANOVA to the data to assess the significance between radon activities and the other variables considered in this study.

RESULTS

The 546 indoor-radon readings from Summit County, OH, are distributed as follows: 35% of buildings had readings less that 2 pCi/L; 34% had readings between 2 and 4 pCi/L; 23.5% had readings between 4 and 10 pCi/L; and 8.5% had readings above 10 pCi/L. Thirty-two percent of the buildings in this study had readings

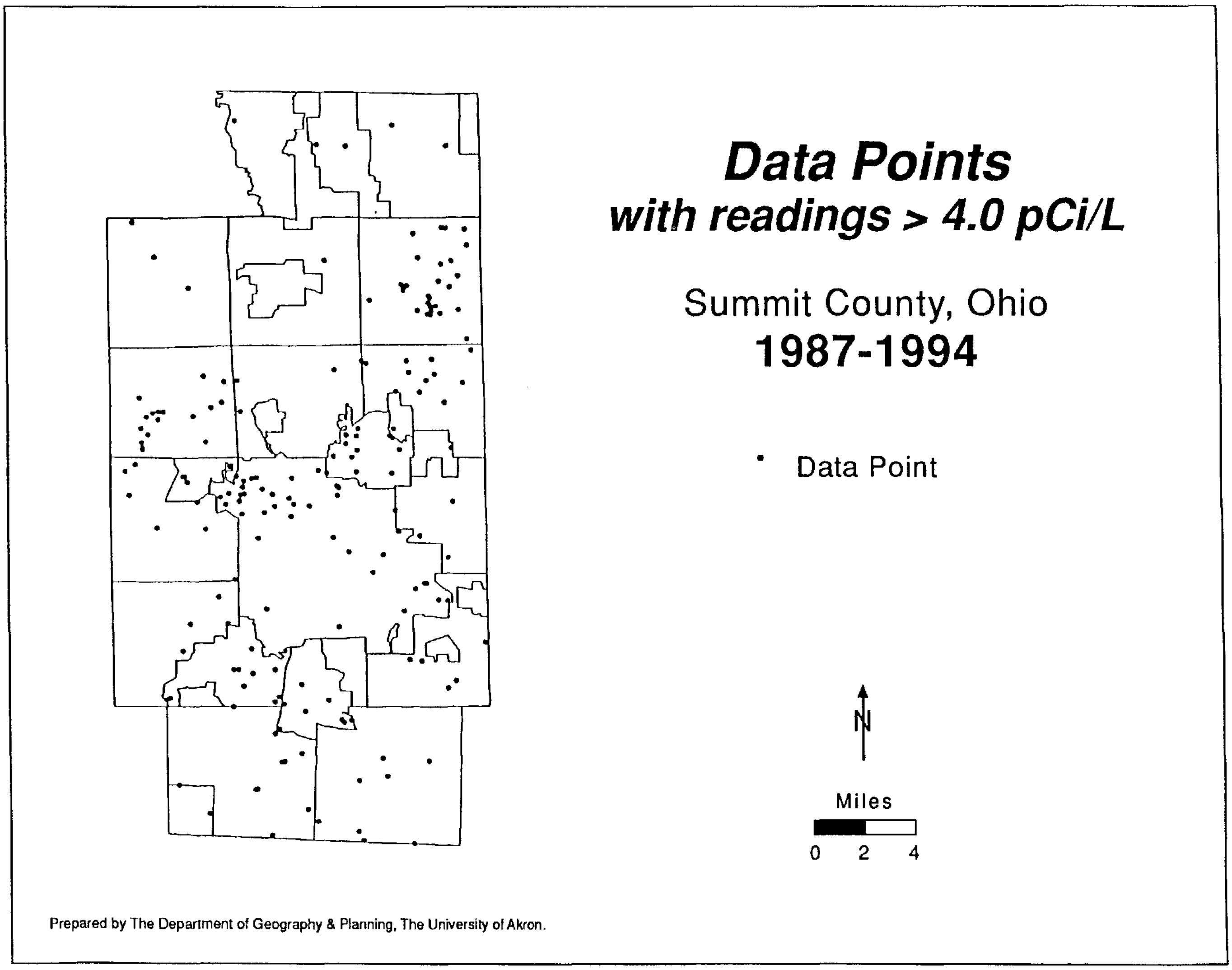

FIGURE 2. Summit County, OH, data points with radon readings greater than 4 pCi/L, 1987-1994.

exceeding 4 pCi/L. The average indoor radon reading for Summit County was 4.01 pCi/L, which is consistent with the EPA placement in Tier 1 of areas averaging above 4 pCi/L. The range for the county was 0.5 to 131.4 pCi/L.

A series of maps and tables were compiled from field data to help "visualize" and "conceptualize" the geographic significance of the indoor radon phenomenon in Summit County. Figure 1 shows the geographic distribution of sites. The uneven pattern is related to population distribution and to the fact that data came from homes tested for people who availed themselves of this service.

Figure 2 shows the distribution of sites exceeding 4 pCi/L in the county. Approximately one-third of all readings taken exceeded this level. Several environmental factors seem instrumental in helping to explain the pattern.

Certain soil types yield higher radon readings than others. This is especially true for soils high in uranium content and with high permeabilities which permit the flow of radon gas to the surface (Owen 1993). Of the total 546 samples, 169 (32%) exceeded 4 pCi/L. The soil types with fairly high percentages of radon readings in excess of 4 pCi/L are: Chili (49%), Wooster (42%), Rittman (34%), Ellsworth (31%), Canfield (27%), and Mahoning (21%). The Soil Survey of Summit County (1990) indicates that these soils are highly to moderately permeable. Furthermore, of the 44 samples above 10 pCi/L, 43% (19) were on Chili soils. Maps were produced showing distribution of radon sites and radon levels on 40 different soils. Figure 3 is an example for Chili soil.

The southern part of the county also has numerous abandoned underground mines where coal was extracted in the early 1900s. Heavy fracturing and voids have facilitated radon flow toward the surface and into homes situated above (Misiquitta 1989). To account for this variable, mines were located on a map and a circle a half-mile in diameter was drawn around each mine site (Fig. 3). Five sampling points were located directly over mines with another 26 points found within the half-mile circles. The average indoor radon reading for the 31 sites was 7.6 pCi/L with one site registering 89.3 pCi/L. This average is notably higher than the average for the entire county (4.01 pCi/L) while the 89.3 pCi/L reading was the second highest single reading in the county.

Statistical techniques of regression analysis, *t*-test, and ANOVA were applied to the data to see the degree to which various factors could explain the radon pattern. Nine factors were found to be statistically significant (Table 1). Environmental factors which heavily influence

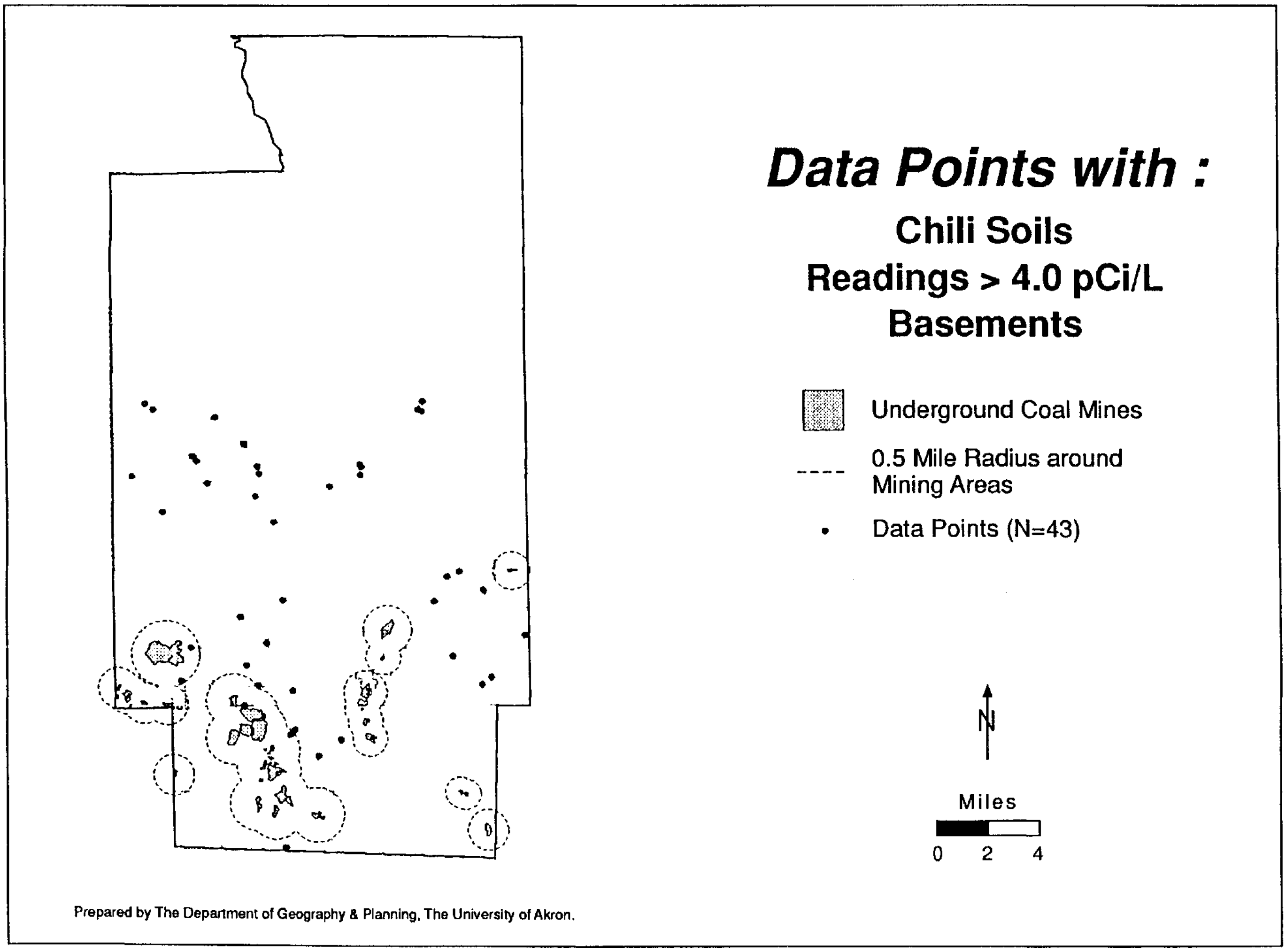

FIGURE 3. Summit County, OH, data points on Chili soil with radon readings greater than 4 pCi/L, 1987-1994.

TABLE 1

Relationship of radon reading level to 11 factors.

	Statistically Significant?	
	Yes	No
Air Pressure (Airp)	x	
Depth to Bedrock (Bedrock)	x	
Depth to Groundwater (Grodwat)		x
Rainfall (Pcip)	x	
Soil Permeability (Perm)	x	
Presence of Basement	x	
Presence of Underground Mine	x	
Season		x
Air Temperature (Temp)	x	
Uranium Content of Soil (Uran)	x	
Wind (Wind)	x	

indoor radon concentrations are soil permeability, low barometric pressure, and uranium content of the soil. The interactions of these factors are more important than any single factor acting alone upon indoor radon levels. There is a positive correlation between radon reading and depth to groundwater. Although correlation appears low, it is statistically significant. Depth to groundwater is also highly correlated with soil permeability (r = .6401) (Table 2). There is a negative correlation between rainfall and reading level, albeit not strong.

Regression analysis indicates the following order of importance of elevated radon levels: 1) barometric pressure; 2) surface uranium concentrations; and 3) soil permeability. The interaction of these variables leads to high radon levels.

DISCUSSION

A study by Kumar et al. (1990) of Ohio gathered data from 1,255 zip code areas. Of the original 1,255 zip code areas, 698 areas, each having five or more radon readings, were scrutinized. In the 698 zip code areas, 35.1% had indoor radon readings greater that 4 pCi/L. Nearly all of these zip code areas are closely associated with glacial till deposits of the Wisconsin age. The authors found that radon originates in the till from one or both of the following sources: 1) uranium-rich Ohio Shale fragments that have been eroded from outcrops in central and western Ohio and incorporated in the till, and 2) uranium enriched calcareous soils developed on till derived from the underlying limestone and dolostone bedrock. Many zip code areas with high radon concentrations are also associated with glacial or alluvial sand and gravel deposits. They state that it is the high permeability of these deposits rather than their composition that is responsible for elevated indoor levels (Kumar et al. 1990).

The hypotheses of the Kumar et al. study (1990) on radon content of Scioto and Miami glacial lobes in southern and western Ohio are: 1) radon comes from

TABLE 2

The significant correlation coefficients matrix.

	Reading	Airp	Grodwat	Pcip	Perm	Temp	Uran	Wind
Reading		-.3794	.1732	.0946	.3079*	.1943	.3262	
		(.000)	(.000)	(.029)	(.000)**	(.029)	(.000)	
Airp	-.3794		-.1117	-.2210	-.1718	-.1712		-.2893
	(.000)		(.000)	(.000)	(.000)	(.000)		(.000)
Grodwat	.1732	-.1117			.6401		.1082	
	(.000)	(.010)			(.000)		(.012)	
Pcip	-.0946	-.2210						
	(.029)	(.000)						
Perm	.3079	-.1718	.6401				.1291	.1359
	(.000)	(.000)	(.000)				(.000)	(.002)
Temp	.1943	-.1712						-.2439
	(.000)	(.000)						(.000)
Uran	.3262		.1082		.1291			
	(.000)		(.012)		(.003)			
Wind				.1022	.1357	-.2438		-.2893
				(.018)	.002	(.000)		(.000)

source materials in the upper tens of feet of the glacial and alluvial deposits, and 2) the radon source materials in these deposits are fragments of Ohio Shale that were eroded from outcrops of this formation. Glaciers then carried this material over adjacent areas and deposited it. Radon derived from local materials is strongly suggested as "horizontal movement of bedrock clasts carried by glaciers and streams was probably no more than several tens of miles from their point of origin" (Kumar et al. 1990). Thus, radon derived from local materials was strongly suggested.

In northeast Ohio, Kumar et al. (1990) state, "high radon concentrations near the glacial boundary in northeast Ohio are perhaps also due to Ohio Shale fragments being brought down from the outcrops along the lake (Erie) to the north." Because Summit County is located approximately 30 miles due south of the Lake Erie shore, this hypothesis may well explain the high radon activities recorded during the study. It should be noted, however, that the uranium content of soils is not high in Summit County, ranging from 1.5 ppm in the southeast to 2.7 ppm in the northwest based on aerial radiometric readings (Duval 1985). Uranium concentrations exceeding 3.6 ppm are considered high. Nevertheless, even though uranium content is not exceedingly high, this may not be the only factor contributing to elevated radon gas readings. More geologic study is needed in the county to explore this supposition.

The presence of sand and gravel deposits and their ability to serve as conduits for radon is favored by Kumar et al. (1990). Surficial materials in Summit County are dominated by glacial deposits of the Wisconsin age. The Hiram Till covers the northern third of the county, the Kent Till the southeastern corner, and most of the remainder of the county is overlain by Mogadore Till. Associated with these three major tills are extensive areas of valley train and kame deposits composed mainly of sand and gravel (Soil Survey Summit County 1990). Where soils are high in sand and gravel content and thus highly permeable, as are found in the southern part of the county, it is expected that movement of radon gas is facilitated.

Overall, results of the Kumar et al. (1990) study and this study of Summit County are quite similar in terms of percentages of readings over 4 pCi/L (Table 3).

This similarity is not surprising since the northeast part of Ohio appears to have geologic conditions similar to those found in other glaciated portions of the state.

Nazaroff and Nero (1988) and Kumar et al. (1990) state that soil permeability is a contributing factor to the migration of radon and our study yields similar results (Table 4). In soils with permeabilites of three to six inches per hour, 53.5% of the samples were above 4 pCi/L and, where permeability was greater than six inches per hour, 20 of 26 samples (77%), exceeded 4 pCi/L. A significant number of sites with high readings are located in the southern part of the county on medium-textured glacial till and gravelly outwash which have high permeabilities.

TABLE 3

Percent of radon readings <4 pCi/L and >4 pCi/L.

		Kumar et al. (1990)	Harnapp et al. (1997)
Less than 4 pCi/L	=	64.9%	68%
Greater than 4 pCi/L	=	35.1%	32%

TABLE 4

Radon samples >4 pCi/L for different permeability categories.

Permeability	0-1"/hr	1"-3"/hr	3"-6"/hr	>6"/hr
# Samples	66	383	71	26
# >4 pCi/L	8	114	38	20
Percent	12.1%	29.7%	53.5%	76.9%

Areas where the Ohio Shale and Chagrin Shale subcrop, the high uranium content and thin soils appear to yield high radon levels. This may help to explain the cluster of high readings in the northeast portion of the county (Fig. 2). This is consistent with the explanations given by Harrell et al. (1991).

Statistical analyses applied by the Kumar et al. study (1990) using bivariate linear correlation coefficients showed that radon has its strongest association with soil uranium ($r = 0.36$). Admittedly weak, the correlation is, nonetheless, statistically significant. Presence/absence of sand and gravel had the next strongest association with an r of 0.16. Statistical techniques of regression analysis, t-test, and ANOVA were applied to the Summit County data to see to what degree various factors could explain the radon pattern. Nine factors were found to be statistically significant (Table 1). Environmental factors which influence indoor radon concentrations are surface uranium concentrations, soil permeability, low barometric pressure, and rainfall. The interaction of these factors appears to be more important than any single factor controlling indoor radon levels. For example, that interaction of several factors comes into play when considering the relationship of radon and depth to groundwater. Even though the correlation analysis shows the relationship to be statistically significant, the regression analysis indicates that the relationship is statistically insignificant. Finally, the correlations between radon activities and temperature and rainfall are positive, but not strong.

Regression analysis further indicates the following order of importance in elevated radon levels: 1) barometric pressure, 2) surface uranium concentration, 3) soil permeability, and 4) precipitation (Table 5). These results generally agree with Kumar et al. (1990) although

TABLE 5

Results of regression analysis.

Variable	B	Beta	T	Signif T*
Airp	-7.240044	-.348985	-8.618	.0000
Bedrock	.790833	.077289	2.103	.0359
Grodwat	-.146454	-.049961	-1.055	.2921
Pcip	-2.591523	-.181169	-4.892	.0000
Perm	.596175	.244843	5.174	.0000
Temp	.029228	.109002	2.831	.0048
Uran	8.111519	.249182	6.770	.0000
Wind	-.102888	-.079732	-1.997	.0464
(Constant)	194.870558		7.844	.0000
Multiple R	.56682	F = 31.12397		
R Square	.32128	Signif F = 0.000		

r values may vary between the two studies. The full statistical results from the Summit County study may be seen in Tables 4-6.

TABLE 6

Comparison of seasonal indoor radon concentrations in Summit County by ANOVA analysis.

	Analysis of Variance			
	Spring	Summer	Fall	Winter
Number of Samples	98	113	241	94
Average Reading (pCi/L)	3.99	4.21	4.18	3.32
F = 1.19	Significance of F = .419			

Table 6, with readings by season, does not support the popular notion that indoor radon concentrations are higher in winter than in other seasons. In fact, the average reading in winter is the lowest among the four seasons. Similar results have been found by Dudney (1990) in the Tennessee Valley area.

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