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RADON IN THE SOILS OF MARION COUNTY, INDIANA

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ABSTRACT: Soil radon content was sampled at 484 sites in Marion County, Indiana, to determine the amount of the radon present in the various glacially derived soil types. No correlation was found between radon level and soil type. Soil radon levels were controlled by the mineralogy of the underlying bedrock units, whose contacts were mapped using the radon levels in the soils.

KEYWORDS: Borden Group, Marion County, Muscatatuck Group, New Albany Shale, Radon, Soil, Wabash Formation.

INTRODUCTION

A number of papers have been written on the measurement of radon emanating from soils. The objectives of these studies have been manifold. Some authors have studied the transport mechanisms of radon through the soil fabric (Tanner, 1964; Fleischer and Mongro-Campero, 1978; Tanner, 1980; Luetzelschwab, *et al.,* 1989). Others have studied radon and radium transport in groundwater supplies (Hess, *et al.,* 1979; Michel and Moore, 1980; Horton, 1983). Radon measurements have been used in uranium exploration, and some authors have even suggested that radon measurements might be useful in oil exploration (Card, *et al.,* 1985).

The accumulation of radon in dwellings has been studied in the United States, Sweden, Switzerland, Germany, and other European countries (Steinhaeusler, 1975; Swedish Radon Commission, 1984; Swedjemark, 1984; Scott and Findlay, 1983; Buchli and Burkart, 1989; Reimer and Gundersen, 1989). Hasenmueller (1988) characterized the radon production potential of different areas of Indiana based upon aerial radioactivity, geology, and soil permeability.

A few studies have looked at the radon distribution in soils on a county-wide basis. Gundersen, *et al.* (1988) sampled 567 sites in Montgomery County, Maryland. Schumann and Owen (1988) sampled 123 sites in Fairfax County, Virginia. Otton, *et al.* (1988) published a map of Fairfax County, Virginia, showing the radon potential of the County.

SETTING

Marion County is located in central Indiana (Figure 1) and has a land area of 402 square miles. Approximately 20 percent of the County is still farmland, but this percentage is decreasing as the capital, Indianapolis, expands onto former farms.

Four main soil associations are found in Marion County (Sturm and Gilbert, 1978). The Crosby-Brookston Association, which is found on gently rolling upland till plains, covers approximately 40 percent of the County. The

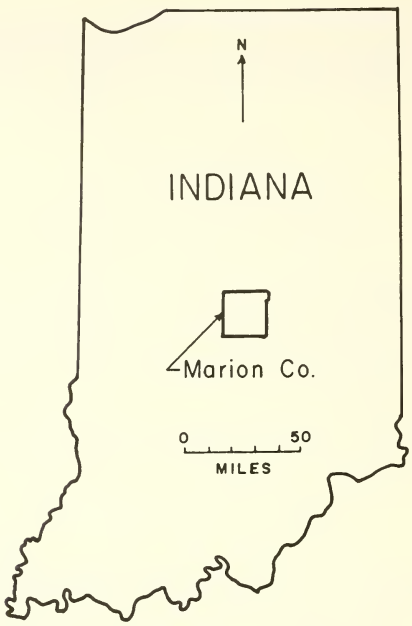

Figure 1. Map of Indiana showing the location of Marion County.

Miami-Crosby Association, which covers approximately 30 percent of the County, is found on dissected upland plains between broad ground moraines and bottom land or between terraces and outwash plains. The Fox-Ockley Association, which covers approximately 18 percent of the County, is found on broad outwash plains and on terraces adjacent to the larger streams. The Genesee-Sloan Association occurs on floodplains along the White River and some of the larger streams, mantling approximately 12 percent of Marion County.

Thirteen soil types were sampled within these four soil associations. The Brookston Series is composed of silty clay loam soils of moderate permeability, which developed on till plains. The Crosby Series consists of silt loam soils with poor permeability, which developed on till plains. The Crosby-Miami soil is a silt loam of moderate permeability, which developed on upland till plains and low knolls. The Eel, Genesee, Shoals, and Sloan Series soils are all silt loams with moderate permeability, which are found on floodplains. The Fox Series soils are loams with moderate to rapid permeability, which occur on outwash plains and terraces. The Hennepin Series soils are loams with moderate permeability,

Table 1. Generalized geologic column of the rock units underlying Marion County (Gray, *et al.,* 1987).

System	Rock unit
Mississippian	Borden Group
Late Devonian	New Albany Shale
Middle Devonian	Muscatatuck Group
Silurian	Wabash Formation

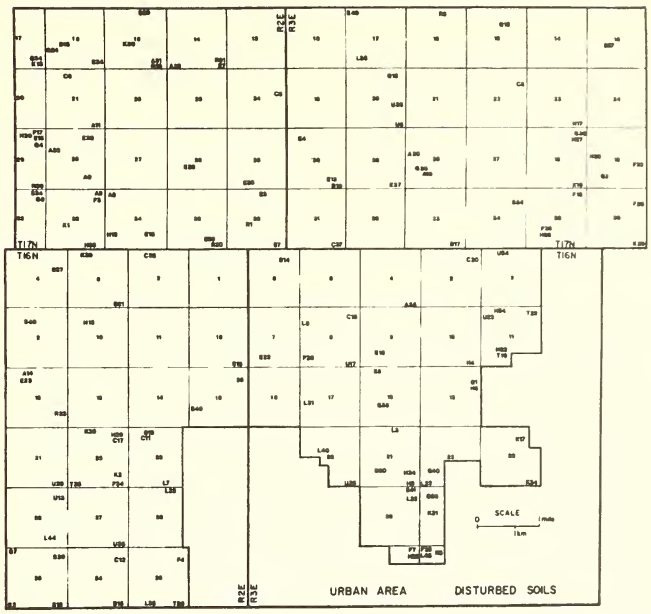

Figure 2. Northwest quarter of Marion County showing soil sample sites; B = Brookston; C = Crosby; R = Crosby-Miami; E = Eel; F = Fox; G = Genesee; H = Hennepin; A = Martinsville; U = Miami; K = Ockley; S = Shoals; L = Sloan; T = Westland.

which developed on steep escarpments. The Martinsville and Ockley Series soils are both silt loams with moderate permeability found on outwash plains and terraces. The Miami Series soils are silt loams with moderate to slow permeability, which occur on till plains. The Westland Series soils are clay loams, which are found on outwash plains and terraces.

Table 2. Soil radon levels in picoCuries/liter (pCi/1) from 421 sample sites in 13 soil types in Marion County, Indiana.

Soil Type	Number Sample Sites	Minimum pCi/1	Maximum pCi/1	Mean pCi/1	Standard Deviation
Crosby	35	0	4650	817	919
Miami	32	50	3600	1055	892
Brookston	37	0	3800	678	706
Genesee	30	0	3050	787	698
Fox	34	50	3150	653	654
Crosby-Miami	32	0	3800	742	749
Sloan	32	100	2500	675	614
Ockley	31	100	3800	942	845
Hennepin	34	0	3400	803	684
Shoals	31	50	2600	690	573
Eel	32	0	2000	494	446
Martinsville	31	50	2750	779	714
Westland	30	50	3800	965	843

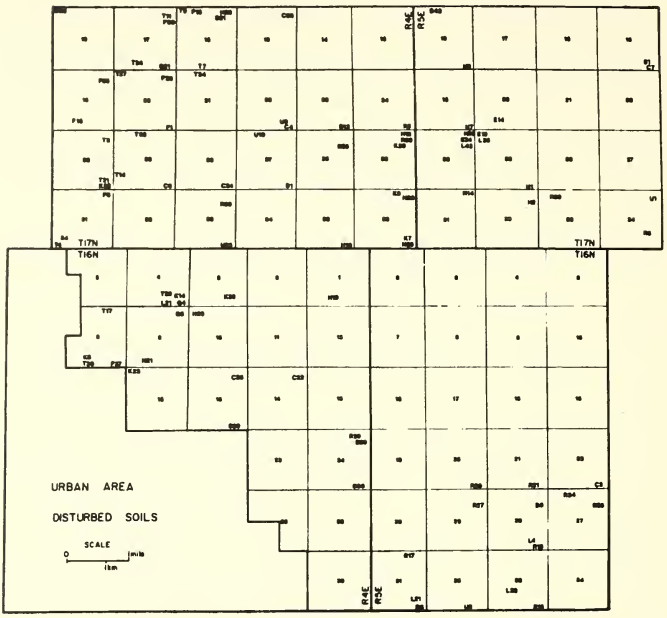

Figure 3. Northeast quarter of Marion County showing soil sample sites; B = Brookston; C = Crosby; R = Crosby-Miami; E = Eel; F = Fox; G = Genesee; H = Hennepin; A = Martinsville; U = Miami; K = Ockley; S = Shoals; L = Sloan; T = Westland.

Large areas of Marion County have been developed for commercial and residential uses. In these areas, the soil structure has been so altered and obscured by construction that identification of the soils is not possible. The areas classified as urban land in the soil survey report of Strum and Gilbert (1978) were not sampled in this study. These areas are in the central part of the County, which has been urbanized for well over one hundred years.

BEDROCK GEOLOGY

The bedrock in Marion County is comprised of sedimentary rock layers dipping gently to the southwest into the Illinois Basin (Harrison, 1963). The oldest bedrock unit is the Silurian Wabash Formation, which is located in the northeastern part of the County and is composed of calcareous shales, argillaceous

Table 3. Soil radon levels from 272 sample sites over four bedrock units as depicted by Gray, *et al.* (1987)

Rock unit	Number Sample Sites	Minimum pCi/l	Maximum pCi/l	Mean pCi/l	Standard Deviation
Borden	36	0	450	249	126
Muscatatuck	64	0	700	230	172
New Albany	129	150	3800	1062	670
Wabash	43	0	4650	1155	1048

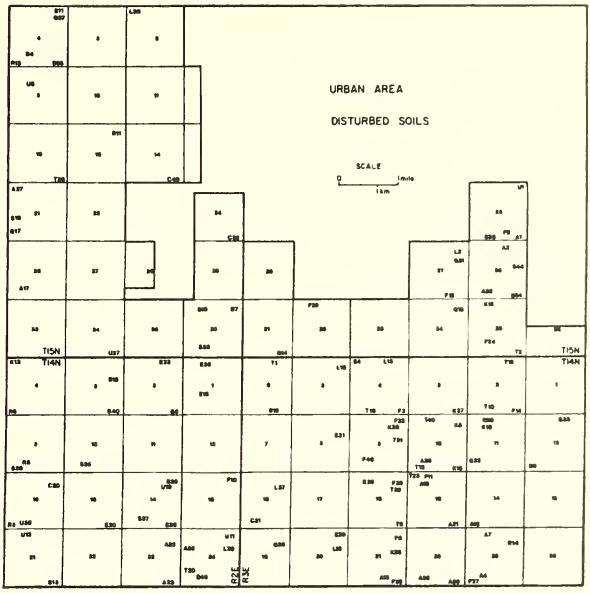

Figure 4. Southwest quarter of Marion County showing soil sample sites; B = Brookston; C = Crosby; R = Crosby-Miami; E = Eel; F = Fox; G = Genesee; H = Hennepin; A = Martinsville; U = Miami; K = Ockley; S = Shoals; L = Sloan; T = Westland.

limestones, and cherty dolomitic limestones. Some reef structures are found within the Wabash Formation, since it was deposited during a time of active reef formation in the Late Silurian. Disconformably overlying the Silurian rocks are the interbedded carbonate rocks of the Devonian Muscatatuck Group. These carbonate rocks are found throughout eastern Marion County. The Middle Devonian to Early Mississippian New Albany Shale overlies the Muscatatuck Group. The New Albany Shale is a carbonaceous black shale which contains small, but measurable, quantities of radioactive elements (Al-Jassar, 1981). The New Albany Shale underlies the northwestern and west-central portions of the County. In southwestern Marion County, the Mississippian Borden Group is found, which consists of thin-bedded limestones, sandstones, siltstones, and shales. The entire County is covered with a mantle of Pleistocene glacial deposits, consisting mainly of tills in the uplands and sands and gravels on the outwash terraces and in the river valleys.

Table 4. Soil radon levels from 484 sample sites over four bedrock units reconfigured based on the bedrock map of Marion County, Indiana (Gray, *et al.* 1987)

Rock unit	Number Sample Sites	Minimum pCi/l	Maximum pCi/l	Mean pCi/l	Standard Deviation
Borden	61	0	450	203	134
Muscatatuck	116	0	700	212	132
New Albany	239	150	3800	1037	642
Wabash	68	0	4650	1193	925

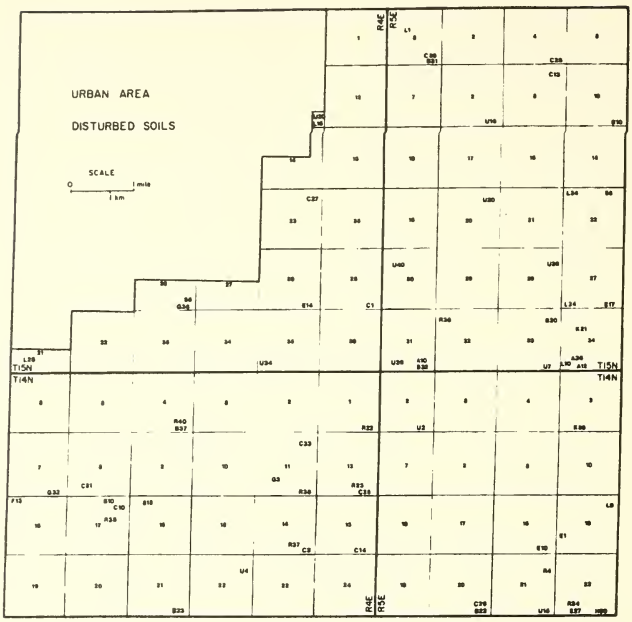

Figure 5. Southeast quarter of Marion County showing soil sample sites; B = Brookston; C = Crosby; R = Crosby-Miami; E = Eel; F = Fox; G = Genesee; H = Hennepin; A = Martinsville; U = Miami; K = Ockley; S = Shoals; L = Sloan; T = Westland.

MATERIALS AND METHODS

At least 30 samples were collected from each of the 13 soil types that cover most of Marion County. The sample sites were chosen with the aid of a computerized random-number generator.

To collect the soil gas, an 8 mm diameter hollow steel probe was pounded into the soil to a depth of 75 cm and then covered with a rubber septum. Three 10 cc samples of soil gas were drawn at each site by inserting hypodermic syringes through the septum. At some of the sites, a soil gas sample could not be collected at this depth, because the soil was too impermeable or too wet at 75 cm. In these cases, samples were collected at shallower depths.

Each sample was stored for at least one hour before analysis to ensure that only 222-Radon was present in the sample. No trace of 220-Radon would remain, because this gas has a half-life of less than one minute. An EDA RD-200 alpha scintillometer with removable phosphor-coated cells was used to analyze each sample. The counting method was similar to that of Reimer (1990), who had similar equipment.

RADON VALUES IN THE SOILS

The radon levels ranged from 0 to 4650 pCi/1 (picoCuries per liter) in the thirteen soil types (Table 2). The sample sites covered approximately 72 percent of Marion County. An analysis of variance run on the radon values in the different soil types showed no statistically significant relationship for the arithmetic mean

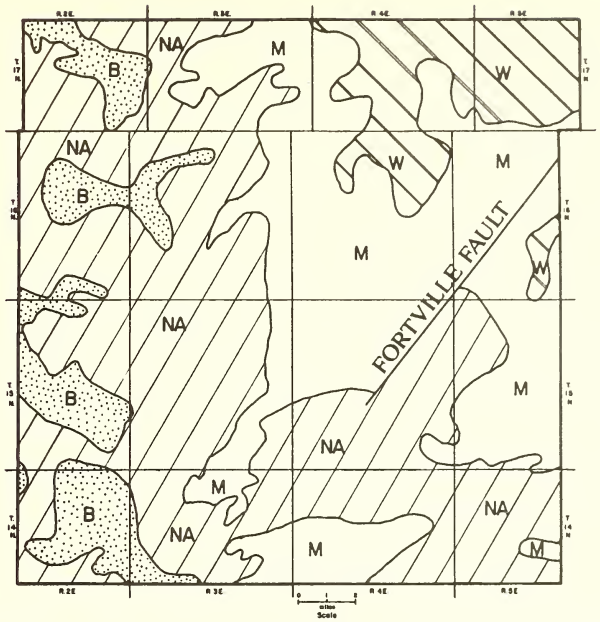

Figure 6. A revised geologic map of Marion County based on data from Gray, *et al.* (1987) and the soil radon data in this report; B = Borden Group; NA = New Albany Shale; M = Muscatatuck Group; W = Wabash Formation. The northeast trending line in Townships 15N and 16N is the trace of the Fortville Fault.

(F = 1.264; df = 12,420; P = 0.2211) or the ln transformation (F = 0.954; df = 12,420; P = 0.5036) of the soil radon data. The soils types were combined into five groups based on their mode of formation: 1) broad till plains, 2) old glacial drainage ways, 3) well-drained outwash plains, 4) modern floodplains, and 5) steep slopes and escarpments. An analysis of variance run on these five groups associated by soil origin failed to reveal a statistically significant relationship within the data both for the arithmetic mean (F = 0.832; df = 4,420; P = 0.5050) and the ln transformation (F = 0.934; df = 4,420; P = 0.4439).

RADON VALUES OVER BEDROCK UNITS

Table 3 summarizes the radon values in the soils directly over the different rock formations in Marion County. Gray, *et al.* (1987) used a considerable amount of well log data to produce the Bedrock Geologic Map of Indiana. There is no reason to doubt the overall validity of their map. However, the radon values appear to indicate that there are definite areas of high and low radon levels which do not correspond to any particular soil type. The 272 sites in Table 3 represent approximately 56 percent of the sample sites. This subset of the data represents the sites where both the Indiana Geological Survey Map and the author agree that the bedrock is the same. Analysis of variance of the radon levels at these sites shows statistically significant relationships for both the arithmetic mean (F = 38.597; df = 3,271; $P << 0.001$) and the ln transformation (F = 29.293; df = 3,271;

$P << 0.001$) of the data. This subset of the data showed that bedrock was the factor controlling soil radon levels in Marion County.

Table 4 summarizes the data for all 484 sample sites based on the author's re-interpretation of the bedrock formation found under each sample site based strictly on soil radon levels. The author believes that the underlying bedrock has a greater effect on soil radon levels than the soil type itself. Further, the bedrock units can be mapped using the soil radon levels. Analysis of variance on the radon levels at these sites over the four different bedrock types indicated a statistically significant relationship between both the arithmetic mean ($F = 85.922$; $df = 3,483$; $P = 0.0$) and the ln transformation ($F = 61.237$; $df = 3,483$; $P = 0.0$) of the data.

The rate of movement of soil radon either in the gaseous phase or dissolved in water is related to the porosity and permeability of the regolith on top of the bedrock. This study was not designed to measure porosity or permeability at the collection sites. Typically, 100 feet of glacial deposits cover the bedrock in Marion County. In some of the river valleys, the overburden averages 50 feet, while on the outwash plains, the overburden may be 200 or more feet in thickness.

CONCLUSIONS

Figure 6 is a revised bedrock map for Marion County, based primarily on the Indiana Geological Survey Bedrock Map (Gray, *et al.,* 1987). Some formation contacts have been redrawn based on soil radon levels found during this study. The soil radon levels could be used to plot the contacts between bedrock units, if there was a significant difference in the amount of radioactive material in each of the bedrock units that were in contact. In this study, the two highest radon-producing units (the New Albany Shale and the Wabash Formation) are separated by two low radon-producing units (the Borden Group and the Muscatatuck Group).

The bedrock might well control soil radon levels in unglaciated terrain, where the soils developed from the underlying bedrock over a long period of time. In Marion County, the soils did not develop from the underlying bedrock but were formed from the glacial materials deposited by the melt waters of retreating Wisconsin glacial ice. To be controlled by bedrock, the radon must travel upward from the bedrock through the regolith in a relatively short period of time, since the half life of 222-Radon is approximately 3.8 days. The transport mechanism is undoubtedly based on a complex interacting set of factors in the bedrock units and the regolith.

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