Expanded Investigation of Naturally-Occurring Radon-222, Total Uranium, and Radium-226 in Private Drinking Water Wells and Radon in Indoor Air in Selected Counties in Western North Carolina, 2008

by

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N.C. Department of Environment and Natural Resources
Division of Water Quality, Aquifer Protection Section
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ABSTRACT

Radon-222 – a naturally occurring carcinogenic radionuclide – was found at elevated levels (40 to 45,800 pCi/L; median = 2350 pCi/L) in ground water samples collected from 67 private wells in Jackson, Macon, McDowell, Cleveland, Gaston, and Mecklenburg Counties, NC. Radon exceeded EPA's proposed maximum contaminant level (MCL) of 300 pCi/L in 96 percent of the wells, and exceeded the proposed alternate MCL of 4000 pCi/L in 33 percent of the wells. The main source of radon is uranium rich rock – including granites and gneisses – prevalent across much of the region.

The highest dissolved radon concentrations were observed in wells in Paleozoic granitic rocks (less than 500 million years old, which includes foliated to massive granitic rock, Cherryville granite, granodiorite, and gabbro of the Concord plutonic suite) (median = 2760 pCi/L; median = 1910 pCi/L in wells in all other rock types). Wells in meta-igneous rocks were higher in dissolved radon (median = 2760 pCi/L) than wells in meta-sedimentary rocks (median = 1920 pCi/L). Wells characterized by oxidizing conditions were higher in dissolved radon (median = 2470 pCi/L) than wells characterized by reducing conditions (median = 910 pCi/L). Each of these findings is consistent with previous studies in this region (Campbell, 2005; Campbell, 2008).

Uranium (maximum = 29 ug/L) did not exceed the EPA MCL in any of the 58 samples and exceeded the detection limit in 21 percent of samples. Radium-226 was low in all sampled wells (less than 1 pCi/L), and was above the detection limit in 19 percent of samples.

Ground water in the study area tended to be slightly acidic (median pH = 5.7), oxygenated (median dissolved oxygen = 6.7 milligrams per liter (mg/L)), and minimally conductive (median specific conductance = 108 microsiemens per centimeter (uS/cm)). The buffering capacity of the ground water was low (median alkalinity = 24 mg/L), and the levels of iron and manganese also were low (median iron < 50 ug/L and median manganese < 10 ug/L). Raw oxidation-reduction potential (ORP) values were moderate (median raw ORP = 126 mV).

Lead was below the laboratory detection limit of 10 ug/L in all but 2 (14 and 13 ug/L) of the 60 samples. Arsenic was below the laboratory detection limit of 5 ug/L in all samples. The median potassium concentration was 1250 ug/L.

Indoor air radon measured in homes associated with the private wells exceeded the EPA action level of 4 pCi/L in 10 of 40 cases, and ranged from 0.1 to 37.1 pCi/L with a median = 0.4 pCi/L).

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INTRODUCTION

Elevated levels of carcinogenic radionuclides – most notably uranium and radon – are known to occur in the ground water drinking supplies of Western North Carolina. This is due in large part to the uranium rich rocks that underlie the region. This is a concern to public health officials because about half of the population relies on ground water as its principal drinking supply (U.S. Geological Survey, website http://nc.water.usgs.gov/wateruse/data/Data_Tables_2000.html, accessed November 3, 2008). A 1993 study reported that of 277 private wells sampled across the mountain region of North Carolina, 83% were above 300 pCi/L for radon, 56% were above 1000 pCi/L, and 10% were above 5000 pCi/L (University of North Carolina, 1993). A study of 103 private wells in Buncombe, Henderson, and Transylvania Counties in Western North Carolina found a median radon level of 6060 pCi/L and a maximum of 45,600 pCi/L (Campbell, 2006). A study of 80 private wells in Madison, Mitchell, Watauga, Jackson, Buncombe, Henderson, and Transylvania Counties found a median radon level of 1889 pCi/L and a maximum of 15,750 pCi/L (Campbell, 2006 b). And a study of 87 private wells in Alleghany, Caldwell, Burke, McDowell, Cleveland, Rutherford, Polk, Cherokee, Buncombe, Henderson, and Transylvania Counties found a median radon level of 1560 pCi/L and a maximum of 16,900 pCi/L (Campbell, 2008).

Eight counties in North Carolina - all in Western North Carolina – are classified as EPA Zone 1 counties, with predicted indoor radon concentrations above the EPA recommended action level of 4 pCi/L (EPA Radon Map, accessed via internet, 8/19/05, http://www.ncradon.org/zone.htm). These include Watauga, Alleghany, Mitchell, Buncombe, Henderson, Transylvania, Cherokee, and Rockingham Counties (fig. 1). According to a statewide statistical survey of indoor air in homes (North Carolina Radiation Protection Section, 1990), average radon concentrations were as follows: Buncombe County, 2.2 pCi/L (94 samples), Cherokee, 3.4 (8 samples), Henderson, 4.5 (45 samples), Mitchell, 1.8 (5 samples), and Transylvania, 4.4 (17 samples). Concentrations were somewhat higher in a statewide non-statistical data compilation study.

Elevated levels of radon are due to the presence of uranium rich rocks – including granites and gneisses - across much of the region. Rock type has been strongly associated with concentrations of dissolved radon, with ground water in granites often containing high levels, up to 100,000 pCi/L (Asikainen and Kahlos, 1979; Brutsaert and others, 1981; Snihs, 1973) and ground water in sedimentary rocks often containing much lower levels, often less than 500 pCi/L (Andrews and Wood, 1972; King and others, 1982; and Mitsch and others, 1984).

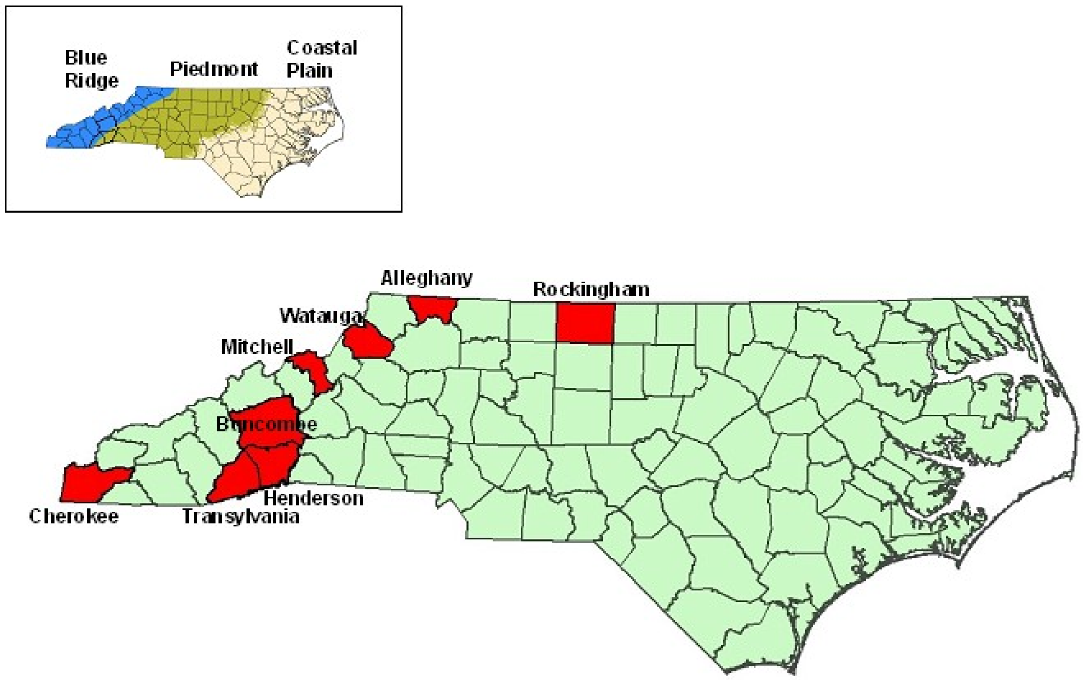

Fig. 1. EPA Zone 1 counties in North Carolina (in red) with predicted indoor radon levels of 4 pCi/L or higher, and North Carolina physiographic provinces (in inset).

Because radionuclides are known to occur in the region and because they are linked to an increased risk of cancer, several key questions are now being addressed. What is the occurrence and distribution of dissolved radionuclides in the region? Are the observed levels safe to drink? Are the dissolved radon levels high enough to cause a substantial increase in the overall exposure to inhaled radon? Is it possible to develop regional radionuclide susceptibility maps on the basis of knowledge of local geology, geochemical conditions, and topographic settings? Are well owners aware of the implications of elevated levels of dissolved radionuclides in their drinking water? Is current policy regarding radionuclides in drinking water adequately protective of public health?

While many of the "suspect" areas containing uranium rich rocks have been sampled for dissolved radionuclides in private wells, data gaps remain in a number of areas. This study was designed to fill some of these data gaps and increase our understanding of the role of geology in the occurrence and distribution of dissolved and indoor air radon-222. The study was targeted to specific counties within Western North Carolina and therefore is limited in scope. It is part of a multi-phased approach to help policy makers and the public to understand the quality of the ground water supply and the extent to which radionuclides may pose a health threat to the citizens of Western North Carolina. This study is a direct response to the North Carolina Division of Water Quality's mandate to help ensure that North Carolina's ground water resources are safe and sustainable. This study was made possible by a matching funds grant from the EPA, and carried out in consultation with the North Carolina Division of Environmental Health's Radiation Protection Section.

Purpose and Scope

The purpose of this report is to document the occurrence and distribution of selected radionuclides in drinking water collected from private wells in Jackson, Macon, McDowell, Cleveland, Gaston, and Mecklenburg Counties of Western North Carolina. Data used to draw conclusions in this report were obtained from raw, untreated, unfiltered ground water samples collected using a consistent method at 67 private drinking water wells. Wells sampled in the study generally were fractured bedrock wells that were cased (polyvinyl chloride or steel) down to the top of bedrock and, beneath this, were open borehole to depth. Well samples were analyzed for total uranium (uranium), radium-226 (Ra-226), radon-222 (radon), potassium, iron, manganese, lead, arsenic, alkalinity, bicarbonate, total dissolved solids, and field parameters. Additional data obtained at the wells included well-construction details (casing material, total depth, casing depth, and well yield), latitude and longitude, topographic setting, and surrounding rock type information. In addition, indoor air radon was measured in 40 of the 72 homes associated with the sampled private wells.

Acknowledgments

The author would like to thank Dr. Felix Fong and the staff at the North Carolina Radiation Protection Section for their support and assistance during this investigation. The author would also like to thank Jonathon Bradley (summer intern from the University of NC Asheville), Andrew Moore (summer intern from Western Carolina University), and the staff of the North Carolina Division of Water Quality, Aquifer Protection Section, who were instrumental in ensuring timely completion of all field work. The staff of the North Carolina Geological Survey provided valuable expertise on geologic interpretations and rock classifications. Special thanks also are offered to the well owners in Western North Carolina who participated in this study. This investigation was made possible by a grant from the EPA administered by the North Carolina Radiation Protection Section.

Data Collection and Analytical Methods

Ground-water samples were collected between March and August 2008, from 67 private wells within the six-county study area (figs. 2, 3, and 4). In addition, 40 indoor

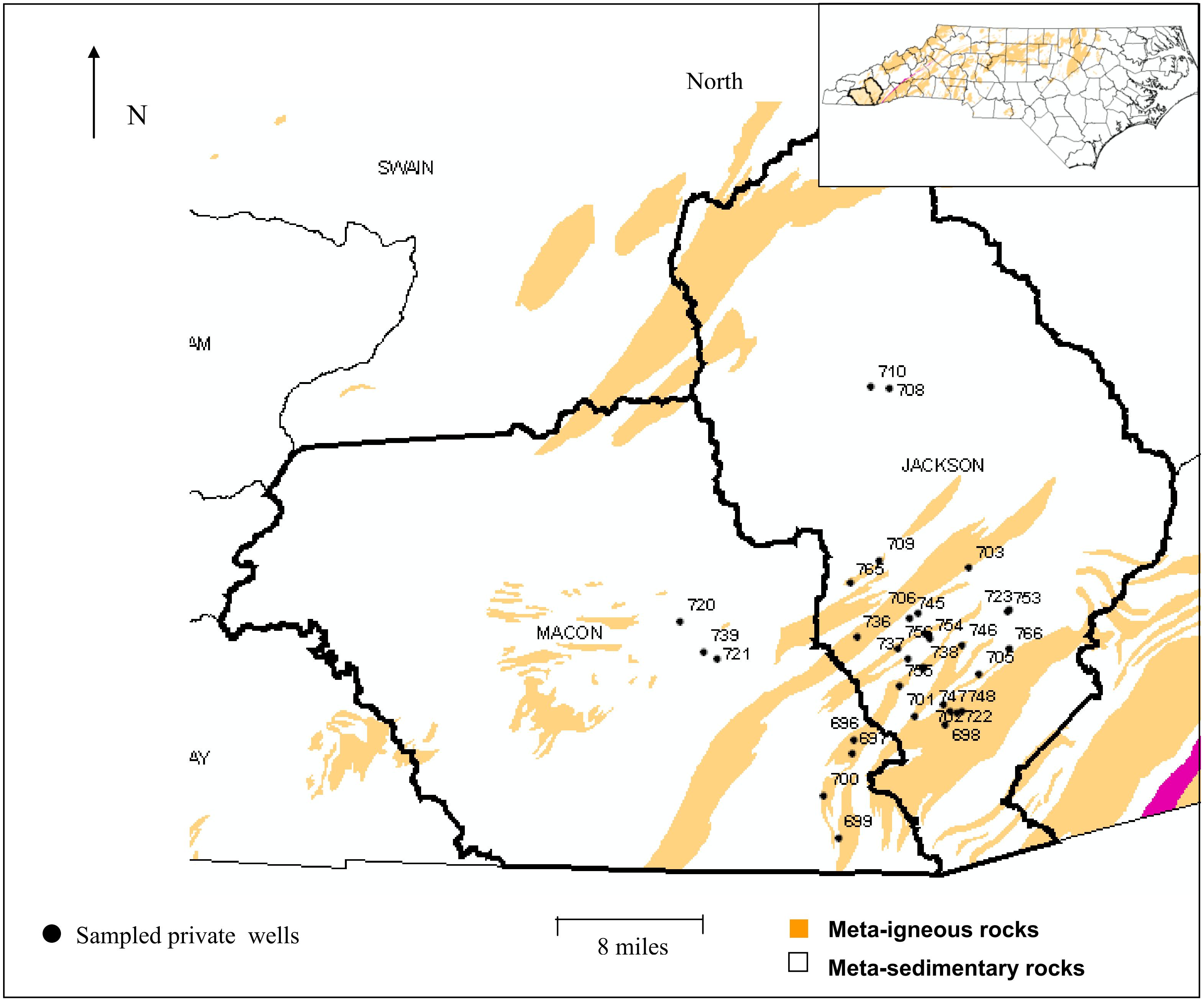

Fig. 2. Private wells sampled during study, superimposed on map of meta-igneous versus meta-sedimentary rocks, Jackson and Macon Counties, North Carolina, 2008.

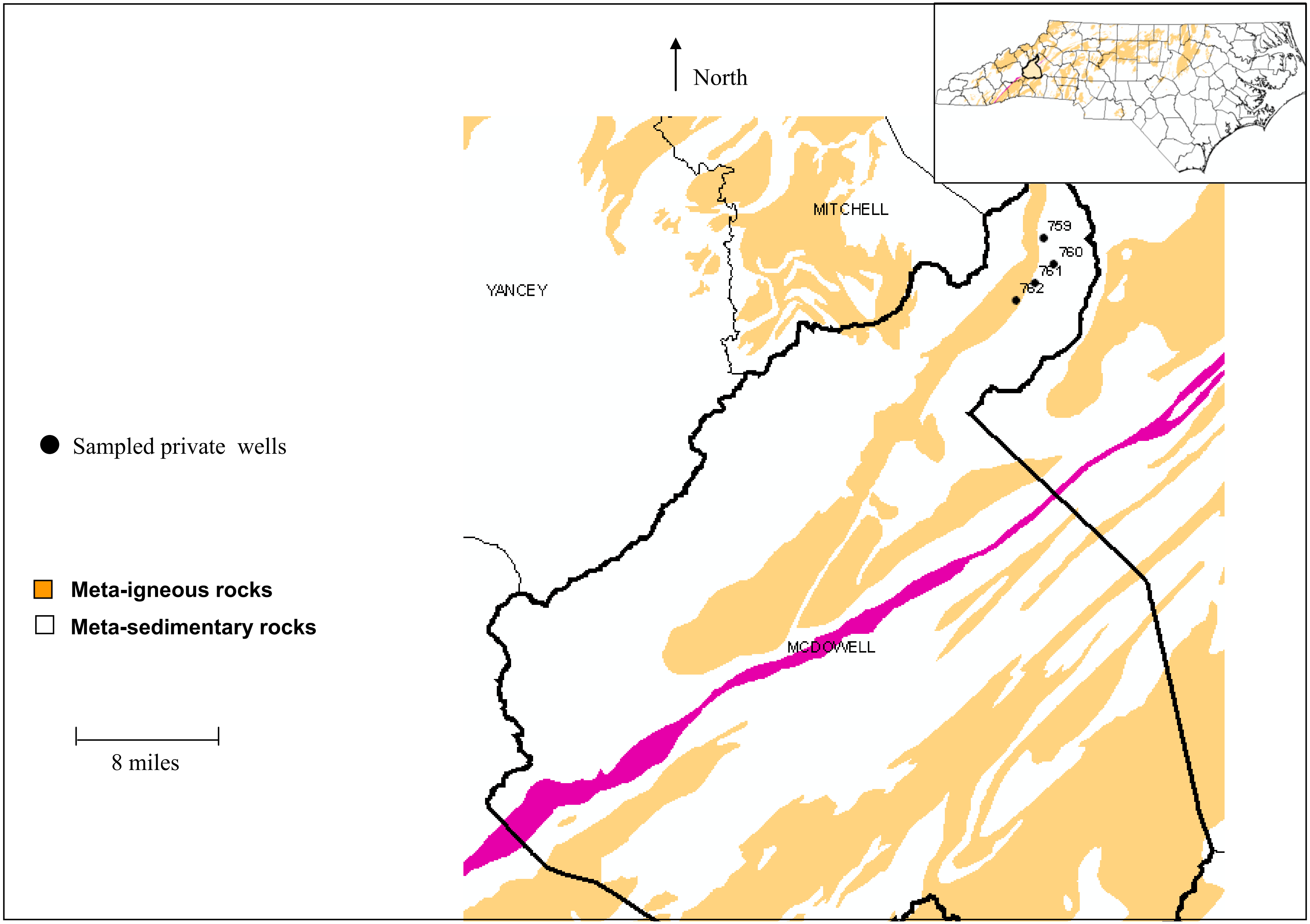

Fig. 3. Private wells sampled during study, superimposed on map of meta-igneous versus meta-sedimentary rocks, McDowell County, North Carolina, 2008.

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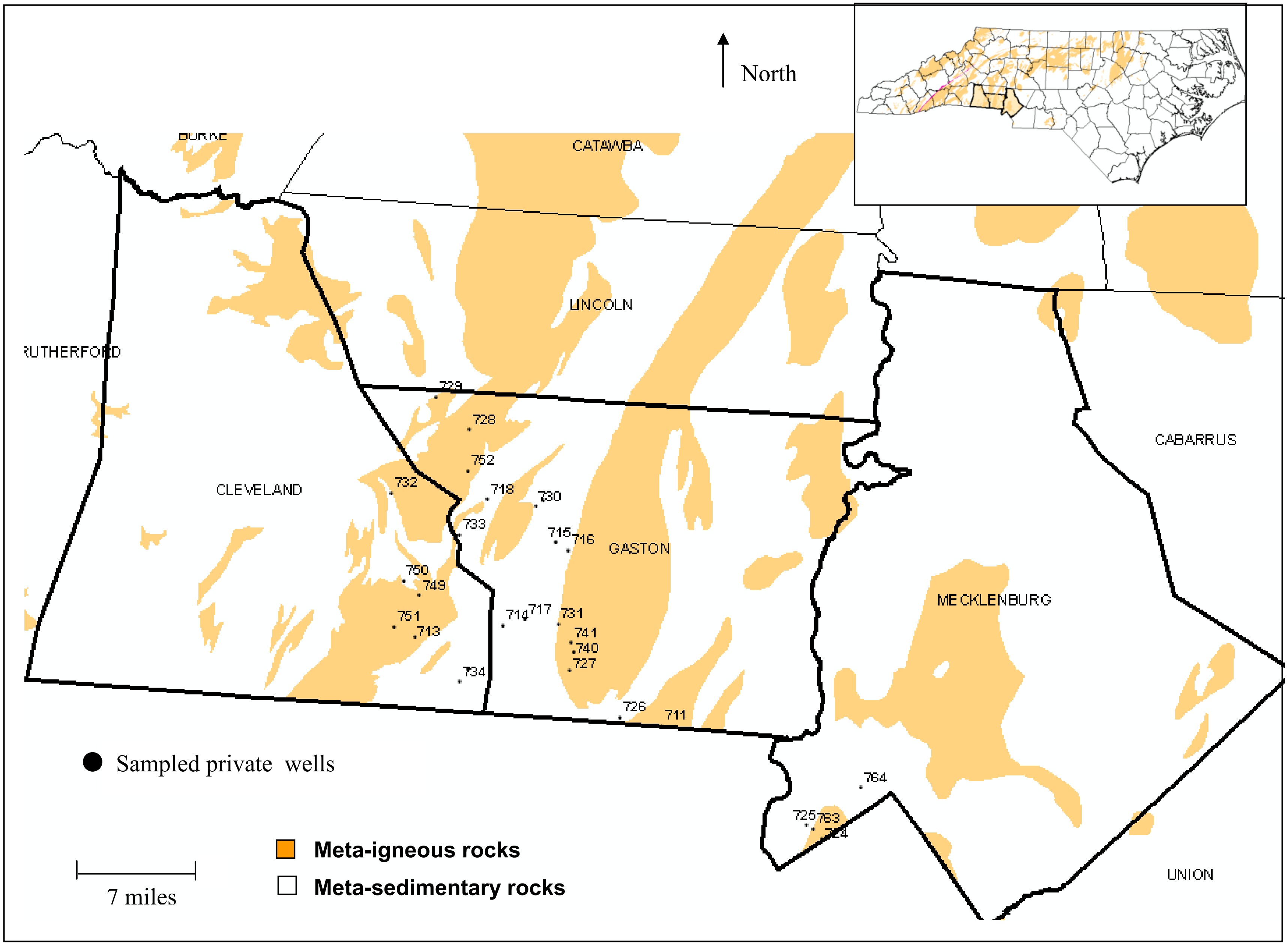

Fig. 4. Private wells sampled during study, superimposed on map of meta-igneous versus meta-sedimentary rocks, Gaston, Cleveland, and Mecklenburg Counties, North Carolina, 2008.

air radon samples were collected from the homes associated with the sampled wells. The remaining 32 homes did not participate in the indoor-air radon sampling or did not obtain reliable results.

Ground water sample locations were designed to cover broad portions of the study area and geology of interest. No attempt was made to cover all areas of each county or to produce a statistically weighted and representative dataset. Newspaper advertisements and word of mouth were used to solicit volunteers for the study.

Since each well was sampled on only one occasion, data collected in this study represent a “snap shot” of radionuclide concentrations at a point in time, and do not account for potential temporal variations due to long-term, seasonal, or pumping-related fluctuations. A single sample does not necessarily represent the overall quality of the ground water resource over a long period of time at that location, but it does provide an indication of the quality of the local ground water contributing water to the well for the time at which it was sampled.

In general, ground water samples were analyzed for total uranium (n = 58), radium-226 (Ra-226) (n = 58), radon-222, potassium, iron, manganese, lead, arsenic, alkalinity, bicarbonate, total dissolved solids, pH, DO, specific conductance, ORP, and temperature. Quality control replicate samples were collected and analyzed for about 10 percent of the samples. Each well sample was identified by a sequential number between 695 and 766 (figs. 2, 3, and 4; appendix).

Indoor air radon samples were obtained by the homeowner typically from the lowest living level in the home and under mostly closed-house conditions. Generally, one indoor air sample was collected per site on one occasion, over a three-day period. Because of this, the sample did not account for changes that may occur due to long-term or seasonal fluctuations. Factors that may affect the observed concentration over time include height of the water table, timing and amount of recent rainfall, degree of indoor ventilation and fresh air circulation, variations in well operation and its proximity to the home, and other factors.

Rock types were identified by on-site observation or by statewide (1:500,000; (North Carolina Geological Survey, 1985) or local scale geologic maps. Rock types and lithologic characteristics can change over very small distances and with depth, and in some cases the geologic setting of a particular home or well had to be inferred. It is recognized that there were limitations in the use of the 1:500,000 scale geologic map to identify rock types at the local scale due to the complex, heterogeneous distribution of rocks in the region. Nevertheless, for purposes of this report, the designations used in this study were believed to be reasonable characterizations that allowed meaningful evaluations of geologic influence on radionuclide concentrations.

Sample-collection methods

A ground water sample was collected as an unfiltered, raw water sample from a plumbing fixture as close to the wellhead as possible, usually at the wellhead itself. The sample was collected after the pump had been operating for at least 20 minutes. This helped to ensure that the sampled water was from the formation and not from a stagnant water column from within the well bore. Ground water was placed in a 4-liter plastic container for the analysis of total uranium and Ra-226. The sample date, time, and location were written on the sample container and on the chain of custody form. The sample was shipped to a certified contract laboratory in Oklahoma. Radon samples were collected using a special procedure designed to prevent aeration. Specifically, 60-milliliter glass radon vials were carefully submerged, filled, and sealed inside a 2-liter plastic beaker or similar container that had been filled with well water under laminar flow. The radon samples were iced to maintain a consistent cool temperature and, for quality control samples, were shipped to the certified laboratory by overnight mail in order to meet the 4-day holding time requirement. The metals samples (arsenic, lead, manganese, and iron) were preserved using ultra-pure nitric acid prior to shipment to the laboratory.

Parameters such as DO, specific conductance, pH, ORP, and temperature, were measured in the field using a calibrated multimeter. Information about well construction (depth, casing depth, yield, and others) was noted and recorded in the field. Global Positioning System (GPS) receivers were used to identify the locations of the sampled wells, and the resulting data were entered into Geographic Information System (GIS) data files.

Indoor air radon samples were collected by the homeowner using deployable short-term activated carbon air-sample kits. The sampler was placed in the lowermost unventilated area of the home – typically a walkout basement if it existed - and left undisturbed for 72 hours. The sampler was then sealed and shipped overnight to the a certified contract laboratory in New York for analysis of the radon concentration.

Laboratory analytical methods

Radon in water was analyzed using the E-Perm ion electret chamber de-emanation procedure (Kotrappa and Jester, 1993). In this method, radon in water off-gases inside a sealed oversized mason jar, and an electret ion chamber measures the voltage drop as the radon de-emanates. The voltage drop is then used in a calculation to determine the amount of radon in water. Quality control samples were analyzed for radon using a procedure based on Standard Method 7500-Rn (EPA, 1999). In this method, radon is partitioned selectively into a mineral-oil scintillation cocktail immiscible with the water sample. The sample is dark-adapted, equilibrated, and then counted in a liquid scintillation counter using a region or window of the energy spectrum optimal for the specific alpha particles emitted from radon. Radium-226 was analyzed using a modification of method SM7500 Ra (EPA, 1995). The method uses alpha spectroscopy methodology. Total uranium was analyzed using method KPA ASTM 5174M

(ASTM, 1994). The sample was digested with nitric acid and peroxide and measured by the laser-based kinetic phosphorescence analyzer (KPA).

STUDY AREA SETTING

The study area is located in Western North Carolina and focuses on areas within six counties – Jackson, Macon, McDowell, Gaston, Cleveland, and Mecklenburg. This area straddles the Blue Ridge and Inner Piedmont physiographic provinces (fig. 5). The topography of the Blue Ridge province was formed by uplift, erosion, and rock resistance, and is characterized by steep, rugged, incised, mountainous terrain, intermontane basins, and valleys. Part of the Appalachian Mountain system, the Southern Blue Ridge province has a large number of peaks, some with elevations of over 6000 ft above sea level (asl). The topography of the Inner Piedmont was formed through the same earth processes and is characterized by gently rolling, rounded hills, long low ridges, and shallow valleys, with elevations ranging from about 600 to 1500 ft asl.

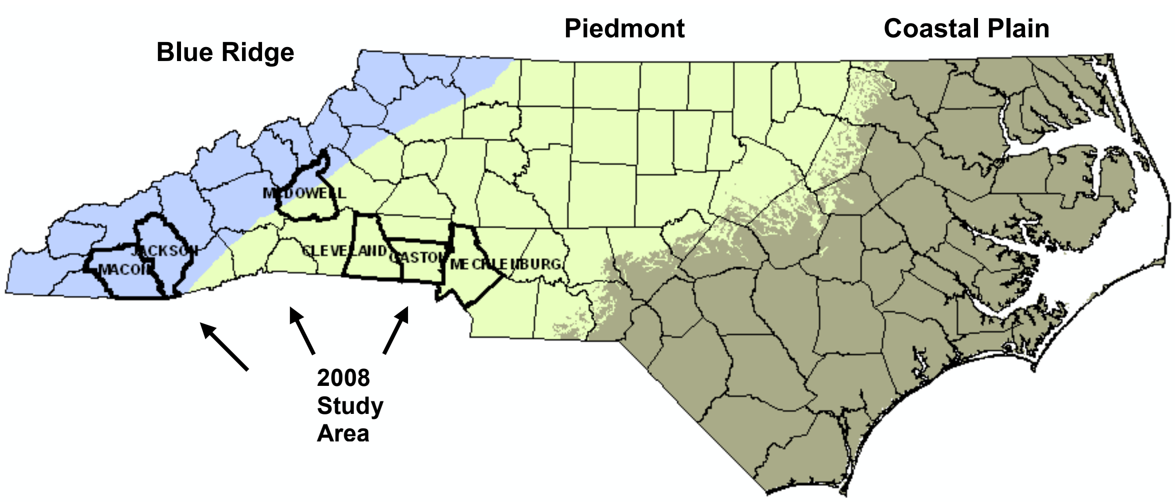

Fig. 5. Physiographic provinces in North Carolina and the six county study area.

Precipitation in the study area ranges from about 45 to 60 inches per year, but approaches 100 inches in localized areas. Ground water is particularly important to this region, and about half of the residents rely on it as their principal drinking supply. Yields from private wells typically range from about 1 to 50 gallons per minute (gpm), with averages of about 10 to 15 gpm (Daniel and Dahlen, 2002). Figure 6 shows a cross section of a typical well in the study area.

Bedrock geology in the study area is complex and consists of inter- and intra-layered, folded, and faulted meta-igneous and meta-sedimentary rocks of Paleozoic to

Proterozoic age. These rocks outcrop throughout the region or, when not present at land surface, they occur beneath a variably thick layer (typically 20 to 80 ft) of soil and weathered to partially weathered saprolite. The Brevard Fault Zone trends to the northeast through the study area and separates the Blue Ridge geologic belt to the west from the Inner Piedmont Belt to the east.

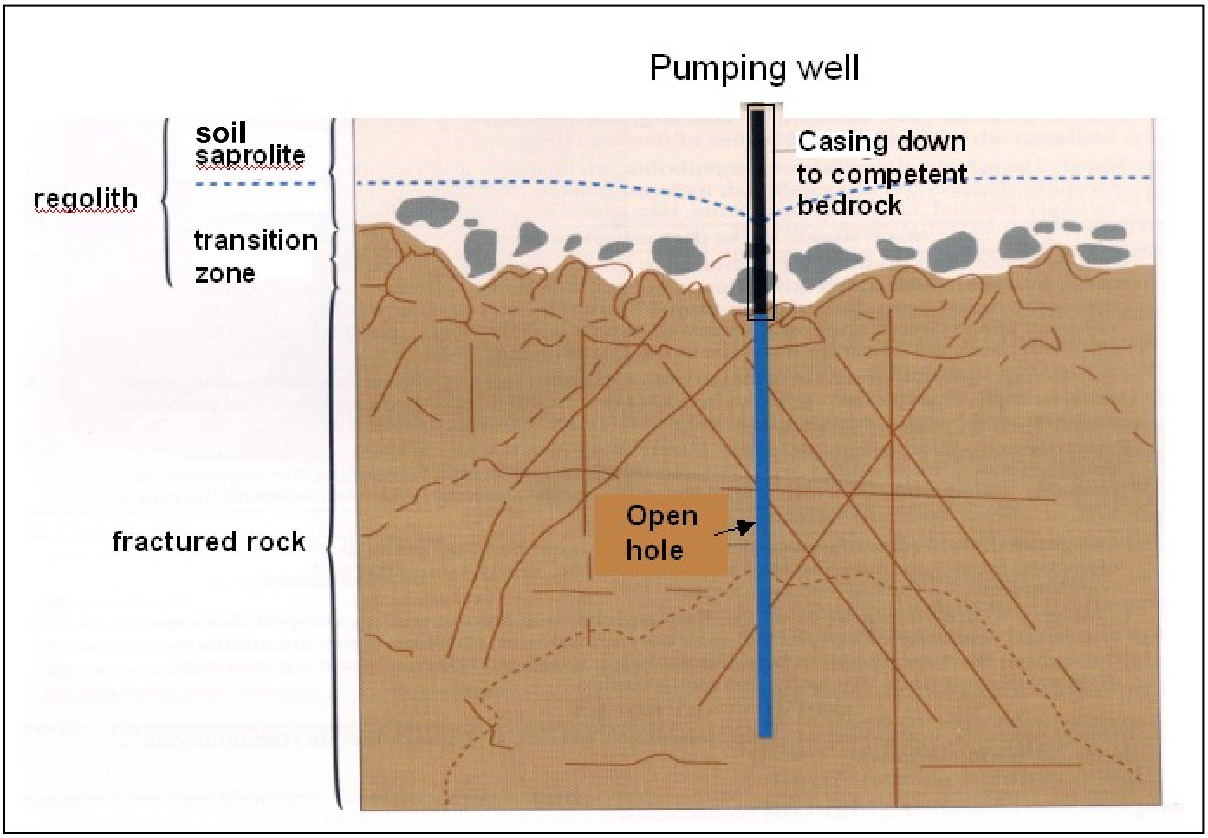

Fig. 6. Schematic showing construction of typical private drinking water well in study area.

In the broadest sense, rocks in the study area can be grouped into either *meta-igneous* or *meta-sedimentary* rocks (fig. 2, 3, and 4; appendix). Meta-igneous rocks are of igneous origin, and meta-sedimentary rocks are of metamorphosed sedimentary origin. Minor amounts of igneous metavolcanic rocks may occur within the rocks grouped as meta-sedimentary in nature.

The meta-igneous and meta-sedimentary rocks in the study area may be further divided into individual formal and informal rock units. Meta-igneous rocks in the study area include, for example, granodiorite, metamorphosed granitic rock, metamorphosed quartz diorite, Cherryville Granite, foliated to massive granitic rock, biotite granitic gneiss, and gabbro of the Concord plutonic suite. Meta-sedimentary rocks in the study area include mica schists, schist of the Kings Mountain Belt, schist and meta-volcanic rocks of the Battleground Formation, schist and amphibolite of the Blacksburg Formation, dolomite, andesite, and siltstone and shale of the Upper Chilhowee Group.

The rock type/formation of each well location was identified by on-site observation or by statewide (1:500,000 scale; North Carolina Geological Survey, 1985) or local scale geologic maps. The percentage of sampled wells located in a given rock type was not intended to correspond to the percentage of area represented by that rock type within the study area (fig. 7).

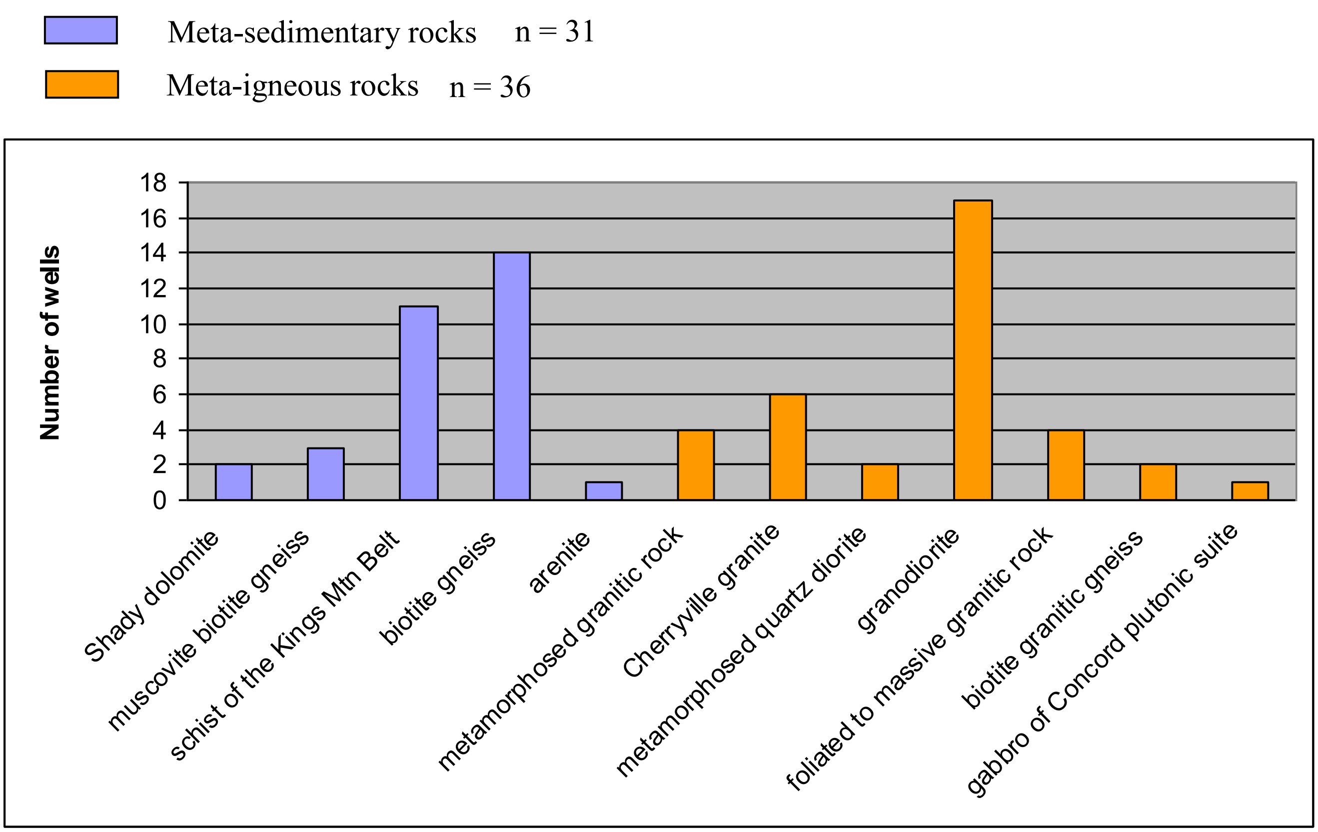

Fig. 7. Number of wells sampled within each rock type, 2008.

Geochemical results obtained during the study are summarized in Table 1. The table also provides information on well depth and on casing depth, a proxy used in this study to estimate the regolith thickness. Taken as a whole, sampled ground water tended to be acidic (median pH = 5.7), oxygenated (median DO = 6.7 mg/L), and minimally conductive (median SC = 108 uS/cm). The buffering capacity of the ground water was low (median alk = 24 mg/L), and the levels of iron and manganese also were low (median Fe < 50 ug/L and median Mn < 10 ug/L). Raw oxidation-reduction potential (ORP) values were moderate (median raw ORP = 124 mV). Lead was above the detection limit of 10 ug/L in two samples, at concentrations of 13 and 14 ug/L. Arsenic was below the detection limit of 5 ug/L in all samples.

Table 1. Descriptive statistics for field parameters and well characteristics measured in study wells in Jackson, Macon, McDowell, Cleveland, Gaston, and Mecklenburg Counties, North Carolina, 2008.

Parameter	No. of samples	Maximum value	Minimum value	Median value
pH	65	8.1	<5	5.7
Specific conductivity, in uS/cm	66	858	13	108
Temperature, in degrees Celsius	66	19.4	9.8	15.2
Dissolved oxygen, in mg/L	66	9.7	0.5	6.7
Oxidation reduction potential, in mV	66	403	-44	126
Total dissolved solids, mg/L	53	533	13	68
Lead, in ug/L	60	14	<10	<10
Arsenic, in ig/L	63	<5	<5	<5
Iron, in ug/L	62	6900	<50	<50
Manganese, in ug/L	62	290	<10	<10
Alkalinity, in mg/L	57	300	3	24
Casing depth, in feet	33	152	20	63
Well depth, in feet	42	805	54	215
Well yield, in gpm	33	60	1	15

uS/cm, microSiemens per centimeter
mg/L, milligrams per liter

Because of moderately high DO levels, moderate ORP levels, and low dissolved iron and manganese, most ground water in the study area was considered to be oxidizing. However, a more thorough analysis (including, for example, dissolved hydrogen and the speciation of iron, nitrogen, manganese, sulfur, and carbon) would be needed to definitively determine the oxidation-reduction state of the ground water system. Further, it is recognized that conditions can change with time and location and are dependent upon many variables not measured in this study. It should be noted that in some cases otherwise *an*oxic ground water (formation water) may become oxygenated inside the well bore due to water level fluctuations caused by intermittent pumping, chlorination, and (or) to a "cascade effect" that can occur when water enters the bore hole from a fracture located above the water level in the well. Reducing or moderately reducing conditions were observed in three sample locations (well numbers 699, 734, 752), where DO values were 0.6, 0.5, and 0.6 mg/L, respectively, ORP values were –44, 36, and 83 mV, respectively, and SC values were 217, 413, 224 uS/cm (well above the normal range for the study area as a whole) (appendix).

OCCURRENCE AND DISTRIBUTION OF SELECTED RADIONUCLIDES IN PRIVATE DRINKING WATER WELLS

Samples of raw, untreated ground water were collected at 67 private wells in the study area comprising parts of Jackson, Macon, McDowell, Gaston, Cleveland, and Mecklenburg Counties, North Carolina (fig. 2, 3, and 4; appendix). All 67 wells were sampled for radon, and 58 wells were sampled for total uranium and radium-226. Indoor air radon was measured in 40 of the 67 homes associated with the sampled wells (appendix). The remaining 27 homes did not sample indoor air radon or results were considered to be unreliable.

ESRI geographic information system software was used to map selected values of radon, indoor air radon, uranium, and radium isotopes and to evaluate geologic and other spatial influences on the observed data. The data were plotted on a geologic map of North Carolina (N.C. Geological Survey, 1985) and assessed for distributions and trends. Elevated radon was observed in most wells, uranium was elevated in only a small percentage of wells, and radium isotopes were very low in all wells. Analytical results are provided in the following section and in tabular form in Appendix 1.

Concentrations and Distribution in Ground Water

Table 2 shows the detection rates (percentage of samples that were above the laboratory's method detection limit) for radon-222, indoor air radon, total uranium, and Ra-226 in the study area. Table 3 shows summary data (maximum, minimum, median) and number of samples exceeding the EPA standard for radon-222, total uranium, Ra-226, and indoor radon.

Table 2. Detection rates (percentage of samples that were above the laboratory's method detection limit) for radon, indoor air radon, uranium, and Ra-226, in Jackson, Macon, Gaston, McDowell, Cleveland, and Mecklenburg Counties, North Carolina, 2008.

radionuclide	percent of samples above detection limit	detection limit
radon	100	40 pCi/L
indoor air radon	100	0.1 pCi/L
uranium	21	1 ug/L
radium-226	19	0.3 to 0.5 pCi/L

pCi/L, picocuries per liter
ug/L, micrograms per liter

Table 3. Summary of radionuclide results obtained from study wells in study area, 2008.

Radionuclide	No. of samples	Maximum value	Minimum value	Median value	USEPA Standard	% exceeding standard
Radon, pCi/L	67	45800	40	2350	300*/4000**	96/33
Uranium, ug/L	58	28.7	<1	<1	30	0
Radium-226, pCi/L	58	1.5	<0.3	<0.3	5***	0
Indoor radon, pCi/L	40	37.1	<0.1	0.4	4	25

* proposed
** proposed alternate
*** combined, Ra-228 + Ra-226
pCi/L, picocuries per liter
ug/L, micrograms per liter

Radon concentrations (n = 67) ranged from less than 100 to 45,800 pCi/L, with a median value of 2350 pCi/L (table 3; appendix). Of the 67 sampled wells, 96 percent exceeded the proposed EPA MCL of 300 pCi/L, and 33 percent exceeded the EPA proposed alternate MCL of 4000 pCi/L. Total uranium concentrations (n = 58) ranged from below the analytical detection limit (about 1 ug/L) to 28.7 ug/L, with a median value of less than 1 ug/L. Radium-226 concentrations (n = 58) ranged from less than the analytical detection limit (0.3 to 0.5 pCi/L) to 1.5 pCi/L, with a median value of less than 1 pCi/L.

Wells drilled in meta-igneous rocks tended to have higher dissolved radon (median = 2755 pCi/L) than wells drilled in meta-sedimentary rocks (median = 1920 pCi/L) (table 4). Radon concentrations by rock type/formation are shown in figure 8. Most well samples contained dissolved radon in the range between 1000 and 5000 pCi/L. An analysis of raw data (Appendix 1) shows that wells drilled in Paleozoic granitic rocks (less than 500 million years old, which includes foliated to massive granitic rock, Cherryville granite, granodiorite, and gabbro of the Concord plutonic suite) were higher in dissolved radon (median = 2760 pCi/L) than wells drilled in other rock types (median = 1910 pCi/L). Wells characterized by oxidizing conditions were higher in dissolved radon (median = 2470 pCi/L) than wells characterized by reducing conditions (median = 910 pCi/L). Additional analyses are being conducted to evaluate controls on radionuclide

Table 4. Radionuclide concentrations observed in settings underlain by meta-igneous versus meta-sedimentary rocks, Jackson, Macon, Gaston, McDowell, Cleveland, and Mecklenburg Counties, North Carolina, 2008.

rock origin	RADON-222, pCi/L			URANIUM, ug/L			RA-226, pCi/L			INDOOR AIR RADON, pCi/L		
	n	median	max	n	median	max	n	median	max	n	median	max
meta-igneous	36	2755	45800	31	<1	16.9	31	<0.5	1	22	0.5	12.3
meta-sedimentary	31	1920	20420	27	<1	28.7	27	<0.5	1.5	18	0.3	37.1

occurrence and distribution across North Carolina and will be presented in a subsequent report. Variables will include geologic formations, geochemistry, hydrologic setting, well construction details, and others.

Figures 9, 10, and 11 show study wells with radon concentrations above EPA proposed standards, superimposed on a map of meta-igneous versus meta-sedimentary rocks. All uranium and radium-226 concentrations were below the EPA standards (appendix).

Concentrations and Distribution of Radon in Indoor Air

Indoor air radon concentrations from 40 well owners' homes ranged from 0.1 to 37.1 pCi/L, with a median value of 0.4 pCi/L. Of the 40 homes in which indoor-air radon was measured, 25 percent exceeded the EPA MCL of 4 pCi/L (fig. 12, 13, and 14).

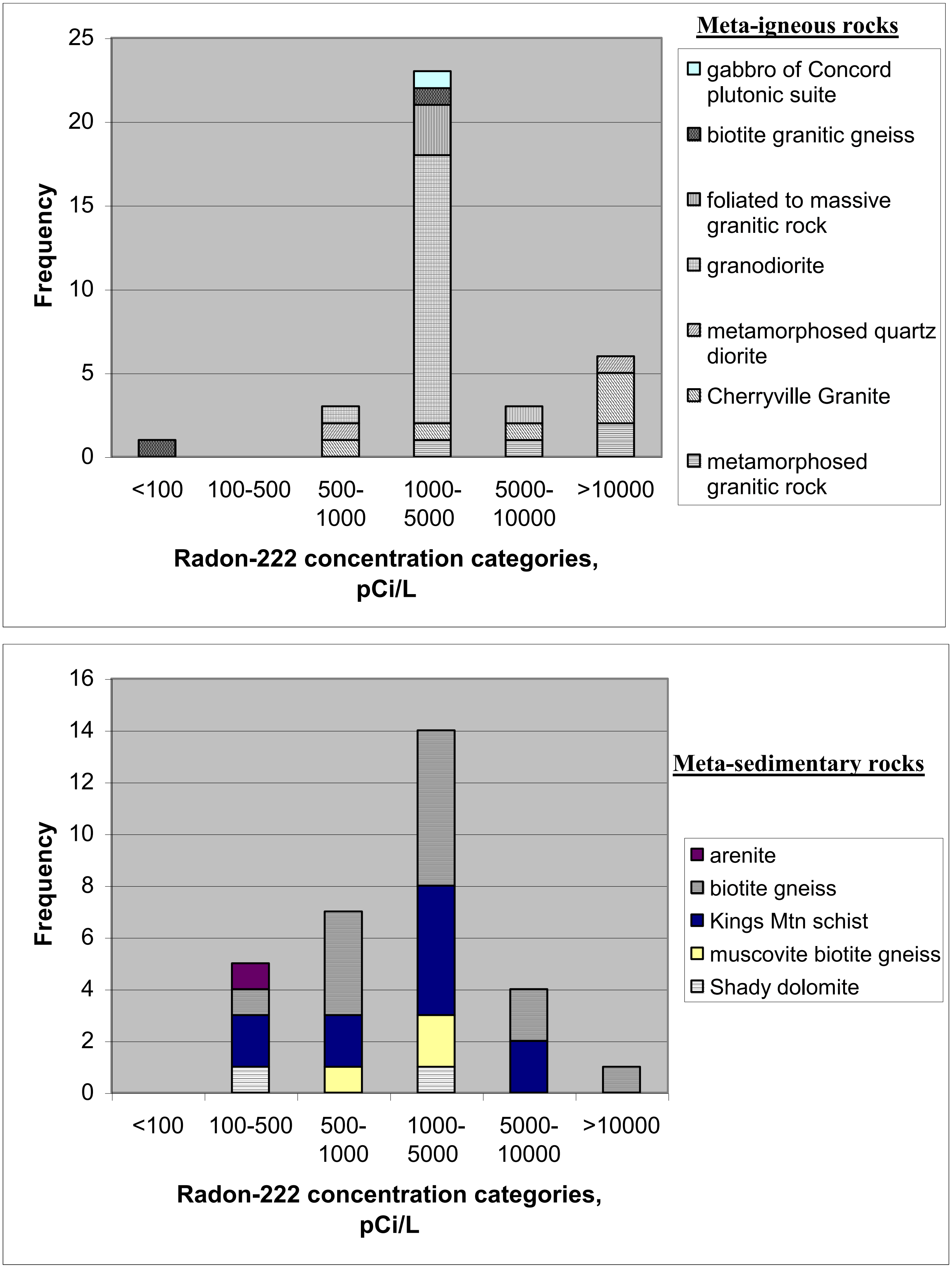

Fig. 8. Dissolved radon-222 water concentrations associated with meta-igneous and meta-sedimentary rocks, Jackson, Macon, Gaston, McDowell, Cleveland, and Mecklenburg Counties, North Carolina, 2008.

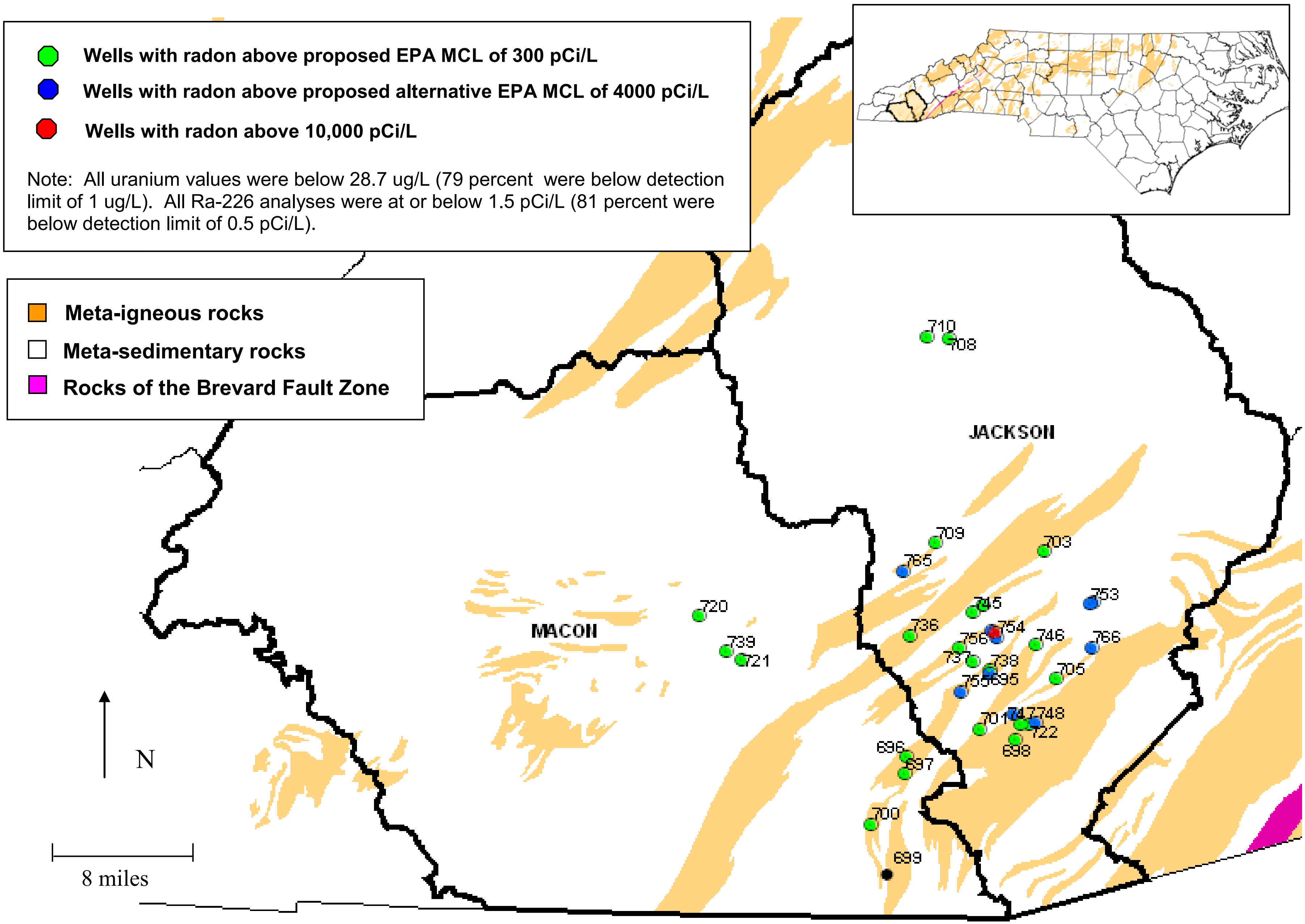

Fig. 9. Dissolved radon in private wells sampled in study area, superimposed on map of meta-igneous versus meta-sedimentary rock (NC Geological Survey, 1985), Jackson and Macon Counties, North Carolina, 2008.

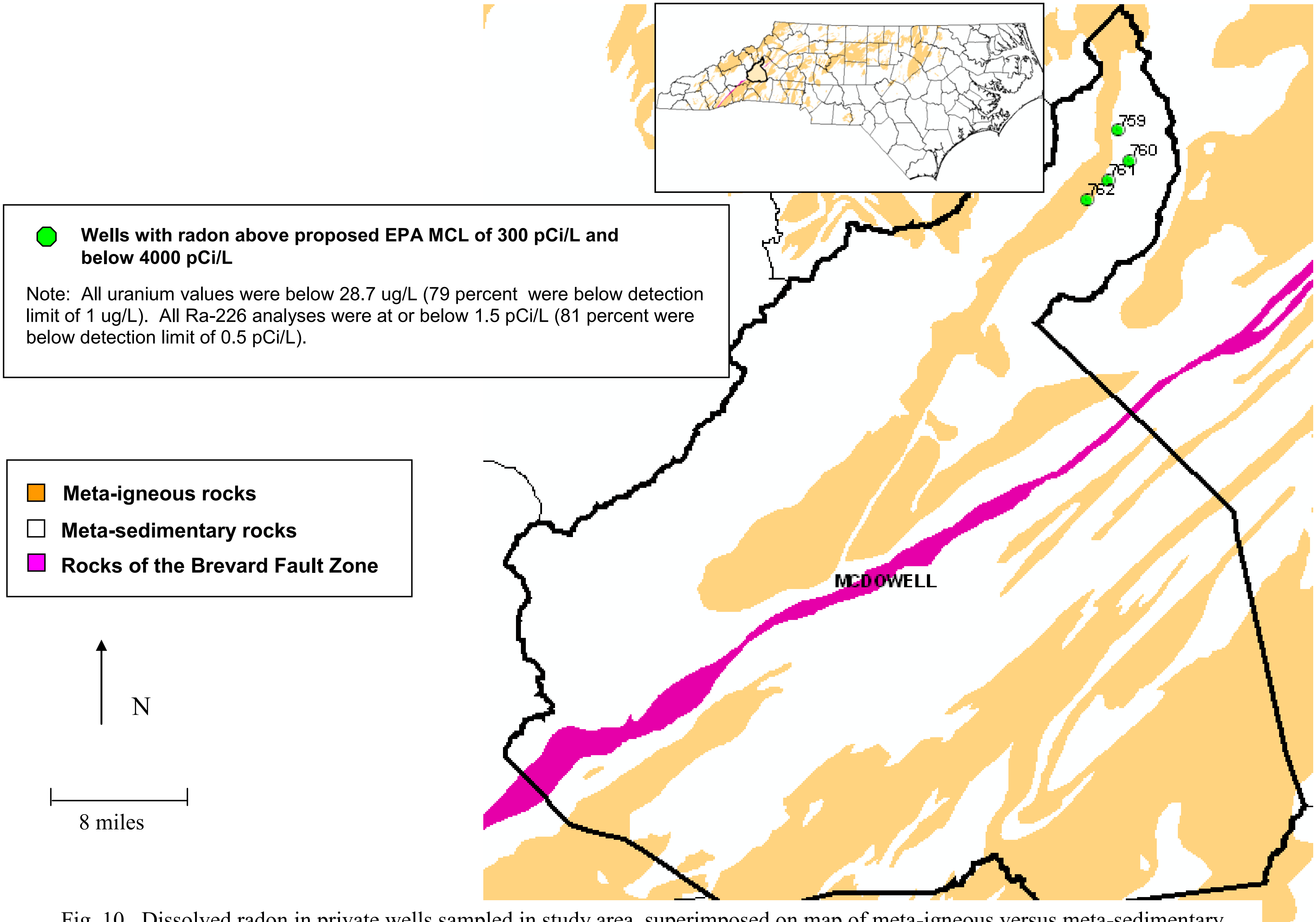

Fig. 10. Dissolved radon in private wells sampled in study area, superimposed on map of meta-igneous versus meta-sedimentary rock (NC Geological Survey, 1985), McDowell County, North Carolina, 2008.

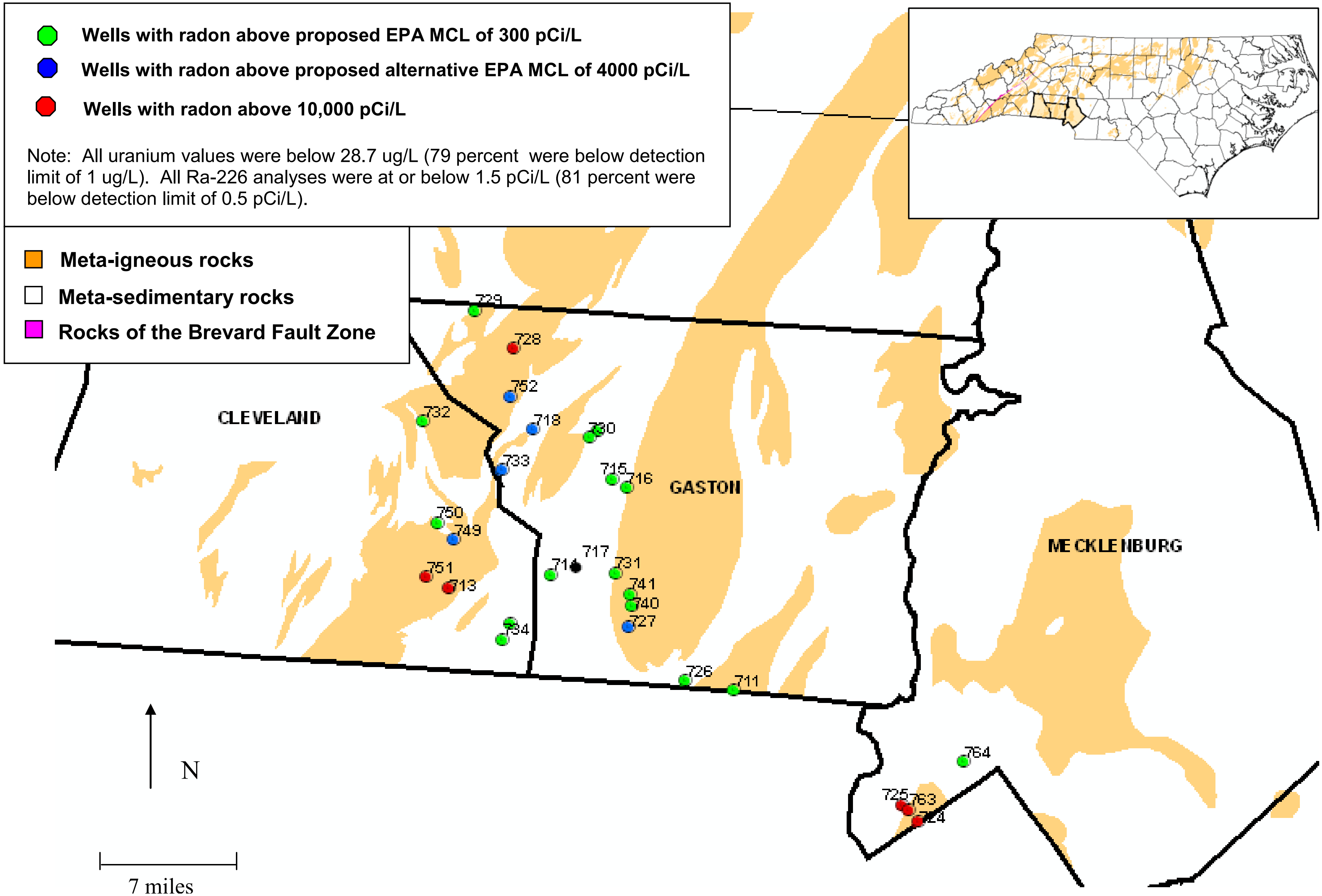

Fig. 11. Dissolved radon in private wells sampled in study area, superimposed on map of meta-igneous versus meta-sedimentary rock (NC Geological Survey, 1985), Cleveland, Gaston, and Mecklenburg Counties, North Carolina, 2008.

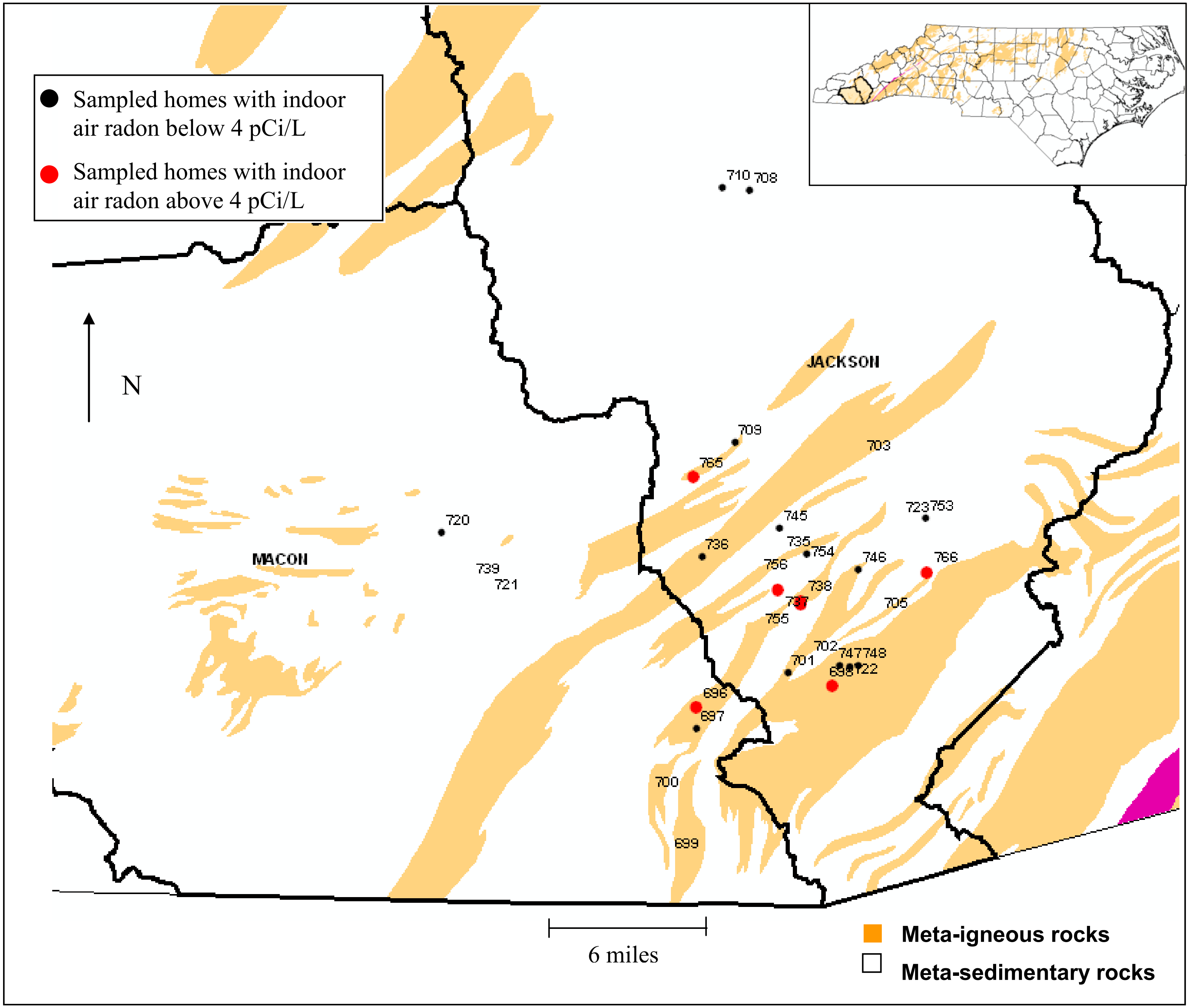

Fig. 12. Homes sampled for indoor air radon during 2008 study, superimposed on map of meta-igneous versus meta-sedimentary rocks, Jackson and Macon Counties, North Carolina, 2008.

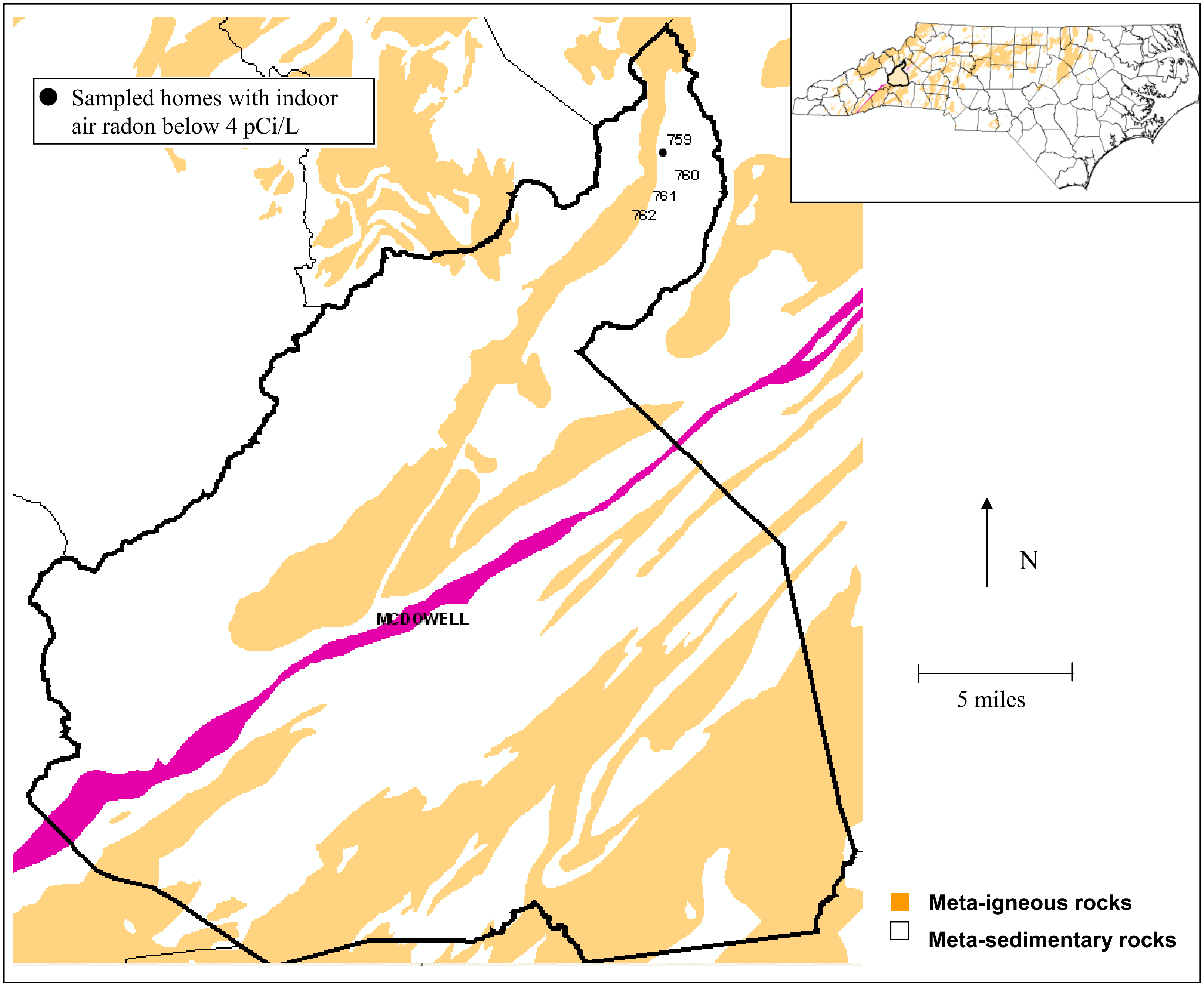

Fig. 13. Homes sampled for indoor air radon during 2008 study, superimposed on map of meta-igneous versus meta-sedimentary rocks, McDowell County, North Carolina, 2008.

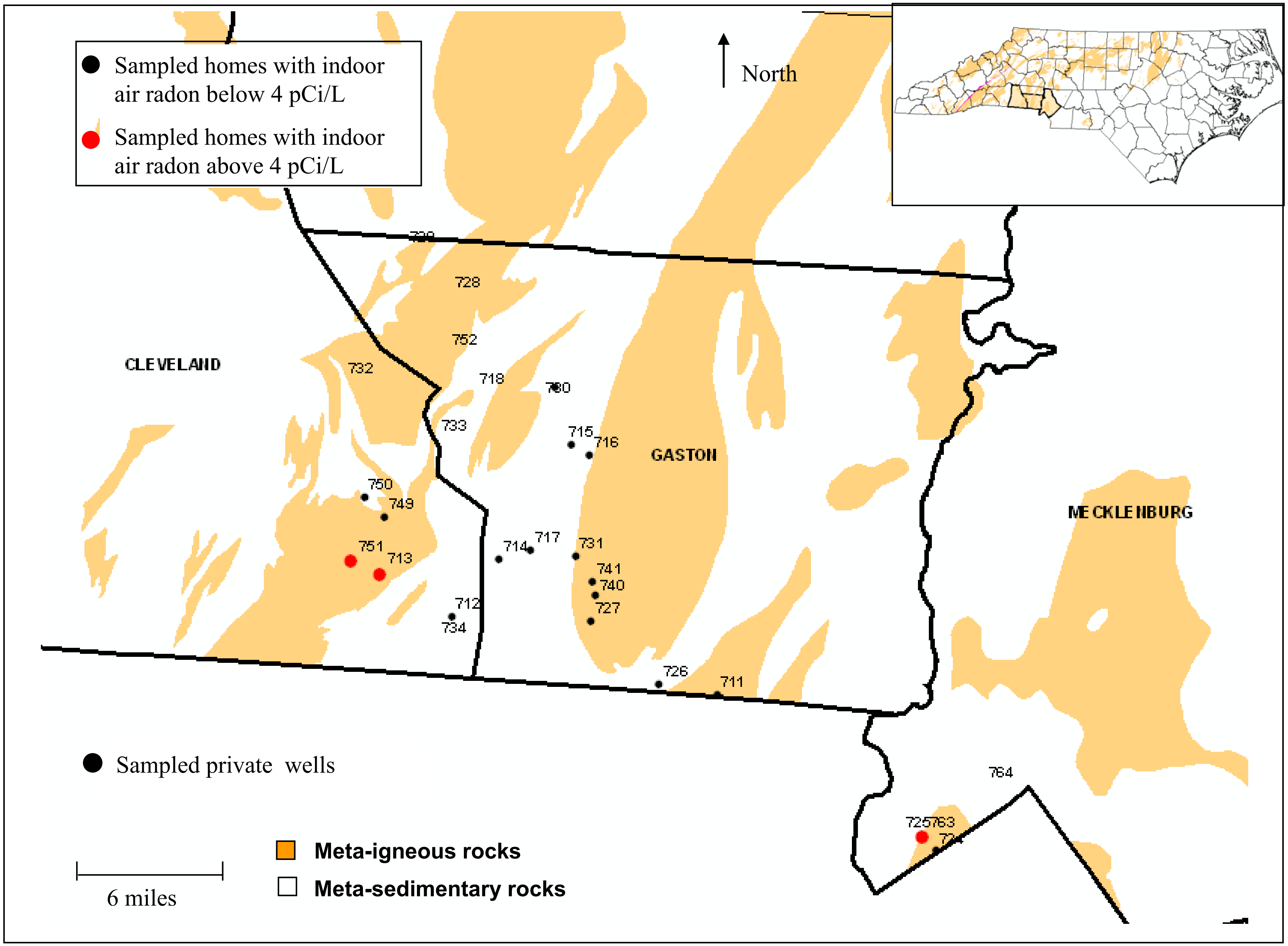

Fig. 14. Homes sampled for indoor air radon during 2008 study, superimposed on map of meta-igneous versus meta-sedimentary rocks, Gaston, Cleveland, and Mecklenburg Counties, North Carolina, 2008.

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SUMMARY

Elevated levels of naturally occurring radionuclides are known to occur in ground water and indoor air (radon) in the Blue Ridge and Piedmont Provinces of Western North Carolina. This occurrence is due to the presence of uranium rich rocks – including granites and gneisses - across much of the region. Radionuclides are human carcinogens and have been linked to bone, kidney, and lung cancers, among others. About half of the citizens of Western North Carolina rely on public and private ground water wells for their principal drinking water supply. Indoor air in Western North Carolina is susceptible to elevated levels of radon, and eight counties in North Carolina - all in Western North Carolina – are classified as EPA Zone 1 counties, with predicted indoor radon concentrations above the action level of 4 pCi/L (EPA Radon Map, accessed via internet, 8/19/05, http://www.ncradon.org/zone.htm).

Ground water samples collected from 67 private wells within Jackson, Macon, McDowell, Gaston, Cleveland, and Mecklenburg Counties were found to contain elevated levels of radon (40 to 45,800 pCi/L; median = 2350 pCi/L). Radon exceeded EPA's proposed MCL of 300 pCi/L in 96 percent of the wells, and exceeded the proposed alternate MCL of 4000 pCi/L in 33 percent of the wells.

Dissolved radon concentrations tended to be higher in wells in Paleozoic granitic rocks (less than 500 million years old, which includes foliated to massive granitic rock, Cherryville granite, granodiorite, and gabbro of the Concord plutonic suite) (median = 2760 pCi/L) than in wells in other rock types (median = 1910 pCi/L). Generally, wells in meta-igneous rocks were higher in dissolved radon (median = 2760 pCi/L) than wells in meta-sedimentary rocks (median = 1920 pCi/L). Wells characterized by oxidizing conditions were higher in dissolved radon (median = 2470 pCi/L) than wells characterized by reducing conditions (median = 910 pCi/L). Each of these findings is consistent with previous studies in the NC Piedmont and Mountains (Campbell, 2005; Campbell, 2008).

Uranium concentrations ranged from less than 1 to 28.7 ug/L (median = less than 1 ug/L) and did not exceed the EPA MCL in any of the 58 sampled wells. Radium-226 concentrations were relatively low in all 58 sampled wells (less than 1 pCi/L). Indoor radon from 40 sampled homes ranged from 0.1 to 37.1 pCi/L, with a median value of 0.4 pCi/L. One quarter of the sampled homes had indoor air radon above the EPA action level of 4 pCi/L.

Subsequent radionuclide investigation will focus on areas of Western North Carolina that lack data. Subsequent investigation will also evaluate potential changes in dissolved radon concentrations over time.

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APPENDIX 1. Raw data collected during study of 67 private drinking water wells in Jackson, Macon, McDowell, Cleveland, Gaston, and Mecklenburg Counties, North Carolina, 2008. [ft = feet; blank = no data; K = potassium; Fe = Iron; Mn = manganese; Pb = lead; As = arsenic; pCi/L = picocuries per liter; ug/L = micrograms per liter; Temp = temperature; C = degrees Celsius; Spec Cond = specific conductance; DO = dissolved oxygen; ORP = oxidation reduction potential; Alk = alkalinity as bicarbonate; BDL = below detection limit; gpm = gallons per minute; uS/cm = microsiemens per centimeter; mg/L = milligrams per liter; mV = millivolts.]

LAST NAME	Well #	SAMPLE DATE	URANIUM, ug/L	RADON, pCi/L	RADIUM-226, pCi/L	INDOOR RADON, pCi/L
DICKEY, R.	695	4-Mar-08	28.7	4390	<0.5	37.1
JOANNIDES	696	4-Mar-08	<1	2660	<0.5	7.6
LABARGE	697	4-Mar-08	<1	3880	<0.5	1.9
GALLAHER	698	4-Mar-08	16.9	1200	<0.5	4.9
HODGES	699	4-Mar-08	1.1	220	<0.5	no data
KEENER	700	1-Apr-08	<1	1500	<0.5	no data
COLLINS	701	1-Apr-08	<1	660	0.61	0.1
PARRIS	702	1-Apr-08	2.8	4500	<0.5	no data
BOSTIC	703	1-Apr-08	<1	1980	0.95	no data
WASHBURN	704	21-Apr-08	no data	40	no data	no data
HAGAN	705	17-Jun-08	<1	960	<0.5	no data
LORD	706	17-Jun-08	<1	2090	0.64	no data
LODA	707	17-Jun-08	<1	4840	<0.5	no data
SMITH	708	18-Jun-08	<1	720	0.56	0.1
HALL	709	18-Jun-08	<1	1020	<0.5	0.1
GARRETT (Jackson Co)	710	18-Jun-08	<1	2470	0.54	0.4
GLOVER	711	23-Jun-08	<1	3090	0.57	0.1
BROWN	712	23-Jun-08	<1	2190	<0.5	0.4
MAPLES	713	23-Jun-08	<1	23120	<0.5	5.4
PIPER	714	24-Jun-08	<1	800	0.51	0.1
FRANKLIN	715	24-Jun-08	<1	1250	<0.5	3.6
CROFT	716	24-Jun-08	<1	490	<0.5	1.2
ATKINS	717	07-Jul-08	<1	220	<0.5	0.1
NEICE	718	07-Jul-08	<1	6620	<0.5	no data
RUFF	719	07-Jul-08	<1	720	<0.5	0.1
HENSHAW	720	07-Jul-08	<1	610	<0.5	0.1
TALLY	721	08-Jul-08	<1	1890	<0.5	no data
BLOZAN	722	08-Jul-08	<1	1610	<0.5	0.1
CAHILL	723	08-Jul-08	21.7	5440	<0.5	no data
MCCURDY	724	09-Jul-08	<1	22810	0.86	2.5
PHILEMON	725	09-Jul-08	<1	10080	<0.5	no data
GARRETT (Gaston Co)	726	09-Jul-08	<1	3010	<0.5	0.1
FLETCHER	727	09-Jul-08	<1	6970	<0.5	0.1
GARDENHIRE	728	14-Jul-08	<1	24420	<0.5	no data
BRADIGAN	729	14-Jul-08	<1	1220	<0.5	no data
STAFFORD	730	14-Jul-08	<1	3660	<0.5	no data
TEAGUE	731	14-Jul-08	<1	3210	<0.5	0.1
LOMICK	732	15-Jul-08	<1	880	<0.5	no data
OBRIEN	733	15-Jul-08	<1	7700	<0.5	no data
WHITE	734	15-Jul-08	<1	910	0.51	no data
SCARGLE	735	16-Jul-08	12.8	20420	<0.5	0.7
NASH	736	16-Jul-08	<1	1560	<0.5	2.0
SCHULTETUS	737	16-Jul-08	13.2	2680	0.54	5.5
KUNZ	738	16-Jul-08	<1	1880	<0.5	5.7
FRANKS	739	16-Jul-08	<1	600	<0.5	no data
IRVIN	740	21-Jul-08	<1	1570	<0.5	0.1
TATE	741	21-Jul-08	<1	2850	<0.5	0.1
LEHMAN	745	23-Jul-08	<1	790	<0.5	0.1
WILDER	746	23-Jul-08	2.7	1360	<0.5	0.1
GRADY	747	23-Jul-08	2.6	2640	<0.5	0.1

LAST NAME	Well #	SAMPLE DATE	URANIUM, ug/L	RADON, pCi/L	RADIUM-226, pCi/L	INDOOR RADON, pCi/L
DUNN	748	23-Jul-08	<1	4190	<0.5	0.6
CHERKA	749	28-Jul-08	<1	7990	<0.5	0.4
STUMBO	750	28-Jul-08	<1	2800	1.50	1.0
BURGESS	751	28-Jul-08	1.0	45800	0.84	12.3
ELLISON	752	28-Jul-08	<1	4960	<0.5	no data
WALTZEK	753	30-Jul-08	<1	6340	<0.5	0.1
GREGORY	754	30-Jul-08	1.4	4680	<0.5	no data
POOLE	755	30-Jul-08	<1	4180	0.89	no data
BEECHER	756	30-Jul-08	10.3	360	<0.5	no data
BIDDIX	759	5-Aug-08	no data	360	no data	0.1
PHILLIPS	760	5-Aug-08	no data	400	no data	no data
ROBINSON	761	5-Aug-08	no data	1920	no data	no data
BROWN	762	5-Aug-08	no data	1690	no data	no data
HOLDEN	763	6-Aug-08	no data	23090	no data	6.9
MORTON	764	6-Aug-08	no data	1250	no data	no data
MAY	765	11-Aug-08	no data	4670	no data	4.3
DICKEY, B.	766	11-Aug-08	no data	4310	no data	6.6

Well #	pH	SPEC COND, uS/cm	TEMP, C	DO, mg/L	ORP, mV	Alk, mg/L
695	6.8	195	10.3	2.5	88	no data
696	6.1	151	12	1.7	264	no data
697	no data	71	11.7	1.9	403	no data
698	4.7	275	9.8	1.2	168	no data
699	6.1	217	12.5	0.61	-44	no data
700	3	118	12.6	1.7	198	no data
701	4.8	37	11.2	2	146	no data
702	6.2	108	13.6	1.9	-14	no data
703	3.3	61	14.2	2	154	no data
704	no data	no data	no data	no data	no data	no data
705	5.5	39	13.4	8.6	50	9.9
706	5	66	13.5	8.6	75	6.9
707	5.3	94	12.9	6.1	103	24
708	6.7	108	15	1.7	44	32
709	5	26	14.9	8.3	103	6.6
710	5.4	49	14.6	8	103	17
711	5.5	114	17.5	4.1	103	26
712	6.2	171	17.5	6.4	93	13
713	5	91	18.35	3.6	94	14
714	6.5	157	18.3	1.8	77	59
715	6	38	17.4	6.2	91	14
716	6.8	108	17.8	5.5	101	48
717	6.5	152	16.1	5.1	100	66
718	6.8	89	15.9	5.4	84	38
719	6.4	78	17.4	7	93	31
720	5.9	131	15.3	4	126	37
721	5.7	90	15	5.5	116	34
722	5.2	80	13.6	7.2	56	12
723	6	65	12.8	7.4	140	28
724	5.7	157	17.4	3.2	134	27
725	5.9	116	17.3	7.8	125	22
726	6	80	17.8	8	115	25
727	6.3	120	17.2	6.7	116	14
728	4.9	102	16.9	9.2	160	14
729	6.1	393	15.4	3	134	61
730	5.5	139	17.4	7.9	123	15
731	5.7	124	17.3	7.8	136	23
732	5.2	136	18.7	8.3	129	17
733	5.5	132	17.6	7.9	100	24
734	7.7	413	17.7	0.5	36	80
735	5.5	102	13.1	6.7	106	17
736	4.5	28	10.9	9.7	72	2.8
737	5.3	84	12.8	9.6	103	15
738	5.6	92	11.6	9.5	173	17
739	7.3	227	16	7.8	103	48
740	6.4	378	18	4.8	234	47
741	6.1	250	17.8	6.6	157	56
745	4.1	100	19.1	7.6	153	4
746	5.6	113	12.9	5.2	148	17
747	4.9	44	14.2	7.3	183	3

Well #	pH	SPEC COND, uS/cm	TEMP, C	DO, mg/L	ORP, mV	Alk, mg/L
748	5.8	195	14.4	5.5	153	12
749	6	179	18	6.7	136	35
750	4.9	192	17	1.5	138	27
751	5.9	103	19.4	7.3	195	11
752	6	224	17.8	0.6	83	37
753	4.1	86	12.1	9.2	175	7.9
754	5.7	76	13.2	3.9	201	28
755	5.5	114	11.7	9.3	107	6.2
756	6.1	75	12.5	7.1	170	27
759	8.1	116	14.1	7	140	51
760	7.9	188	14.4	8	122	94
761	6	30	15.8	6.7	172	14
762	6.3	82	14.2	6.6	175	35
763	5.2	79	17.7	8.1	193	29
764	6.9	858	18.7	1.4	130	300
765	3.8	13	16.3	7.9	175	3
766	5.2	59	13.1	6.7	213	6

Well #	County	Fe, ug/L	Mn, ug/L	K, ug/L	Pb, ug/L	As, ug/L	Hydrologic setting
695	Jackson	<50	<10	480	<10	<5	recharge
696	Jackson	2100	<10	1400	13	<5	midslope
697	Jackson	<50	<10	70	<10	<5	recharge
698	Jackson	<50	<10	1200	<10	<5	recharge
699	Jackson	6900	<130	1700	<10	<5	recharge
700	Jackson	no data	no data	no data	<10	<5	recharge
701	Jackson	no data	no data	no data	no data	no data	recharge
702	Jackson	no data	no data	no data	no data	no data	recharge
703	Jackson	no data	no data	no data	no data	no data	recharge
704	McDowell	no data	no data	no data	no data	no data	no data
705	Jackson	83	<10	1600	<10	<5	recharge
706	Jackson	<50	<10	1300	<10	<5	recharge
707	Jackson	<50	<10	1100	<10	<5	discharge
708	Jackson	220	24	2100	<10	<5	discharge
709	Jackson	660	<10	660	<10	<5	recharge
710	Jackson	<50	<10	880	<10	<5	midslope
711	Gaston	<50	<10	920	<10	<5	recharge
712	Cleveland	<50	<10	380	<10	<5	recharge
713	Cleveland	290	14	1600	<10	<5	midslope
714	Gaston	<50	45	830	<10	<5	recharge
715	Gaston	<50	<10	350	<10	<5	recharge
716	Gaston	180	<10	2200	<10	<5	recharge
717	Gaston	<50	<10	7100	<10	<5	recharge
718	Gaston	<50	<10	880	<10	<5	recharge
719	Gaston	190	<10	440	<10	<5	recharge
720	Macon	80	<10	2300	<10	<5	discharge
721	Macon	<50	<10	2700	<10	<5	midslope
722	Jackson	<50	<10	1000	<10	<5	discharge
723	Jackson	<50	<10	1400	<10	<5	recharge
724	Mecklenburg	<50	<10	1700	<10	<5	midslope
725	Mecklenburg	<50	<10	1700	<10	<5	midslope
726	Gaston	<50	<10	1300	<10	<5	midslope
727	Gaston	690	<10	1900	<10	<5	midslope
728	Gaston	<50	<10	1900	<10	<5	midslope
729	Gaston	<50	15	3400	<10	<5	midslope
730	Gaston	69	<10	1500	<10	<5	midslope
731	Gaston	<50	<10	1000	<10	<5	midslope
732	Cleveland	<50	<10	2200	no data	<5	midslope
733	Gaston	<50	<10	970	no data	<5	midslope
734	Cleveland	<50	260	410	no data	<5	midslope
735	Jackson	<50	<10	1000	<10	<5	midslope
736	Jackson	<50	<10	380	<10	<5	midslope
737	Jackson	<50	<10	980	<10	<5	recharge
738	Jackson	96	<10	630	<10	<5	midslope
739	Macon	120	<10	1800	<10	<5	midslope
740	Gaston	<50	<10	3400	<10	<5	midslope
741	Gaston	<50	<10	3000	<10	<5	midslope
745	Jackson	<50	13	1300	<10	<5	discharge
746	Jackson	<50	<10	1200	<10	<5	midslope
747	Jackson	<50	<10	220	<10	<5	midslope

Well #	County	Fe, ug/L	Mn, ug/L	K, ug/L	Pb, ug/L	As, ug/L	Hydrologic setting
748	Jackson	<50	17	1100	<10	<5	midslope
749	Cleveland	<50	<10	2100	<10	<5	midslope
750	Cleveland	1100	22	2000	<10	<5	midslope
751	Cleveland	<50	<10	3000	<10	<5	midslope
752	Gaston	3300	250	2500	<10	<5	midslope
753	Jackson	<50	<10	390	<10	<5	midslope
754	Jackson	<50	<10	890	14	<5	midslope
755	Jackson	<50	<10	4400	<10	<5	discharge
756	Jackson	<50	<10	1200	<10	<5	discharge
759	McDowell	97	<10	1100	<10	<5	midslope
760	McDowell	<50	<10	670	<10	<5	discharge
761	McDowell	50	<10	600	<10	<5	midslope
762	McDowell	69	<10	1900	<10	<5	recharge
763	Mecklenburg	<50	<10	1700	<10	<5	midslope
764	Mecklenburg	120	290	4900	<10	<5	midslope
765	Jackson	<50	<10	400	<10	<5	recharge
766	Jackson	<50	<10	1000	<10	<5	midslope

Well #	Well depth, ft	Casing depth, ft	Well yield, gpm	Rock origin	Rock type
695	no data	no data	no data	meta-sedimentary	biotite gneiss
696	no data	no data	no data	meta-igneous	granodiorite
697	no data	no data	no data	meta-igneous	granodiorite
698	400	no data	11	meta-igneous	granodiorite
699	600	no data	1	meta-sedimentary	biotite gneiss
700	110	40	5	meta-igneous	granodiorite
701	600	70	5	meta-igneous	granodiorite
702	390	38	60	meta-igneous	granodiorite
703	600	40	1	meta-igneous	granodiorite
704	no data	no data	no data	meta-igneous	biotite granitic gneiss
705	500	48	0.5	meta-sedimentary	biotite gneiss
706	90	80	no data	meta-sedimentary	biotite gneiss
707	180	63	60	meta-igneous	granodiorite
708	143	no data	45	meta-sedimentary	biotite gneiss
709	120	31	36	meta-sedimentary	muscovite biotite gneiss
710	90	no data	no data	meta-sedimentary	biotite gneiss
711	100	no data	no data	meta-igneous	metamorphosed granitic rock
712	245	68	no data	meta-sedimentary	schist of Kings Mtn Belt
713	no data	no data	no data	meta-igneous	Cherryville granite
714	no data	no data	no data	meta-igneous	metamorphosed quartz diorite
715	110	55	30	meta-sedimentary	schist of Kings Mtn Belt
716	no data	no data	no data	meta-sedimentary	schist of Kings Mtn Belt
717	72	72	4	meta-sedimentary	schist of Kings Mtn Belt
718	no data	no data	no data	meta-sedimentary	schist of Kings Mtn Belt
719	125	45	30	meta-sedimentary	schist of Kings Mtn Belt
720	280	50	12	meta-sedimentary	biotite gneiss
721	380	51	30	meta-sedimentary	muscovite biotite gneiss
722	no data	no data	no data	meta-igneous	granodiorite
723	no data	no data	no data	meta-sedimentary	biotite gneiss
724	no data	no data	no data	meta-igneous	metamorphosed granitic rock
725	158	115	23	meta-igneous	metamorphosed quartz diorite
726	130	118	30	meta-sedimentary	schist of Kings Mtn Belt
727	no data	no data	no data	meta-igneous	foliated to massive granitic rock
728	105	90	20	meta-igneous	Cherryville granite
729	54	54	20	meta-igneous	metamorphosed granitic rock
730	110	96	10	meta-sedimentary	schist of Kings Mtn Belt
731	no data	no data	no data	meta-igneous	foliated to massive granitic rock
732	120	no data	no data	meta-igneous	Cherryville granite
733	no data	no data	no data	meta-sedimentary	schist of Kings Mtn Belt
734	no data	no data	no data	meta-sedimentary	schist of Kings Mtn Belt
735	326	no data	no data	meta-sedimentary	biotite gneiss
736	200	51	12	meta-igneous	granodiorite
737	270	20	no data	meta-sedimentary	biotite gneiss
738	600	no data	2	meta-igneous	granodiorite
739	230	65	15	meta-sedimentary	muscovite biotite gneiss
740	74	66	6	meta-igneous	foliated to massive granitic rock
741	no data	no data	no data	meta-igneous	foliated to massive granitic rock
745	400	24	no data	meta-sedimentary	biotite gneiss
746	400	120	0.5	meta-igneous	granodiorite
747	80	no data	no data	meta-igneous	granodiorite

Well #	Well depth, ft	Casing depth, ft	Well yield, gpm	Rock origin	Rock type
748	no data	no data	no data	meta-igneous	granodiorite
749	285	152	20	meta-igneous	Cherryville granite
750	no data	no data	no data	meta-sedimentary	schist of Kings Mtn Belt
751	285	57	30	meta-igneous	Cherryville granite
752	300	140	7	meta-igneous	Cherryville granite
753	no data	no data	no data	meta-sedimentary	biotite gneiss
754	805	63	1	meta-sedimentary	biotite gneiss
755	200	31	12	meta-igneous	granodiorite
756	no data	no data	no data	meta-igneous	granodiorite
759	260	135	25	meta-sedimentary	Shady dolomite
760	150	116	25	meta-sedimentary	arenite
761	no data	no data	no data	meta-sedimentary	Shady dolomite
762	no data	no data	no data	meta-igneous	biotite granitic gneiss
763	no data	no data	no data	meta-igneous	metamorphosed granitic rock
764	no data	no data	no data	meta-igneous	gabbro of Concord plutonic suite
765	no data	no data	no data	meta-igneous	granodiorite
766	350	29	30	meta-sedimentary	biotite gneiss