Occurrence and Health Risks of Radon in Private Drinking Water Wells in North Carolina

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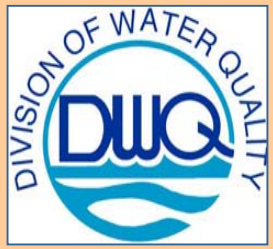
Piedmont-Mountains

Resource Evaluation Program



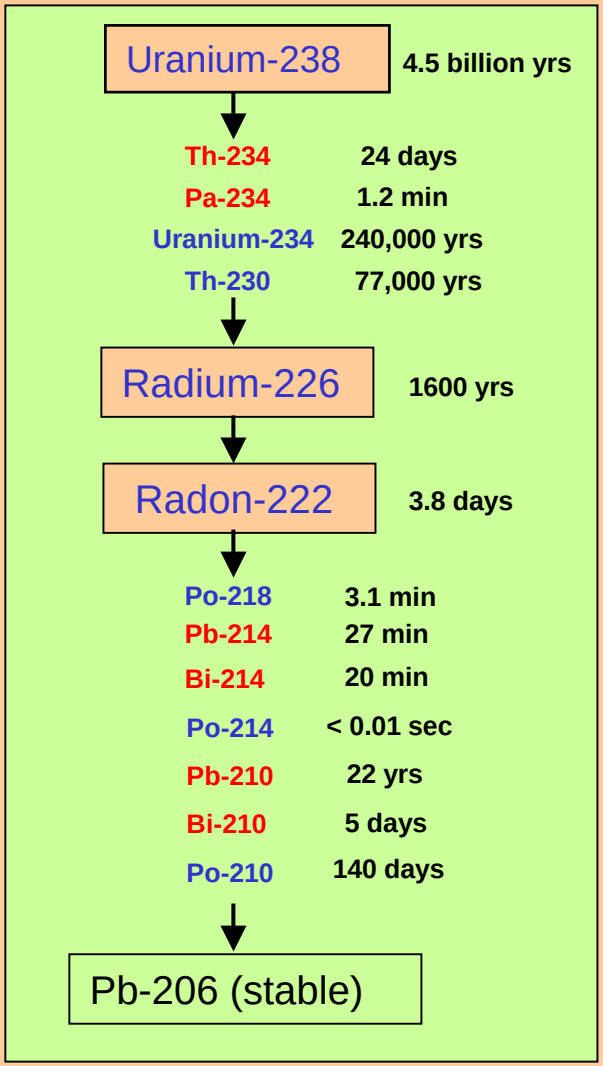
Coweeta Hydrologic Lab
Bent Creek Experimental Forest
Duke University
Appalachian State University
NC Division of Radiation Protection
NC Geological Survey
NC Zoo

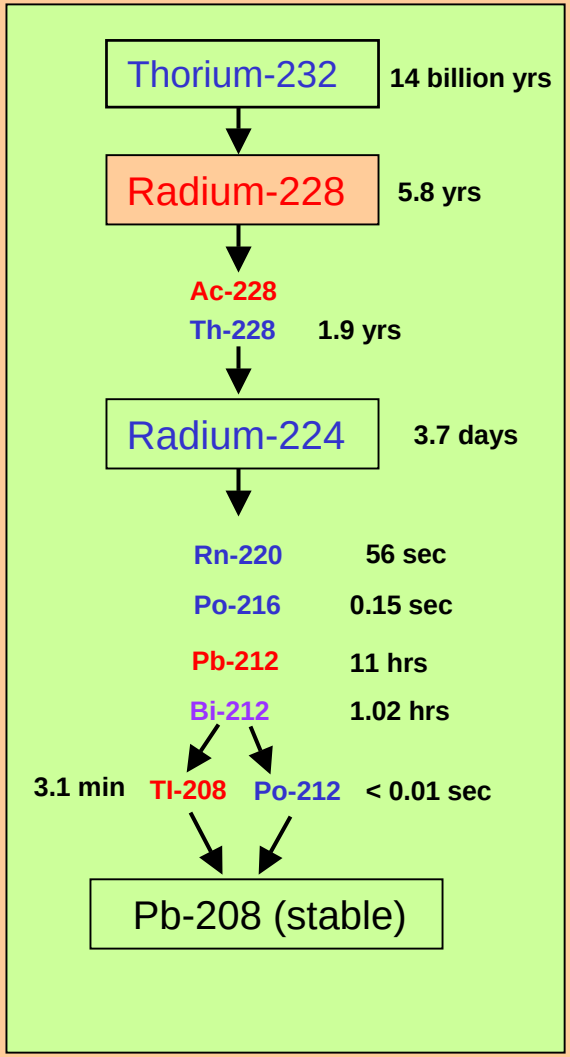
Municipalities
Counties
Local and Regional Water Associations
Citizens
Others

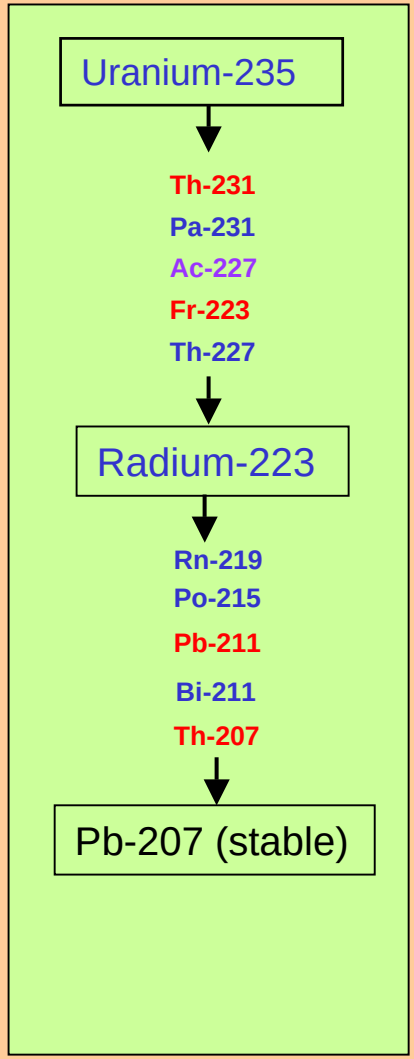
Radionuclide Decay Series

Alpha emitters in blue

Beta emitters in red







Naturally Occurring Radionuclides in Ground Water Drinking Supplies in Piedmont-Mountains of NC

Uranium exceeds MCL (30 ug/L) in ~ 1 to 2% of wells

Gross Alpha exceeds MCL (15 pCi/L) in ~ 1 to 2% of wells

Radium-226 exceeds MCL (5 pCi/L, combined with Radium-228) in less than 1% of wells

Radium-228 exceeds MCL (5 pCi/L, combined with Radium-226) in less than 1% of wells

Radon…

Review of Radon-222

- a radioactive gas produced by the decay of uranium-238

- a human carcinogen; 2nd leading cause of lung cancer after smoking

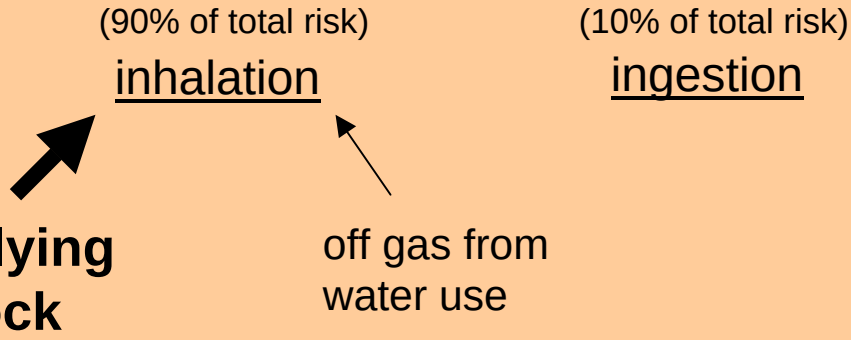
- found everywhere….migrates from rock and soils into atmosphere and indoor air….very mobile…..even outdoor air contains small concentrations

- radon gas dissolves in water, so is common in ground water supplies

- also readily de-gasses from water, so radon-rich water entering a home can be a secondary source of indoor air radon; and is not common in surface waters

Review of Radon-222

- two exposure pathways:



- "10,000 to 1" rule of thumb: 10,000 pCi/L in water = 1 pCi/L in indoor air; this estimate varies widely and does not fully account for daily short-term doses from shower off-gassing

- EPA has proposed an MCL of 300 pCi/L and an alternate MCL of 4,000 pCi/L for radon in water

- EPA has a "target action level" of 4 pCi/L for indoor air radon

Review of Radon-222

- a Class A carcinogen radon; follows a “linear no-threshold” risk model, so any dose above zero theoretically carries risk; MCLG = zero

- risk is not from radon itself, but from the short-lived polonium isotopes that are ionized (they attach to the lung) and are alpha-emitting

- ~20,000 lung cancer deaths per year in US; most residents are aware of this issue; active educational program in place

- risks from radon in water are greater than those of most other EPA-regulated compounds, including uranium, combined radium, nitrate, benzene, TCE, disinfection bi-products, and others

Review of Radon-222

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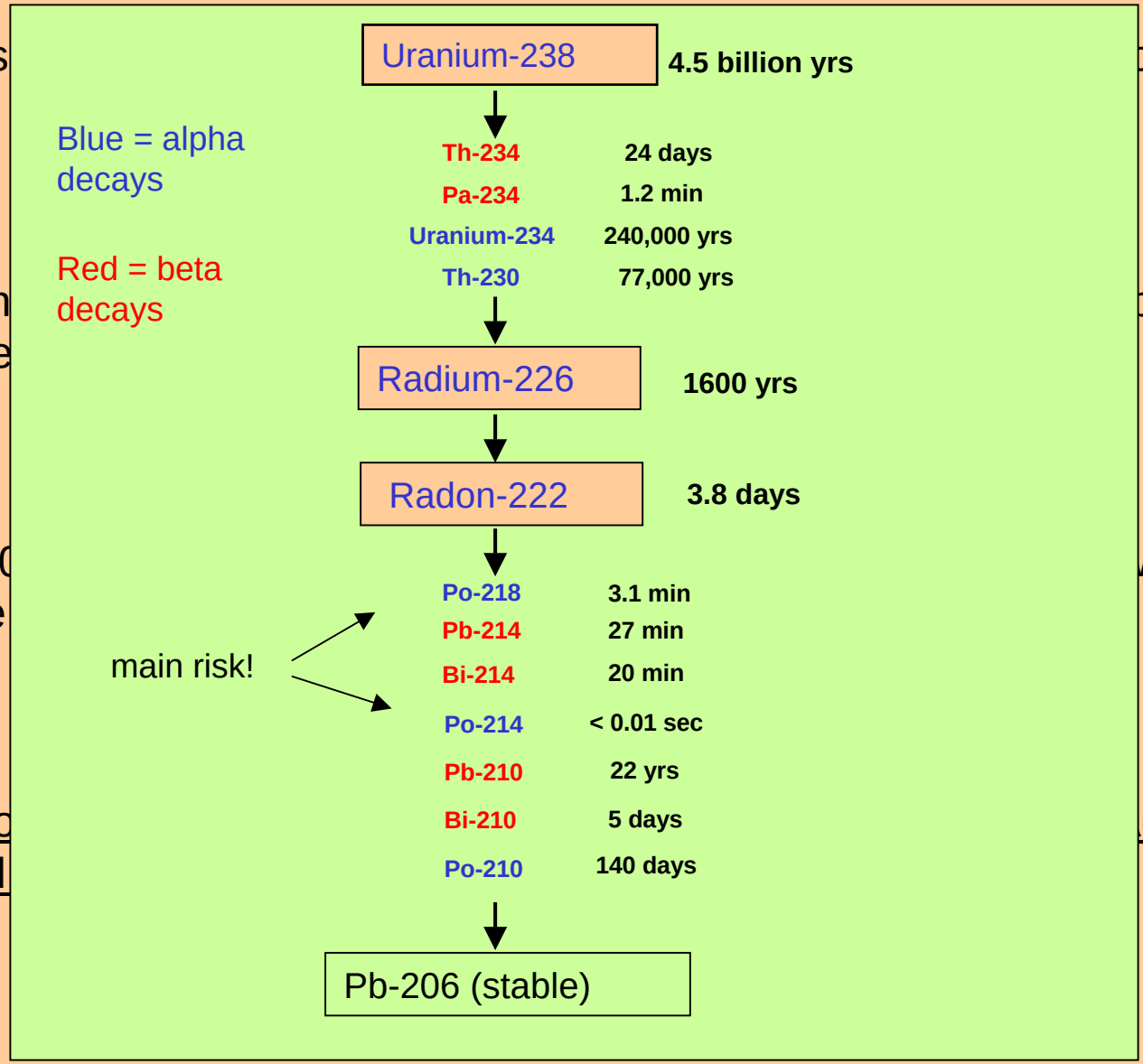
- risk is n … pes that are ionize …
- ~20,000 … vare of this issue …
- risks fro … - regulated … benzene, …



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How prevalent is radon in water in the USA?

	Across USA (from Focazio and others, 2006)
Radon	9% of wells are above 4000 pCi/L
	75% of wells are above 300 pCi/L

For comparison…

Nitrate	8% of wells are above 10 mg/L (MCL)
Arsenic	11% of wells are above 10 ug/L (MCL)

Radon-222

- number of annual deaths in USA due to radon in water is relatively low because most populations are not exposed to elevated levels of radon in water (~160 deaths from radon inhalation and ~23 deaths from radon ingestion) (NRC, 1999)

- regulating radon is unique…. Federal policy makers have not yet reached agreement on a regulatory approach because 1) the bulk of risk typically is from soil and rock (and not radon in water) and public health dollars are limited, and 2) radon is naturally occurring (no anthropogenic "source" to pay for mitigation)

Some states have begun to establish their own standards/advisories for radon in water.

Examples: Connecticut = 5,000 pCi/L

New Jersey = 300 pCi/L

New Hampshire = 2,000 pCi/L

Vermont = 5,000 pCi/L

Maine = 4,000 pCi/L

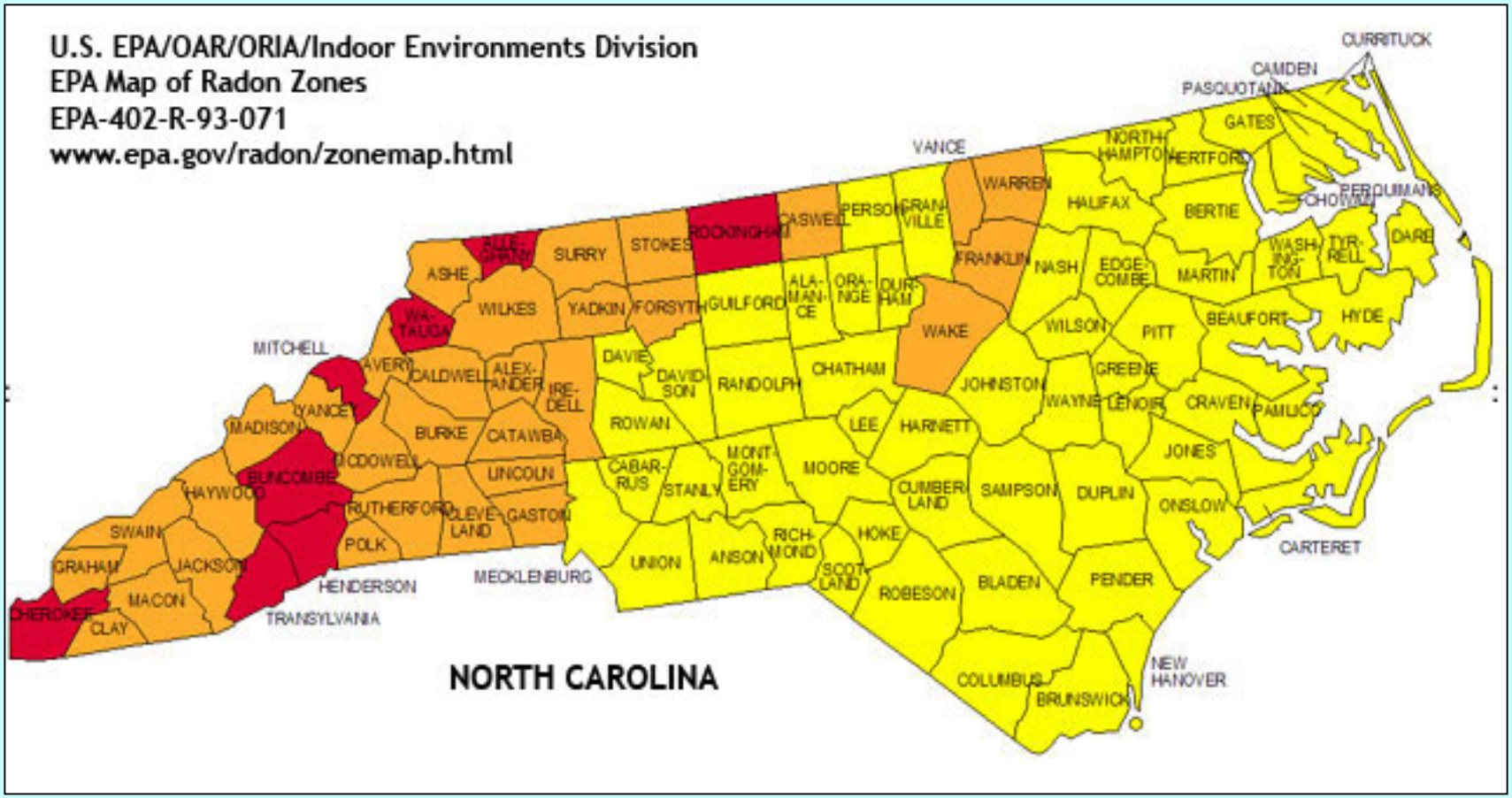
Massachusetts = 10,000 pCi/L

Wisconsin = 5,000 pCi/L

North Carolina …. IN DRAFT

Radon in Indoor Air in NC

- 8 counties are classified as EPA Zone 1, with predicted average levels above 4 pCi/L
- the Zone 1 counties are in Western NC, in the Blue Ridge and Inner Piedmont Provinces
- the uranium rich rocks prevalent across the Piedmont and Mountains are a natural source of radon in indoor air
- most residents are aware of the issue; active educational program in place



Indoor radon above 4 pCi/L – EPA Zone 1

Indoor radon from 2 to 4 pCi/L

Indoor radon less than 2 pCi/L

Radon in Water in NC

- the uranium rich rocks prevalent across the Piedmont and Mountains are a natural source of radon in ground water

- elevated levels are widespread in some areas

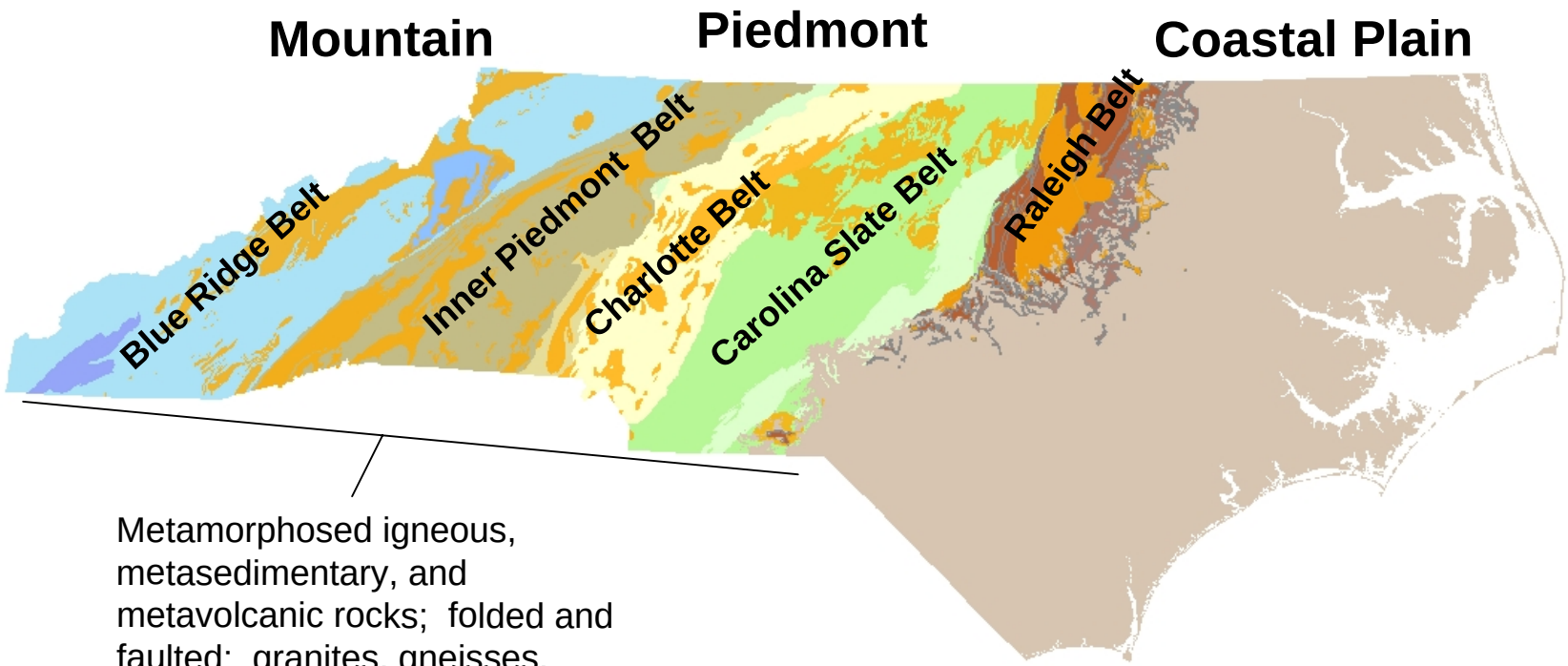
- about half the population of NC relies on ground water as its principal potable supply

- efforts are underway to determine the factors that control radon occurrence and mobilization and to map areas of radon susceptibility

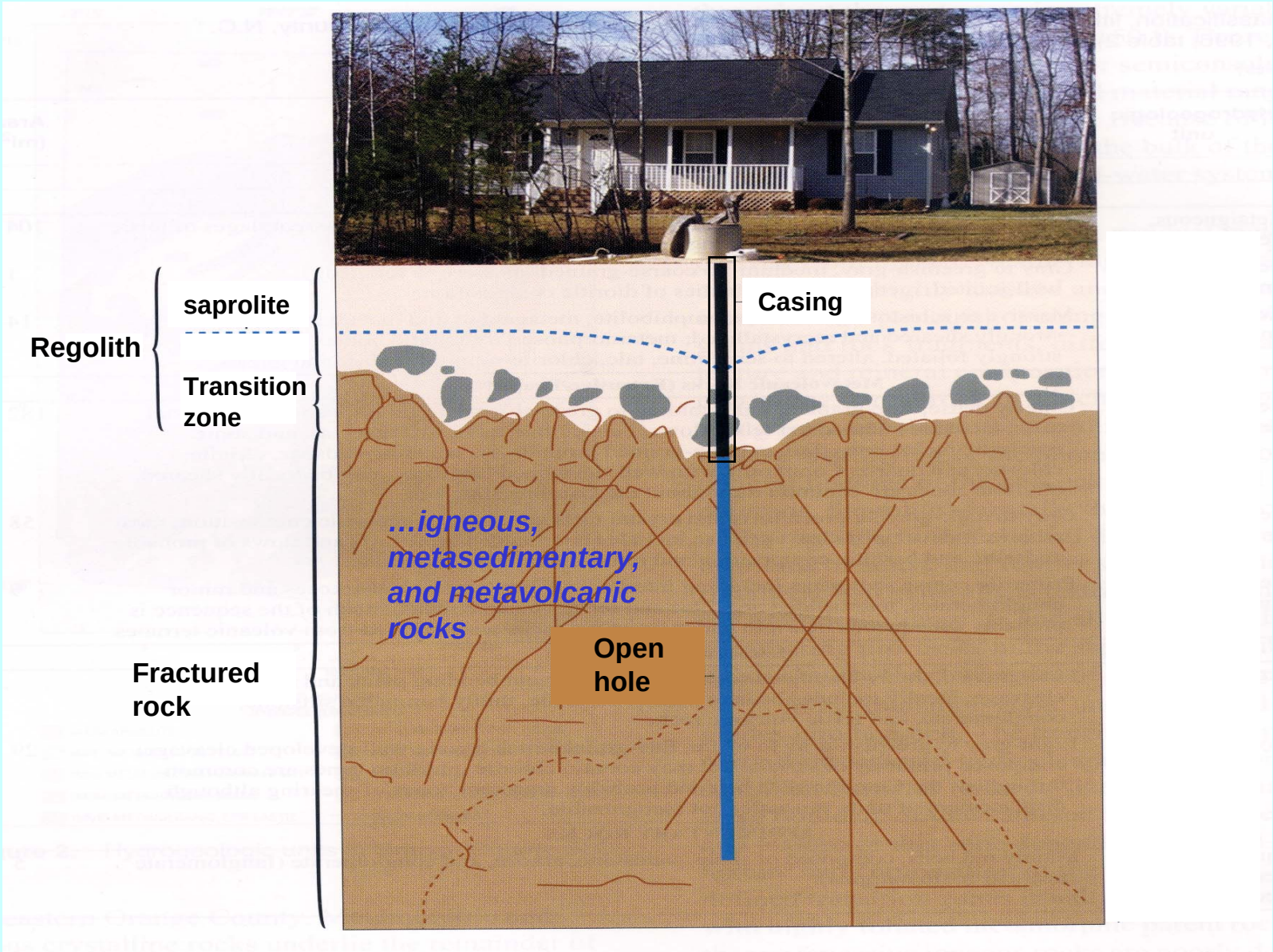
- two areas of the State are now being studied in detail: “Raleigh-Charlotte Belts” and “Blue Ridge-Inner Piedmont Belts”

- many counties still have very little or no radon data and most residents are not aware of the issue

Meta-igneous rocks (associated with elevated uranium content) in NC

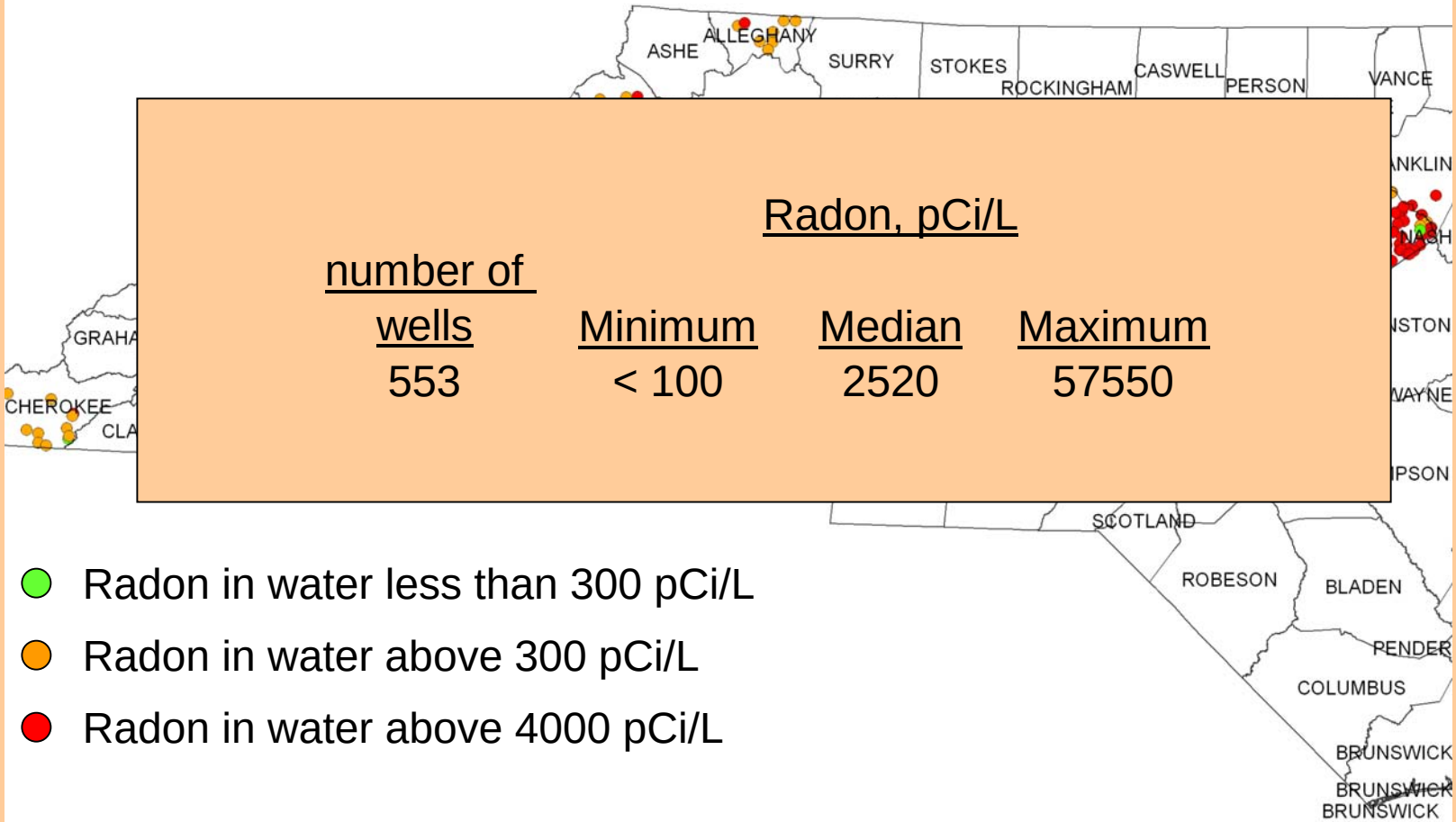


Metamorphosed igneous, metasedimentary, and metavolcanic rocks; folded and faulted; granites, gneisses, schists, mafics


Regolith
saprolite
Transition zone
Fractured rock
Casing
...igneous, metasedimentary, and metavolcanic rocks
Open hole

Summary of Radon in Water Data in Piedmont/Mountains of NC

n = 553 private wells



	Radon, pCi/L		
number of wells	Minimum	Median	Maximum
553	< 100	2520	57550

- Radon in water less than 300 pCi/L
- Radon in water above 300 pCi/L
- Radon in water above 4000 pCi/L

Controls on dissolved radon occurrence

PRIMARY

- Rock origin: Meta-igneous vs Meta-sedimentary
- Rock age
- Rock composition

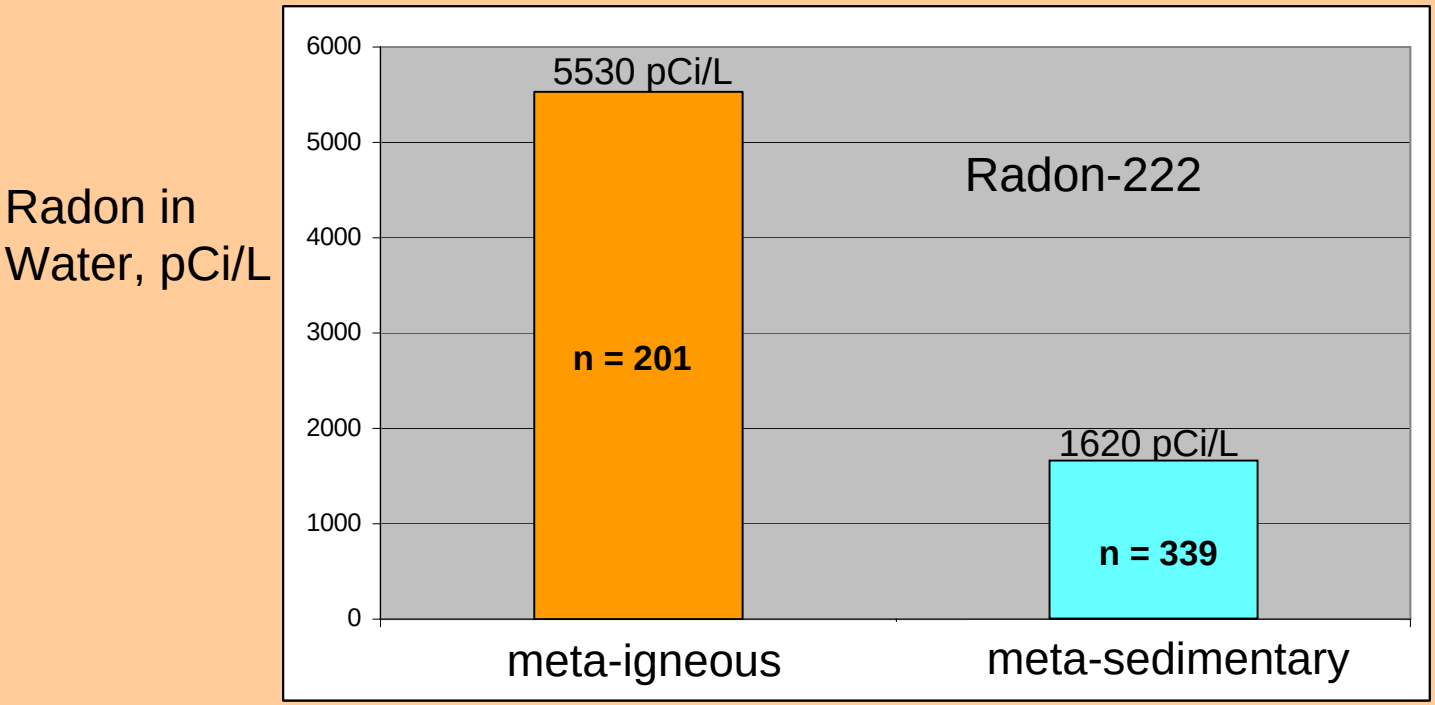
SECONDARY

- Redox conditions
- Regolith thickness
- Well yield per foot of open hole

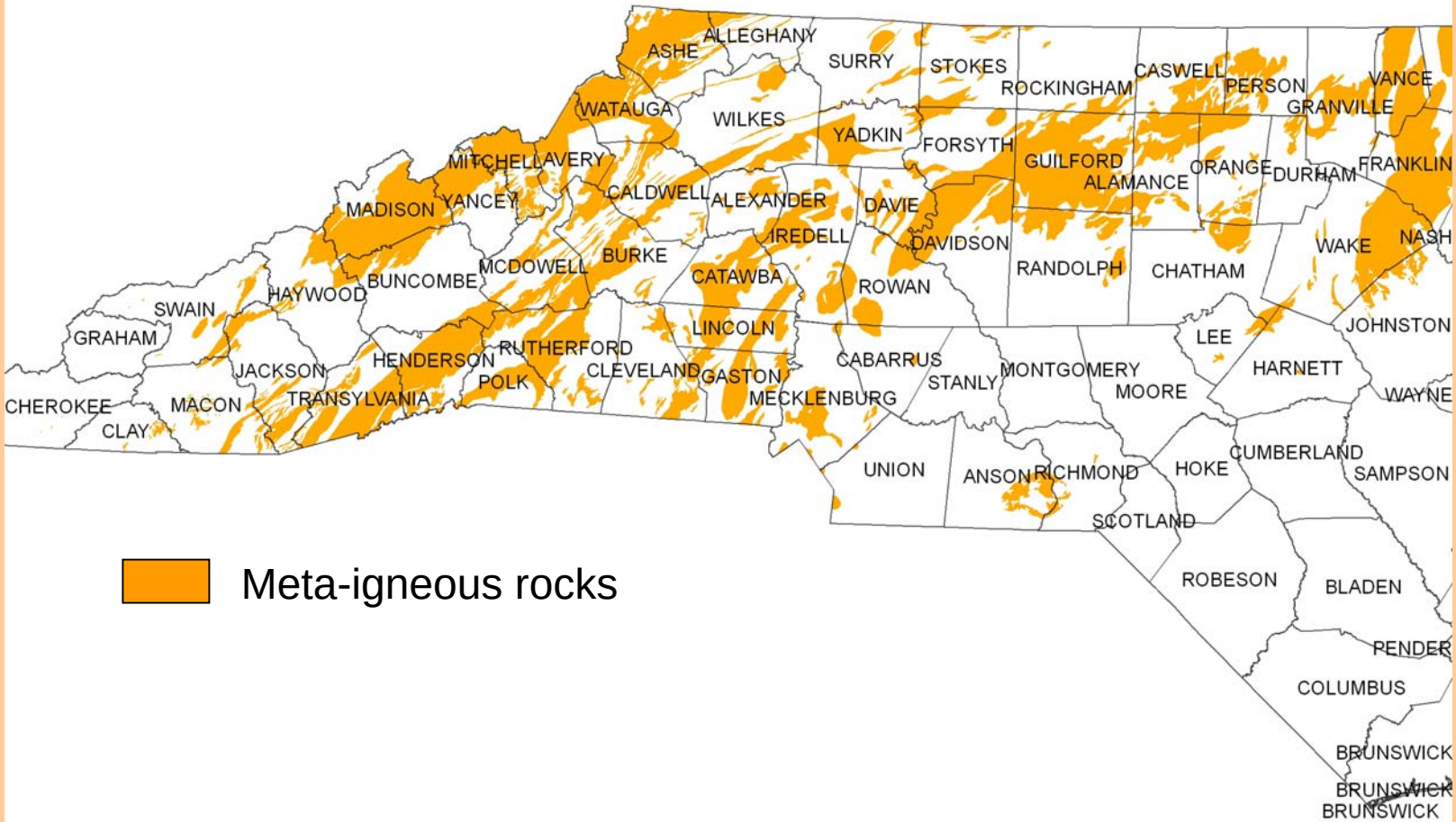
Rock Origin

Rock Origin

Median Radon in Water vs Rock Origin

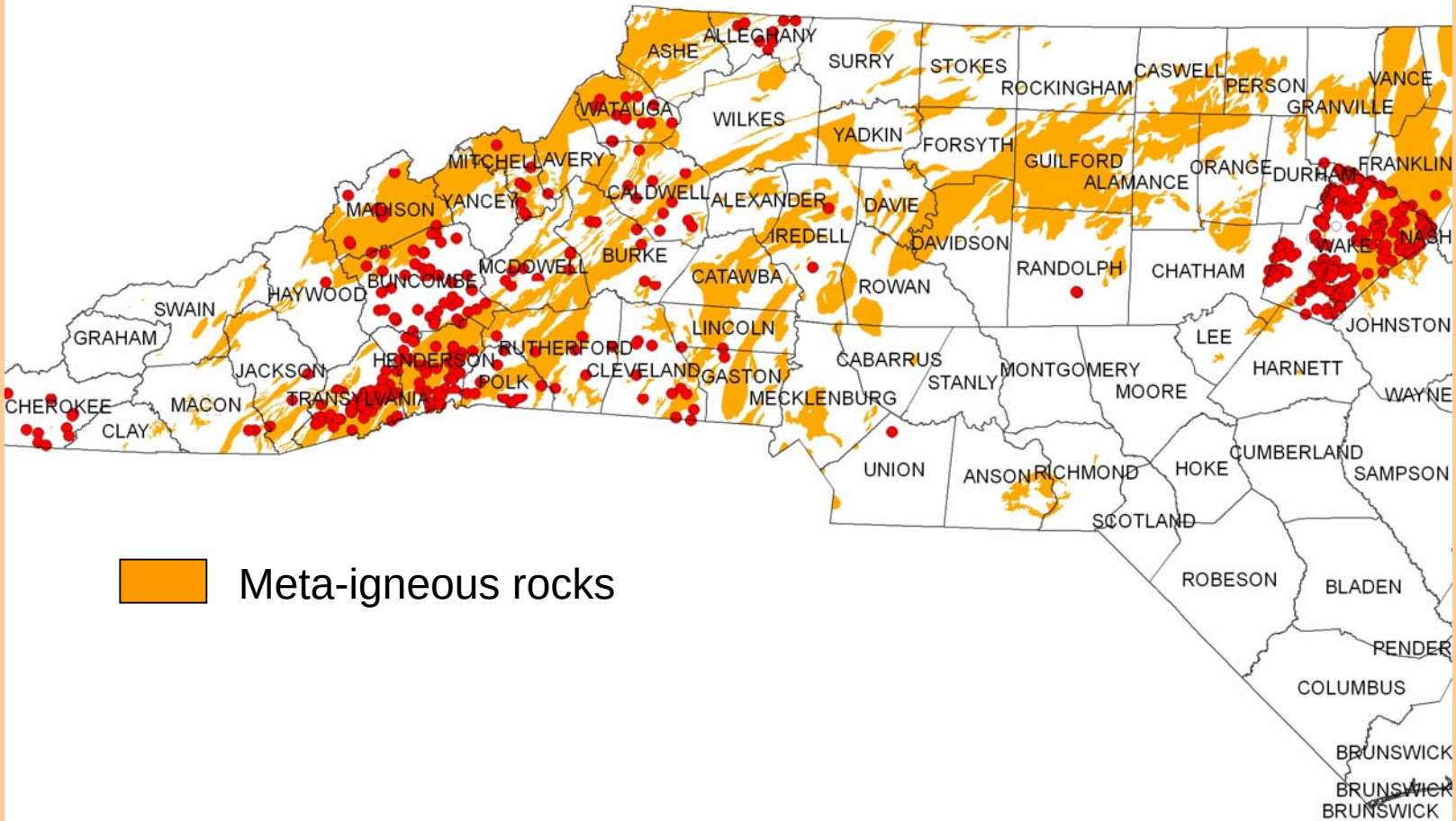


Rock Origin


ASHE
ALLEGHANY
SURRY
STOKES
ROCKINGHAM
CASWELL
PERSON
VANCE
GRANVILLE
WATAUGA
WILKES
YADKIN
FORSYTH
GUILFORD
ALAMANCE
ORANGE
DURHAM
FRANKLIN
MITCHELL
AVERY
MADISON
YANCEY
CALDWELL
ALEXANDER
DAVIE
IREDELL
DAVIDSON
WAKE
NASH
BURKE
MCDOWELL
CATAWBA
ROWAN
RANDOLPH
CHATHAM
BUNCOMBE
HAYWOOD
SWAIN
GRAHAM
LINCOLN
JOHNSTON
LEE
RUTHERFORD
HENDERSON
CABARRUS
JACKSON
CLEVELAND
GASTON
STANLY
MONTGOMERY
HARNETT
POLK
MECKLENBURG
MOORE
WAYNE
CHEROKEE
MACON
TRANSYLVANIA
CLAY
UNION
ANSON
RICHMOND
HOKE
CUMBERLAND
SAMPSON
SCOTLAND
ROBESON
BLADEN
PENDER
COLUMBUS
BRUNSWICK
BRUNSWICK
BRUNSWICK
Meta-igneous rocks

Rock Origin

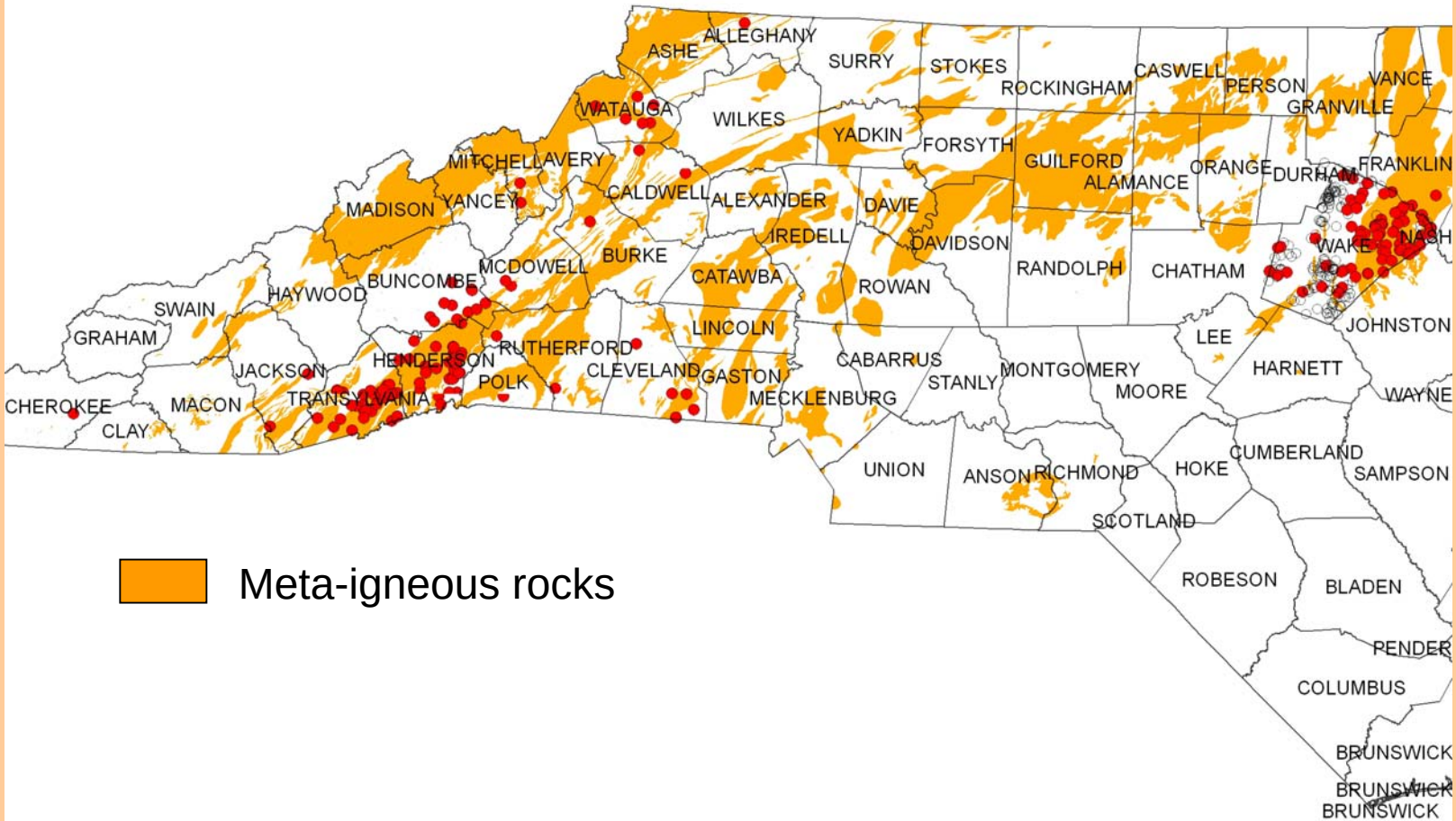
- Radon in water above 300 pCi/L



Meta-igneous rocks

Rock Origin

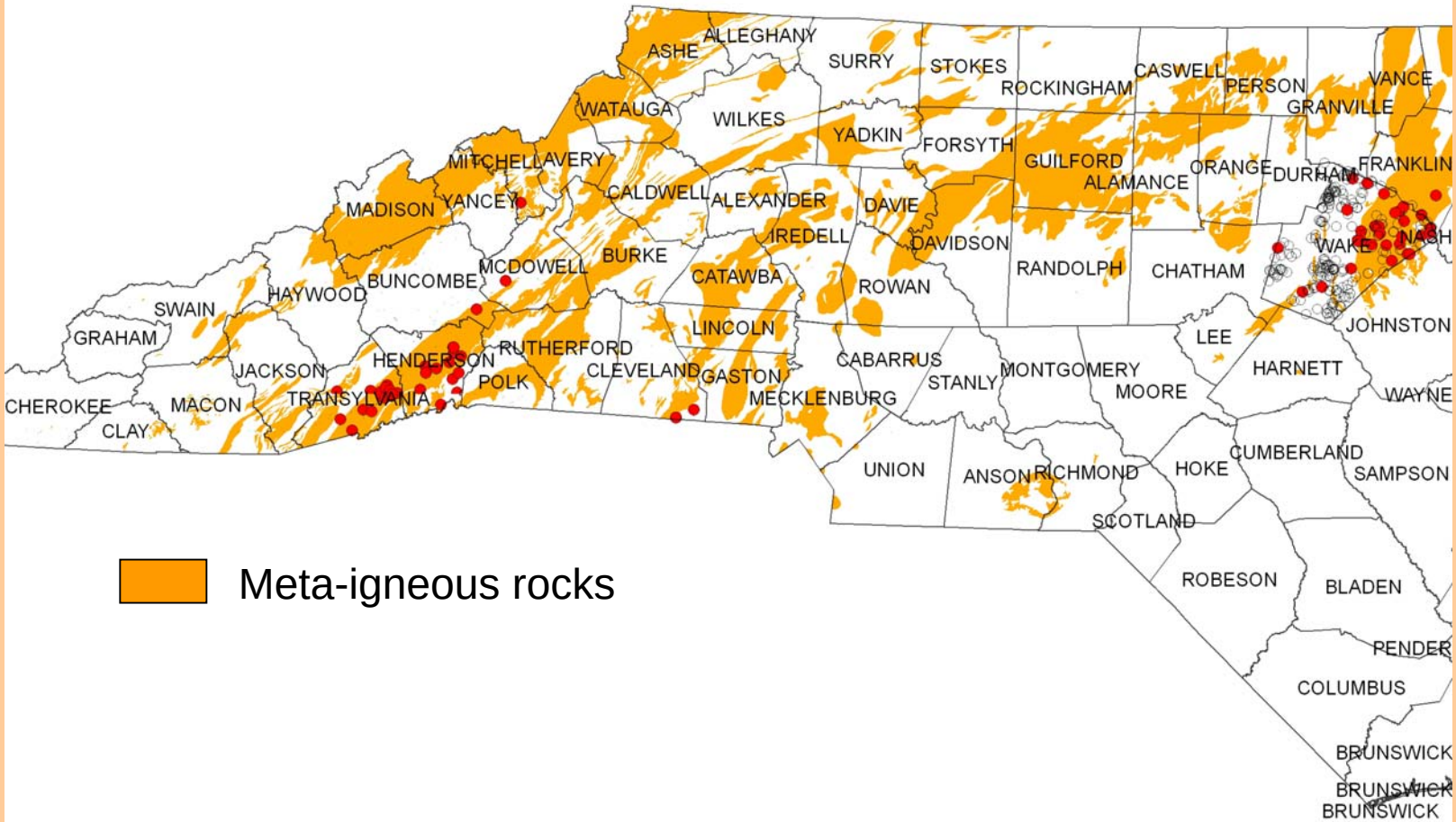
- Radon in water above 4000 pCi/L



Meta-igneous rocks

Rock Origin

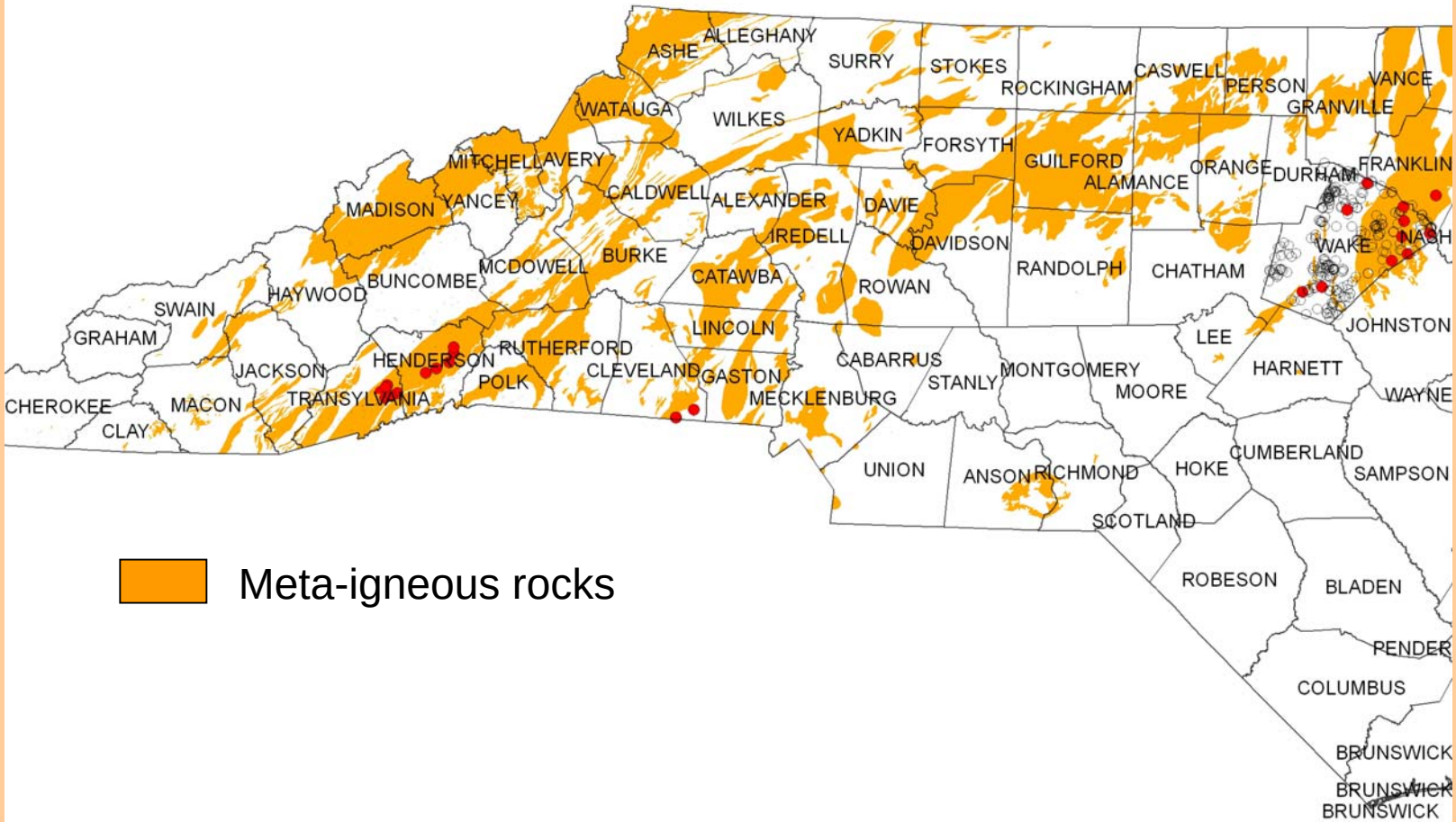
- Radon in water above 10,000 pCi/L



Meta-igneous rocks

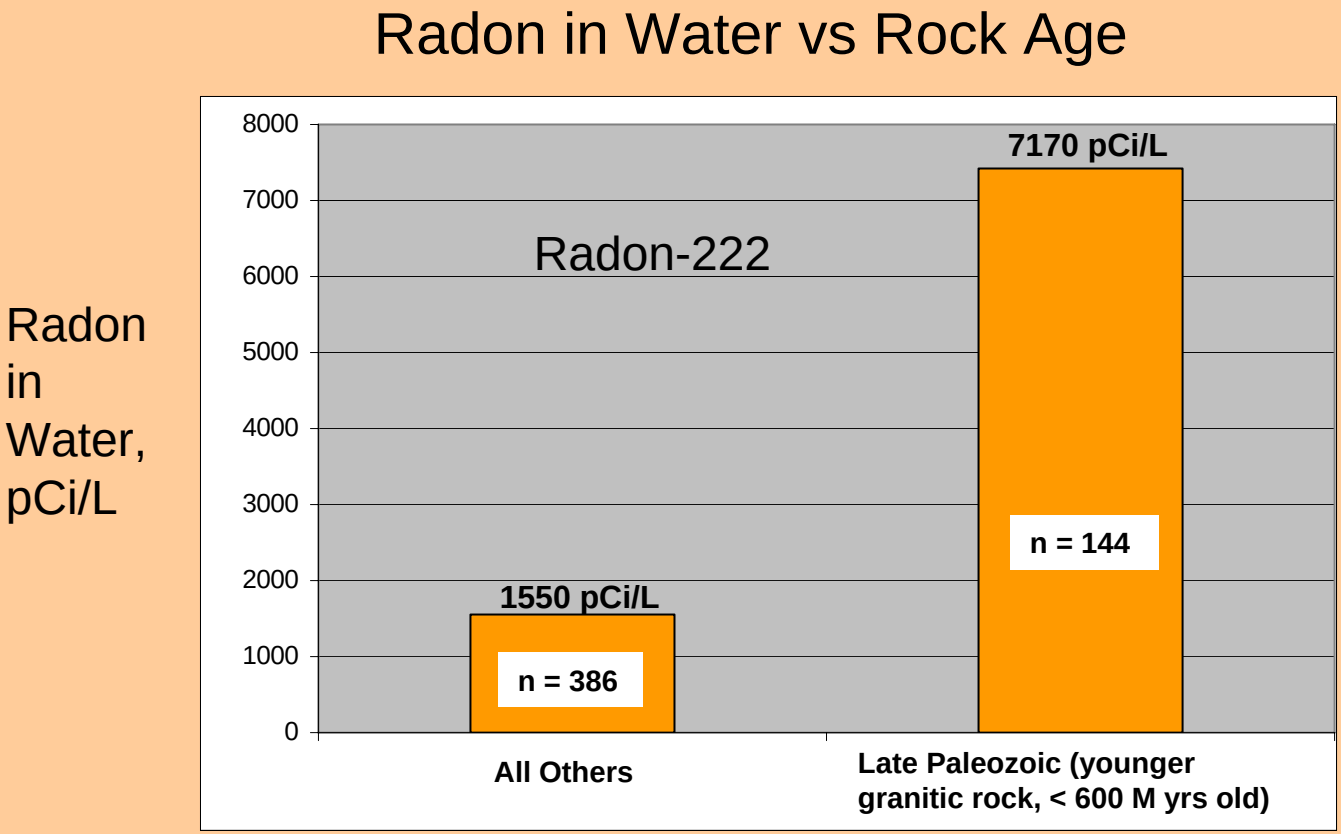
Rock Origin

- Radon in water above 15,000 pCi/L

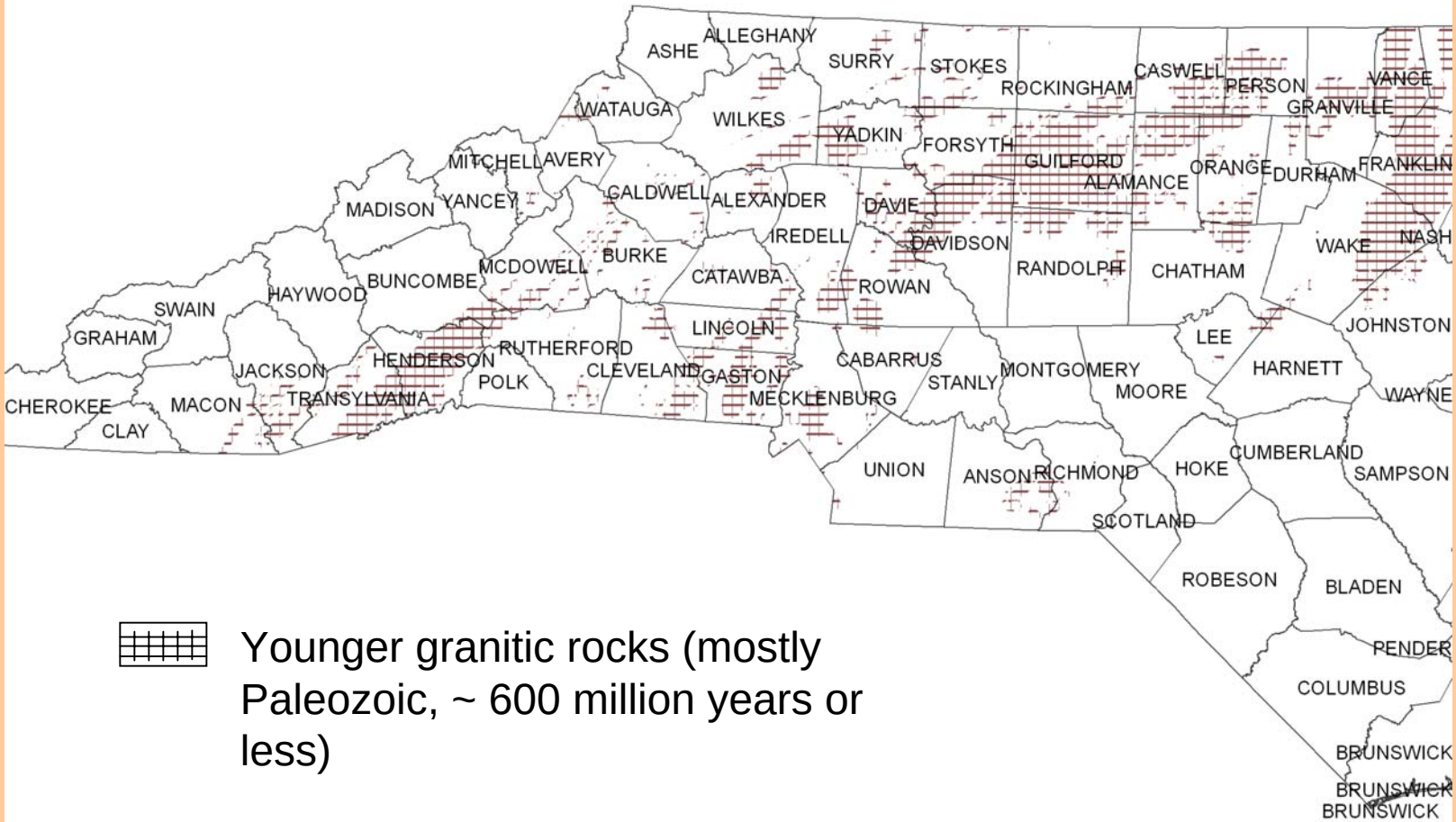


Rock Age

Rock Age


Radon in Water vs Rock Age
Radon in Water, pCi/L
8000
7000
6000
5000
4000
3000
2000
1000
0
Radon-222
1550 pCi/L
n = 386
7170 pCi/L
n = 144
All Others
Late Paleozoic (younger granitic rock, < 600 M yrs old)

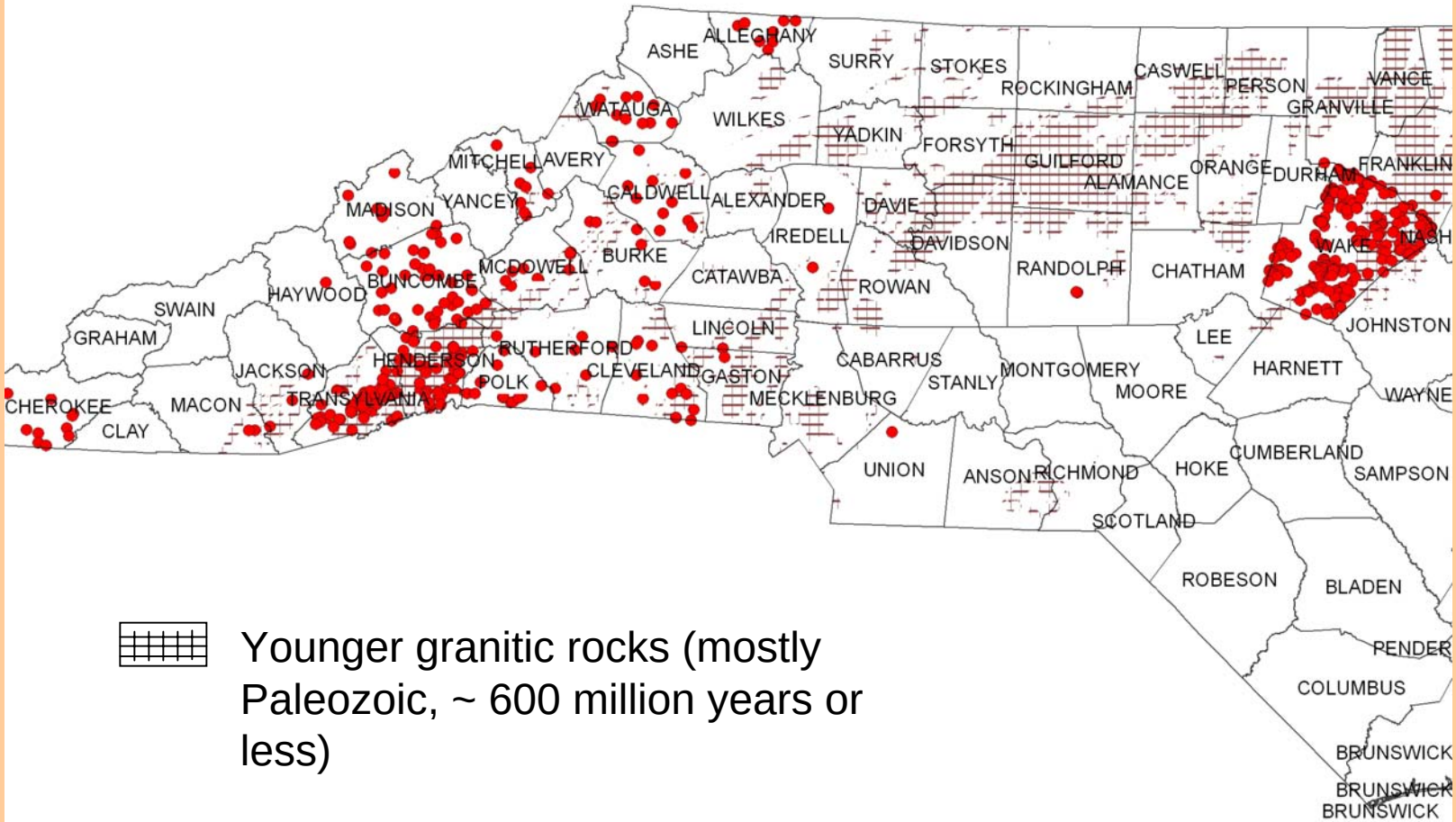
Rock Age



Younger granitic rocks (mostly Paleozoic, ~ 600 million years or less)

Rock Age

- Radon in water above 300 pCi/L



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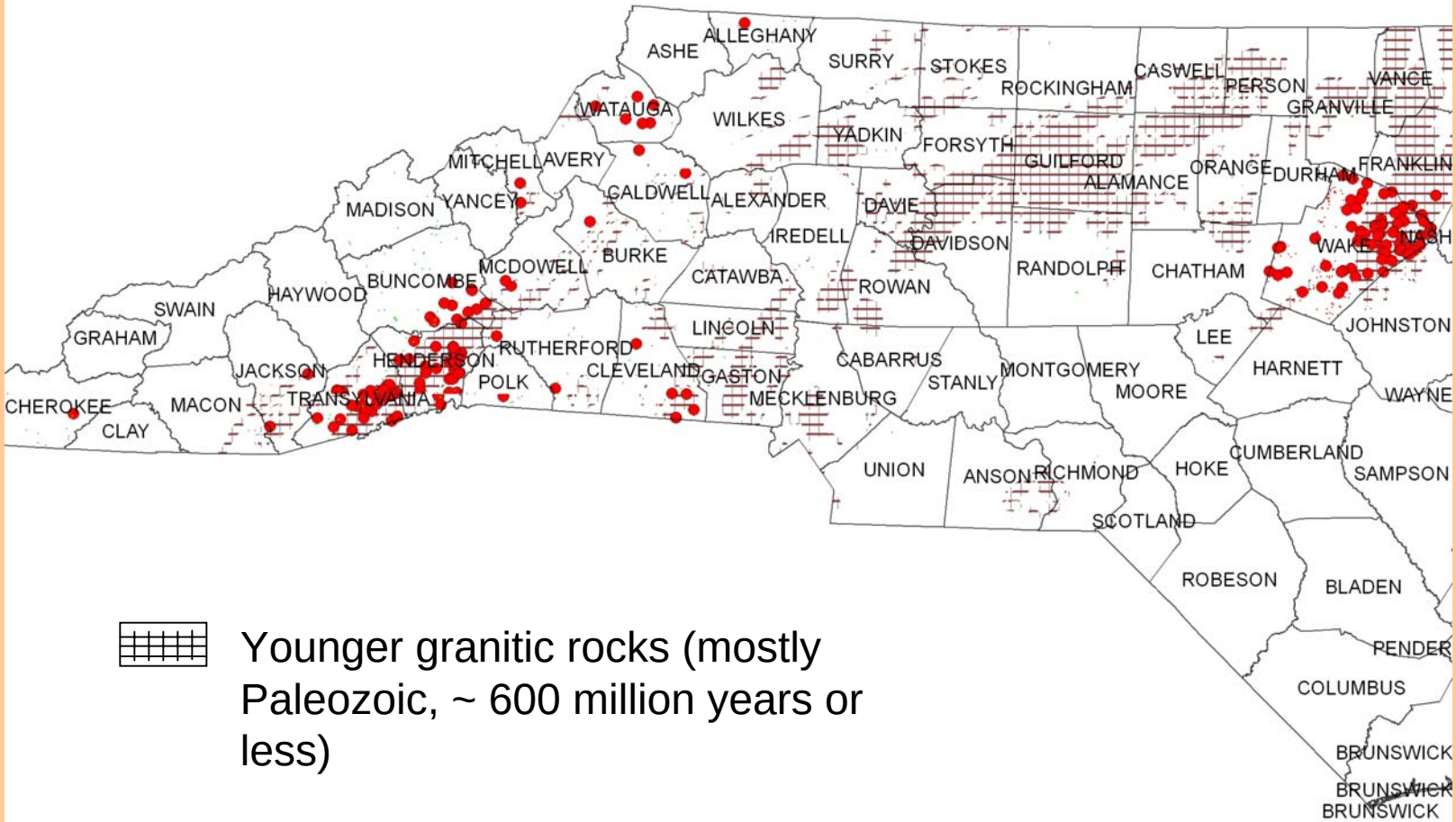
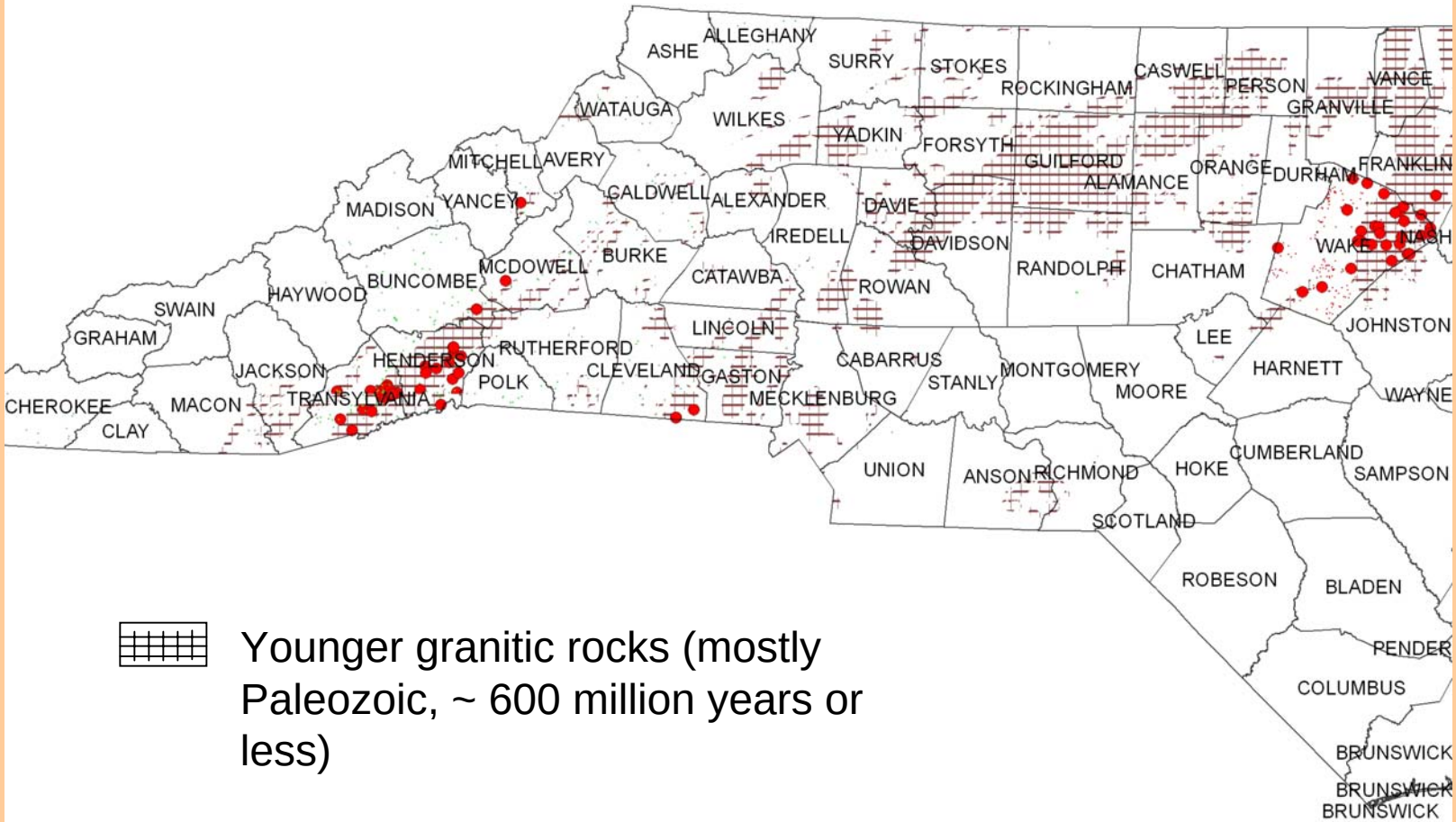


Younger granitic rocks (mostly Paleozoic, ~ 600 million years or less)

Rock Age

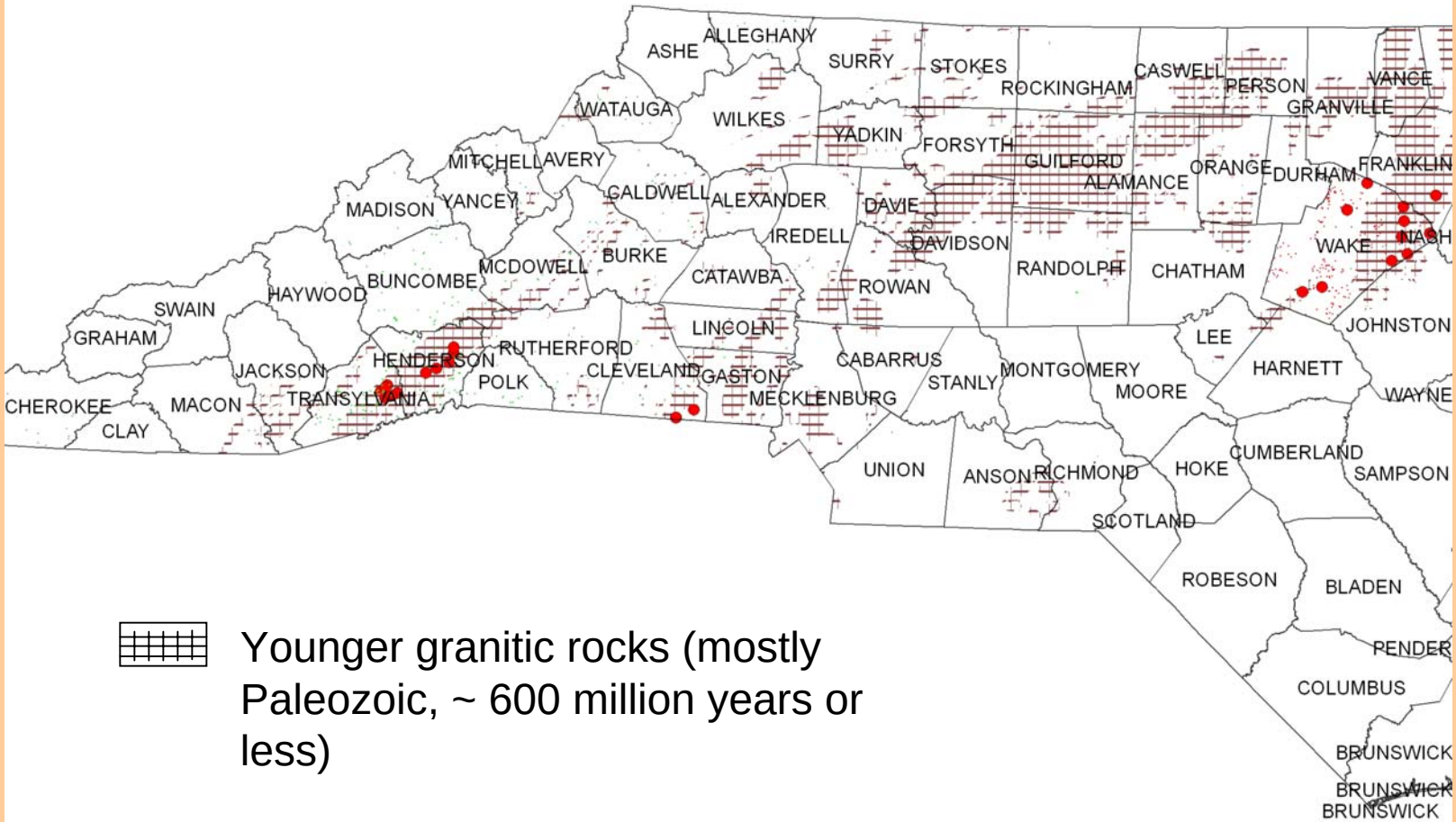
- Radon in water above 10,000 pCi/L



Younger granitic rocks (mostly Paleozoic, ~ 600 million years or less)

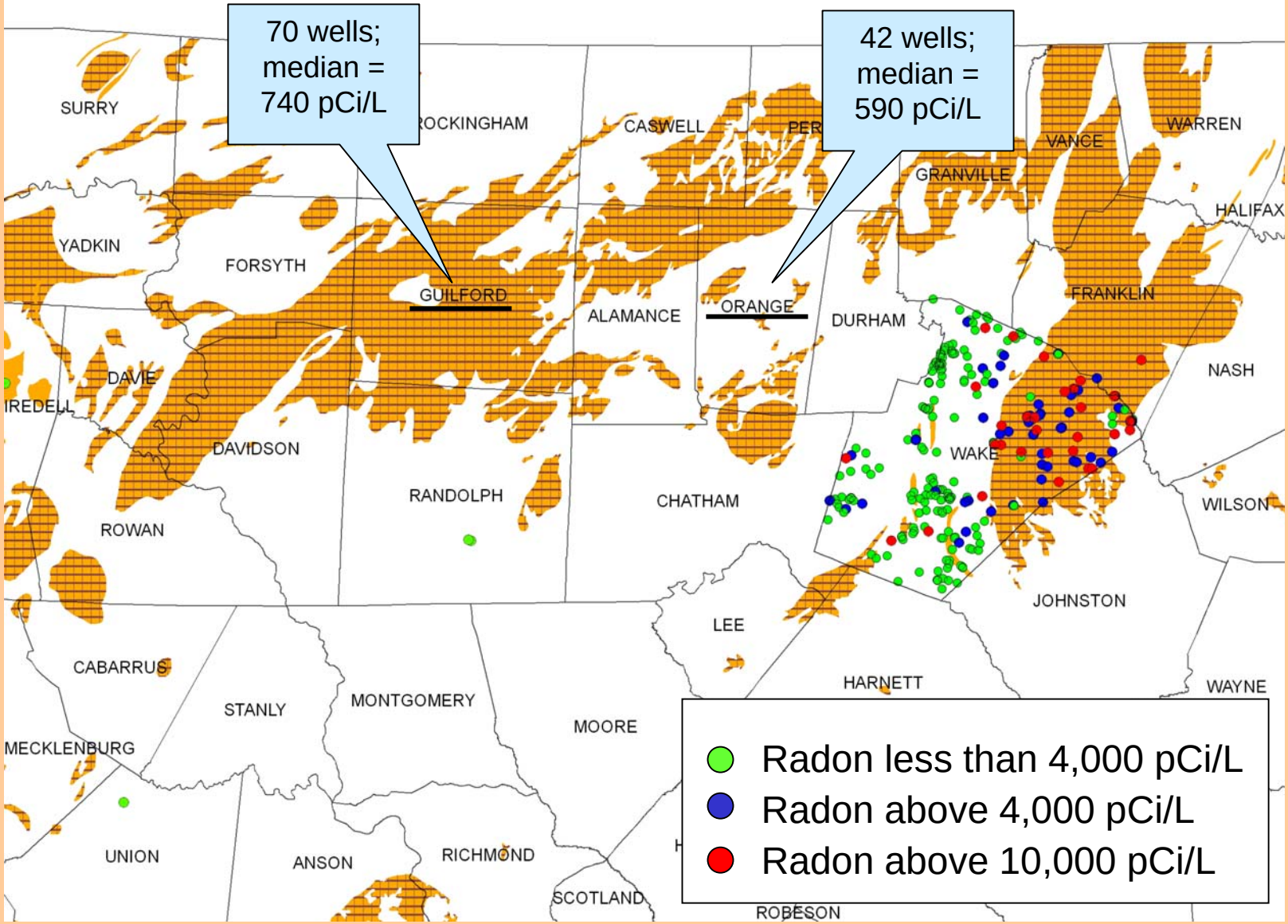
Rock Age

- Radon in water above 15,000 pCi/L



Younger granitic rocks (mostly Paleozoic, ~ 600 million years or less)

Radon in Water in Piedmont/Mountains of NC



Rock Composition

Meta-igneous

Proterozoic granitoid gneiss

granodiorite gneiss

biotite granitic gneiss

migmatitic biotite hornblende gneiss

Toxaway Gneiss

granite gneiss

Henderson Gneiss

granitoid

porphroblastic gneiss

quartz diorite / granodiorite

Caesars Head Granite

granodiorite

mafics

meta-ultramafic rocks

amphibolite

Meta-sedimentary

meta-fine grained clastics

garnet-mica schist

rocks of the Brevard Fault Zone

metasiltstone

meta-coarse grained clastics

muscovite-biotite gneiss

metagraywacke

biotite gneiss

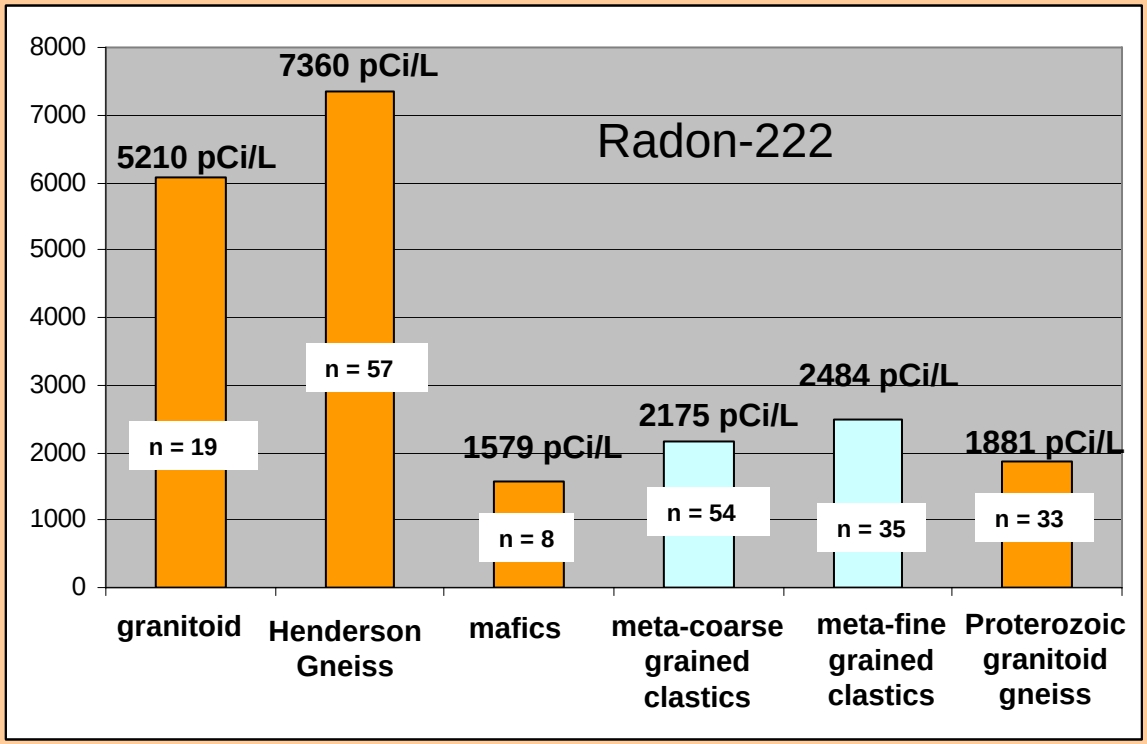
gneiss

sedimentary

Rome Formation

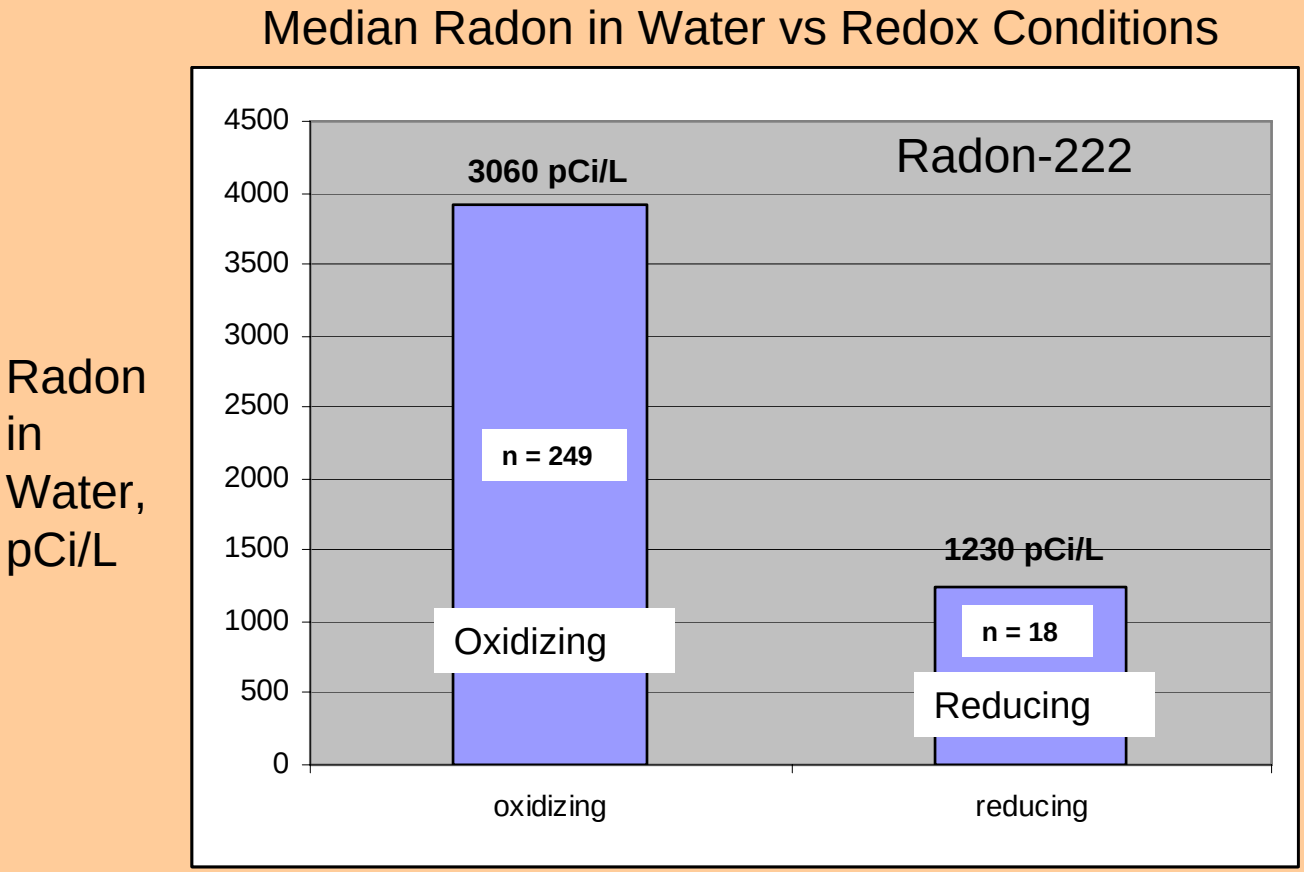
Rock Composition

Median Radon in Water vs Rock Grouping



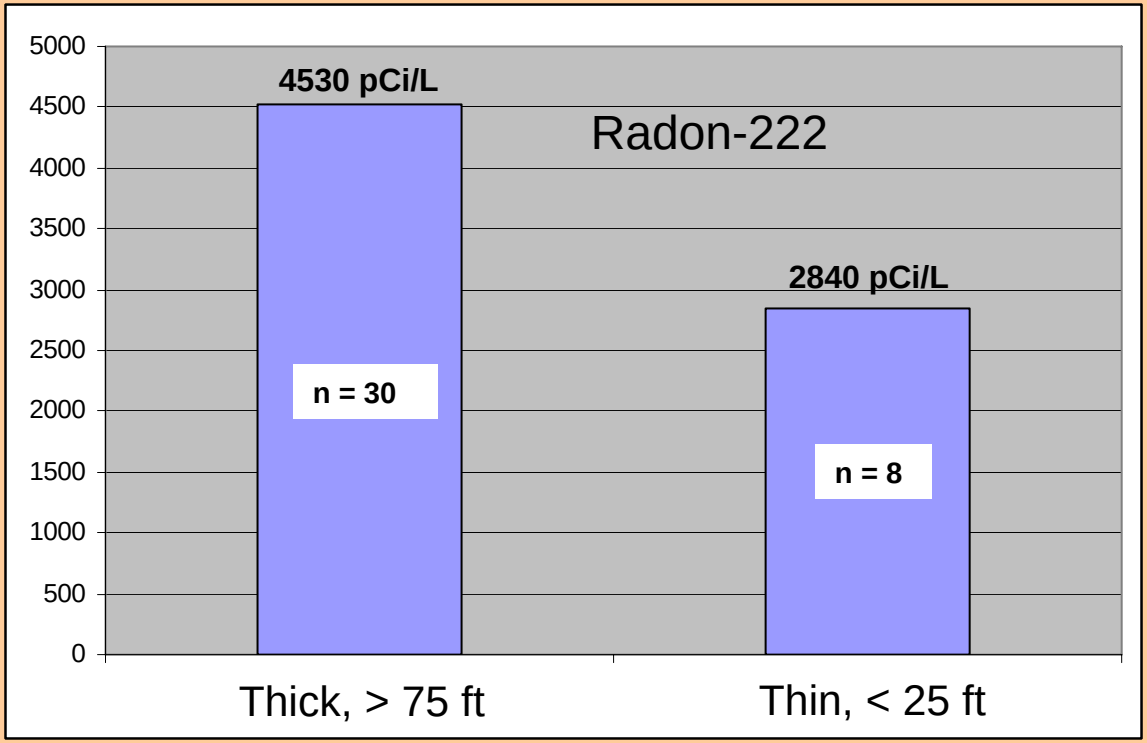
ROCK GROUPING	N	Min	Max	Median	Std. Deviation
Henderson Gneiss	57	417	45600	7360	8447
granitoid	19	1493	14300	6060	4074
meta-fine grained clastics	35	90	10600	2484	2730
meta-coarse grained clastics	54	87	8000	2175	2024
Proterozoic granitoid gneiss	33	115	29800	1881	6574
mafics	8	109	13820	1579	4978

Redox Conditions



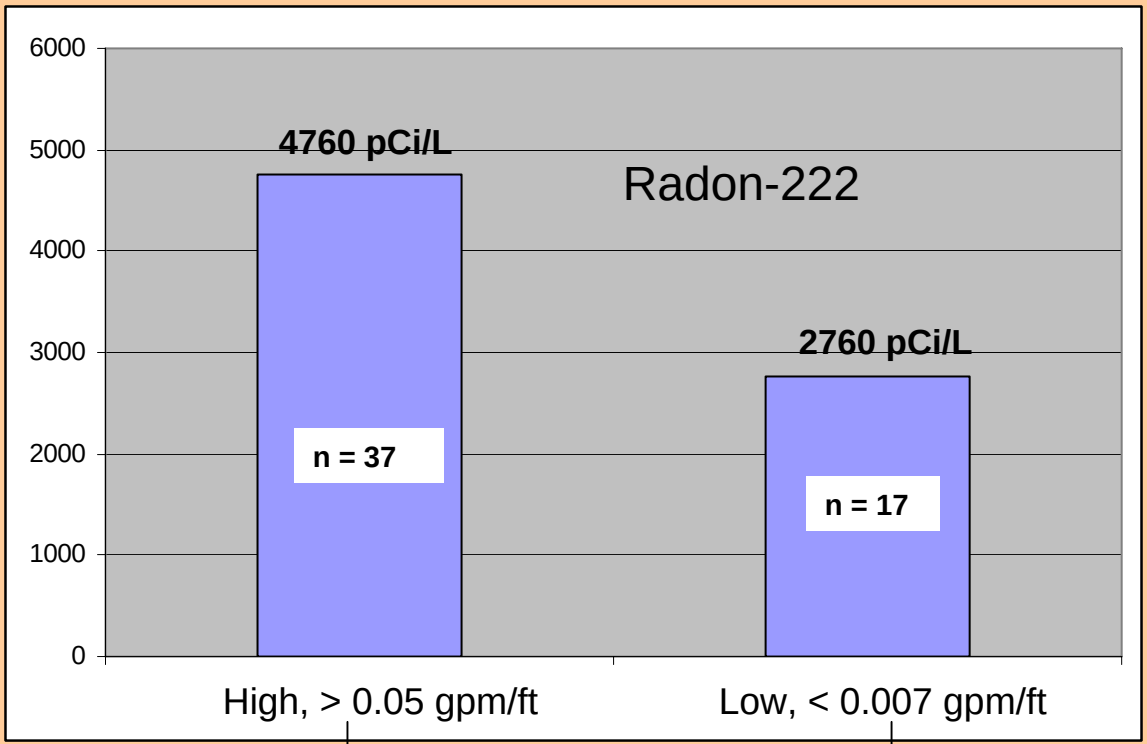
Regolith Thickness

Radon in Water vs Regolith Thickness



Well Yield Per Foot

Median Radon in Water vs Yield Per Foot of Open Hole



~ 5 gpm per 100 ft of depth

~ 0.7 gpm per 100 ft of depth

Other Observations

- generally, “co-occurrence” was not observed
- median Radon-222/Radium-226 ratio = 20,000 (2 to 6 orders of magnitude)
- median Radium-226/Radium-228 ratio = 2.8 (0.4 to 52)
- statistical correlations between radon and field parameters (Spearman Rank Correlation Coefficients) tended to be weak
- no statistically significant regression model to predict levels

So What Does All This Mean for the Citizens of North Carolina?

Risks Associated with Radon in Water:

At what concentration does radon substantially impact a ground water supply?

What is an acceptable risk?

How does the radon-in-water risk compare to other risks?

	Lifetime risk
Cigarette smoking ……	1 in 13
Air pollution ……	1 in 1,000
EPA regulated compounds	
10 ppb of arsenic (EPA MCL) ……	1 in 150
5 ppb of trichloroethelyene (EPA MCL) ……	1 in 17,000
5 ppb of tetrachloroethelyene (EPA MCL) ……..	1 in 100,000
5 ppb of benzene (EPA MCL) ……..	1 in 200,000
Radon in water	
300 pCi/L of radon (EPA proposed MCL) * ……..	1 in 5,600 inhalation risk
	1 in 47,000 ingestion risk
	1 in 5,000 combined risk
4000 pCi/L of radon (EPA proposed alternate MCL) * ….	1 in 420 inhalation risk
	1 in 3,500 ingestion risk
	1 in 375 combined risk
Radon in indoor air	
2 pCi/L of radon * ……	1 in 80
4 pCi/L of radon (EPA target action level) * ……	1 in 40
8 pCi/L of radon * ……	1 in 20

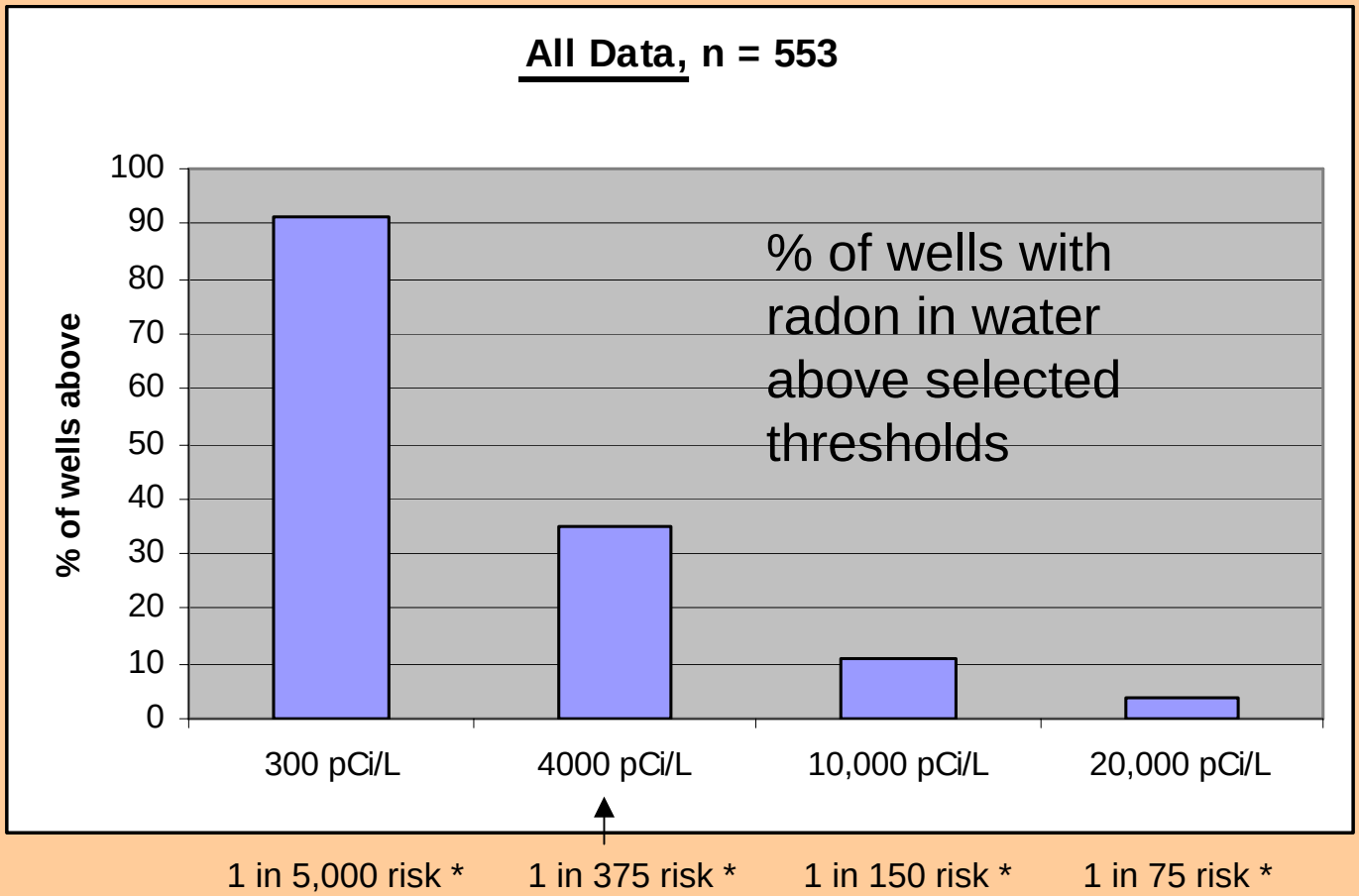
** From NRC, 1999, p. 16; inhalation (smokers and nonsmokers) = 1.6x10-8; ingestion = 0.19x10-8; total = 1.8x10-8.*

Radon in Water in Piedmont/Mountains of NC

	Radon, pCi/L		
number of wells	Minimum	Median	Maximum
553	< 100	2520	57550

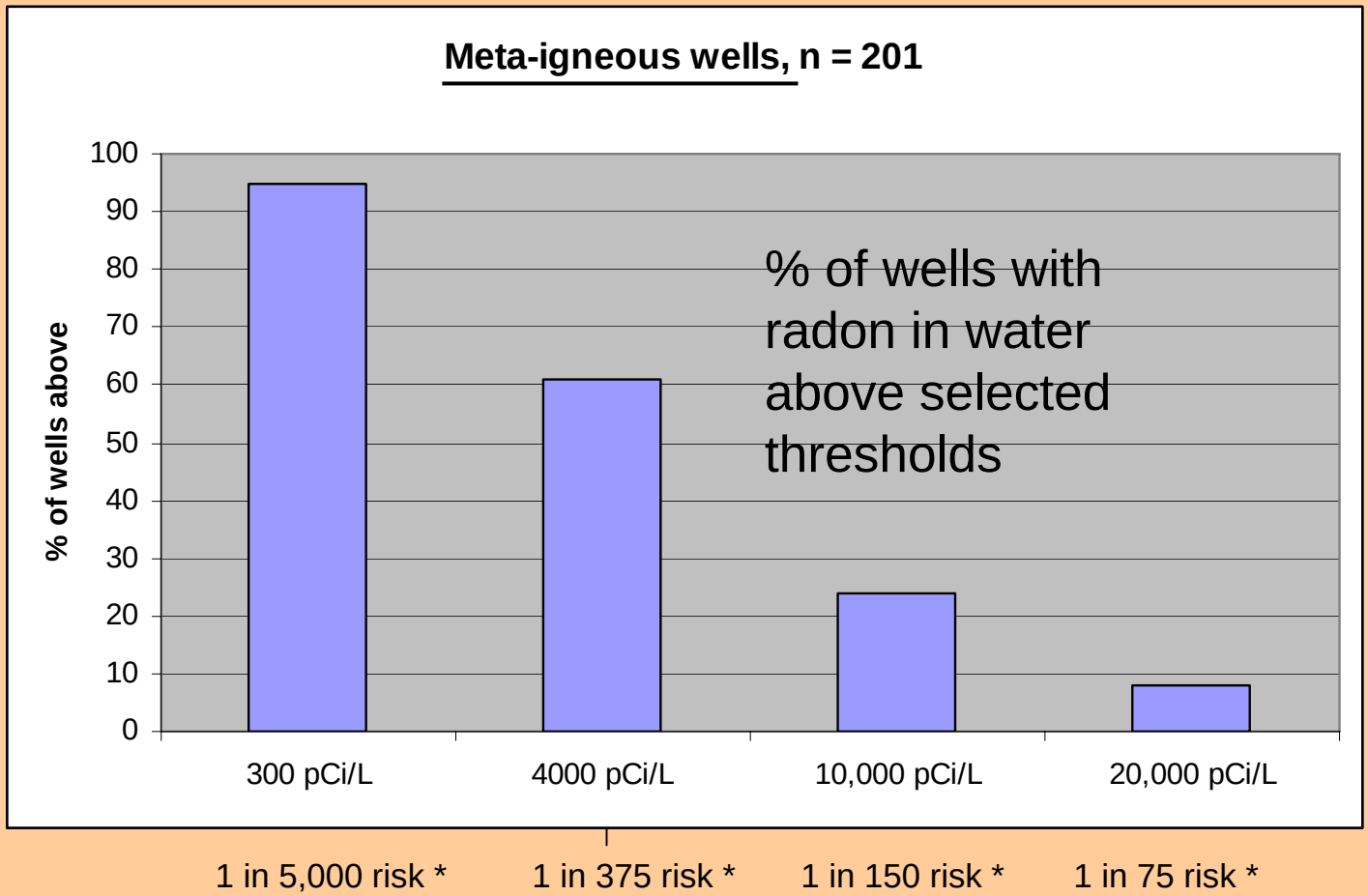
~ 1 in 600
lifetime risk

Radon in Water in Piedmont/Mountains of NC



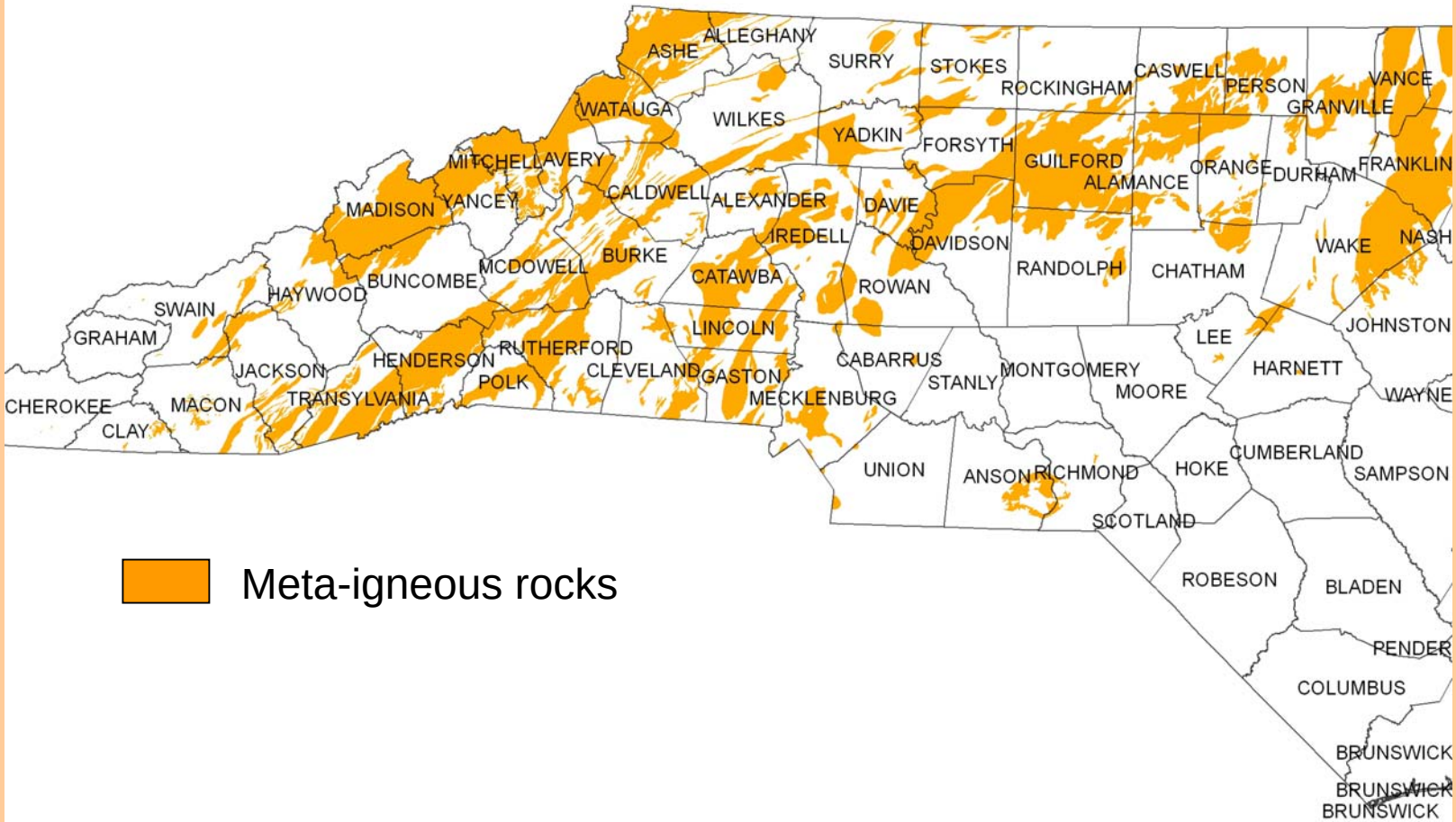
* Risk estimates from NRC, 1999

Rock Origin

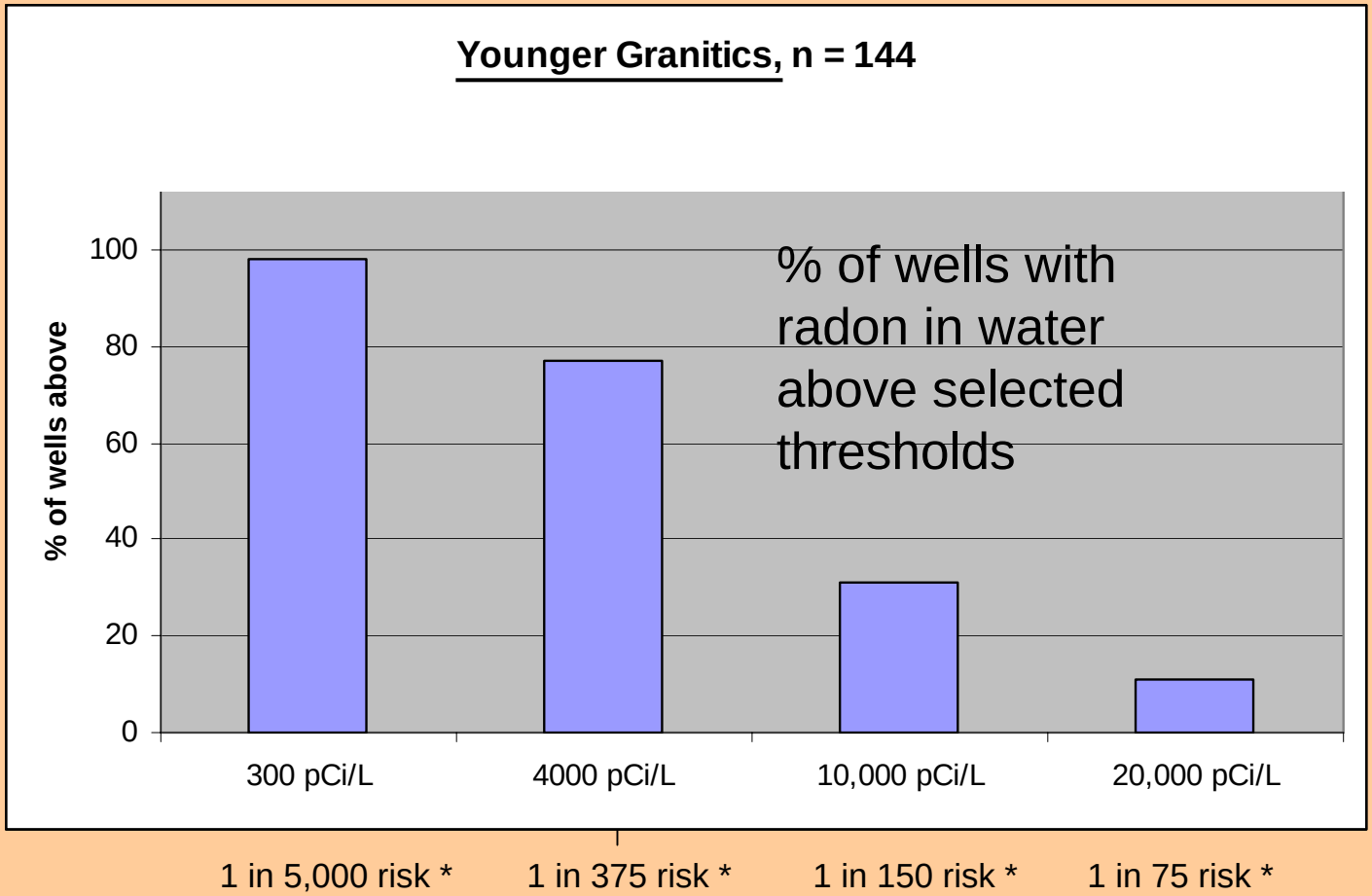


* Risk estimates from NRC, 1999

Areas underlain by meta-igneous rocks…

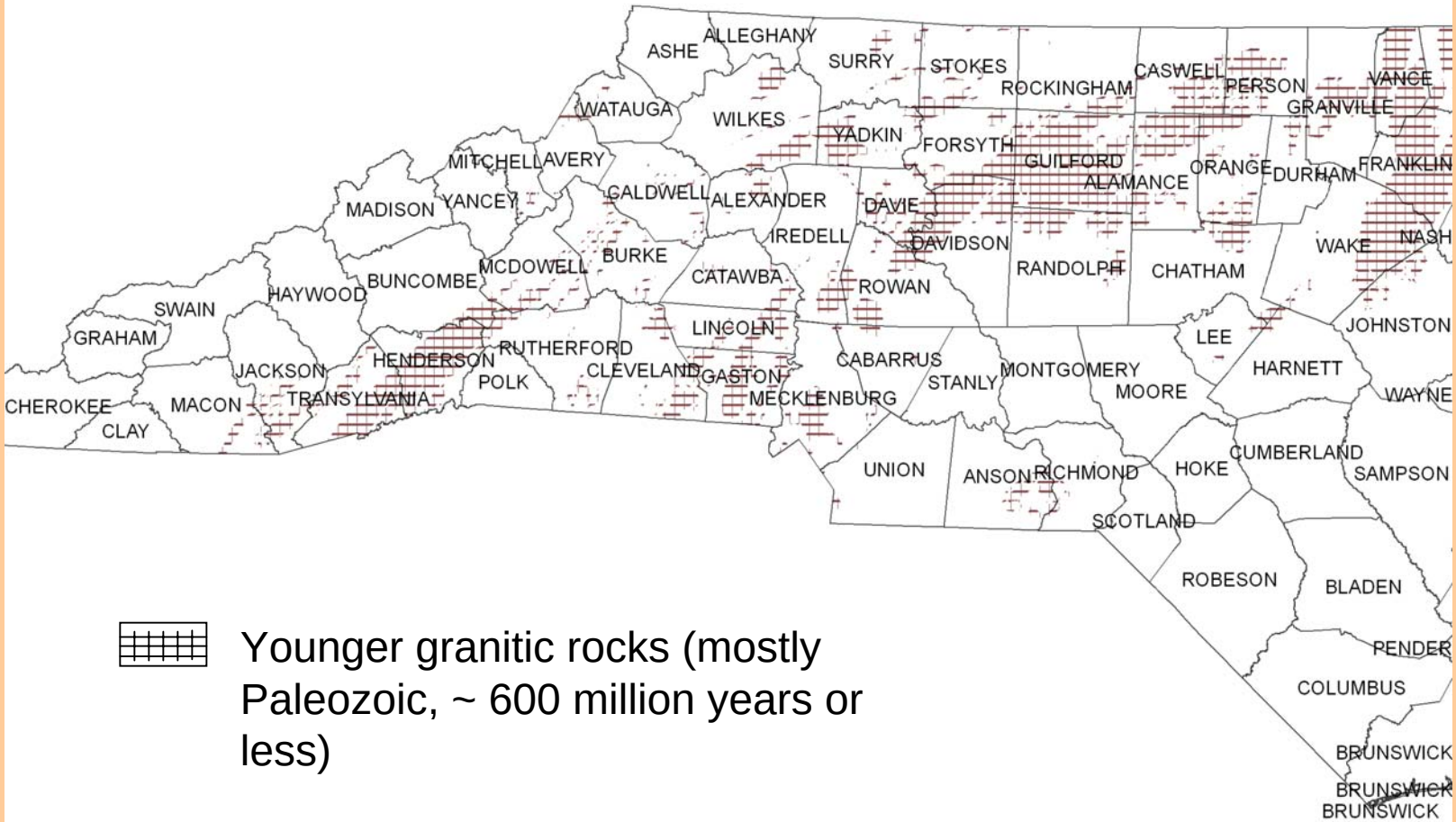


Rock Age



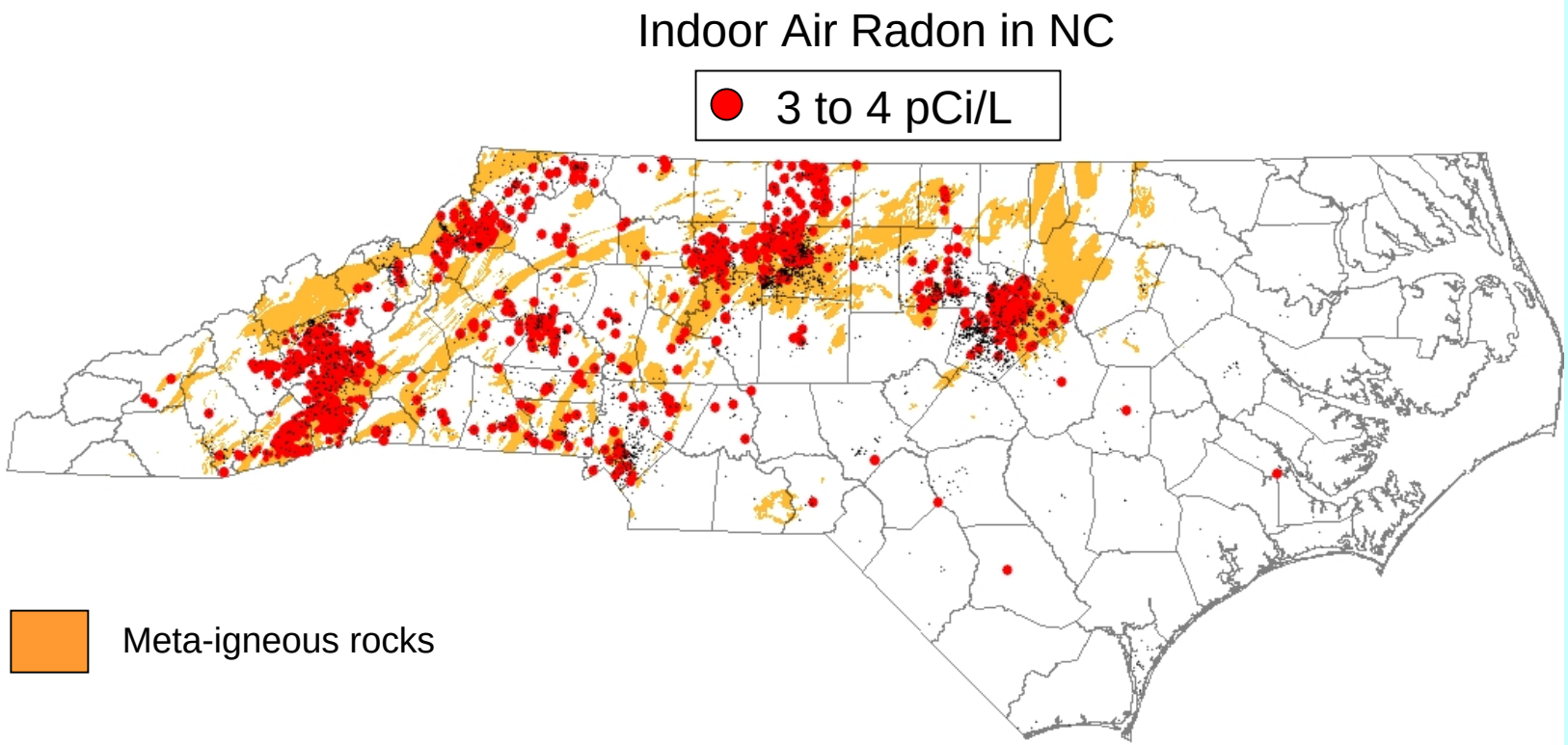
* Risk estimates from NRC, 1999

Areas underlain by younger granitic rocks…



Younger granitic rocks (mostly Paleozoic, ~ 600 million years or less)

Unaddressed risk?



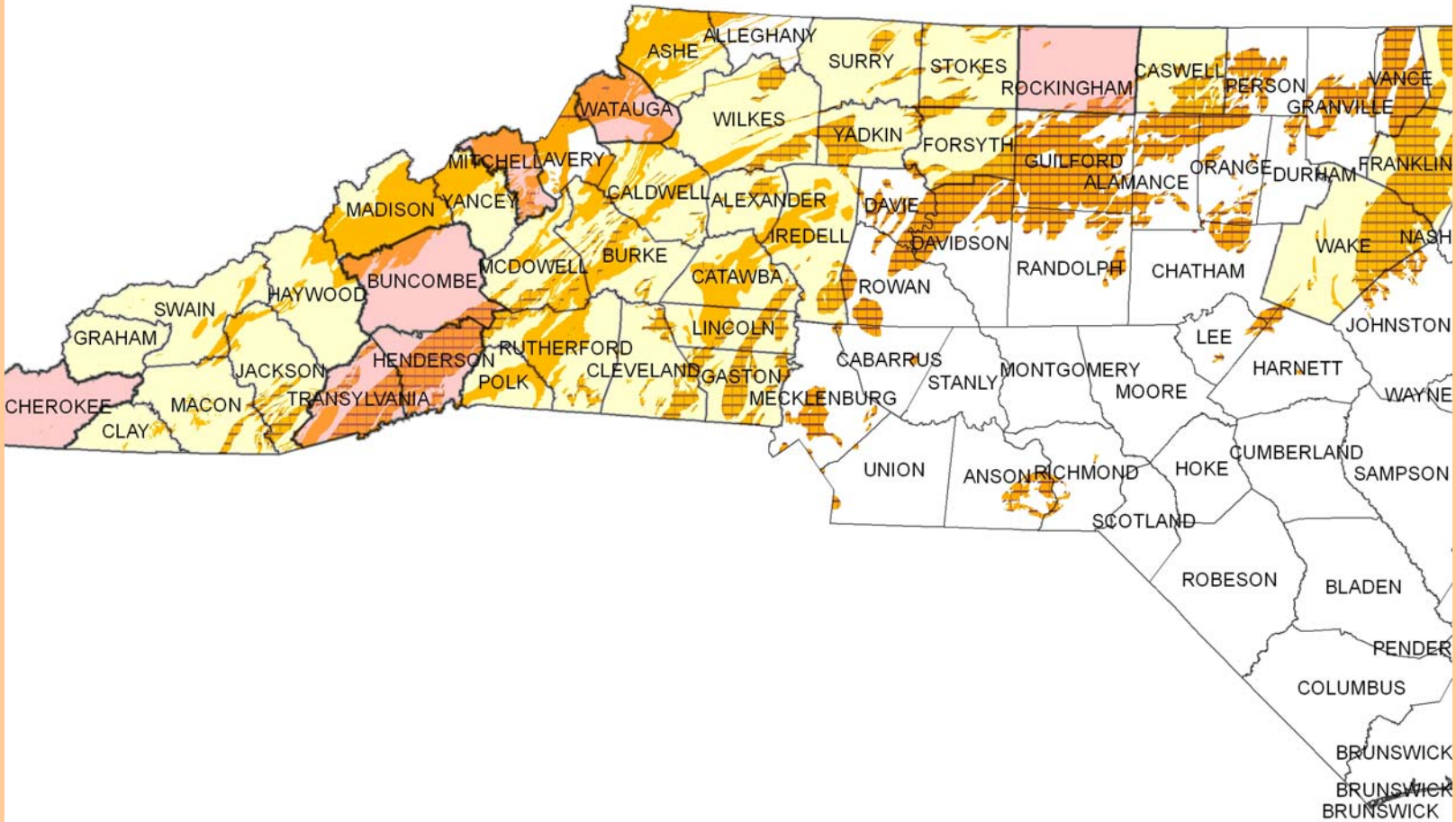
* Data from Airchek, Inc, 2006

n = 16,384
max = 2146 pCi/L
median = 1.6 pCi/L

Radon in Water in Piedmont/Mountains of NC

EPA Zone 1 county (avg indoor air radon above 4 pCi/L)

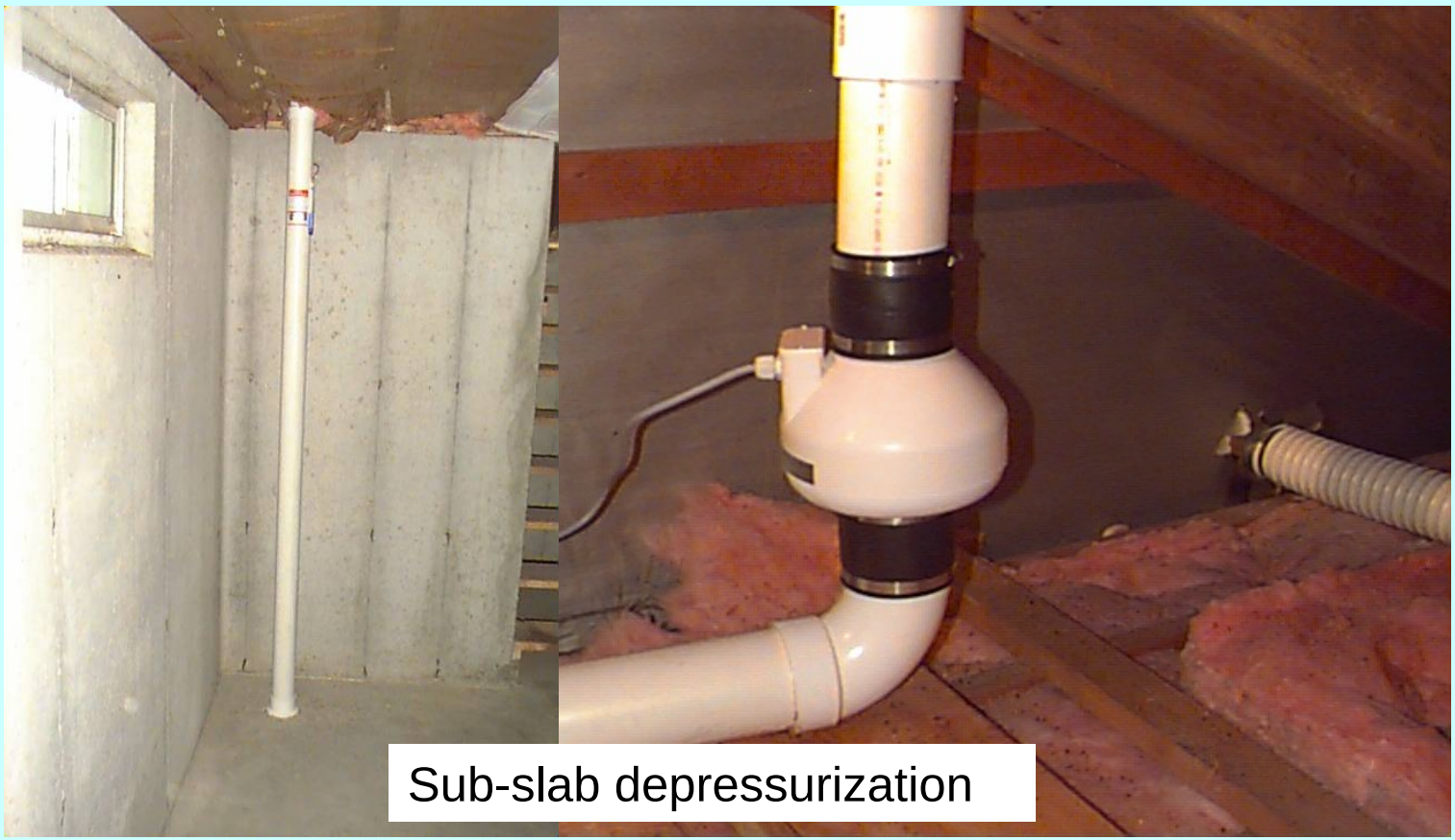
EPA Zone 2 county (avg indoor air radon at 2 to 4 pCi/L)



Mitigation of Indoor Air Radon

- testing is easy; as low as $10 for indoor radon test and $25 for radon-in-water test

- radon can be removed from indoor air by sub-slab depressurization ($1000 to $2000)



Sub-slab depressurization

Mitigation of Radon in Water

• radon can be removed from a water supply by aeration ($2500 to $4000), storage, or GAC filter

• Although $$$ spent on mitigation should usually address radon emanating from soil gas, one should consider levels of indoor radon *and* radon in water when determining an optimal home treatment system

Products

Radon and Other Naturally-Occurring Radionuclides in Domestic Drinking Water Wells and Radon in Indoor Air in Henderson, Buncombe, and Transylvania Counties, North Carolina, 2005

Fact Sheet – Elevated Radon in Ground Water Drinking Supplies in the Piedmont and Mountains of Western North Carolina, May 2006

Radon-222 and Other Naturally-Occurring Radionuclides in Private Drinking Water Wells and Radon in Indoor Air in Selected Counties in Western North Carolina, 2006

Radon-222 and Other Naturally-Occurring Radionuclides in Private Drinking Water Wells and Radon in Indoor Air in Selected Counties in Western North Carolina, 2007

Products

Radon in Ground Water Awareness Map for Buncombe, Henderson, and Transylvania Counties, North Carolina

Radon-222 Transfer from Ground Water Used in Showers to Indoor Air

Statewide Radon in Ground Water Database for North Carolina

Upcoming…. Factors Controlling Radon Occurrence and Distribution in Ground Water Supplies of North Carolina, 2005 to 2008

Temporal Variations in the Occurrence of Radon in Water in North Carolina

For more information:

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