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RADON AND GEOLOGY IN THE ATLANTA AREA

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ABSTRACT

2,791 indoor radon screening tests are plotted on 40 geologic formations where there are five or more measurements. Each is presented with average, range, and house construction type. 29 formations have houses with measurements > = 4.0 pCi/l. For the region, 6.6% of homes measure > = 4.0 pCi/l. The percent of houses > =4.0 pCi/l varies from 0 to 50% by geologic formation. The range is 0.0 to 57.3 pCi/l.

Marked differences in radon levels are observed when plotted by geologic formation. Areas of higher radon potential can be determined for the purpose of planning radon surveys or testing programs in areas of highest potential. The higher potential areas do not necessarily coincide with the EPA radon potential map.

INTRODUCTION

Radon, as the decay product of uranium in rock and soil, is at its most basic level a geologic phenomenon. As all rock and soil has some uranium in it, radon is ubiquitous. As the level of uranium in rock and soil varies markedly, so do radon levels. This paper demonstrates the variance in radon levels follows the geology of the rock and the soil above it. It is presumed those rocks and soils with the highest levels of uranium have the highest levels of radon emitted from them. It follows then that homes and buildings built upon rock and soil with higher levels of uranium will have higher levels of radon, all other things being equal.

On the basis of this presumption, a database of 2,791 houses tested for radon gas during the period from October 1989 through August of 1995 has been collected that includes, among other things, the 1) radon level measured, 2) house construction type; and, 3) geologic formation the house sits upon. This data base is analyzed by geologic formation as to 1) average, 2) range, and 3) percentage of houses 4.0 pCi/l and above.

GEOGRAPHY OF THE GREATER ATLANTA REGION

Atlanta sits amid the Piedmont province that is sometimes characterized as the piedmont plateau (Hunt: 1974) which is then a part of the Appalachian province. It is a rolling upland that in the southern United States is usually 500 to 1,000 feet in elevation and in the northern U.S. below 500 feet. The average elevation in the Greater Atlanta region is about 900 feet above sea level. The area covered by this paper follows the area of the 1:100,000 Greater Atlanta Regional Map produced by the United States Geological Survey with a few extensions beyond. This map includes areas that are in the Valley and Ridge province to the northwest as well as a band of Blue Ridge Province rock that traverses it from the northeast to the southwest. The data includes some radon measurements from the Upper Coastal Plain Province to the southeast of Atlanta. The bulk of the over 2,000,000 population live on the Piedmont.

GEOLOGY OF THE GREATER ATLANTA REGION

Rock

The geology of the area covered by the database can be characterized in four basic rock types: 1) sedimentary consolidated rock of the Valley and Ridge province, 2) unconsolidated sands of the Upper Coastal Plain province, 3) metamorphic rocks in both the Piedmont and Blue Ridge provinces, and 4) igneous intrusions into the Piedmont. Chart 1 describes the rock units covered by this report, and Chart 2 is a regional geologic map.

1) The Valley and Ridge area lies in the northwest quadrant of the study area and consists primarily of a vast area of Knox dolomite that has weathered to a nearly flat valley, often called a part of the Great Valley of the Appalachians. The surface material is a thin (under three feet) soil horizon over a thick (15 to 30 feet) layer of saprolite. The weathering has reduced the dolomite to the point that the most common rock remaining are the chert nodules from the original dolomite. The dolomite is non-phosphatic. In areas of faulting and folding, formations of clay and sandstone and other limestones are common, but as they are predominantly part of the ridge area, few houses are measured on these rocks, with the notable exception of the Conasauga shale. 127 houses tested are plotted in this area.

2) The Upper Coastal Plain lies 80 miles to the south of Atlanta and outside the mapped region. Houses tested here (6) are on unconsolidated sands not mapped to formation.

3) The rock of Atlanta in the Piedmont can be characterized as highly metamorphosed crystalline rock of many origins. Many are from sands, shales (pelitic origin); calcareous (calcitic origin) rock, namely limestone and dolomite; granites (granitic origin); and various kinds volcanic flows mostly of basaltic or dacitic origin (mafic origin rock high in ferro-magnesian minerals). Some of the rock has been metamorphosed up to five different times (Dallmeyer: 1989) which makes determination of ultimate origin difficult. This also greatly complicates the mapping of the area, and much of the mapping is incomplete.

The bulk of the rock can be called a biotite gneiss, and is often called granite locally. It is very hard and gray, so the confusion is expected. The term metagraywacke is perhaps more appropriate for several of the larger formations as it implies a pelitic origin (dirty sandstone) for the current rock and helps to focus on its source. Many local areas of amphibolite and other mafic and ultramafic rock pepper the area. Schists are far less common except in the areas of lesser metamorphism, particularly between the Allatoona and Chattahoochee faults where greenschist is common in areas of mafic rock. South of the Brevard Fault Zone are areas of sillimanite grade metamorphism producing a very hard schist that is nearly a gneiss.

4) The area has four granite intrusions into the metamorphic rock and a number of diabase dikes criscrossing the southeast area. Stone Mountain granite, the most famous of the region, is relatively small at about 8 miles east-west by 1 mile north-south. Ben Hill granite is about 8 times larger, and Palmetto granite is about 10 larger. Both produce primarily flat rock and boulder outcrops. Panola granite is of quite a different character, but only one house has been tested on that rock. The formation mapped as Lithonia gneiss is a migmatite of very complex character with small granite intrusions into the country rock with very localized metamorphism of the granite and country rock. The granites all contain a significant amount of uranium that clearly show up on NURE (National Uranium Resource Evaluation) maps. Many of the gneiss's are of granitic origin.

The area is split dramatically by the Brevard Fault Zone, a tectonic remnant of continental collision that has its evidence in a distinct zone of cataclasis. Other major faults, all thrust faults part of the Georgiabama Thrust Sheet, separate the Piedmont from the Blue Ridge (Allatoona Fault) and the Blue Ridge from the Valley and Ridge (Cartersville Fault--the Georgia name for the Great Smoky Mountains Fault in Tennessee that continues through Georgia into Alabama). The Piedmont consists of very old rock thrust up and over younger (mainly Paleozoic) rock. The Valley and Ridge portion of the study area is similar to the rock that the Georgiabama Thrust Sheet has moved over, and is presumably underneath the Piedmont metamorphic rock at some level. The depth of the Piedmont rock is undermined, but generally thought to exceed 40,000 feet (inferred from maps in McConnell, 1984). The faulted areas tend to show in the rock as areas of highly fractured or jointed rock. The formations away from faults tend to be massive and little jointed other than surface unloading joints. A number of broad regional folds parallel the Brevard Fault Zone.

Soil and Saprolite

The piedmont is considered a mature physiographic landscape and the Atlanta area is nearly a peneplain. This results in a soil that has weathered from basement rocks in place with no fluvial or alluvial transport, except in localized streams and rivers. The resulting soils then have very similar chemical composition to the parent material, and no distinction need be made between soil and rock in the region. Soils are generally thin and of little radon importance when compared with the 15 to 30 foot thick blanket of saprolite that lies beneath the soils and above the parent material. Saprolite is essentially "rotten rock" and is a dominant factor in Atlanta area geology. Virtually every road or building cut exposes saprolite. In nearly every case, the structure of the parent material can be discerned. The saprolite contains the same amount of uranium as the parent material and thus produces the same potential for radon output as the parent material.

The weathering process that forms saprolite produces a complex assortment of clays. The physical structure of most of the clay is similar to that of a deck of cards, with thin, laminar layers of crystals stacked on top of each other. This structure has the effect of closing cracks and joints in the parent material. Thus the saprolite acts as a kind of barrier to upward mobility of radon gas, since a given quantity of radon has about ten half-lives (38.2 days) to reach a given location. In areas of greater saprolite thickness, it is more difficult for radon gas to move upward and enter buildings.

This observation may explain the relatively low radon risk in the study area. This study does not include a comparison of saprolite to rock outcrop patterns of radon measurements in buildings. This conclusion is based solely upon a non-scientific approach of reviewing several thousand radon measurements.

MATERIALS AND METHODS

Houses tested were in the context of a real estate transaction. Testing was done with (in order of use) E-PERMs (2,445), continuous radon monitors (199 with FemtoTech 510 CRM; 195 with FemtoTech 210 CRM; 16 with a Jim Dandy CRM; and 9 with a Thomsen-Nielsen CRM), diffusion barrier charcoal canisters (150), and continuous working level monitors (8 with Thomsen-Nielsen CWLM). From 1989 through late 1993, testing was done on the lowest livable level (LLL). From late 1993 to the present, about two-thirds of testing took place on the lowest level suitable for occupancy (LLSFO). This is significant because approximately 55% of Atlanta houses have basements (Ranger, 1993) with the majority being unfinished and not LLSFO. On both placement and retrieval of the primary device, three air grab working level samples were taken as a double check against the primary method. A gamma radiation survey was made of the foundation and masonry for each house and any exposed rock outcrop in the yard with a Scintrex BGS-3 Scintillation Counter. The underlying rock of each house was checked where possible as a check against the mapped rock unit. A thick layer of saprolite topped with luxuriant vegetation makes definitive rock identification uncertain for many houses, and determination for those houses was made using the geologic map. Radon Georgia is EPA listed as primary for E-PERMs and continuous monitors, and secondary for charcoal canisters in the Radon Measurement Proficiency Program.

CONCLUSIONS

As a purely practical approach, the percent of houses greater than or equal to the EPA Action Level of 4.0 pCi/l (Chart 4) seems the most useful for judging radon levels. The average radon level (Chart 5) very closely follows the order percent > =4, however. Chart 3 holds the raw data.

Expectations: granites and faulted areas of high metamorphism would produce the highest radon levels;

amphibolites, dolomite and sands would produce the lowest radon levels. Gneiss's of granitic origin would produce higher radon levels than granites of pelitic origin.

Results High: Granite produces the highest average levels of radon in houses, with Stone Mountain (CS) producing 37.9% >= 4 pCi/l, Ben Hill (CB) 30.0%, and Palmetto (CP)13.3%. Granite gneiss's are also higher with the Lithonia gneiss (LIG) 19.4%, Austell gneiss (AG) 18.2%, Inman Yard gneiss (IY) 15.4%, and Promised Land gneiss's (PL) 14.5%. Some of the schist's, particularly those in the Brevard Fault Zone where mylonites and fracturing no doubt contribute to radon upward mobility produced higher levels including the Powers Ferry schist (PFS) 20.0%, Norris Lake (N) 16.1, Bill Arp (BA) 15.8%, and the button schist's of the Brevard zone (BZ) 12.3%. Dark shale's such as the Floyd (MFS) 16.7% and Conasauga (CCS) 11.5% are also higher.

Results Low: Lowest levels of radon are in the mafic and ultramafic rocks with Acworth gneiss (ACG), Kellogg Creek mafic complex (KCC), Laura Lake mafic complex (LLU), Lost Mountain amphibolite (LMA) all producing no houses with elevated levels. Non-granitic lower grade metamorphic (sillimanite) gneissic rock such as Clarkston schist (CA), Senoia schist (SE), and Stonewall biotite gneiss (ST) also produced no houses with elevated levels. Dolomitic and non-phosphatic limestone such as the Knox dolomite (OCK) 2.8% and Rome limestone (OCR) 0% are also very low radon producers. Coastal plain sands (UNS) produced no elevated levels.

Unexpected Results: Amphibolites as mafic rock produce little radon, with the notable anomaly of the Wolf Creek amphibolite (10.2%) in three pockets of the mapped formation where uranium obviously occurs in greater than expected levels for a mafic rock. All of the elevated levels on the Wolf Creek are very localized. There are some pockets of undifferentiated biotite gneiss's that reach up through the amphibolite in mappable units, but no elevated houses have been found in these areas. This anomalous result can possibly be explained by considering a pelitic rather than volcanic origin for this amphibolite. Some recent thinking (Hacke, personal communication) postulates that an alternative source for amphibolite can be shale's and slates. Shale's and slates are known to contain significant uranium (witness the Reading Prong and Chattanooga shale).

Because 32% of the houses tested lie on the Powers Ferry metagraywacke, particular attention should be paid to this formation. It is the largest single mapped unit in the area, and is basically an undifferentiated mass of biotite gneiss of predominantly pelitic origin. Virtually all of east Cobb, north Fulton and all of Forsyth counties sit on this formation. 4.4% of house have elevated levels. The more schistose areas of this formation have higher levels, with the Powers Ferry schist producing 20% elevated. The Chattahoochee Palisades quartzite (CPQ) forms a series of parallel, narrow ridges of quartzite within the Powers Ferry unit, and produces 7% elevated. Where the quartzite meets the schist and gneiss appears to have a greater chance for elevated levels. This may be due to a very discernible joint between the very hard and resistant quartzite and the more easily weatherable surrounding rock. This contact zone may provide radon with an easier path to houses.

Forsyth county is one of the most rapidly growing counties in the nation, yet is considered a Zone 2 county, while Cobb and Fulton are Zone 1. All have essentially the same geology and potential for radon. The Georgia Radon Program looked at the number of houses projected to be elevated to develop recommendations for the EPA potential map. With the fast growth of Forsyth county, it is easy to note limitations to such an approach.

The geologic map of Atlanta can be effectively used to determine areas of greater or lesser concern for radon levels.It cannot be used to predict the radon level of any particular home or even specific locality. When geology is compared to the EPA Map of Radon Zones in Georgia that uses county lines, marked differences can be seen where the EPA cuts a geologic formation off in a lower zone county where it probably should be in a higher zone. Any effort to plot radon test results with geology would be a fruitful effort.

CHART 1

KEY TO THE GEOLOGIC FORMATIONS OF THE GREATER ATLANTA REGION

Arranged Alphabetically by Abbreviation to Match Charts

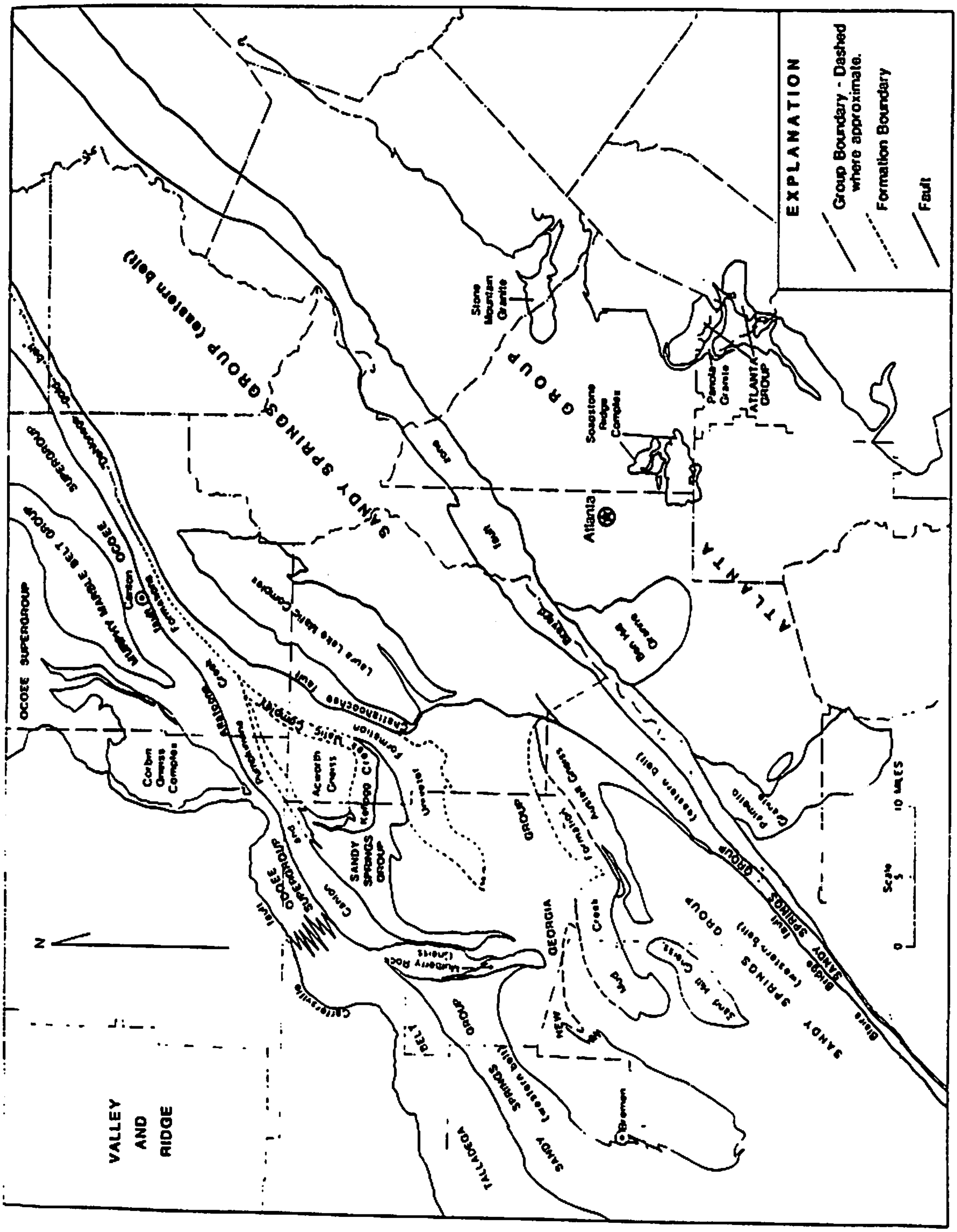
ABR	GEOLOGIC FORMATION
ACG	**Acworth Gneiss:** Medium-grained biotite-quartz-plagioclase orthogneiss with accessory muscovite and epidote. Mafic xenoliths occur locally. Dacitic (volcanic). [New Georgia Group]
AG	**Austell Gneiss:** Fine- to coarse-grained blastophorphyritic to nonporphyritic orthogneiss composed of muscovite, biotite, oligoclase and microcline. Granitic.
BA	**Bill Arp Schist:** Interlayered garnet-biotite-muscovite-plagioclase-quartz schist; muscovite schist; quartz-muscovite-biotite schist; muscovite-biotite-quartz-plagioclase schist; and metagraywacke. Pelitic and calcitic. [Sandy Springs Group]
BCI	**Big Cotton Indian Biotite Gneiss:** Intercalated biotite-plagioclase gneiss (locally porphyritic), hornblende-plagioclase amphibolite, and biotite-muscovite schist. Pelitic. [Atlanta Group]
BZ	**Button Schist Ductiley Sheared Zone:** Primarily undifferentiated ductiley sheared rock in the Brevard Fault Zone, the largest area of button schists, with lesser areas of mylonite.
CA	**Clarkston Sillimanite Schist:** Sillimanite-garnet-quartz-plagioclase-biotite-muscovite schist interlayered with hornblende-plagioclase amphibolite. Lower grade metamorphic schists of pelitic (?) origin. [Atlanta Group]
CB	**Ben Hill Granite:** Coarse-grained, porphyritic muscovite-biotite quartz-plagioclase microcline granite.
CC	**Camp Creek Granite Gneiss:** Massive granite gneiss interlayered with thin, fine-grained, dark-green hornblende-plagioclase amphibolite. [Atlanta Group]
CCS	**Conasauga Shale:** Cambrian siliceous shale and thin-bedded sandstone to mostly siliceous shale to dark black shale.
CL	**Clairmont Biotite Gneiss:** Interlayered medium-grained biotite-plagioclase gneiss and fine- to medium-grained hornblende-plagioclase amphibolite. Pelitic. [Atlanta Group]
CP	**Palmetto Granite:** Coarse-grained porphyritic granite composed of microcline, quartz and plagioclase with accessory biotite, muscovite, perthite, sphene, apatite, epidote and zircon.
CPQ	**Chattahoochee Palisades Quartzite:** Massive, white, yellowish, or bluish, sugary to vitreous quartzite locally containing accessory mica, feldspar, and elongate garnets. Graded bedding is apparent locally. Pelitic. [Sandy Springs Group]
CS	**Stone Mountain Granite:** Fine- to medium-grained granite composed of biotite, muscovite, microcline, quartz and oligoclase with characteristic rosettes of tourmaline.
DRU	**Dog River Metagraywacke:** Undifferentiated muscovite-biotite-quartz-feldspar gneiss (metagraywacke), garnet-muscovite schist, and amphibolite. [Sandy Springs Group]
FS	**Factory Shoals Metagraywacke:** Intercalated light-gray, lustrous, garnet-biotite-oligoclase or muscovite-biotite-plagioclase metagraywacke, kyanite-quartz schist, and staurolite-muscovite quartz schist. Locally, schist grades into a garnet-graphite-schist. Pelitic. [Sandy Springs Group]
IY	**Inman Yard Gneiss:** Porphyritic-blastic biotite-plagioclase gneiss porphyroblastic granite gneiss and sillimanite-muscovite schist. [Atlanta Group]
KCC	**Kellogg Creek Mafic Complex:** Garnet-hornblende-plagioclase amphibolite, metagabbro and lesser amounts of ultramafic rocks. [New Georgia Group]
LIG	**Lithonia Gneiss:** Evenly banded biotite-quartz-feldspar gneiss, quartz-rich garnetiferous layers and migmatitic muscovite-biotite-plagioclase-microcline-quartz gneiss. A very complex area of poorly understood and defined geology. Extremely migmatitic.

LLU	**Laura Lake Mafic Complex:** Migmatitic garnet amphibolite with smaller amounts of pyroxene (relict)-bearing metagabbro, meta-quartz diorite, meta-ultramafic rock and banded iron formation. Magnetite occurs as common porphyroblasts in amphibolite.
LMA	**Lost Mountain Amphibolite:** Hornblende-plagioclase amphibolite, hornblende gneiss and local lenses and layers of banded iron formation. Univeter Formation [New Georgia Group]
LS	**Lavender Shale:** a dark, compact calcareus member of the Mississipian Fort Payne Chert
MFS	**Floyd Shale:** a gray to black fissile shale of Mississipian age
N	**Norris Lake Schist:** Interlayered garnet-biotite-muscovite schist, biotite-muscovite schist, thin amphibolites and minor biotite gneiss. Part of the Snellville Formation. [Atlanta Group]
NG	**Norcross Gneiss:** Light-gray epidote-biotite-muscovite-plagioclase gneiss locally containing amphibolite. Pelitic (?). [Atlanta Group]
OCK	**Knox Dolomite:** Upper Cambrian and Lower Ordovician light- to medium-gray, fine to coarse-grained, thickly to massively bedded cherty dolomite and brownish-gray, medium to coarse-grained "asphaltic" dolomite. Surface expression nearly exclusively chert.
OCR	**Rome Limestone:** Cambrian limestones generally to the west of Knox Dolomite and of similar origin.
OCRS	**Rome Sandstone:** Cambrian thin-bedded, fine-grained sandstones and sandy shales.
PFS	**Powers Ferry Schist:** a mappable mica schist member of the Powers Ferry formation
PFU	**Powers Ferry Metagraywacke:** Undifferentiated biotite-quartz-plagioclase gneiss (metagraywacke), mica schist and amphibolite. Pelitic. The largest single mapped unit in the area. [Sandy Springs Group]
PL	**Promised Land Granite Gneiss:** Massive to thinly-layered, medium-grained, gray, banded biotite granite gneiss interlayered with fine-grained, dark-green to greenish black, blocky amphibolite. [Atlanta Group]
RCS	**Rose Creek Schist:** Garnet biotite-muscovite schist locally varying to garnet-hornblende-muscovite-quartz schist. Part of the Univeter Formation. Mafic. [New Georgia Group]
SE	**Senoia Schist:** Garnet-biotite-muscovite schists interlayered with fine-grained amphibolite, local thin layers of spessartine quartzite, Sillimanite schist and biotite gneiss. Low-grade metamorphic schist of pelitic (?) origin. [Atlanta Group]
ST	**Stonewall Biotite Gneiss:** Intercalated fine-grained biotite gneiss, hornblende-plagioclase amphibolite and sillimanite-biotite schist. Low-grade metamorphic gneiss of pelitic (?) origin. [Atlanta Group]
UNA	**Unnamed Amphibolite:** Widely scattered amphibolites of unknown affinity.
UNB	**Unnamed Biotite Gneiss:** A large area primarily to the southeast of Atlanta of unknown affinity.
UNM	**Unnamed Metamorphics:** A mixture of metamorphic rocks, primarily amphibolites, hornblende gneiss and felsic gneiss, primarily to the west area of unknown affinity.
UNS	**Unnamed Sands:** Coastal plain sediments south of the fall line.
UNK	**Unknown:** rock of undermined type, primarily in the eastern Piedmont
WAC	**Wahoo Creek Biotite Gneiss:** Slabby, medium-grained muscovite-plagioclase-quartz gneiss, amphibolite, mica schist and epidote-calcite-diopside gneiss (calcsilicate). Pelitic and calcitic. [Atlanta Group]
WC	**Wolf Creek Amphibolite:** Thinly laminated, fine-grained amphibolite interlayered with lustrous, silvery, gray, biotite muscovite schist. Pelitic (?). [Atlanta Group]

Descriptions taken largely from McConnell & Abrams with additions and modifications. Names here include the predominant rock in the formation or named rock unit that are not included in Abrams text. When keying to Chart 2, use the group name for locating the general area of this rock. Chart 2 does not include individual formations as the scale precludes printing.

CHART 2

Group and formation boundaries of the crystalline rocks of the Greater Atlanta Region Regional Map



Group and formation boundaries of the crystalline rocks of the Greater Atlanta Regional Map.

Chart 3: Raw Data

Formations Arranged Alphabetically by Abbreviation

ABR	GEOLOGIC FORMATION	n =	low	high	average	% 4.0+
ACG	Acworth Gneiss	15	0.0	2.8	1.0	0.0
AG	Austell Gneiss	10	0.4	7.2	2.8	18.2
BA	Bill Arp Schist	31	0.2	15.0	3.1	15.8
BCI	Big Cotton Indian Biotite Gneiss	43	0.0	4.1	1.4	2.3
BZ	Button Schist Ductiley Sheared Zone	160	0.0	25.4	2.5	12.3
CA	Clarkston Sillimanite Schist	113	0.0	3.9	1.3	0.0
CB	Ben Hill Granite	9	0.1	5.7	3.2	30.0
CC	Camp Creek Granite Gneiss	20	0.1	5.7	1.6	9.5
CCS	Conasauga Shale	23	0.2	6.4	2.1	11.5
CL	Clairmont Biotite Gneiss	146	0.0	9.0	1.8	5.3
CP	Palmetto Granite	11	0.1	7.3	2.2	13.3
CPQ	Chattahoochee Palisades Quartzite	68	0.1	8.0	1.7	7.0
CS	Stone Mountain Granite	20	1.1	57.3	7.1	37.9
DRU	Dog River Metagraywacke	7	0.0	3.6	1.2	0.0
FS	Factory Shoals Metagraywacke	121	0.0	8.5	2.1	9.4
IY	Inman Yard Gneiss	10	0.0	6.6	2.0	15.4
KCC	Kellogg Creek Mafic Complex	20	0.0	1.5	0.7	0.0
LIG	Lithonia Gneiss	54	0.6	15.1	2.9	19.4
LLU	Laura Lake Mafic Complex	196	0.0	3.9	0.8	0.0
LMA	Lost Mountain Amphibolite	60	0.0	3.1	0.7	0.0
LS	Lavender Shale	5	0.4	3.4	1.3	0.0
MFS	Floyd Shale	6	0.4	4.3	1.4	16.7
N	Norris Lake Schist	26	0.3	6.8	2.4	16.1
NG	Norcross Gneiss	63	0.0	4.4	1.4	2.9
OCK	Knox Dolomite	68	0.0	7.4	1.3	2.8
OCR	Rome Limestone	18	0.0	3.5	1.3	0.0
OCRS	Rome Sandstone	7	0.3	2.7	1.3	0.0
PFS	Powers Ferry Schist	5	0.8	5.4	2.2	20.0
PFU	Powers Ferry Metagraywacke	896	0.0	10.3	1.6	4.4
PL	Promised Land Granite Gneiss	57	0.4	6.7	2.4	14.5
RCS	Rose Creek Schist	10	0.6	4.1	2.0	10.0
SE	Senoia Schist	18	0.2	3.4	1.4	0.0
ST	Stonewall Biotite Gneiss	63	0.0	3.0	1.0	0.0
UNA	Unnamed Amphibolite	15	0.2	2.1	1.0	0.0
UNB	Unnamed Biotite Gneiss	24	0.3	5.2	1.6	4.2
UNK	Unknown	6	0.5	6.5	3.2	33.3
UNM	Unnamed Metamorphics	155	0.0	10.3	1.4	4.3
UNS	Unnamed Sands	6	0.5	1.8	1.1	0.0
WAC	Wahoo Creek Biotite Gneiss	84	0.0	7.8	1.7	5.6
WC	Wolf Creek Amphibolite	122	0.0	23.4	2.3	10.2

	n =	low	high	average	% 4.0+
ATLANTA AREA	2791	0.0	57.3	1.7	6.6

Chart 4: % Houses >=4pCi/l

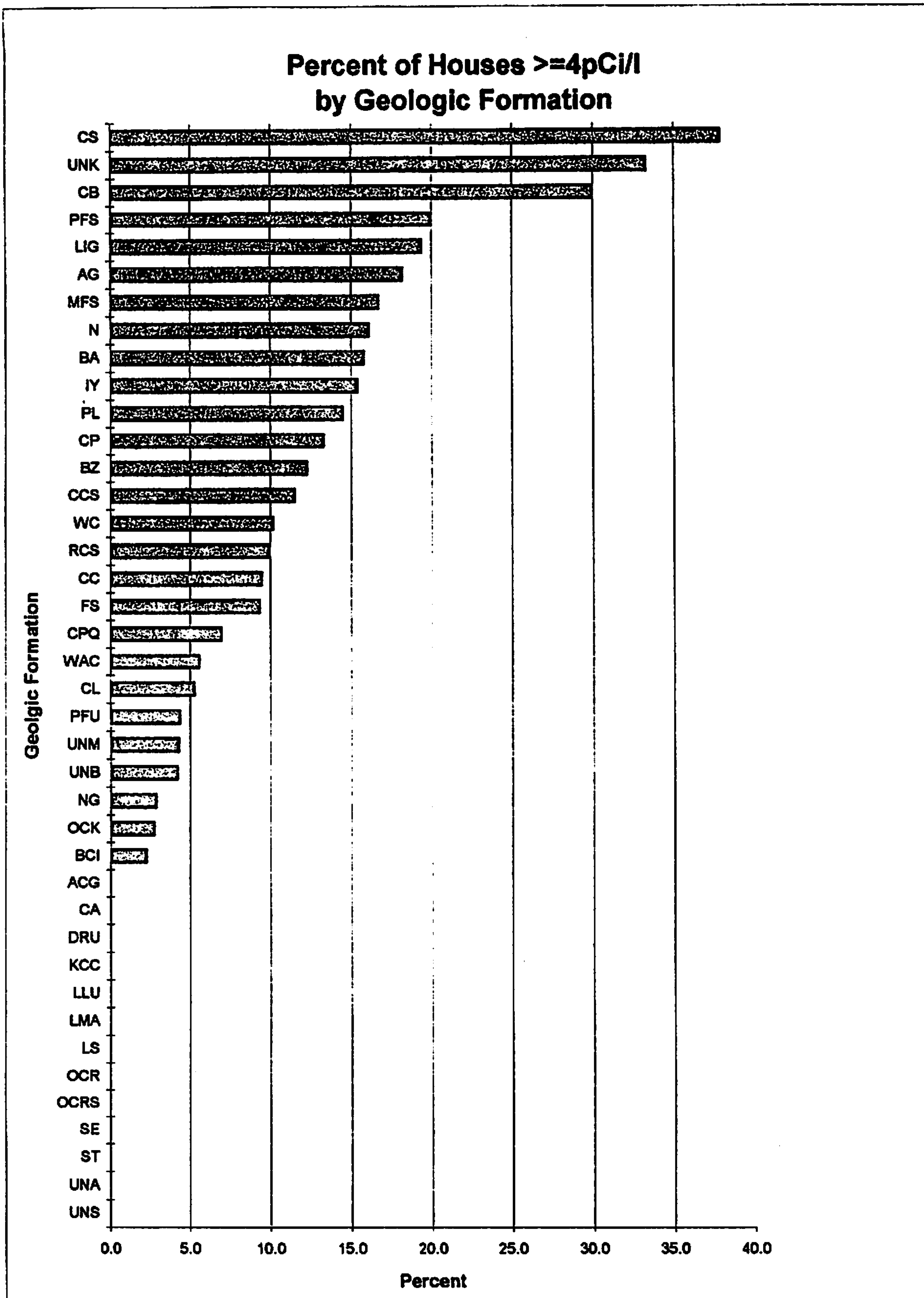
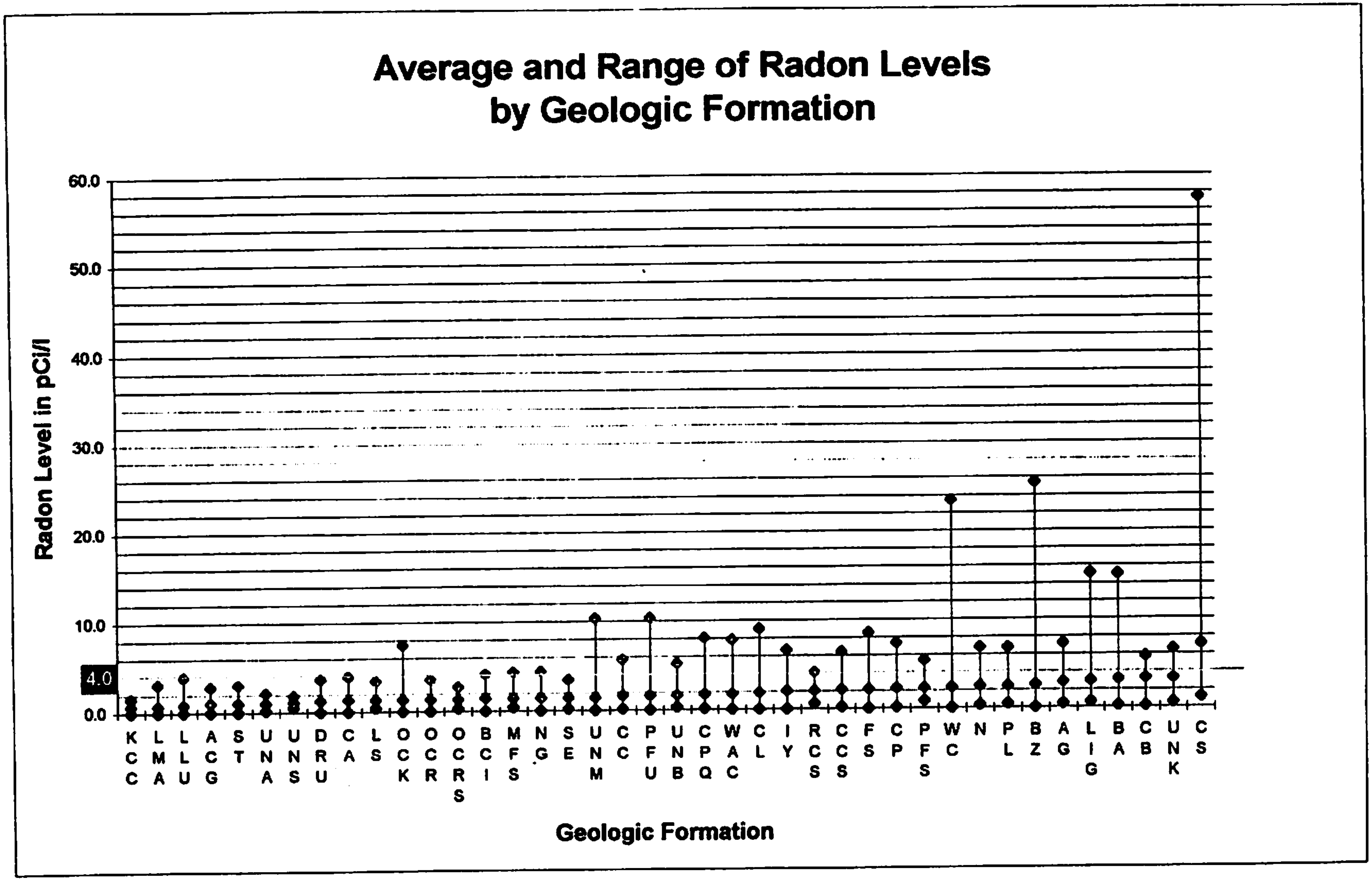


Chart 5: Average and Range of Radon Levels by Geologic Formation



REFERENCES

Butts, C. and Gildersleeve. B. 1948. Geology and mineral resources of the Paleozoic area in northwest Georgia. Georgia Geologic Survey Bulletin 54.

Georgia Geologic Survey. 1976. Geologic Map of Georgia. Atlanta. Georgia Geological Survey.

Georgia Radon Program. 1993. Georgia Radon Program Map of Radon Zones. Atlanta. Georgia Radon Program.

Georgia Radon Program. 1993. Projected Housing Units > 4 pCi/l. Atlanta. Georgia Radon Program.

Gregg, L.T., and Costello, J. 1990. Geologic control on radon occurrence in Georgia. In, Bearce, D.T. and Neilson, M.J., eds., Case studies in applied geology in the eastern United States. Georgia Geologic Survey Bulletin 122, p. 40.47.

Hacke, Mike. 1995. Personal Communication. (Mike is a geologist with the USGS in Atlanta)

Herrmann, L.A. 1954. Geology of the Stone Mountain-Lithonia district, Georgia. Georgia Geologic Survey Bulletin 61.

Higgins, M.W. 1968. Geologic Map of the Brevard Fault Zone Near Atlanta, Georgia. Washington. United States Geological Survey, Miscellaneous Geologic Investigations Map 1-511.

Higgins, M.W. 1966. The geology of the Brevard lineament near Atlanta, Georgia. Atlanta. Georgia Geologic Survey Bulletin 77.

Horton, J.W. Jr.: Drake, A.A. Jr.: Rankin, D.W. 1989. Technostratigraphic terranes and their Paleozoic boundaries in the central and southern Appalachians. In: Dallmeyer, R.D., editor: Terranes in the Circum-Atlantica Paleozoic Orogens. Boulder, CO: The Geological Society of America Special Paper 230.

Hunt, C.B. 1974. Natural Regions of the United States and Canada. San Francisco: W.H. Freeman and Company.

McConnell, K.: Abrams, C.E. 1984. Geology of the Greater Atlanta Region. Atlanta: Georgia Geologic Survey Bulletin 96. (This reference includes the Geology of the Greater Atlanta Region map, 1:100,000.)

Ranger, L.S. 1993. Geologic Control of Radon in the Greater Atlanta Region, Georgia. In proceedings of the 1993 International Radon Conference, page IV2-11. AARST.

Smith, W.H. 1985. Guide to the geology of Bartow county, Georgia. Cartersville, Georgia. Budget Publications.

U.S. Environmental Protection Agency. 1993. EPA Map of Radon Zones: Georgia. U.S. EPA.

Vincent, H.R., McConnell, K.I, and Perley, P.C. 1990. Geology of selected mafic and ultramafic rocks of Georgia: a review. Georgia Geologic Survey Information Circular 82.