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Statistical Analysis of Indoor Radon Data and Relationships to Geology in Wisconsin

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STATISTICAL ANALYSIS OF INDOOR RADON DATA AND RELATIONSHIPS TO GEOLOGY IN WISCONSIN

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Thursday May 11

Technical Session III

Session Chairs: George Hudak *(University of Wisconsin-Oshkosh),* Laurel Woodruff *(United States Geological Survey)*

9:55 a.m. **Mudrey, Michael G. Jr.**

Statistical analysis of indoor radon data and relationships to geology in Wisconsin

!!!KEY CONCLUSIONS!!!

- **Elevated indoor radon is found in all areas of Wisconsin as predicted by geological analysis.**
- **Soil derived from granite and carbonate rock is the principal geological factor leading to elevated indoor radon in Wisconsin.**
- **(not discussed here) Construction variables are the dominant control on radon entry.**

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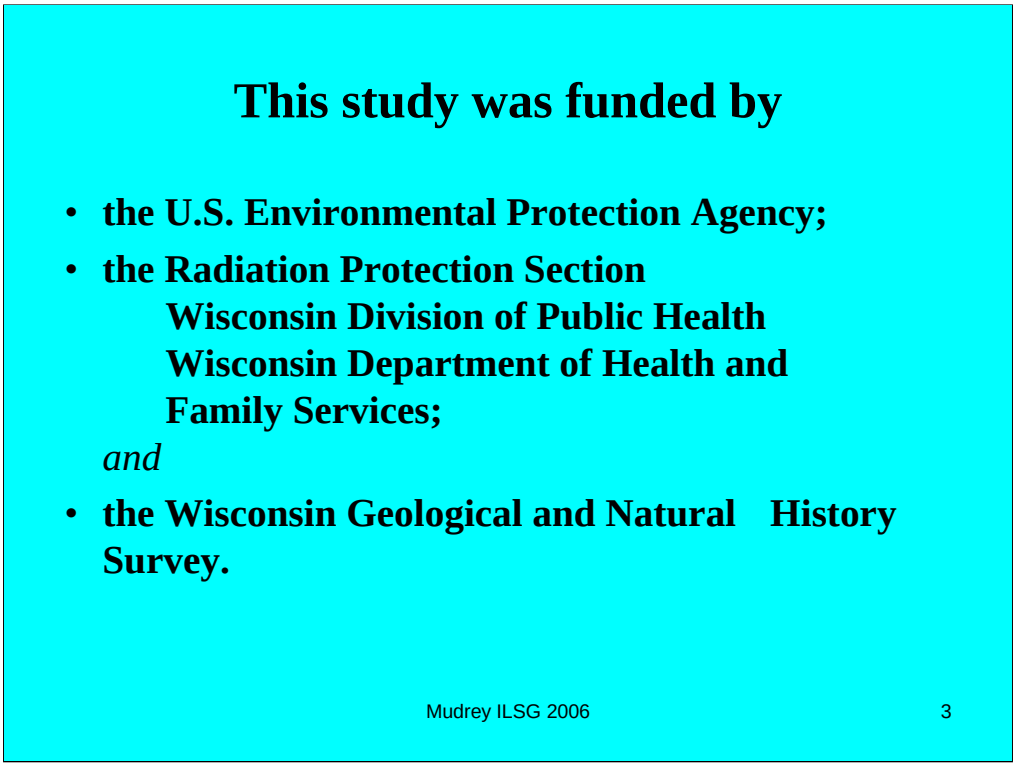
I am dealing here today with public health policy ramifications of environmental geology related to STATISTICAL ANALYSIS OF INDOOR RADON DATA. The key conclusions from our work at the Wisconsin Geological and Natural History Survey, the Wisconsin Department of Health and Family Services and the US EPA is that elevated radon can be found in all areas of Wisconsin; that soil derived from granite and carbonate rock and the Pleistocene material derived from that rock is the principal geologic factor; and as a consequence, testing of all buildings is more cost effective in identifying elevated indoor radon than trying to predict the radon.



This work was funded by the U.S. Environmental Protection Agency; the Radiation Protection Section Wisconsin Division of Public Health Wisconsin Department of Health and Family Services; *and* the Wisconsin Geological and Natural History Survey since 1986. Technical articles have been presented to various radiologic and health conferences. In the past few years we have focused on acquiring additional data, and performing a geologic analysis to better understand the various components that lead to elevated indoor radon.

Background of Survey

- **In the 1986 the US Environmental Protection Agency initiated a nation-wide study to determine the population and geographical risk associated with radon. Because Wisconsin has a strong state radiation protection program, and known occurrences of uranium and other radionuclides, it was one of 10 initial states to be analyzed.**

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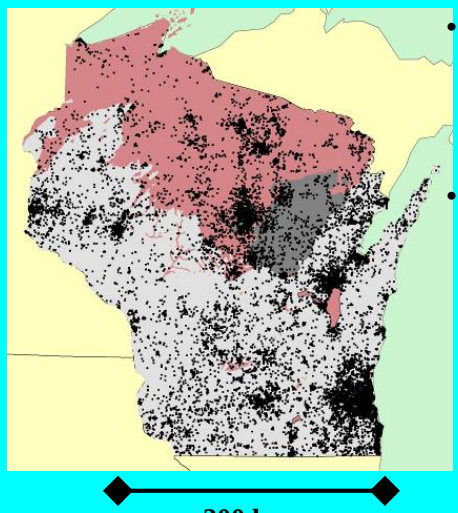
84,262 residential indoor radon in air measurements have been collected since 1986



- **These <u>data are not randomly distributed</u> and reflect collection by interested home owners.**
- **Nearly <u>50% of the analyses have been accurately located and digitized permitting geologic analysis</u>; the remainder has only zipcode locational information.**

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We have been able to obtain approximately 85,000 indoor radon in air measurements. We also have an extensive data base on radioelements in water, soil and rock. This body of data represents approximately $2,000,000 in laboratory costs, and probably an additional $5,000,000 in labor costs to acquire the data. The data are not randomly distributed as seen on this diagram, but rather represent the distribution of interested home owners in acquiring data. As a consequence, the data should be viewed as a snapshot of public exposure to radon, and not a geographic/geologic distribution.

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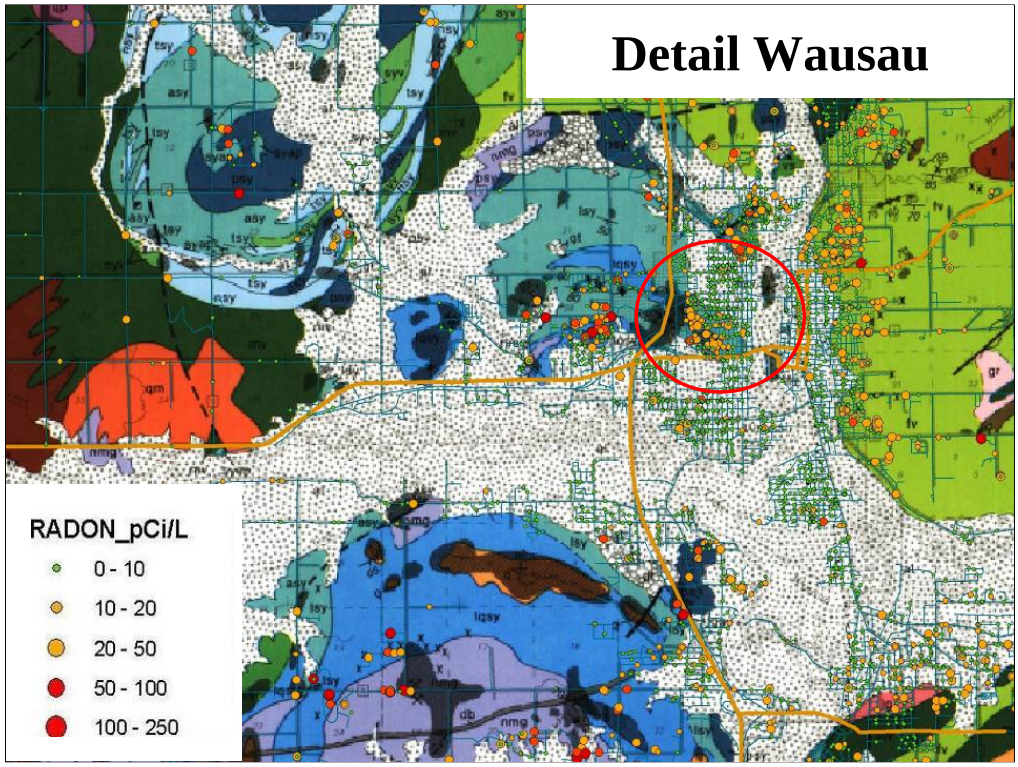
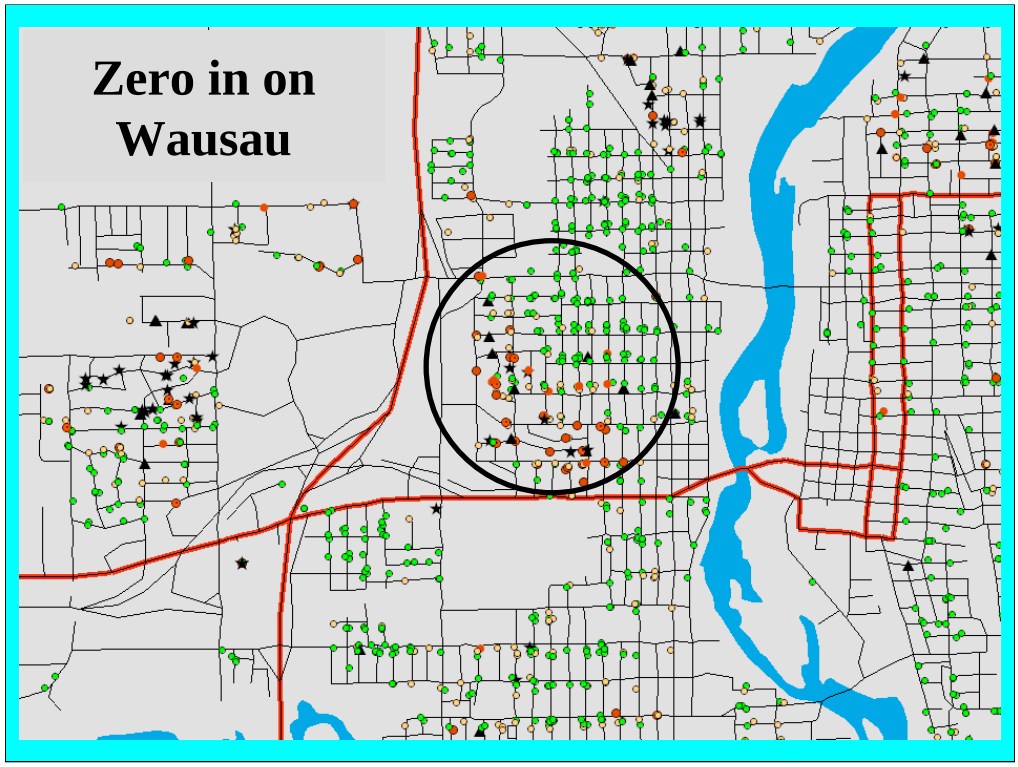


This detail from the Wausau area not only shows the density of data, but also magnitude of elevated radon with geographic locale. There are a large number of elevated houses over the Wausau and Stetin Syenite Complexes, which produced uranothrorite during World War II. Houses built on colluvium from the syenite in the Wisconsin River Valley are elevated, as are houses on the Eau Pleine River which originates to the east over the Wolf River Batholith.



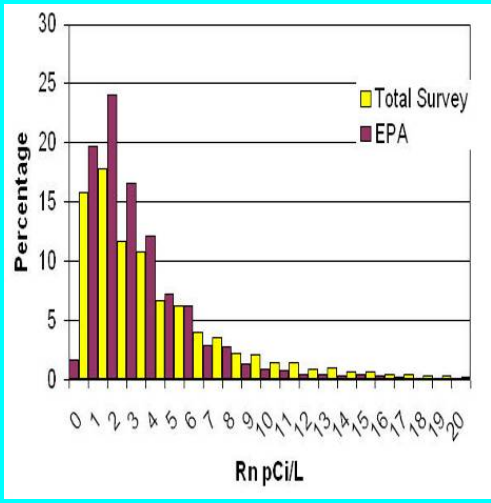
This area shows in much greater detail the density of data available in metropolitan areas. It also illustrates a point I will make at the poster session in that the area circled has exactly the same bedrock geology, Pleistocene geology, soil type, and depth to bedrock. The only difference is in the details of housing construction. The stars are radon over 30 pCi/l, the green is less than 4 pCi/L.

Frequency Analysis

Rn pCi/L	Total Survey %	*EPA %*	*Geolocated %*	*No Dups %*
0	7.5	1.7	5.6	6.5
1	15.9	19.7	11.5	13.1
2	17.8	24.0	16.8	18.7
3	11.7	16.6	13.7	15.0
4	10.8	12.1	10.7	11.3
5	6.7	7.3	8.1	7.8
6	6.2	6.2	6.4	5.9
7	4.0	2.8	4.9	4.5
8	3.6	2.8	3.9	3.3
9	2.3	1.3	2.8	2.3
10	2.2	0.9	2.3	1.8
> 10	11.4	4.5	13.4	9.7

Nearly 50% of the analyses have been accurately located and digitized permitting geologic analysis; the remainder has only zipcode locational information. Comparison of the accurately located data with the larger dataset shows minimal statistical differences.

EPA survey is considered the only statistically useful survey for evaluating average values



- **Mean of 3.4 pCi/L**
- **Q1 of 1.2 and a Q3 of 4.1**
- **The data are highly skewed**
- **More recent data are skewed to higher values**

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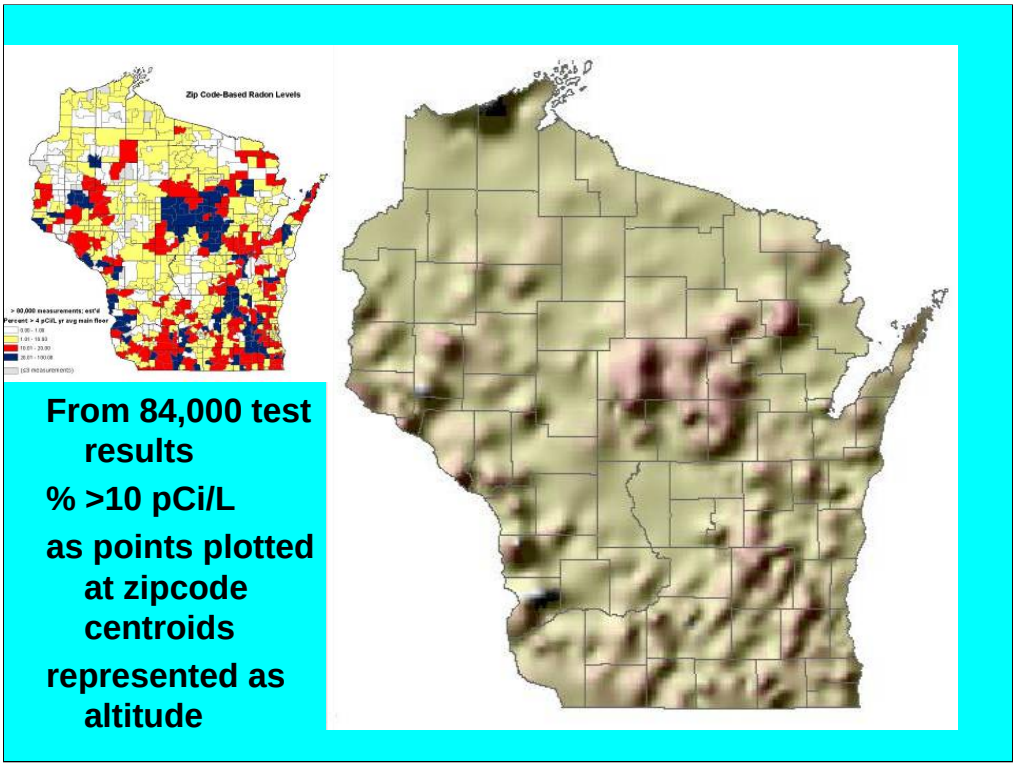
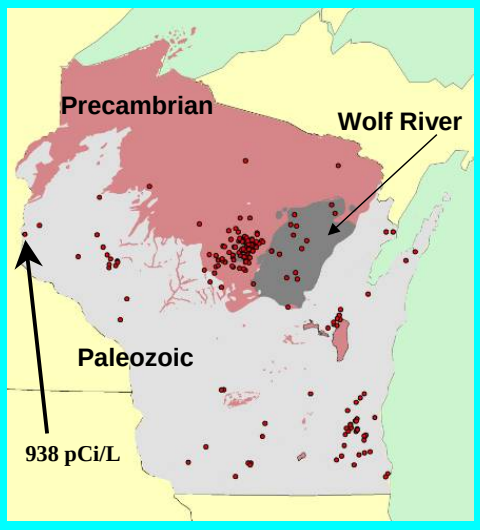
However, because of the non-random nature of all but the EPA Survey. All the data are lognormally skewed, which I will illustrate later. All subsequent surveys are shifted to the right, raising the apparent median and mean, and producing a larger and longer high value tail. The more recent, larger data sets, are generally skewed to higher values, probably reflecting some degree of self-selection by home owners.



For risk communication to the general public, we generally work in zipcode space. Areas in the upper left in blue are those zipcodes in which 20 to 100 percent of the homes have a short-term measurement in excess of 10 pCi/L, and thus probably have a year-long average value in excess of the EPA action level of 4 pCi/L. The advantage of using zipcodes is that data is intrinsically averaged, and lower density population areas have larger areas, and hence the population-based data are somewhat smoothed.

The larger map is the zipcdoe averaged data plotted as a shaded relief map with colors. I will come back to this map with geology in a minute. You will notice that two large areas manifest themselves for elevated radon in Wisconsin: the central part around Wausau, and an ill defined arcuate pattern in the west, around the south and up the eastern side of Wisconsin. The elevated zone does not include Milwaukee County, but does include the counties immediately west of Milwaukee.

Elevated indoor radon is found in all areas of Wisconsin (> 50 pCi/L shown)



- **Soil derived from granite and carbonate rock is the principal geological factor leading to elevated indoor radon in Wisconsin.**
- **Because radon can migrate only a few meters over the 3.8 day half-life, soil chemistry and soil texture principally influence elevated indoor radon**

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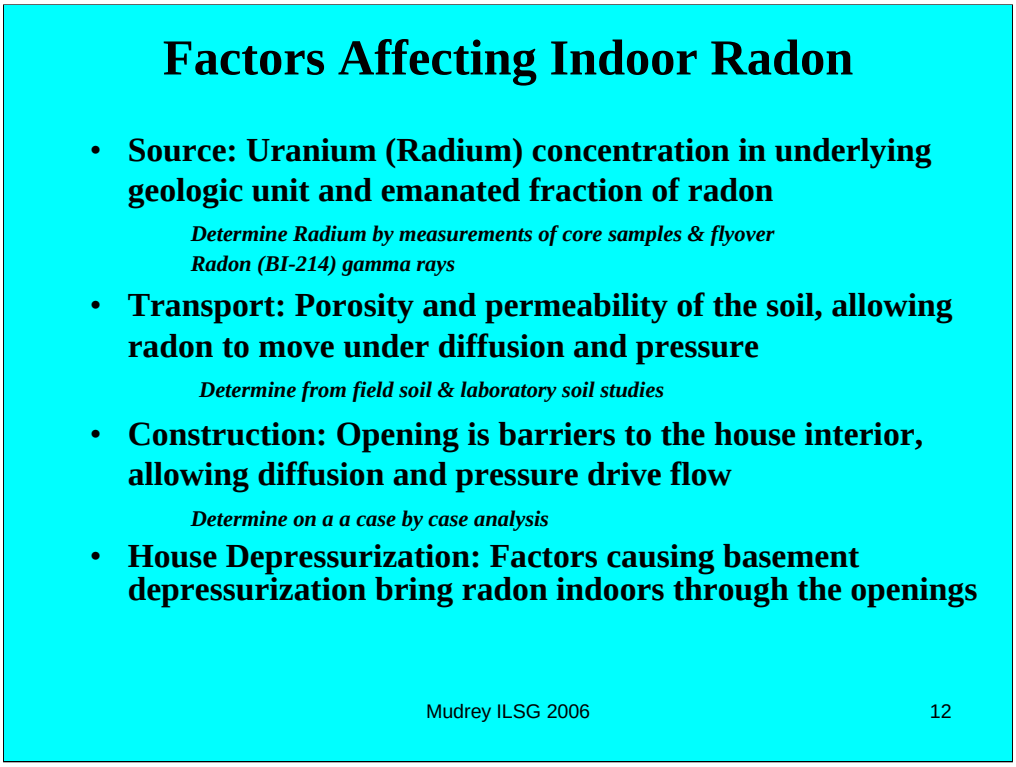
This map has only the 550 measurements 50 pCi/L or greater, the highest being nearly 1000 pCi/L. Significantly elevated radon is found throughout Wisconsin. As I will show in the next few slides, it is soil derived from radioactive granite (Wolf River related units), and dolomite that is the principal geological factor leading to elevated indoor radon in Wisconsin. Radon has a half-life of 3.8 days. Based on diffusion from mineral structures and migration in soil vapor, radon can migrate less then 10 meters. It is the soil chemistry and soil texture the principally influence elevated indoor radon. Unweathered bedrock is NOT the source of radon in houses. If, however, the bedrock is weathered, then it might be a part of the causal story.



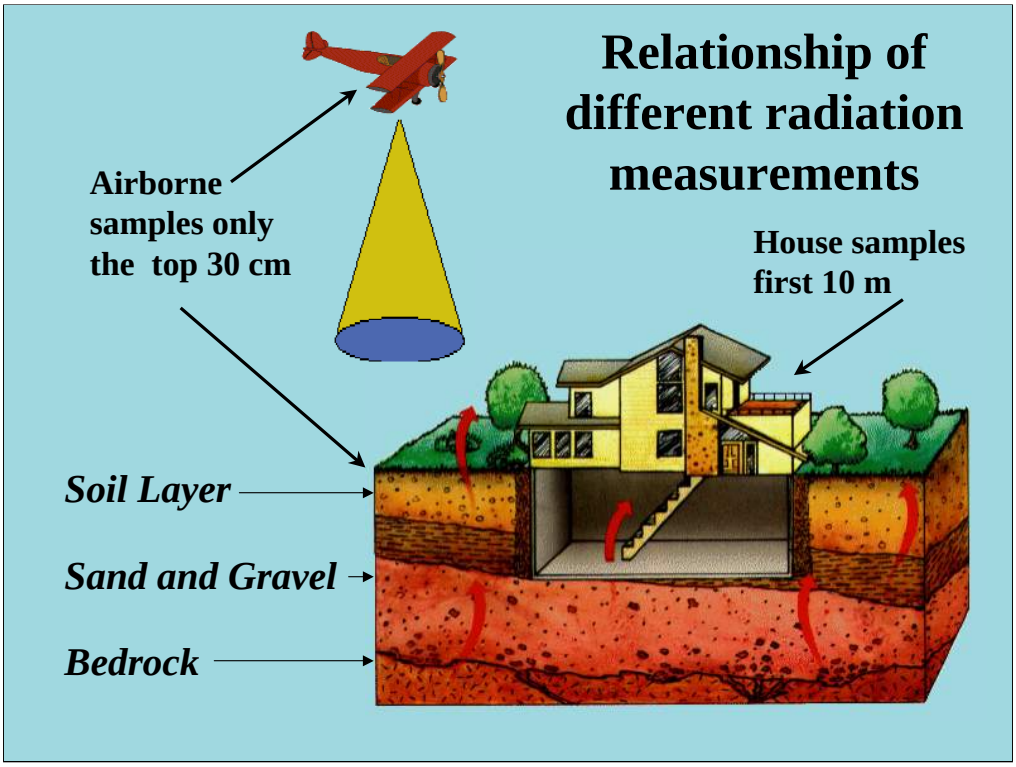
We generally identify four factors that influence indoor radon.

There must be a radium source term. A low uranium soil of 1 ppm yeilds soil gas radon is excess of 1000 pCi/L. The highest soil gas that we have measured is 7,000 pCi/L.

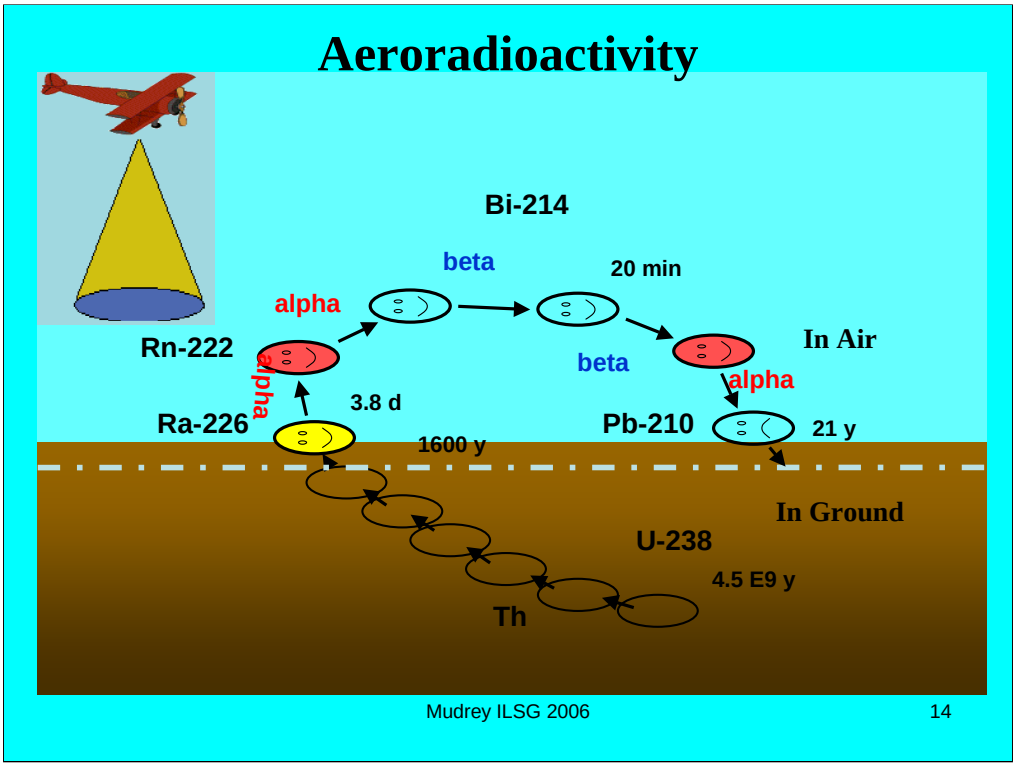
There must be transport of the radon from the site of decay of radium to the house foundation. This is influenced by the physical characteristics of the immediate subjacent soil.

Construction of the building is the greatest barrier to radon entry, but even a well built, non-radon resistant house will permit entry of radon by about 1 percent through minor cracks and utility penetrations. The poster session will cover this in more detail.

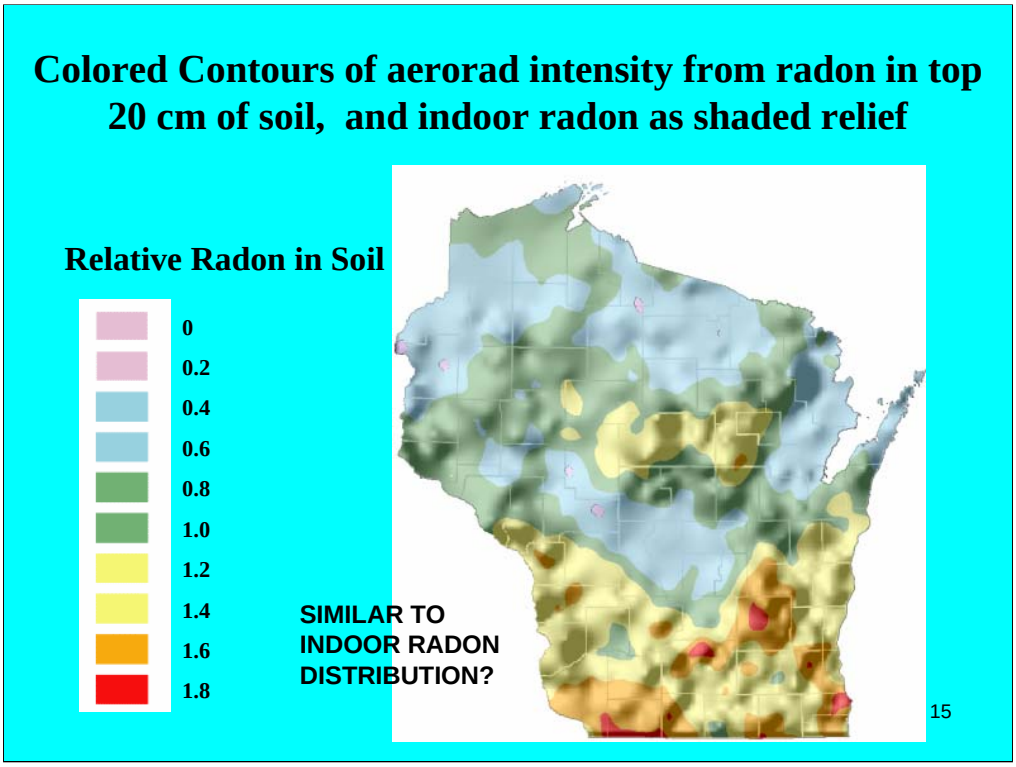
There must be a driving force to suck the radon from the soil into the building. Solar heating during the day introduces sufficient pressure differential to drive the radon in.



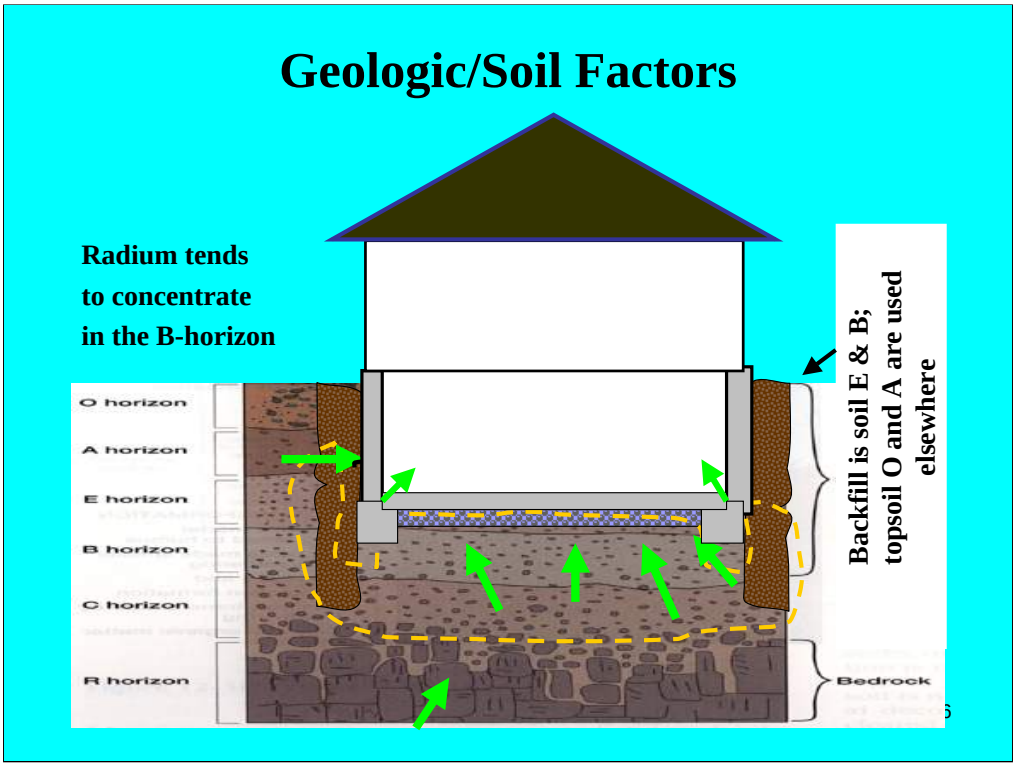
Three techniques are available to monitor radium. Airborne surveys measure Bi-214 but only in the first 30 cm of surface material. Below that depth, the gamma signal is shielded. One can sample the soil, surficial material and bedrock, however this sampling must be undertaken to the full depth of the foundation of a building with the radon zone under the building. Few measurements are made to a depth of 10 m. We have chosen to view a house as an inverted beaker covering 10 meters on a side placed into the earth as a sampling container. This home, thus represents a sampling tool that averages the first 10 m of geo-substrate in the 2-7 day sampling time. Temporal variations in measurements are illustrated at the poster session.



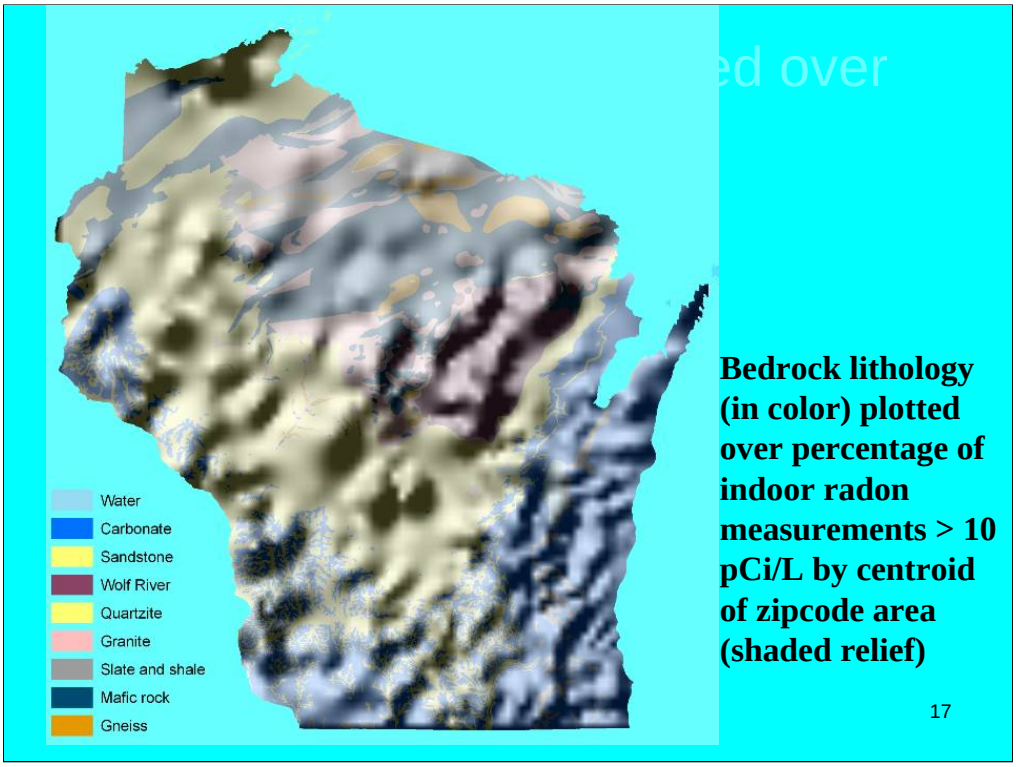
Radon 222 to lead 210 are either gases or aerosols. All of the other nuclides in this greatly simplified diagram are part of the geochemical story. Radium, for instance, behaves as calcium and is concentrated along fractures in dolomite and limestone. Weathering of the carbonate releases the bound radon which then explains the elevated radon found in carbonate terranes and terra rosa soil.



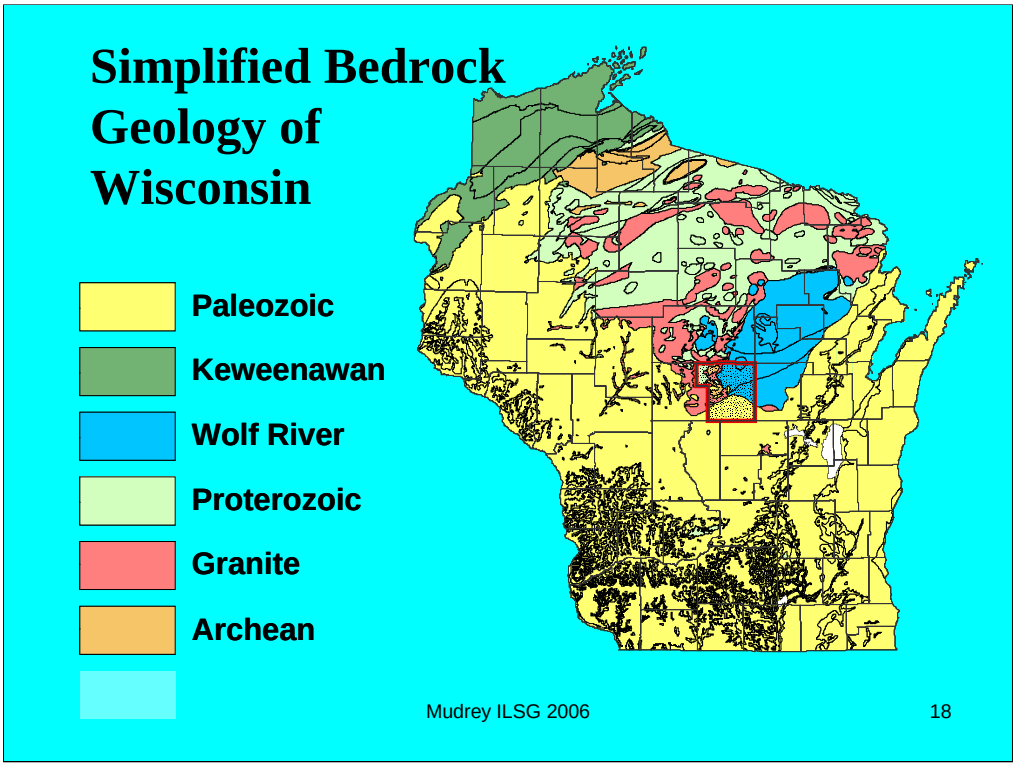
This diagram is similar to the zipcoded indoor radon data, but represents analysis of the aerorad surveys in Wisconsin. The colored scale is in equivalent ppm uranium over a shaded relief map of the same data. This information was reduced by Joe Duval of the USGS from US DOE NURE data flown in the late 1970s. Again, notice that the central part of Wisconsin is elevated; and there is a generally U shaped pattern in the west, across the south and in the east.



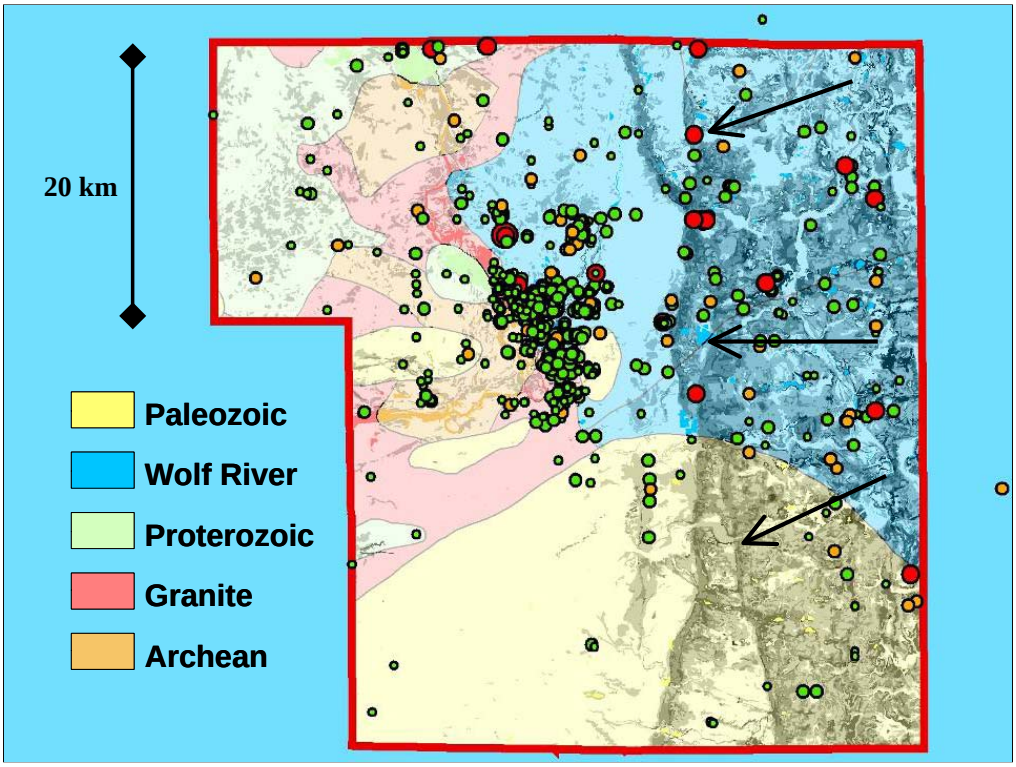
A typical house is not built into bedrock, but rather in the soil and surficial material at a site. Radium concentrates in the carbonate and organically rich B horizon which typically found at foundation depth. In addition, the back fill around a foundation is typically the B horizon material. Thus the most radioactive part of the soil profile is immediately adjacent to the foundation and available for radon entry.



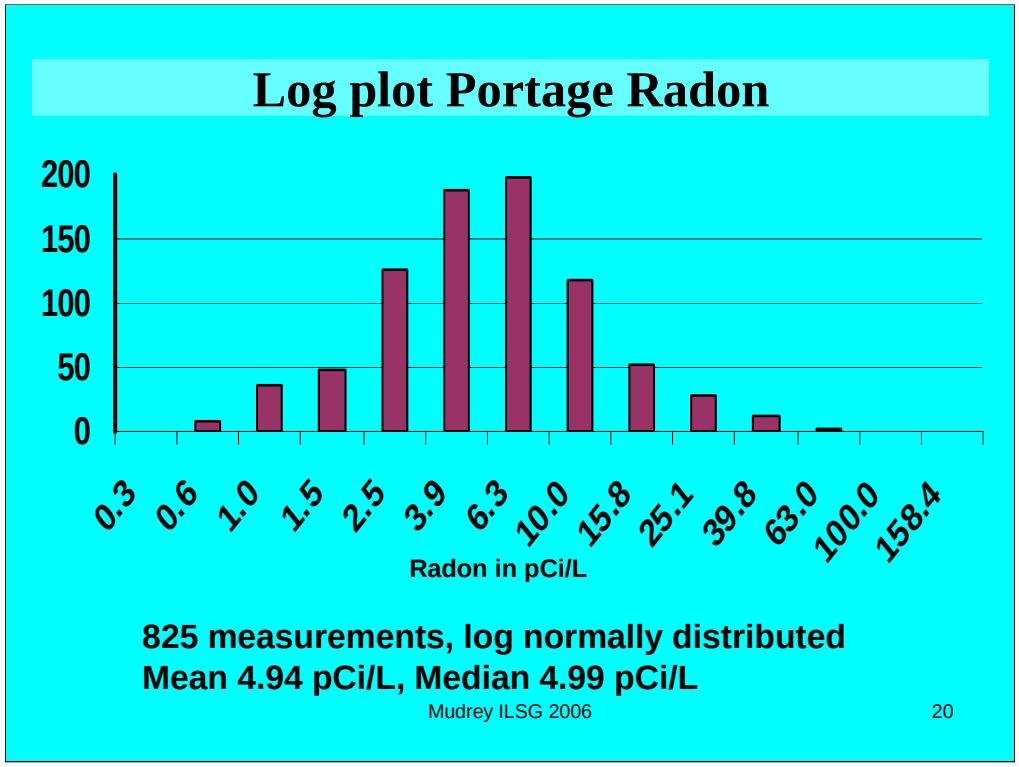
Please bear with me on this diagram. The Wolf River batholith is shown in maroon, and dolomite in blue. Notice that granite in northern Wisconsin generally does not show elevated radon, in part because of demographics and because of thickness of surficial material. Isolated hot spots can be found in the sand and sandstone areas; those are usually related to construction problems.



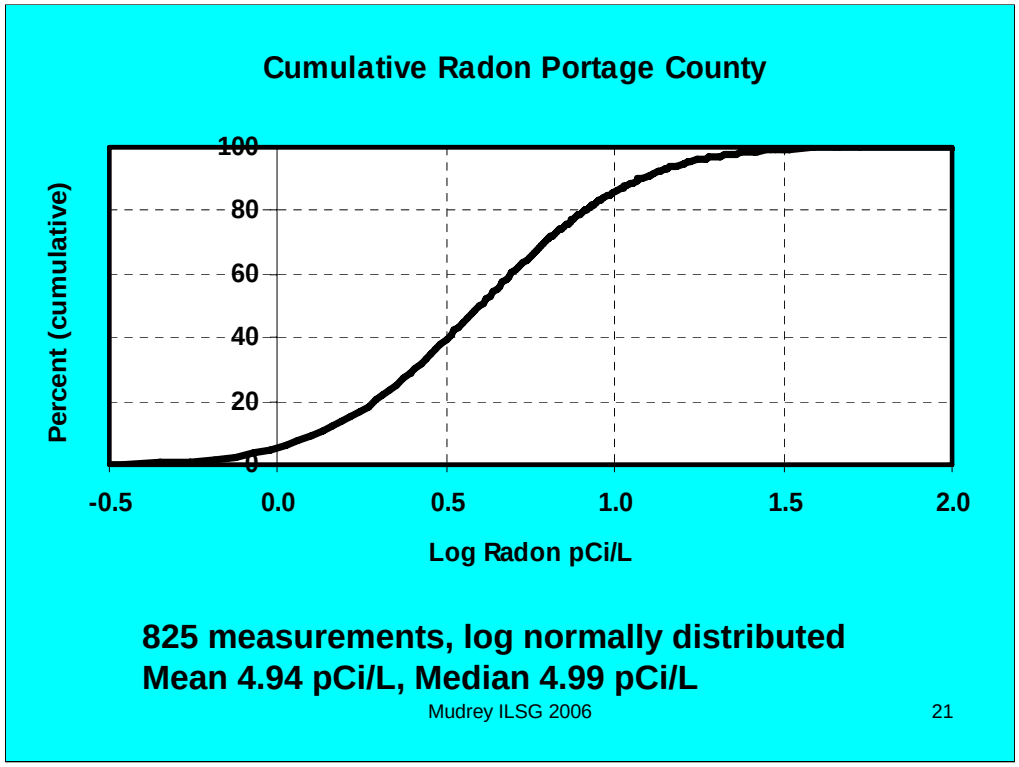
I will now take you to central Wisconsin, the Stevens Point area shown in red outline. Blue is the Wolf River Batholith, and yellow is Paleozoic rock, which in Stevens Point is sandstone.



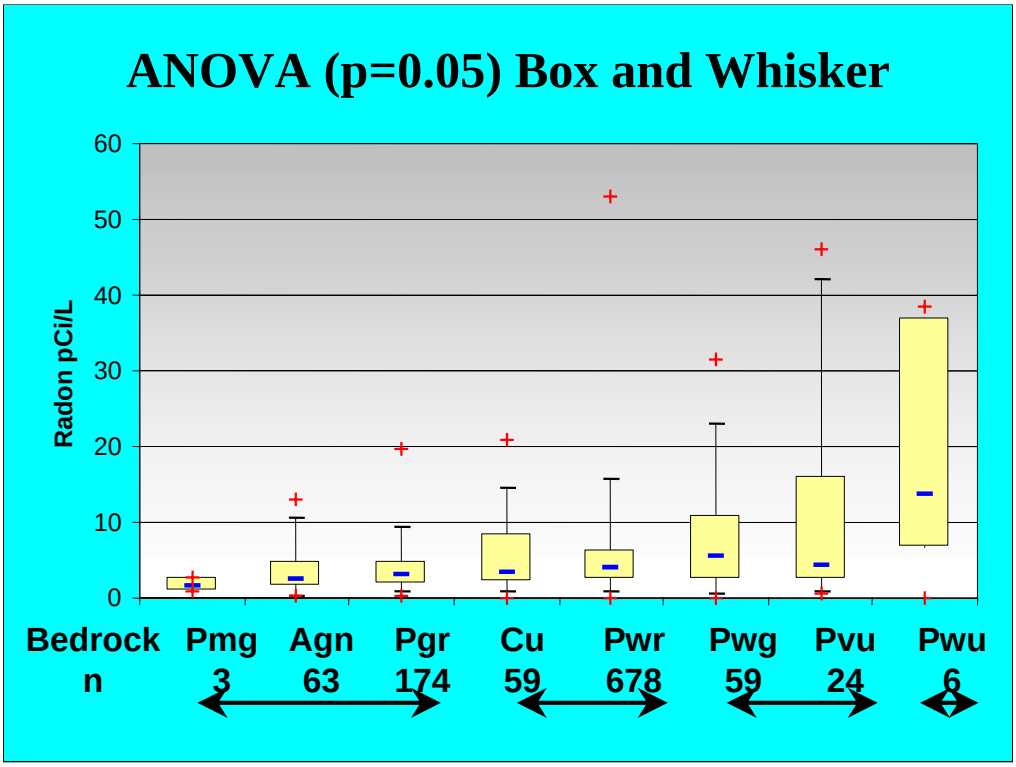
I have superposed the bedrock geology over a Pleistocene map. The arrows denote the direction of glacial movement and material flow in the Green Bay lobe to the east. The terminal moraines are the shaded area in the east; the unshaded area is glacial outwash and lacustrine material of Glacial Lake Wisconsin. Colored spots are the approximately 1000 radon measurements in Portage County, red being the highest. Bedrock geology consists of 2.8 Gy gneiss, 1.9 Gy granite and greenstone, 1.5 Gy Wolf River Batholith, and 550 my sandstone.



This is the data in Portage County. It is lognormally distributed, with a mean of 4.94 and a median of 5.0.



The upper and lower 20 percent of the data depart from lognormality, with the tail positively skewed, ie high values. There is no obvious polymodality in the data.

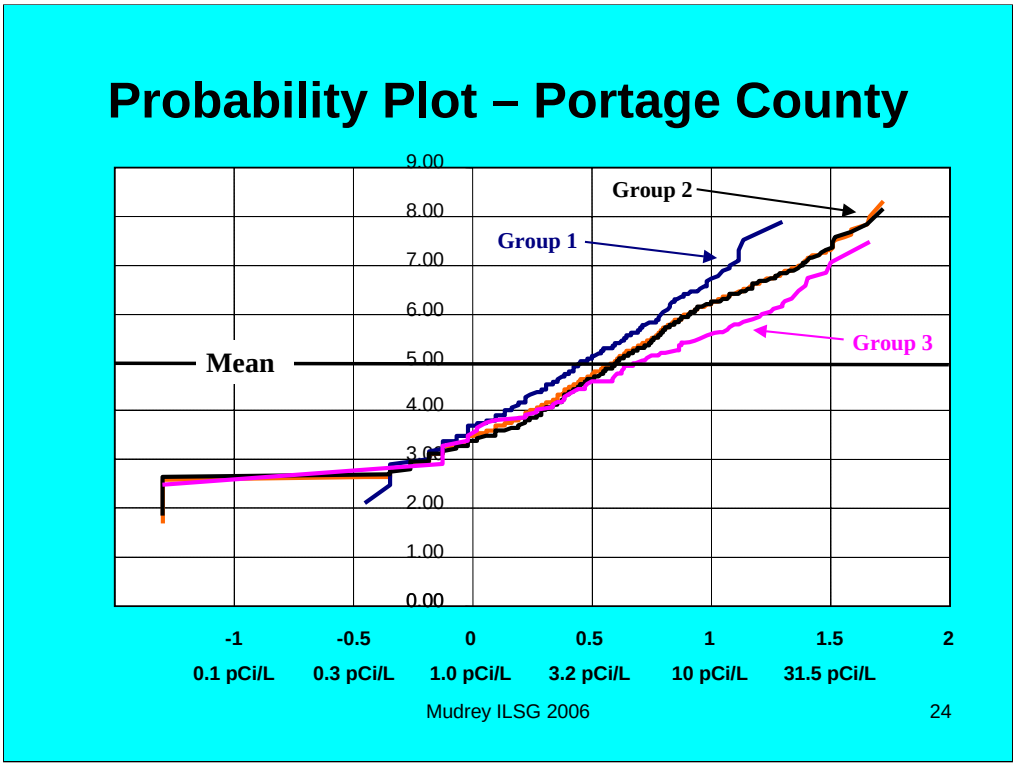


Analysis of Variance Analysis (ANOVA) defines four groupings. Please note that the Cambrian sandstone is statistically grouped with one of the phases of the Wolf River Granite, and Proterozoic volcanic rock with another phase of the Wolf River.

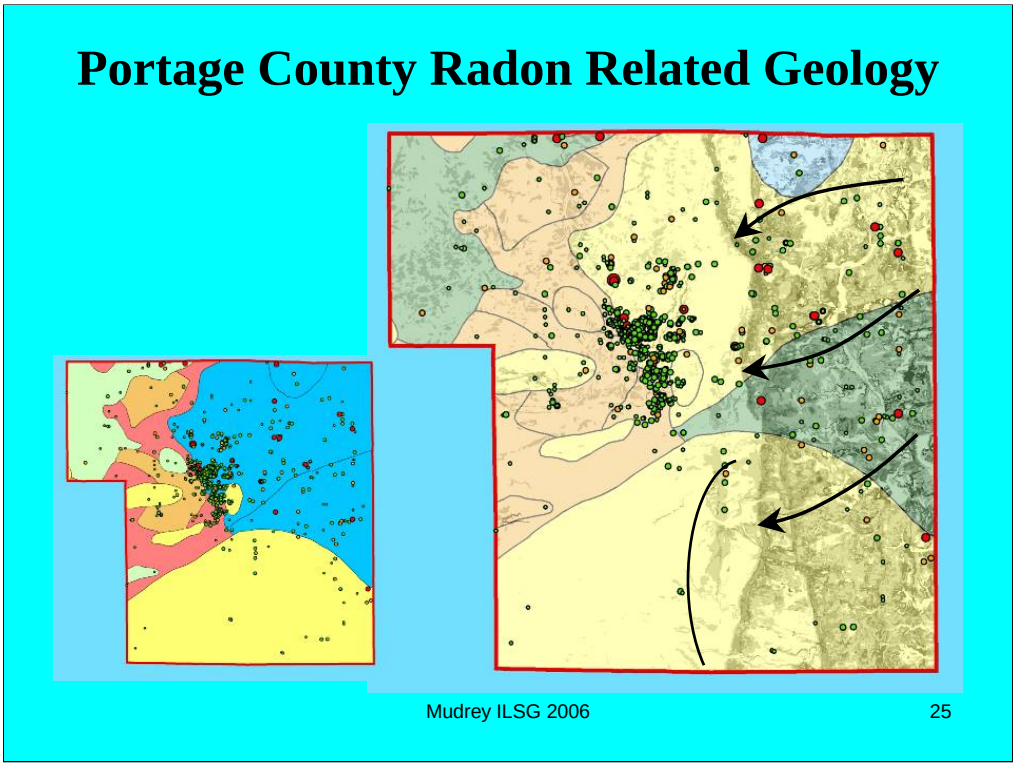
Anova Bedrock Groupings

		N	Mean	Std.Dev.
	Pmg	3	1.70	0.92
1	Agn	63	3.53	3.09
	Pgr	174	3.82	2.82
	Cu	59	5.33	4.61
2	Pwr	678	5.53	5.63
	Pwg	59	7.78	7.05
3	Pvu	24	9.59	11.48
4	Pwu	6	18.42	15.61

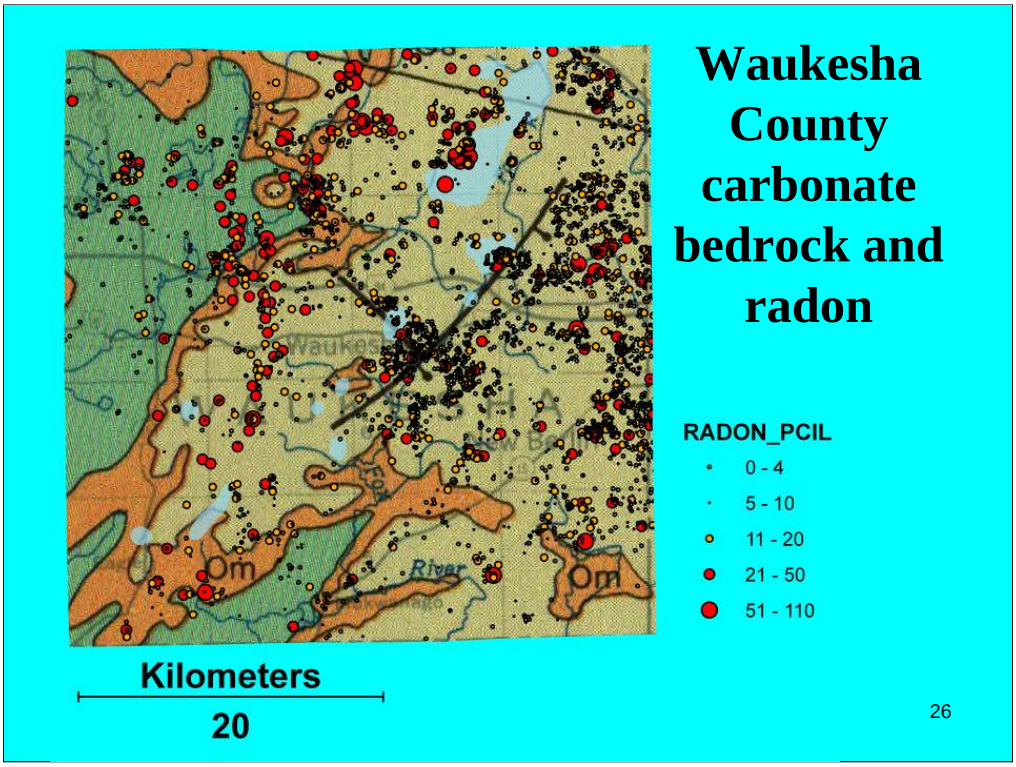
There is no statistical difference between the Cambrian Sandstone and Pwr, nor between volcanics and Pwg.



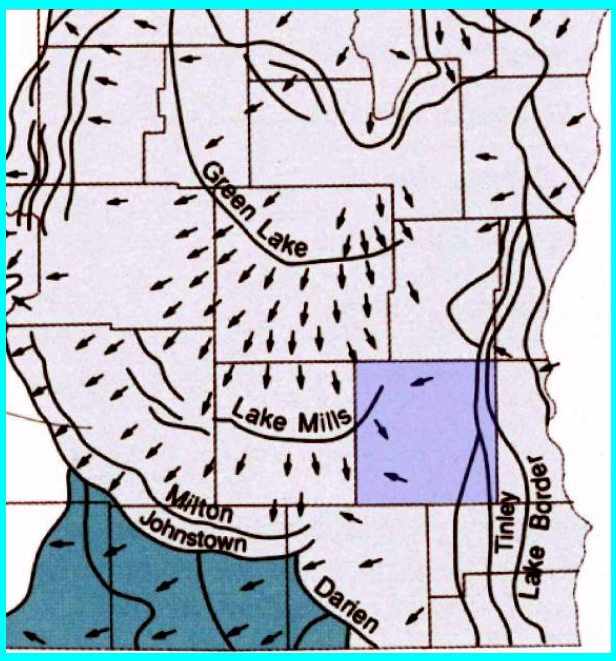
This probability plot diagram illustrates the differences among the various groups. Both and slope and the value where the line crosses the mean are significant. Group 1 (Archean gneiss and Proterozoic Granite) have a lower group average and are statistically tighter, that is the line slope upward more rapidly; Group 2 (Wolf River Red River Granite and Cambrian sandstone) are in the middle; and Group 3 (Wolf River Granite and Proterozoic volcanics) have the highest group average and the greatest standard deviation.



Why is this? The left diagram is the bedrock geology, blue the Wolf River, yellow the sandstone, and green the volcanics. On the right is a map that groups the units based on the radon analysis; it is significantly different than bedrock reality. However, noticed that in the south the glacial material rest on the sandstone. The glacial material originated from the Wolf River to the east. I believe that this statistical summary, that I have presented elsewhere, demonstrates clearly that bedrock is NOT a predictor.



I would like to now focus on Wausha County west of Milwaukee. Bedrock consists dominantly of Ordovician and Silurian dolomite. Unit Om is the Ordovician Maquoketa shale. The pale blue overprint is those areas where bedrock is 10 meters of less from the surface. Notice that the elevated areas do not coincide with shallow bedrock.



Waukesha County and relations to glacial lobes

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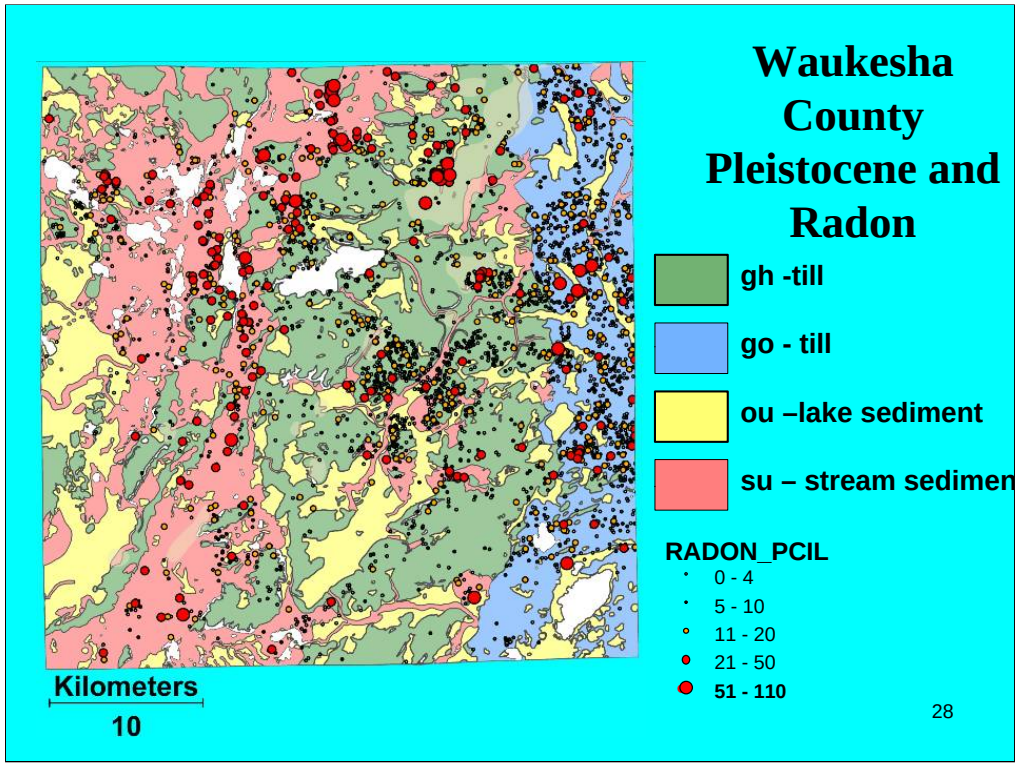
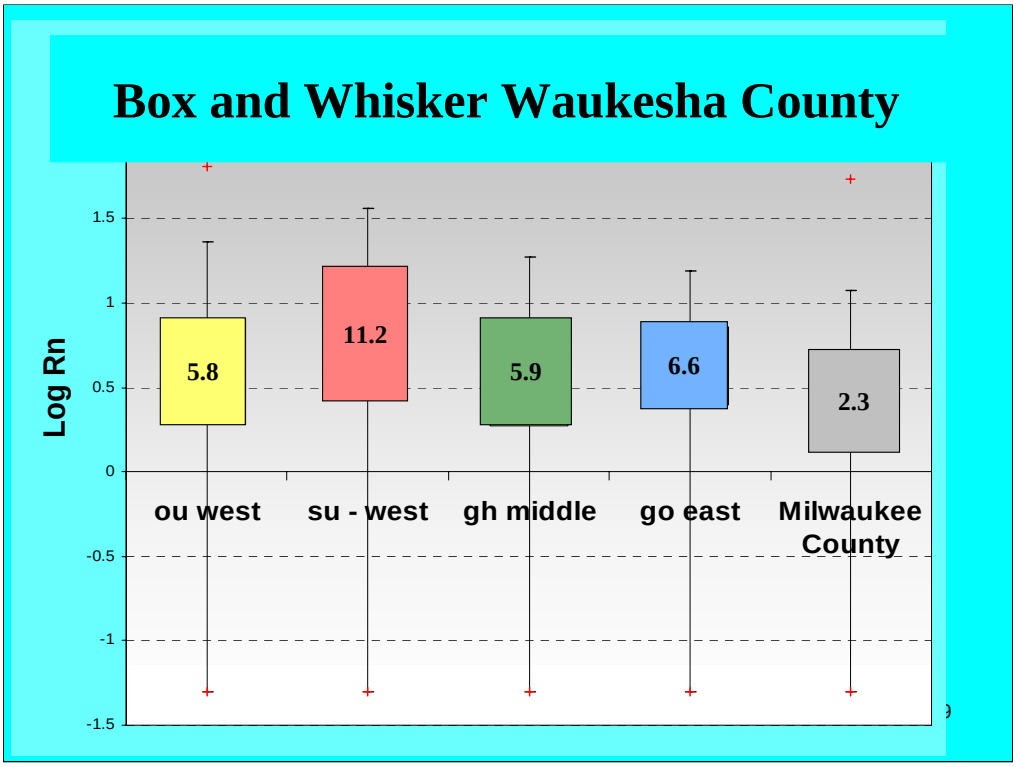
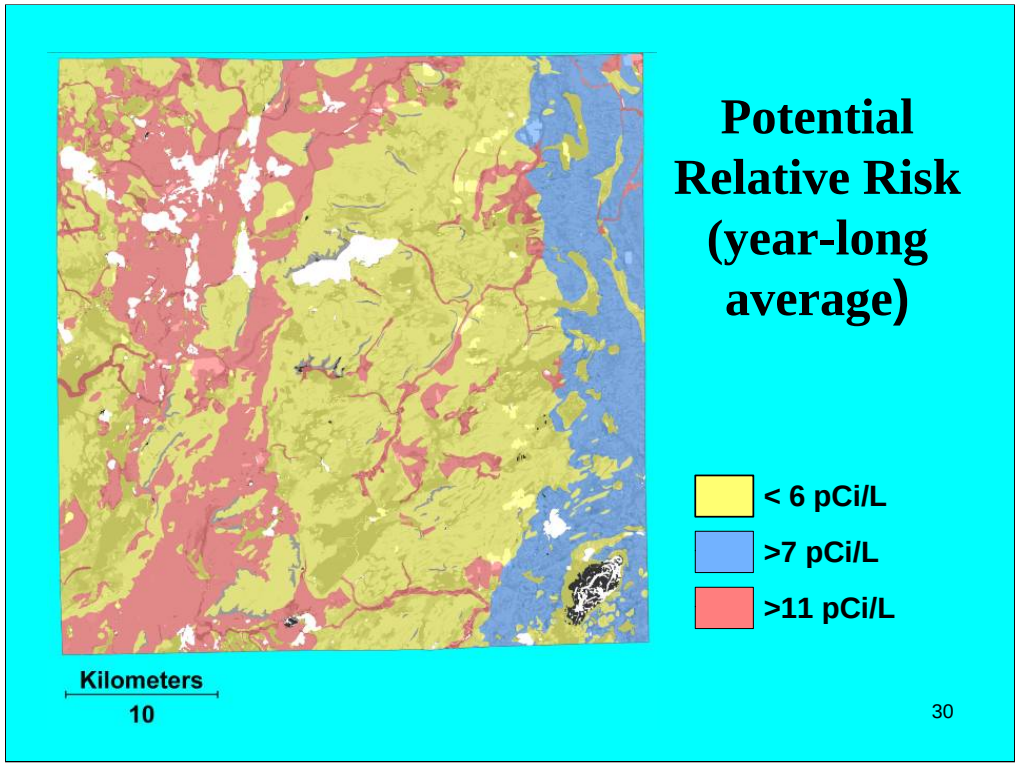
Waukesha County is shown in blue. The Pleistocene units consist of till from the east originating in the Lake Michigan basin; till in the west originating to the north from granite and Wolf River material; and a central zone of outwash and lacustrine deposits.



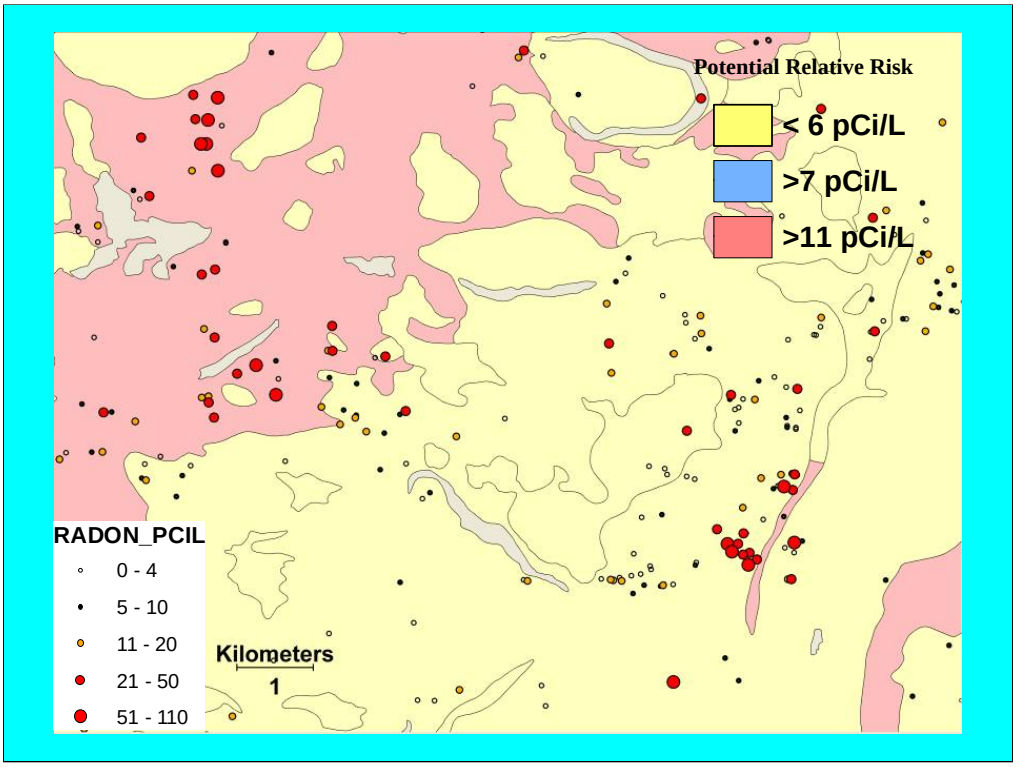
This simplified Pleistocene map by Lee Clayton of the Wisconsin Geological Survey illustrate the dominant role of glacial parent material in the radon story. Till is shown in green and blue; yellow is lake sediment; and pink is outwash. Pale overprint is shallow bedrock. There is a strong spatial relationship of the pink unit, su, with significantly elevated indoor radon. There are about 4,000 measurement in this diagram.



ANOVA analysis, similar to that of Portage County, relates units ou with gh, units go and su as independent units. The diagram is a lognormal plot of the data related to the Pleistocene geology, the values are arithmethic averages for those units. I have included Milwaukee County to the east. It is entirely underlain by till from the Lake Michigan Lobe and is statistically unrelated to the radon in Waukesha County.



This kind of analysis permits the construction of relative risk maps. A factor not shown here is the percentage of homes that may be elevated, it approaches 70 percent over most of the area. However, coupled with percentage of homes, one must also consider the value that might be recorded. Based on the previous diagrams and some other statistical reasoning, it is possible to make a map such as this which average year-long values could be estimated, absent radon proofing, however, and a big however…



This detail of a part of the county illustrates why we do not wish to be more precise. Even in areas of high risk with large numbers of elevated home, low values are found; and even in areas of low relative risk, individual structures may have elevated radon because of construction and other variables.

!!!KEY CONCLUSIONS!!!

- **Elevated indoor radon is found in all areas of Wisconsin as predicted by geological analysis.**
- **Soil derived from granite and carbonate rock is the principal geological factor leading to elevated indoor radon in Wisconsin.**
- **(not discussed here) Construction variables are the dominant control on radon entry.**

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The key conclusions from our work is that elevated radon can be found in all areas of Wisconsin; that soil derived from granite and carbonate rock and the Pleistocene material derived from that rock is the principal geologic factor; and as a consequence, testing of all buildings is more cost effective in identifying elevated indoor radon than trying to predict the radon.