Radium and Radon in Ground Water in the Chickies Quartzite, Southeastern Pennsylvania

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
	Flow	
gallons per minute (gal/min)	0.06309	liter per second
	0.00006309	cubic meter per second
	Volume	
gallon (gal)	3.785	liter
gallon per minute per foot [(gal/min)/ft]	0.207	liter per second per meter
	3,785	milliliter
	Radioactivity	
picocuries per liter (pCi/L)	0.037	becquerel per liter
	1.46	micrograms per liter as uranium-natural

Other Abbreviations

micrograms per liter (µg/L)
micrometer (µm)
milliequivalents per liter (meq/L)
milligrams per liter (mg/L)

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows:

°C = 5/9 (°F- 32)

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929) -- a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

RADIUM AND RADON IN GROUND WATER IN THE CHICKIES QUARTZITE, SOUTHEASTERN PENNSYLVANIA

By Lisa A. Senior and Karen L. Vogel

ABSTRACT

The Chickies Quartzite, a Lower Cambrian-age formation comprised of quartzite and slate overlying a basal conglomerate, forms narrow ridges and crops out discontinuously over 112 square miles in the Piedmont physiographic province of southeastern Pennsylvania. The formation is a low-yielding, fractured-rock, water-table aquifer recharged primarily by local precipitation. It is the sole source of water supply for thousands of domestic users. Ground water in the Chickies Quartzite generally is soft and acidic.

During 1986-88, the U.S. Geological Survey sampled water from 160 wells that penetrate the Chickies Quartzite to determine the magnitude and distribution of radium-226 (Ra-226), radium-228 (Ra-228), and radon-222 (Rn-222) activities in ground water in the formation and to characterize the geochemical environment associated with elevated activities of radium (Ra). In addition, 28 wells penetrating adjacent geologic units and 1 well in the Hardyston Quartzite were sampled to determine relative background Ra and Rn-222 activities in ground water. Analyses included determination of activities of dissolved Ra-226, Ra-228, and Rn-222, and concentrations of dissolved uranium (U), dissolved organic carbon (DOC), and major and minor dissolved inorganic ions. Rock samples were analyzed for U and thorium (Th) and geophysical logs were run to determine sources of Ra and Rn-222 in the Chickies Quartzite. Activities of up to 41 pCi/L (picocuries per liter) for Ra-226, 160 pCi/L for Ra-228, and 32,300 pCi/L for Rn-222 were measured in ground water in the Chickies Quartzite. Forty-seven percent of the samples contained Ra-226 and Ra-228 activities greater than 5 pCi/L. Median activities measured were 1.2 pCi/L for Ra-226, 2.6 pCi/L for Ra-228, 4.2 pCi/L for combined Ra-226 and Ra-228, and 2,400 pCi/L for Rn-222. Ra-228 activity exceeded Ra-226 activity in about 92 percent of 100 water samples; the median Ra-228/Ra-226 activity ratio was 2.4. Ra-228/Ra-226 activity ratios commonly were greater in ground water than calculated Th/U ratios in rock samples, suggesting preferential leaching of Ra-228 from aquifer solids. Of ground water in the adjacent geologic units, the highest activities (up to 2.9 pCi/L for Ra-226, 12 pCi/L for Ra-228, and 25,300 pCi/L for Rn-222) were measured in ground water in the Harpers Phyllite and Antietam Quartzite.

Nonparametric (Spearman rho test) statistical correlations show that the activity of dissolved Ra is inversely related to pH and directly related to concentrations of total dissolved solids, DOC, barium, and sulfate. Low pH decreases adsorption of Ra onto the aquifer matrix. The other factors may favor Ra mobility by enhancing complexation or increasing solubility. Rn-222 activity does not correlate with and is not supported by the activity of its parent, Ra-226, in solution. Ra-226 activity correlates positively, but weakly, with U concentrations. Ra-226 does not appear to be supported by its parent, U-238, in solution.

Observed distributions of Ra-228, Ra-226, and Rn-222 activities in ground water in different lithologies of the Chickies Quartzite reflect different geochemical controls on adsorption and distribution of parent thorium-232 (Th-232) and uranium-238 (U-238) in the formation. Radium activities were greatest in acidic ground water in the conglomerate and quartzite (median pH of 5.0 and 5.2, respectively) and least in the more neutral water in the slate (median pH of 6.4). For ground water in the conglomerate, quartzite, and slate, respectively, median activities measured were: 1.3, 1.5, and 0.2 pCi/L for Ra-226; and 3.7, 2.5, and 1.0 pCi/L for Ra-228. Natural-gamma-ray geophysical logs and results of rock analyses indicate that the conglomerate may contain more Th and U than the quartzite and that the conglomerate may be more enriched in Th with respect to U than the quartzite; Th and U distribution in both lithogies is variable. Median Rn-222 activities in ground-water samples generally are greater progressively from the slate (1,400 pCi/L) to the quartzite (2,000 pCi/L) to the conglomerate (3,400 pCi/L) and may reflect differences in U content of the lithologies.

Ra-226, Ra-228, and Rn-222 activities in ground water vary locally and temporally. Lithology controls the geochemical environment, topography, and ground-water flow paths, and, therefore, the spatial distribution of Ra and Rn-222 activities. Temporal variations are seasonal; maximum Ra and Rn-222 activities in ground water occur with water-table lows in autumn and minimum Ra and Rn-222 activities occur with water-table highs in the spring.

INTRODUCTION

In 1985, during routine sampling of public supply wells, the Pennsylvania Department of Environmental Resources (PaDER) discovered activities of radium (Ra) that exceeded the U.S. Environmental Protection Agency (USEPA) maximum contaminant level (MCL)[1] for drinking water (U.S. Environmental Protection Agency, 1986) of 5 pCi/L (picocuries per liter) in water samples from several wells drilled into the Chickies Quartzite. The MCL is for the sum of the activities of Ra isotopes, of which radium-226 (Ra-226) and radium-228 (Ra-228) are the most abundant in nature. Ground water in the Chickies Quartzite is the sole source of supply for thousands of private users and a few public-supply systems. According to Cothern (1987), ingestion of water containing elevated activities of Ra can cause bone cancer. The health effects of ingesting drinking water that contains elevated concentrations of radon-222 (Rn-222), a radioactive isotope produced from the radioactive decay of Ra-226, are not clearly known. Degassing of Rn-222 from well water into closed buildings may pose a health risk (lung cancer) by inhalation (Cothern, 1987).

During 1986-89, the U.S. Geological Survey (USGS), in cooperation with the PaDER Bureau of Topographic and Geologic Survey and PaDER Bureau of Radiation Protection, conducted a study of the occurrence of Ra-226, Ra-228, and Rn-222 in ground water in the Chickies Quartzite to determine the distribution and magnitude of elevated Ra and Rn activities. The investigation included the collection and analysis of ground-water and rock samples.

Purpose and Scope

This report presents and summarizes data on the occurrence of Ra-226, Ra-228, Rn-222, uranium (U), and major and minor dissolved constituents in ground-water samples collected from the Chickies Quartzite and adjacent formations during 1986-89. It presents data on U and thorium (Th) in the rocks of the Chickies Quartzite as well as results of data analysis by statistical and graphical methods and describes a conceptual model for the occurrence of Ra in ground water. The report identifies the distribution and magnitude of the Ra and Rn anomalies in ground water of the Chickies Quartzite and characterizes the geochemical and hydrologic environments associated with elevated Ra and Rn activities in ground water.

Description of Area

The Chickies Quartzite crops out discontinuously over 112 mi^2 in the Piedmont Physiographic Province of southeastern Pennsylvania (fig. 1). Trending east-northeast, the formation crops out in eight counties in Pennsylvania: Adams, York, Lancaster, Berks, Chester, Montgomery, Philadelphia, and Bucks. The Chickies Quartzite forms a series of discontinuous narrow ridges that define three distinct and separate (fig. 1) structural and lithologic areas: a western area in Adams, York, and western Lancaster Counties; a central area in eastern Lancaster, Berks, and Chester Counties; and an eastern area in Montgomery, Philadelphia, and Bucks Counties. Generally, the ridges formed by the Chickies Quartzite are flanked by stratigraphically younger carbonate rock underlying valleys and by stratigraphically older, crystalline rock underlying rolling uplands.

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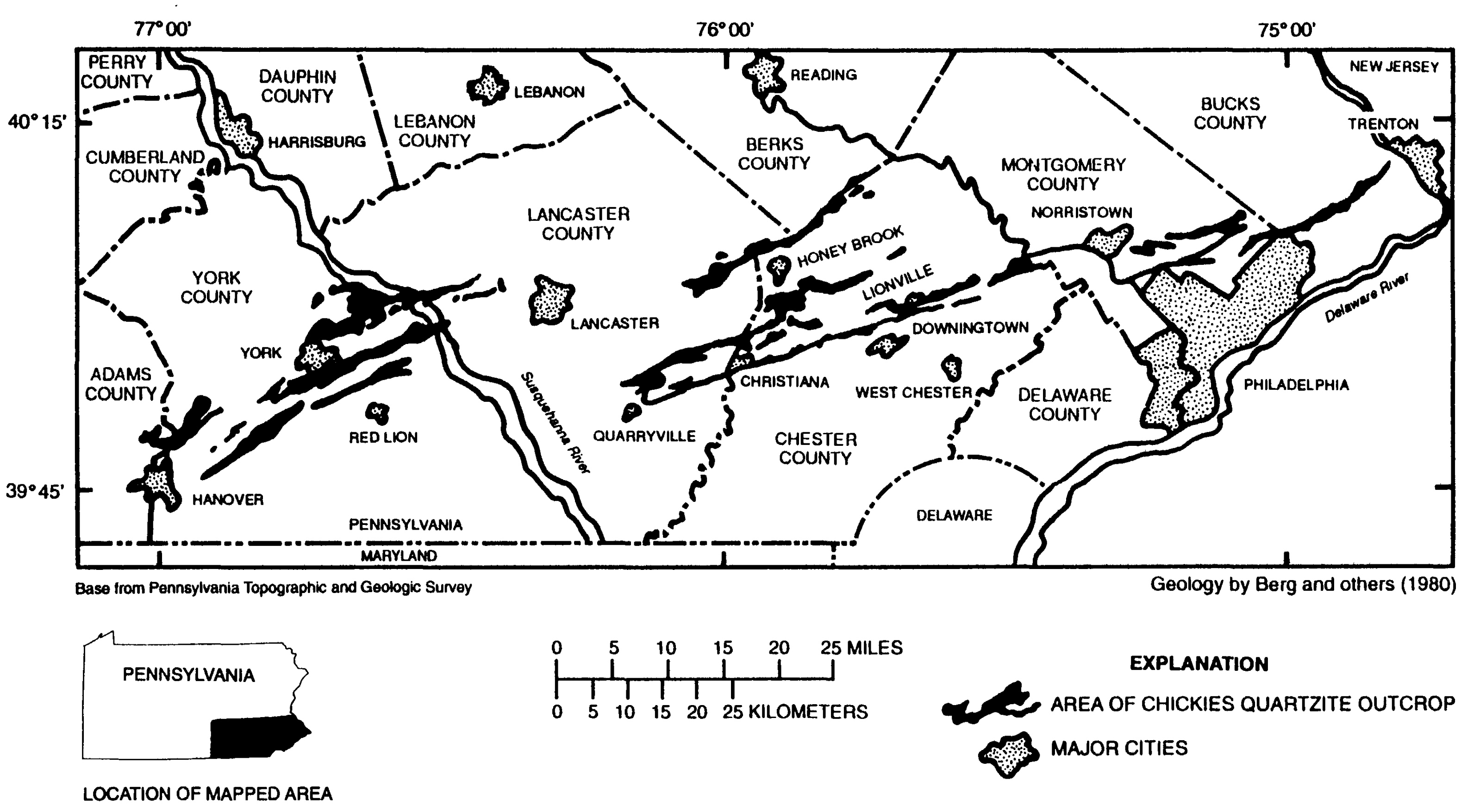
[1] The USEPA in 1991 proposed a MCL for radium of 20 pCi/L for Ra-226 or 20 pCi/L for Ra-228 in drinking water.



Base from Pennsylvania Topographic and Geologic Survey

Geology by Berg and others (1980)

Figure 1. Location of the Chickies Quartzite, southeastern Pennsylvania.

Population and Land Use

The Chickies Quartzite crops out near areas of high- and low-density population. Several tens of thousands of people rely on ground water from the Chickies Quartzite for their water supply. Economic use of rock and minerals of the Chickies Quartzite includes past mining for iron ore and clay and present quarrying for building stone and aggregate.

In the eastern part of the study area, the formation underlies the northwestern edge of the City of Philadelphia and its associated suburbs. The eastern part of the study area is the most urbanized, and most of the area's water needs are met by public surface-water supplies and wells in aquifers other than the Chickies Quartzite. Golf courses, country clubs, and a few domestic wells withdraw ground water from the Chickies Quartzite for irrigation, swimming pools, and domestic use.

The central and western parts of the study area are changing rapidly, with farms and forest giving way to residential, commercial, and industrial development. Until recently, ridges underlain by the Chickies Quartzite were forested and sparsely populated because of their relatively steep slopes and thin, poor soil unsuited for agriculture. Most residents rely on wells for water supply and have on-lot septic systems for disposal of waste water. The isolation of the ridges also has made them attractive sites for legal and illegal waste disposal. Two active landfills are located on the formation, one of which is in an abandoned quarry. Several inactive waste-disposal sites are on the USEPA's National Priorities List (Superfund-site designation).

Well-Numbering System

The well-numbering system in this report consists of a local well number and a site-identification number. The local well number consists of two parts: (1) a two-letter abbreviation that identifies the county in which the well is located, and (2) a sequentially assigned number. Wells located in Berks, Bucks, Chester, Lancaster, Montgomery, and York Counties are identified by the prefixes BE, BK, CH, LN, MG, and YO, respectively. No wells were sampled in Adams or Philadelphia Counties.

The 15-digit site-identification number is based on latitude and longitude. The first six digits are the degrees, minutes, and seconds of latitude; the next seven digits are the degrees, minutes, and seconds of longitude; and the last two digits are the sequence number. The sequence number is assigned to distinguish among sites located within a common 1-second grid block of latitude and longitude.

The combined prefix of a county abbreviation and SP denotes a spring in that county. Locations of selected wells and springs are shown on plate 1. Construction and production data for wells and springs are listed by county and local well number in table 20.

Methods of Data Collection and Analysis

Samples of ground water were collected and analyzed for activities of dissolved Ra-226, Ra-228, and Rn-222, and concentrations of other chemical constituents in three phases between November 1986 and September 1988. Ground-water samples were from 1 spring and 160 wells completed in the Chickies Quartzite and from 1 spring and 28 wells completed in adjacent geologic units. The first phase of data collection was a reconnaissance to determine the extent and magnitude of elevated Ra activity and to define, in general terms, ground-water chemistry. Sites were selected to distribute sample collection evenly over area of outcrop, with about two wells sampled on each 7.5-minute topographic quadrangle map where the Chickies Quartzite crops out. The next two phases of data and sample collection increased the areal sampling density, increased sampling coverage in an area where the hydrogeology was relatively well known, and provided additional data on hydrologic and geologic factors controlling Ra activity in ground water. Hydrologic data collected included well yield, specific capacity, depth, length of casing, and depth to water. Geologic data included lithology, gamma-ray and other geophysical logs of wells, rock-sample analyses, and mineral identifications. Several clusters of closely-spaced wells were sampled to study the range of Ra activity in water from wells within a small area. Several transects of wells penetrating different intervals in the Chickies Quartzite and adjacent formations were sampled to study the lithologic and flow-path controls on Ra activity in ground water.

Most of the sampling sites were domestic wells equipped with submersible pumps. Pumping rates ranged from 2 to 9.5 gal/min. All filters and treatment systems were bypassed. Wells were pumped until temperature, pH, and specific conductance stabilized, usually 30 to 60 minutes. Probes to monitor pH, temperature, and specific conductance were placed below the surface of a continuously overflowing sampling container supplied by the well discharge; use of the overflowing container reduced contact of the water with the atmosphere.

Field measurements of pH, temperature, alkalinity, dissolved oxygen (DO) concentration, and specific conductance of ground-water samples were made by established methods (Wood, 1976). Alkalinity titrations were conducted to an endpoint of 4.5 pH units and are reported as milligrams per liter of calcium carbonate ($CaCO_3$). Bicarbonate (HCO_3) is assumed to be the dominant component of alkalinity in dilute ground waters with neutral to acidic pH and (or) organic content. For water with an initial pH of 4.5 or less, alkalinity is reported as zero mg/L $CaCO_3$. DO concentration was determined by use of the azide modification of the Winkler titration method (American Public Health Association and others, 1975).

Samples of ground water for inorganic chemical and radiochemical analysis were filtered through a 0.45-µm filter. Samples for dissolved organic carbon (DOC) analysis were filtered through a 0.1-µm silver filter by use of a peristaltic pump. Sample preservation included acidification for radiochemical and metals analysis, chilling for DOC analysis, and addition of mercuric chloride and chilling to 4 °C for nutrient analysis. Concentrated hydrochloric acid was used to preserve samples for radionuclide analysis during phase one of sampling; otherwise, concentrated nitric acid was used for all acidified samples. At each site, two samples for radon analysis by liquid scintillation were collected with a syringe (U.S. Environmental Protection Agency, 1978).

Analysis of ground-water samples for inorganic constituents, including nutrients, and DOC was done by the USGS National Water-Quality Laboratory by use of standard methods (Fishman and Friedman, 1989). Inorganic constituents analyzed were: calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), iron (Fe), manganese (Mn), barium (Ba), chloride (Cl), fluoride (F), sulfate (SO_4), boron (B), nitrate (NO_3), nitrite (NO_2), ammonium (NH_4), and phosphate (PO_4). Minimum reporting levels for metals depends on the analytical method; reporting levels for Ba, Fe, and Mn are higher for analysis by atomic absorption spectrometry than for analysis by atomic emission spectrometry by use of inductively-coupled plasma.

Radiochemical analysis of ground water included the determination of Ra-226, Ra-228, and gross alpha- and beta-particle activities and U concentrations by use of methods outlined by Thatcher and others (1977). Rn-222 was measured by liquid scintillation by use of methods outlined by Pritchard and Gesell (1977) at the University of Maine,[2] Orono, Maine. Ra-226, Ra-228, and gross alpha- and beta-particle activity and dissolved U concentrations were determined by Teledyne Isotopes,[2] Westfield, N.J., for phases one and two of the study and by U.S. Testing,[2] Richland, Wash., for phase three. Several duplicate samples from phases two and three and 12 samples from well CH-3335 were analyzed by the PaDER Bureau of Laboratories; samples compared acceptably, with no laboratory showing bias. Ra-226 activity was determined by Rn-222 emanation. Ra-228 activity was determined by coprecipitation with barium sulfate and subsequent beta counting. Dissolved U concentration was determined by laser fluorometry (Teledyne) or laser-induced phosphorimetry (U.S. Testing). Gross alpha- and beta-particle activity was determined by precipitation of solids on planchet and counting. Alpha standards were americium-241 for analyses by Teledyne Isotopes and results are reported as pCi/L. Alpha standards were natural-uranium (U-nat) for analyses by U.S. Testing, and results are reported as µg/L as U-nat. Eighteen samples also were analyzed for isotopic U (U-238,

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[2] The use of names of private laboratories is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

U-235, and U-234) by U.S. Testing by use of alpha spectrometry. Lowest level of reporting (lower limit of detection) and margin of error for each radionuclide varied depending on laboratory and background radioactivity during counting. Generally, the magnitude of counting error increases with the magnitude of the determined activity for radionuclides. Reported activity values should be interpreted with caution because of the uncertainty associated with measurement.

Borehole geophysical logging of domestic and monitoring wells penetrating the Chickies Quartzite was completed by the USGS. Geophysical logs included some or all of the following on each well: caliper, fluid-temperature, fluid-resistivity, electrical (single-point-resistance and spontaneous-potential), natural-gamma-ray, and fluid-velocity (brine-trace) logs. Logging probes and tools for gamma-ray and electrical logs were not calibrated, and logs are interpreted relative to each other. The gamma-ray-logging tool measures total gamma-ray radiation in a selected energy range and does not differentiate among gamma-ray emitters. Usually, about 90 percent of the gamma radiation detected originates within 12 in. of the borehole, and higher energy radiation travels farther than lower energy radiation (Keys, 1989). Among natural gamma-ray emitters, gamma activities of the Th-232 and U-238 decay series are much greater than that of K-40 (Keys, 1989).

The Ra-226 and Ra-228 activities in six rock samples were determined by use of standard methods for dissolved Ra-226 and Ra-228 following total dissolution of the rock by PaDER Bureau of Laboratories. Rock samples and well cuttings were analyzed using neutron activation to determine total U concentration by delayed neutron counting and Th content by instrumental activation analysis (INAA) by Nuclear Activation Services, Ann Arbor, Mich. Gamma-ray spectrometry of well cuttings and suspended solids collected by filtering ground-water samples were performed by Teledyne Isotopes. Gamma-ray spectrometry measures the gamma-ray activity of several high-energy gamma rays, including those of K-40 and some radionuclides in the U-238 and Th-232 decay series.

Heavy minerals were identified in collaboration with C. Gil Wizwall and David Sinson at West Chester University, West Chester, Pa., and by Linda C. Gunderson, USGS, in Reston, Va. Rock samples and well cuttings were crushed, sieved, and panned. Dense liquids (bromoform) were used to further separate the heavy minerals, and a Frantz magnetic separator at Bryn Mawr College was used to remove magnetite.

Nonparametric statistics were used in data analysis. Parametric statistics traditionally are used in the analysis of normally distributed data sets; however, hydrologic data, and water-quality data in particular, commonly are not normally distributed (Helsel, 1987, p. 180). Ra-226, Ra-228, and Rn-222 activity data are positively skewed. In addition, the data are bounded at the detection limit of the analytical method, and some concentrations are reported as less than the detection limit. Nonparametric statistics are powerful and robust when used to analyze nonnormally distributed data, such as badly skewed environmental data.

Multiple detection limits for radionuclides arise because of (1) variances in the background radioactivity during counting at time of the analysis, and (2) the use of two laboratories having different reporting levels. All data less than the maximum detection limit is set equal to that detection limit; nonparametric statistical tests assign the same rank to all concentrations that are the same (Helsel, 1987, p. 189). The maximum detection limits for Ra-226 and Ra-228 activities are 0.1 pCi/L and 1.0 pCi/L, respectively.

Differences in Ra-226, Ra-228, and Rn-222 activities in ground water in different lithologies were tested by use of the Kruskal-Wallis test, a nonparametric one-way analysis of variance (ANOVA). The Kruskal-Wallis null hypothesis is that a number of independent groups come from the same population or from populations with equal mean rank. The significance of the equality of the means of the ranks is tested against the chi-square distribution. For this study, the null hypothesis was rejected at a 95-percent confidence level. If the null hypothesis is rejected, the alternative hypothesis is that at least one group is from a different population. However, the test does not indicate which group is different. Further testing by use of a nonparametric multiple comparison test (MCT) must be performed to identify the group or groups that come from a separate population.

A multiple comparison test (MCT) is a procedure to determine the relative ordering of population mean rank. This test was used only after the null hypothesis of the ANOVA was rejected. The MCT using the Kruskal-Wallis statistic recommended by Campbell and Skillings (1985) was used. The purpose of the MCT is to find differences in smaller subsets as long as test results are statistically significant; for this study, the null hypotheses of no differences was rejected at the overall 95-percent confidence level.

Spearman's rho correlation coefficient (r_s) test was used to determine the specific chemical constituents and properties that correlated with Ra-226, Ra-228, and Rn-222 in ground water. Spearman's rho is a nonparametric test to measure monotonic correlation between two variables. Monotonic correlations are not necessarily linear but arise when two parameters either change magnitude at any rate in the same or opposite directions. It is calculated by use of rank-transformed data. Positive correlation results when large values of the first variable are associated with large values of the second variable. A negative correlation results when large values of the first variable are associated with small values of the second variable. All correlations discussed in this report have at least a 95-percent significance level (p-values less than 0.05).

Values of r_s should not be interpreted in the same manner as values for the equivalent parametric test, Pearson's product-moment correlation coefficient (r). If the relation between the two variables is curvilinear rather than linear, the value of r_s will tend to be higher (closer to -1 or +1) than the value for r (Iman and Conover, 1983, p. 127 and 340). Spearman's rho, unlike Pearson's product-moment correlation coefficient, is not sensitive to outliers in the data since ranks of the values are used instead of the actual values. It is an inappropriate procedure to square r_s to determine the percent variability of y explained by x (D.R. Helsel, U.S. Geological Survey, oral commun., 1989).

A positive or negative correlation between a chemical constituent and radionuclide activity may be used in two ways. A statistically significant correlation can be used to characterize the environment associated with elevated radionuclide activities. A significant, but low, r_s indicates that a relation exists between the two parameters. This relation does not necessarily imply cause and effect; therefore, the correlations are evaluated in terms of possible geochemical reactions or physical processes that may control the concentration and distribution of radionuclides and other chemical constituents that behave in a manner similar to the radionuclides. A statistically significant correlation between a chemical constituent can also be used to indicate the presence (positive correlation) or absence (negative correlation) of elevated radionuclide activity if the r_s is high and the plot of the two variables does not show much scatter. An $r_s = 0.60$ is considered a strong correlation for the nonparametric Spearman's rho correlation (D.R. Helsel, U.S. Geological Survey, oral commun., 1989).

Previous Investigations

The geology of the Chickies Quartzite was first described by Rogers (1858). The formation was later studied by Lesley and Frazer who differentiated it from other "primal quartzites" and named it Chickies Quartzite in 1878, on the basis of the type locality of Chickies Rock in Lancaster County (Knopf and Jonas, 1929). Bascom and others (1909), Bascom and Stose (1938), Knopf and Jonas (1929), Stose and Jonas (1939), Stose and Stose (1944), and Willard and others (1959) further describe the formation. A summary of the early work is given by Engelder (1976). More recent geologic investigations have been performed for senior and master's theses, covering topics such as structural relations with underlying crystalline rocks (Murphy, 1973), facies descriptions (Hyde, 1971), and friability and geochemistry (Engelder, 1976). Recent papers focusing on the Chickies Quartzite include discussions of tectonic implications (Adams and Goodwin, 1975), and sedimentary structures and environments of deposition (Goodwin and Anderson, 1974). Chemical analyses of Chickies Quartzite whole rock and minerals are given in Berkheiser (1985).

In addition to geologic description, Bascom and Stose (1938), Knopf and Jonas (1929), and Stose and Jonas (1939) included remarks about economic use and water resources in their reports. General economic, engineering, and hydrologic characteristics of the formation are given in McGlade and others (1972) and Wilshusen (1979).

Publications presenting data and preliminary results of this study include Cecil, Smith, and others (1987), Cecil (1989), and Cecil, Senior, and others (1991). A relation between elevated Ra and low pH was reported by Cecil and others (1987).

Acknowledgments

The cooperation of well owners for providing data and granting access to wells for water samples is gratefully acknowledged. Assistance in quality assurance and interpretation of Ra and Rn analyses of water samples was provided by Margaret Reilly of the PaDER Bureau of Radiation Protection, Michael Webb of the PaDER Bureau of Laboratories, and Charles T. Hess of the University of Maine, Orono. Donna Snyder of the Pennsylvania Bureau of Topographic and Geologic Survey (PAGS) provided driller's records of wells. The cooperation of geologists of Environmental Resources Management, Inc. and Jack Kelly of the USEPA for data is appreciated.

Valuable contributions to solid-phase investigations were made by Robert C. Smith, II, of the PAGS, C. Gil Wizwall and David Sinson of West Chester University, Michael Webb, PaDER, Bureau of Laboratories, and William Crawford and Robert Cook of Bryn Mawr College.

HYDROGEOLOGIC SETTING

The Chickies Quartzite crops out in the Piedmont Physiographic Province of southeastern Pennsylvania. In the Piedmont, ground-water basins are relatively small and generally have boundaries or divides coincident with ridge tops. Ground water discharges to nearby perennial streams. Geologic formations are not flatlying, and water is present in fractures in bedrock and in the overlying weathered material. Flowpaths are short and are controlled, in part, by topography.

Geology

The Chickies Quartzite is the basal member of the Lebanon Valley sequence (Berg and others, 1986) and Chester and Conestoga Valley sequences (Lyttle and Epstein, 1987) of Paleozoic metasediments that crop out in the Piedmont Physiographic Province. The Chickies Quartzite—a basal metaconglomerate, quartzite, and slate—is Lower Cambrian in age and rests unconformably on deformed and metamorphosed Precambrian crystalline rocks. The Chickies Quartzite is one of several Cambrian quartzose formations that rest unconformably on older crystalline rocks in the Piedmont. In Pennsylvania, the conglomerates are basal members of these quartzose formations and crop out in discontinuous east-northeast- or northeast-trending belts. To the north of the Chickies Quartzite in east-central Pennsylvania is the Hardyston Quartzite, a Cambrian-age basal conglomerate and quartzite formation that is associated with the Reading Prong of the New England Physiographic Province.

The Antietam Quartzite and Harpers Phyllite are Cambrian-age quartzite, quartz schist, and phyllite units that lie conformably above the Chickies Quartzite. In the eastern part of the study area, the Antietam Quartzite and Harpers Phyllite are missing or not recognized. In this region, the Cambrian-age Ledger Dolomite and Cambrian- and Ordovician-age Conestoga Limestone are mapped in depositional contact with the Chickies Quartzite. The Antietam Quartzite and Harpers Phyllite are mapped as one undifferentiated unit in most areas. A generalized section (fig. 2) for the central part of the study area shows the stratigraphic relations.

The rocks of the Piedmont and Great Valley Physiographic Provinces have undergone several episodes of deformation and metamorphism, resulting in structurally complex assemblage of greenschist and greenschist-retrograde metamorphic rocks (Lyttle and Epstein, 1987). The Chickies Quartzite in association with Precambrian crystalline rocks and overlying Paleozoic sediments has been mapped as part of large anticlinal and synclinal structures (Bascom and others, 1909; Stose and Stose, 1944). These structures have been further deformed and commonly are overturned and cut by faults. The Chickies Quartzite in some places is in fault contact with Precambrian basement and younger Paleozoic metasediments. Regional faults bound larger structures and generally trend northeast-southwest, with faults and folds commonly dipping to the southeast.

Composition of the underlying Precambrian crystalline basement rocks varies. Felsic gneiss is present in the eastern part of the study area; felsic and intermediate gneiss and mafic gneiss are present in the central part of the study area; and metavolcanic rocks, such as metarhyolite, are present in the western part of the study area. The variable composition of the basement could, in part, reflect the structural juxtaposition of different crystalline rock units prior to deposition of the Chickies Quartzite.

After deposition, the Chickies Quartzite was deformed and metamorphosed (up to greenschist facies). Some telescoping of basement units and associated cover rocks may have occurred, such that different slices of the Chickies Quartzite presently located near one another may have originally been deposited far apart with different source areas for clasts. Sources for clasts were sedimentary, igneous, and metamorphic rocks and probably were located to the northwest of the Chickies Quartzite (Hyde, 1971).

Along the northern edge of the outcrop area, contacts between the Chickies Quartzite and overlying sedimentary units (Antietam Quartzite, Harpers Phyllite, Ledger Dolomite, or Conestoga Limestone) are covered in places by the Triassic Stockton Formation of the Newark Basin and the

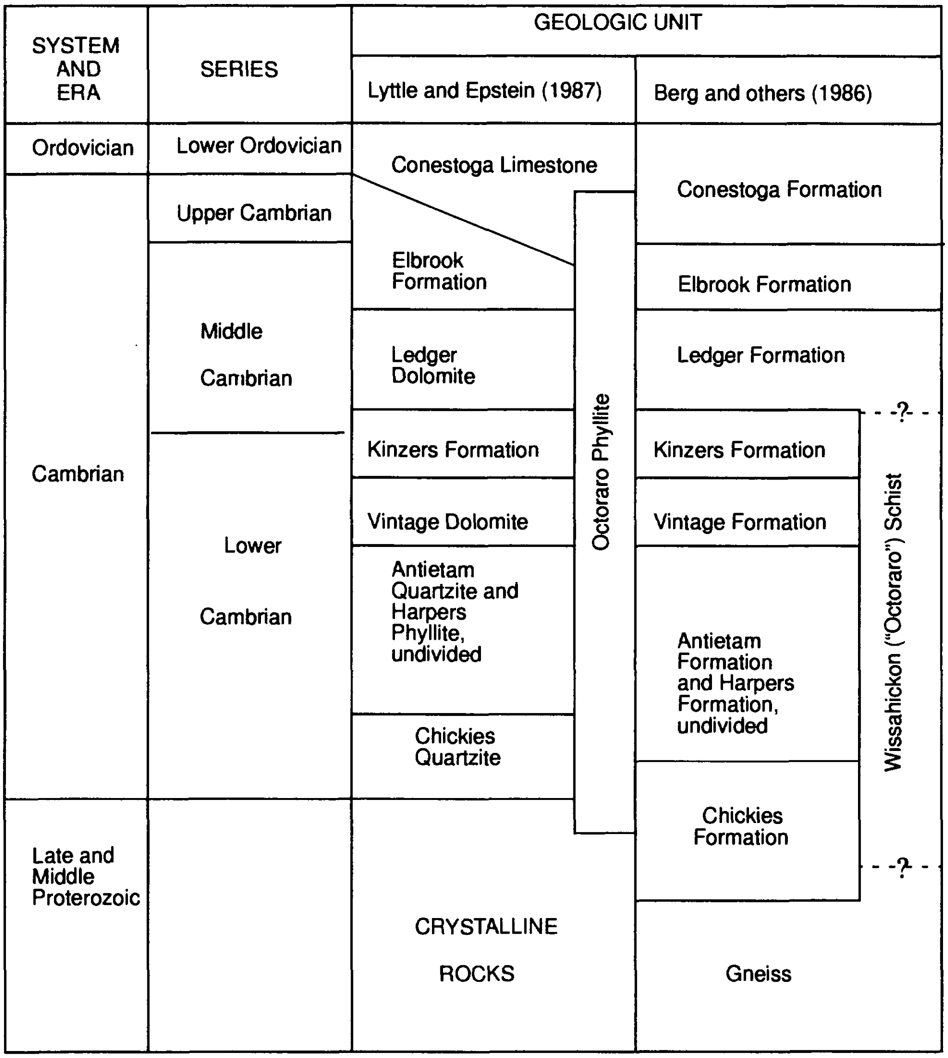


Figure 2. Generalized stratigraphy of lower Ordovician and older rocks in northcentral Chester County, Pennsylvania.

New Oxford Formation of the Gettysburg Basin. Lower Mesozoic diabase dikes intrude the Chickies Quartzite, cutting across contacts with underlying and overlying rocks.

The Chickies Quartzite is comprised of three lithologies—conglomerate, quartzite, and slate—that previously have been mapped as three members of the formation, the lower Hellam Member and the upper Chickies Quartzite and Chickies Slate Members (Bascom and Stose, 1938; Stose and Stose, 1944). The PAGS uses the names of these members and the term Chickies Formation to refer to the separate lithologies and the entire formation, respectively (Berg and others, 1986; Wilshusen, 1979). This report uses the nomenclature of the USGS, Chickies Quartzite, to describe the entire formation. The type locality of the Chickies Quartzite is an exposure of quartzite and slate named Chickies Rock on the east bank of the Susquehanna River in Lancaster County. The Chickies slate lithology has been mapped separately only in York County (Stose and Stose, 1944), and both other lithologies have been mapped in all counties where the formation occurs. Hyde (1971) recognized six facies within the formation: conglomerates, cross-stratified quartz arenites, burrowed quartz arenites, feldspathic wackes and arenites, quartz wackes, and mudstone. Thickness of the Chickies Quartzite is reported to range from 430 to 1,300 ft (Lyttle and Epstein, 1987). The environments of deposition have been interpreted as braided streams and intertidal and subtidal zones along a coastal margin (Hyde, 1971; Adams and Goodwin, 1975; Goodwin and Anderson, 1974).

The basal part of the Chickies Quartzite ("Hellam Member") is a coarse feldspar- and quartz-pebble conglomerate grading into conglomeratic quartzite, with a quartz and sericitic matrix and accessory zircon, magnetite, and hematite (Bascom and Stose, 1938; Knopf and Jonas, 1929), rutile (G.C. Wizwall, West Chester University, oral commun., 1989), monazite, titanite and apatite (L.C. Gunderson, U.S. Geological Survey, oral commun., 1989). The conglomerate commonly consists of blue quartz pebbles in a pale green matrix. Interbeds of slate are reported by Stose and Stose (1944). Tourmaline crystals formed in-situ are found in the central and eastern areas of exposure of the conglomerate. Thickness of the conglomerate ranges from 200 to 500 ft (Bascom and Stose, 1938; Stose and Jonas, 1939). The conglomerate is most prominent in York County, where it forms the Hellam Hills east of York; here are the coarsest conglomerate beds of the entire exposed formation. Sources of clasts in the conglomerate may have included the Precambrian crystalline rocks that currently are exposed and differ in composition from east (mafic gneiss and felsic gneiss) to west (metabasalt and metarhyolite).

Above the conglomerate, the Chickies Quartzite is a light-gray to white, vitreous to granular, massive to thin-bedded quartzite and sericitic quartz schist (Bascom and Stose, 1938). Thickness of the quartzite lithology ranges from 200 to 800 ft. In general, the quartzite is very "clean" but may contain small amounts of feldspar and accessory zircon, rutile, apatite, monazite, limonite after pyrite, hematite, magnetite, and unidentified opaque minerals. The sericitic quartz schist is pale gray to pale green. Murphy (1973) identified the pale-green mica as the phengite variety of muscovite. The quartzite and quartz schist has undergone recrystallization and commonly contains tourmaline (often stretched) and mica, especially in the central and eastern areas. Thin discontinuous beds of kaolinite in the quartzite have been interpreted as weathered mica- or feldpar-rich layers (Bascom and Stose, 1938). Quartz veins are present between and within beds. Hyde (1971) divided the quartzite lithology into four facies: (1) argillaceous quartzite and (2) quartz wacke dominant in the eastern area; (3) cross-bedded and burrowed quartz arenites in the east-central, north-central, and western areas; and (4) feldspathic wackes in the south-central area.

Some of the compositional differences between the facies of the quartzite are shown by rock-sample analyses. In the eastern part of the study area, sericitic quartzite from Bucks and Montgomery Counties is reported to contain up to 22 percent Al_2O_3 and 12.6 percent K_2O (table 1). In the east-central and north-central areas in Chester and Lancaster Counties, the quartzite is a relatively clean quartzite, and some samples are 99 percent or more SiO_2 (Berkheiser, 1985). Bulk chemistry of the quartzite in western Lancaster County was determined by Engelder (1976) from 26 samples (table 1). The Fe content of the quartzite increases to the west from Lancaster County (Berkheiser, 1985). Large pyrite crystals are common in the quartzite in York County.

Engelder (1976) determined that the quartzite contains more K and titanium (Ti) and less Si, Ca, and Na than an average quartzite or an average arkose; more Al and Mn than an average orthoquartzite; but less Al, Fe, Mg, and Mn than an average arkose. The samples of quartzite from Bucks and Montgomery Counties (table 1) also contain less Ca and more Ti and K than the average arkose or orthoquartzite (Pettijohn, 1963). In an analysis of texture, mineralogy, and composition, quartz correlated negatively with feldspar, mica, and matrix associated with K, Fe, Mg, and Ti (Engelder, 1976).

Table 1. Average bulk composition of 26 rock samples of the Chickies Quartzite, Lancaster County, 1 rock sample from the type locality, and 3 rock samples from Bucks and Montgomery Counties

[In percent; --, no data]

Constituent	Lancaster County[1]	Bucks County[2]	Bucks County[2]	Montgomery County[2]	Type locality[3]
SiO_2	93.17	87.87	58.97	56.35	97.10
Al_2O_3	2.88	6.61	22.61	22.28	1.39
Fe_2O_3	[4].62	2.39	5.67	3.21	1.25
MgO	.14	Trace	.25	1.40	.13
MnO	.06	.13	--	Trace	--
CaO	.02	.24	.08	.19	.18
TiO	.42	.38	1.11	.82	--
Na_2O	.02	.19	.32	.38	--
K_2O	1.24	1.73	7.34	12.63	--
Na_2O/K_2O	.01	.11	.04	.03	--

[1] From Engelder (1976).

[2] From Bascom and others (1909).

[3] Chickies Rock, Lancaster County, from Jonas and Stose (1930).

[4] Given as total Fe.

Engelder (1976) interpreted the quartzite in western Lancaster County to be arkosic and a near-source deposit of sediment based on chemical analyses and mineral distributions. Goodwin and Anderson (1974) described the environment of deposition of the quartzite as a mosaic of subtidal channels, intertidal flats, and tidal flat ponds based on identifiable physical and biogenic structures, such as stratification, bed form, grain size, and fossil burrow forms. The variable composition of the quartzite is a result of the environment of deposition (Berkheiser, 1985) as well as possible differences in source material.

The Chickies slate lithology lies above the conglomerate and is probably stratigraphically equivalent to the quartzite. It is mapped as a separate unit (Stose and Jonas, 1939) south of the Hanover-York carbonate valley in York County. The slate lithology consists of interbedded slate, phyllite, and quartzite and contains quartz, albite, chlorite, muscovite, magnetite, zircon, and tourmaline (Stose and Stose, 1944). Slate and quartzite have been mapped separately within the Chickies slate unit (Stose and Stose, 1944). The Chickies slate unit corresponds to the mudstone facies of Hyde (1971) that was deposited in a subtidal shelf.

Ground-Water System

The Chickies Quartzite is a water-table aquifer recharged directly by precipitation. Generally, soil cover is thin (1 to 5 ft), and depth to competent bedrock commonly is 10 ft or less. Openings to the surface and within the aquifer have developed along a complex interconnected network of bedding, joints, and structurally controlled planes, such as cleavage, faults, and fractures.

Generally, the water table is a subdued replica of the topography, and ground-water divides coincide with ridge tops. Median depth to water was 69 ft in wells on hilltops (31 measurements ranged from 29 to 105 ft) and 50 ft in wells on slopes (67 measurements ranged from 1.3 to 130 ft). Springs on slopes are indicative of a shallow water table and (or) a local flow system. Because the Chickies Quartzite is resistant to erosion, it forms ridges and is topographically higher than adjacent geologic units; therefore, ground water from the Chickies discharges to the surface or to adjacent geologic units. Ground water flows from the quartzite, which commonly underlies ridge crests, through the conglomerate that underlies slopes, and toward the contact with underlying Precambrian crystalline rocks to one side of the ridge. On the other side of the ridge, ground water flows from the quartzite through the Antietam Quartzite and Harpers Phyllite, which underlie slopes, and toward the contact with overlying carbonates. The strike of the Chickies Quartzite is roughly parallel to the ridge line. Ground-water divides commonly coincide with ridge crests, and, thus, geologic, topographic, and hydrologic conditions coincide to create a situation where the maximum horizontal hydraulic gradient is approximately perpendicular to strike.

Ground-water flow in the Chickies Quartzite is driven by the hydraulic gradient through a network of fractures. Each fracture opening penetrated by a well may have a different hydraulic head, and ground water flows from higher to lower head. The existence of a vertical hydraulic gradient between openings is shown by the downward movement of a tracer observed in the geophysical log of a ridge-top well (CH-3315). Water-level data and geophysical logs from four pairs of deep and shallow monitoring wells drilled for the investigation of William Dick Lagoons National Priorities List (Superfund) site suggest that vertical gradients (down) are greatest near the ridge crest and decline to almost zero near mid-slope areas of discharge.

Analysis of frequency of water-bearing zones in the Chickies Quartzite shows most zones are within 150 ft of land surface (table 2). Frequency of water-bearing zones decreases with depth, and no zones are reported at depths greater than 400 ft below land surface, although data are limited below 400 ft. This analysis supports the model of a shallow, local flow system in the Chickies Quartzite similar to other geologic units in the Piedmont (Trainer, 1988). The data do not preclude ground-water flow at depths greater than 400 ft.

Table 2. Number of water-bearing zones per 100 feet of uncased borehole for 151 wells drilled in the Chickies Quartzite

Interval of depth below land surface (in feet)	Number of water-bearing zones [1]	Footage of open hole sampled	Water-bearing zones per foot × 100
0-50	32	808	3.96
51-100	103	4,134	2.49
101-150	82	4,887	1.68
151-200	43	3,189	1.35
201-250	22	2,046	1.08
251-300	17	1,117	1.52
301-350	3	374	.80
351-400	2	150	1.33
Below 400	0	57	0
Total	304	16,762	1.81

[1] Most data are from driller reports. Some data are from geophysical log interpretations.

Well-Construction Characteristics

Wells in the Chickies Quartzite are drilled by air hammer, air-rotary, or cable-tool methods. Wells are commonly 6 in. in diameter, although nondomestic wells may be larger. Steel or plastic casing is set into competent rock, and the interval below the casing is left as an open hole. Water enters the well from one or more water-bearing zones intercepted by the uncased section of the well. Submersible pumps commonly are set about 20 ft above the bottom of the hole.

The range and median of well depth and casing length for wells completed in the Chickies Quartzite and sampled for this study are given in table 3. Median depth and casing length for wells in the Chickies Quartzite are similar to those for other minor aquifers in Chester County (Poth, 1968) and York County (Wilshusen, 1979). Wells on hilltops tend to be deeper and require less casing than wells on slopes or at the base of slopes. In the Chickies Quartzite, the median well depth is slightly greater for wells drilled on hilltops than slopes; the median casing length is slightly less for wells drilled on hilltops than slopes (table 3).

Table 3. Range and median of depth and casing length of wells drilled in the Chickies Quartzite

[Min, minimum; Max, maximum]

Well characteristics	Number of wells	Range		Median
		Min	Max	
Well depth (feet)				
All wells	137	40	500	162
Hilltop	50	70	500	169
Slope	87	40	407	160
Conglomerate	51	63	500	150
Quartzite	79	40	407	175
Slate	7	100	300	160
Casing length (feet)				
All wells	120	13	168	47
Hilltop	40	20	168	43
Slope	80	13	145	47
Conglomerate	45	13	125	43
Quartzite	70	20	168	52
Slate	5	30	42	40

The median well depth and casing length is greater for wells drilled in the quartzite than the conglomerate or the slate (table 3). The quartzite commonly underlies hilltops, although at depth, the quartzite may weather to a loose quartz sand. In Chester County, well owners in some areas report continual pumping of fine sand.

Well Yield and Specific Capacity

Reported yield and specific capacity are indicators of aquifer productivity and hydraulic conductivity (permeability). Nondomestic wells commonly are drilled and constructed for the largest yield obtainable. Specific capacity is the measure of well yield per foot of drawdown of water level in a well. The range and median yield and specific capacity for 116 domestic and 4 nondomestic wells completed in the Chickies Quartzite and sampled for this study are given in table 4. Specific capacities are less than 1.0 (gal/min)/ft for more than 80 percent of the wells. Median specific capacity and yield of wells completed in the Chickies Quartzite are less than those reported for most major and some minor aquifers in Chester County (Poth, 1968) and York County (Wilshusen, 1979). Few public supply wells are completed in the Chickies Quartzite.

Table 4. Range and median of reported yield and specific capacity of wells drilled in the Chickies Quartzite

[Min, minimum; Max, maximum; <, less than; --, no data]

Well characteristic	Number of wells	Range		Median
		Min	Max	
Reported yield (gallons per minute)				
All wells	120	0.5	100	10
Hilltop	41	1	40	8
Slope	79	.5	100	10
Conglomerate	43	.5	100	11
Quartzite	72	.5	96	7.8
Slate	5	4	20	10
Specific capacity (gallons per minute per foot of drawdown)				
All wells	48	<.01	15	.14
Hilltop	15	.02	15	.14
Slope	33	<.01	2.5	.15
Conglomerate	13	.02	1.7	.34
Quartzite	35	<.01	15	.13
Slate	--	--	--	--

Differences in well yield and specific capacity related to topography and lithology appear to be small for the Chickies Quartzite. The range and median yield and specific capacity for wells drilled on hilltops and slopes in different lithologies of the Chickies Quartzite are given in table 4. The median yield and specific capacity are slightly greater for wells drilled on slopes than on hilltops. Rocks underlying slopes erode more easily and may be more permeable than rocks underlying hilltops. The median yield and specific capacity is greater for wells completed in conglomerate, which commonly underlies slopes, than in quartzite, which commonly underlies hilltops. Median yield for wells completed in the slate (underlying slope and hilltop) is slightly less than that for the conglomerate.

Ground-Water Quality

The chemical composition of ground water in a water-table aquifer is determined by the chemical composition of recharge and the subsequent chemical reactions along the flow path through the soil zone and aquifer. Many chemical reactions and processes are associated with mineral weathering, including dissolution and precipitation of minerals, oxidation-reduction, ion-exchange, and adsorption. Some reactions may be biologically mediated. Recharge water can acquire additional NO_3 and salts from anthropogenic sources such as fertilizer, road salt, and septic-system discharge.

The Chickies Quartzite is recharged primarily by acidic precipitation. In 1979-80, 22 samples of precipitation were collected in central Chester County for chemical analysis. Median total concentrations measured were 0.2 mg/L Na, 0.1 mg/L K, 0.6 mg/L Ca, 0.15 mg/L Mg, 0.4 mg/L Cl, 0.6 mg/L NO_3 as N, 4.3 mg/L SO_4, and 1.5 mg/L DOC; the median pH was 4.1. Maximum concentrations were 1.2 mg/L for Na, 5.8 mg/L for Ca, 19 mg/L for Mg, 2.9 mg/L for Cl, and 10 mg/L for SO_4; pH was as low as 3.6.

The Chickies Quartzite is composed mostly of quartz, which is a source of dissolved SiO_2; however, quartz has a low solubility in the pH range of most natural waters. Some silicate minerals, such as mica and feldspar, are soluble in the pH range of the ground water. Silicate-mineral weathering results in an increase in pH, alkalinity, and concentrations of SiO_2, Ca, Mg, K, and Na in ground water. Silicate-mineral sources include microcline for K; plagioclase for Ca; micas (biotite, sericite, phengite) for K, Mg, and Fe; and tourmaline for B. Ba and other trace elements may be present as replacement ions in or be adsorbed by silicates, by Mn-oxides or Fe-oxides, or by other minerals in the Chickies Quartzite. The weathering of pyrite involves the oxidation of sulfur and results in a decrease in pH and an increase in SO_4 concentration in ground water; Fe released may be precipitated as an iron oxide.

The ground water of the Chickies Quartzite is generally acidic, soft (less than 60 mg/L Ca plus Mg), and low in total dissolved solids (TDS) and alkalinity. Table 5 lists the range and median of analyzed chemical constituents and measured chemical properties for well-water samples. Acidic recharge water, low solubility of quartz, sparsity of easily dissolved Ca- and Mg-bearing minerals in the aquifer, and the small amount of mineral weathering because of a short residence time of ground water can account for the soft, acidic, and dilute character of the ground water.

The median concentrations of major ions in ground water of the Chickies Quartzite are up to 20 times greater than the median concentrations of those ions measured in precipitation in central Chester County. The ground water acquires these ions from sources other than precipitation. Because median concentrations of Na, Cl, and Mg in ground water are up to 20 times as great as those in precipitation and Na, Cl, and Mg are not known to be abundant in the aquifer materials (table 1), enrichment of salts in ground water from septic systems or road salt is likely. The maximum concentrations of Na (59 mg/L), Cl (100 mg/L), and NO_3 (16 mg/L in ground water) (table 5) probably are from wells affected by septic systems, road salt, and (or) fertilizers.

The median DOC concentration of 0.8 mg/L (table 5) is similar to the median DOC concentration of 0.7 mg/L in ground water for aquifers in the United States (Leenheer and others, 1974), but less than the median DOC concentration of 1.5 mg/L measured in precipitation in Chester County. The specific organic compounds contributing to naturally occurring DOC is not known, although fulvic and humic acids are the most abundant naturally occurring compounds in ground water (Thurman, 1985). Naturally elevated DOC concentrations may indicate short residence time or rapid infiltration of organic-rich recharge waters. Concentrations above 5 mg/L are uncommon and may indicate unnatural sources of DOC (Leenheer and others, 1974). The sample that contains 10 mg/L DOC is from a well (CH-3113) contaminated by benzene and other manufactured organic compounds.

Ground water in the Chickies Quartzite generally is well oxygenated; the median DO concentration is 7.6 mg/L. DO at detectable concentrations (greater than 0.1 mg/L) is associated with recharge areas having sandy or gravelly soils and shallow ground water or areas having little or no soil overlying permeable fractured rock (Freeze and Cherry, 1979). Dissolved oxygen concentrations similar to those in surface water may persist far into the flow system if ground water does not react

Table 5. Range and median concentrations of selected chemical constituents and properties for 160 well-water samples from the Chickies Quartzite

[mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; <, less than]

Constituent or property	Number of samples	Range	Median
Dissolved chemical constituents			
Ca (mg/L)	159	<0.1 - 33	3.4
Mg (mg/L)	159	.2 - 14	2.9
Na (mg/L)	159	.7 - 59	4.0
K (mg/L)	159	.3 - 11	1.8
Ba (µg/L)	159	<2 - 380	63
B (µg/L)	58	<10 - 290	<10
Fe (µg/L)	159	<3 - 27,000	20
Mn (µg/L)	159	<1 - 870	36
Cl (mg/L)	160	.3 - 100	7.3
SO_4 (mg/L)	160	<.2 - 62	5.7
F (mg/L)	160	<.1 - .5	<.1
SiO_2 (mg/L)	160	3.4 - 28	8.3
NO_3 (mg/L as N)	57	<.1 - 16	1.1
NH_4 (mg/L as N)	57	<.01 - 1.4	<.01
PO_4 (mg/L as P)	58	<.001- .052	<.001
DOC (mg/L)	147	.30 - 10	.80
Total chemical constituent			
Fe (µg/L)	159	<10 - 44,000	180
Total dissolved solids (mg/L)	159	7 - 299	51
Chemical and physical properties measured in the field			
pH units	160	4.3 - 6.9	5.1
Alkalinity (mg/L as $CaCO_3$)	156	<1 - 130	6.0
Specific conductance (µS/cm)	160	10 - 633	85
Dissolved oxygen (mg/L)	154	<.1 - 12.1	7.6
Temperature (°C)	159	9.0 - 16.0	12.0

with oxidizable species, the most important being organic materials and reduced inorganic minerals, such as pyrite and siderite (Hem, 1986). The oxidation of pyrite, a mineral in the Chickies Quartzite, would be favored in the acidic and oxygen-rich ground water.

Dissolved and total iron concentrations greater than 1 mg/L were measured in water from wells in all areas. Concentrations of dissolved Mn and Fe exceed USEPA secondary maximum contaminant level (SMCL) standards for these constituents (50 µg/L and 300 µg/L, respectively) in 35 percent of the samples analyzed for Mn and 15 percent of the samples analyzed for Fe. Over the observed pH range, bivalent (reduced) Fe and Mn cations probably are stable in solution. Field determination of ferrous and total Fe at a few sites by use of a spectro-photometric method (American Public Health Association and others, 1975) showed that the ferrous form predominates, consistent with low-pH conditions.

The range of compositions shown on piper diagrams (figs. 3 and 4) indicates that the ground water in Chickies Quartzite does not have narrowly defined chemical character in terms of relative ion concentrations, although some differences in chemical character in different geographic areas and lithologies are indicated. Samples that have a cation-anion balance (difference less than 10 percent) are plotted on piper diagrams (figs. 3 and 4). In dilute waters, small differences or errors in ion concentrations have a large relative effect on composition. The sum of major cations for all samples ranges from 0.1 to 7.0 meq/L, with a median of 0.9 meq/L.

Na and K are the dominant cations in some ground-water samples, especially those from the central area and from the quartzite and conglomerate lithologies. In other water samples, especially those from the eastern and western areas and from the slate lithology, Ca and Mg are the dominant cations and HCO_3, and Cl (plus NO_3, when available) are the dominant anions. In a few water samples, mostly from the quartzite and conglomerate lithologies in the central area, SO_4 is the dominant anion. Ground water in the slate is less acidic (median pH is 6.4) than ground water in the conglomerate, quartzite, or slate quartzite (median pH of 5.0, 5.2, and 5.7, respectively).

Associations between major ions vary. The nonparametric Spearman rho correlation test performed on chemical constituents identified some statistically significant correlations at the 95-percent confidence interval (table 6). Na most strongly correlates with Cl and is associated to a successively lesser degree with NO_3 and other major ions. K most strongly correlates with NO_3 and less strongly with Cl and other major ions. Ca and Mg most strongly correlate with each other and with NO_3, Cl, Na, and SO_4, but less strongly with K, SiO_2, and alkalinity (HCO_3). Increases in all major cations are accompanied by increases in specific conductance. Relatively high pH correlates with high alkalinity and high SiO_2 and Ca concentrations and low K, Cl, and SO_4 concentrations. Relatively high DO concentrations correlate with low pH and alkalinity and low concentrations of all ions. Relatively high DOC concentrations correlate with low pH, high concentrations of most major ions, but low alkalinity and low SiO_2 concentrations.

Ba is similar to Ca in correlation with other ions except that relatively high concentrations of Ba, unlike Ca, correlate with low pH and alkalinity and low concentrations of SiO_2. Relatively high concentrations of Mn correlate with low pH and alkalinity, low concentrations of DO and SiO_2, and high concentrations of DOC, Ba, and most major ions. Although Fe (total and dissolved) also negatively correlates with DO, Fe, unlike Mn, only positively correlates with pH and alkalinity. The correlations for Mn and Fe suggest that these metals are present in relatively greater concentrations in reducing water (relatively low DO concentrations) but differ in their relation to other chemical constituents and pH. The correlations for NH_4, PO_4, and B are based on small numbers of samples having concentrations greater than the reporting level and may not indicate important ion associations; concentrations greater than reporting level were measured in 29 of 57 water samples for NH_4, in 21 of 58 samples for PO_4, and in 10 of 58 samples for B. NH_4 only correlates with K, and the positive correlation could reflect similar chemical properties as monovalent cations. Relatively high concentrations of PO_4 correlate with high pH and concentrations of SiO_2, and low concentrations of SO_4, Ba, Fe (total and dissolved), Mn, and DOC. B, probably present in ground water as undissociated boric acid, is similar to Cl and SO_4 in correlation with other chemical constituents and properties.

These ion associations indicate that the ground water in the Chickies Quartzite (1) is contaminated with nitrogen and salts, especially NaCl, from septic systems and(or) road salt; (2) partly reflects the weathering of Ca- and Mg-bearing silicate minerals; (3) tends to be more dilute where more oxygenated; and (4) is acidic and contains more Mn, Ba, SO_4, and K where concentrations of DOC are relatively high.

Spearman rho correlations are significant at the 95-percent confidence interval between specific capacity and NO_3 ($r_s = 0.70$) and also between specific capacity and Cl ($r_s = 0.39$), suggesting that contaminant transport (of contaminants from surface sources, such as septic tanks and road salt) increases with increasing hydraulic conductivity.

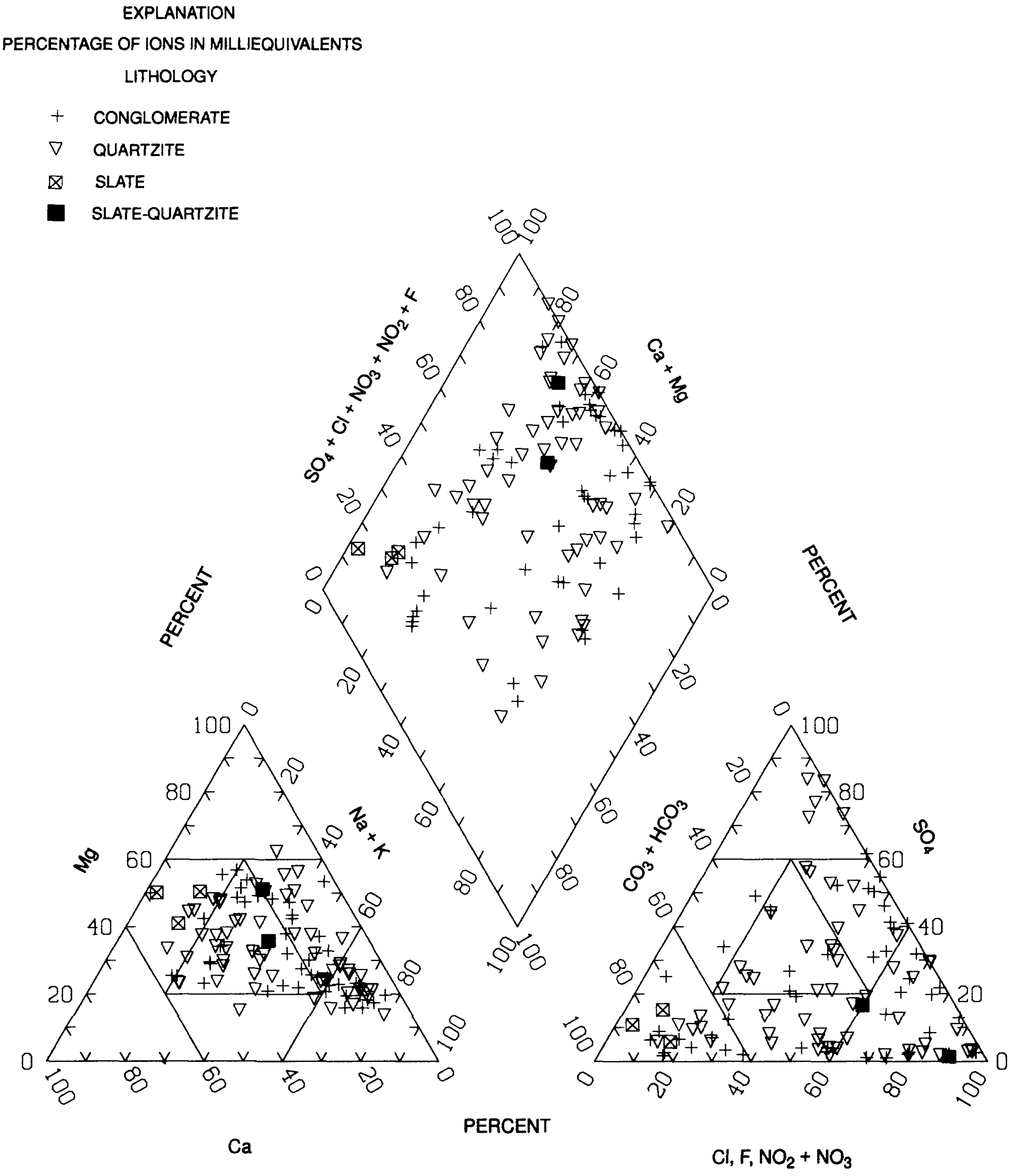


Figure 3. Chemical composition of ground water in the quartzite, conglomerate, slate, and slate-quartzite lithologies of the Chickies Quartzite.

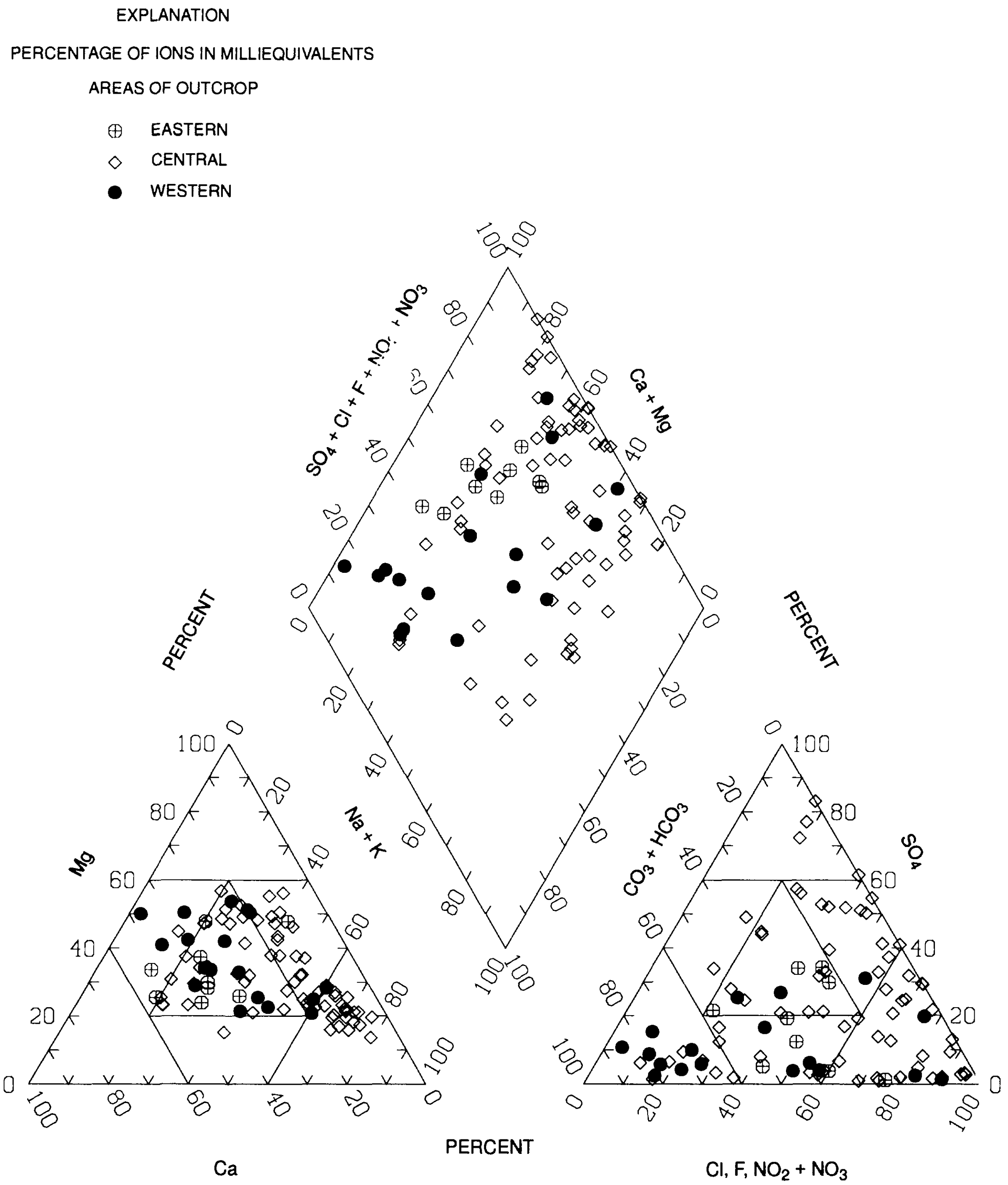


Figure 4. Chemical composition of ground water in the eastern, central, and western areas of outcrop of the Chickies Quartzite.

Table 6. Spearman rho correlations for selected chemical constituents in 160 well-water samples from the Chickies Quartzite. Correlations are significant at the 95-percent-confidence level

[x, correlation not significant]

	Ca	Mg	Na	K	Cl	SO_4	NO_3	Ba	SiO_2	F	B	Fe, total	Fe, dissolved	Mn	DOC	pH	Specific conductance	DO	Alkalinity	NH_4	PO_4
Ca	1																				
Mg	.84	1																			
Na	.59	.65	1																		
K	.32	.38	.45	1																	
Cl	.61	.70	.92	.48	1																
SO_4	.57	.59	.37	.27	.40	1															
NO_3	.62	.76	.71	.62	.73	.27	1														
Ba	.25	.41	.39	.43	.47	.38	.50	1													
SiO_2	.24	.17	x	.16	x	-.17	x	-.20	1												
F	.20	.26	x	x	x	.32	.41	.19	x	1											
B	.35	.38	.50	.39	.45	.29	.46	.30	x	x	1										
Fe, total	x	x	x	x	x	x	x	x	x	x	x	1									
Fe, dissolved	x	x	x	x	x	x	x	x	x	x	x	.66	1								
Mn	.28	.38	.22	.22	.22	.41	.34	.44	-.24	.37	.29	.31	.32	1							
DOC	.19	.27	.31	.39	.37	.50	.38	.52	-.44	.25	.41	x	x	.38	1						
pH	.25	x	x	-.18	-.16	-.17	x	-.48	.55	-.27	-.34	.24	.22	-.26	-.53	1					
Specific conductance	.80	.85	.82	.48	.84	.60	.78	.47	x	.21	.46	x	x	.35	.42	x	1				
DO	-.43	-.40	-.42	-.12	-.33	-.23	-.29	x	-.24	x	-.33	-.21	-.18	-.33	x	-.29	-.40	1			
Alkalinity	.33	.17	x	x	x	x	.x	-.35	.57	-.22	x	.30	.24	-.20	-.38	.65	x	-.41	1		
NH_4	x	x	x	.36	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	1	
PO_4	x	x	x	x	x	-.36	x	-.37	.32	x	x	-.39	-.49	-.41	-.37	x	x	x	.35	x	1

RADIUM AND RADON IN GROUND WATER

Radionuclides are present in ground water in variable concentrations because sources are present and physical and chemical conditions favor mobilization or retardation specific radionuclides in the ground-water-flow system. In the Chickies Quartzite, minerals in the aquifer are the sources of Ra and Rn in the ground water. Physical and chemical controls on the presence of Ra and Rn in ground water involve rock-water interactions and include aquifer mineralogy, chemical composition of recharge, aquifer hydraulic conductivity, and paths of ground-water flow. In this study, the spatial distribution of elevated Ra and Rn activities in ground water is described and related to factors that include sources within the aquifer, and lithology, aquifer and well-construction characteristics, ground-water chemistry, and hydrogeologic setting.

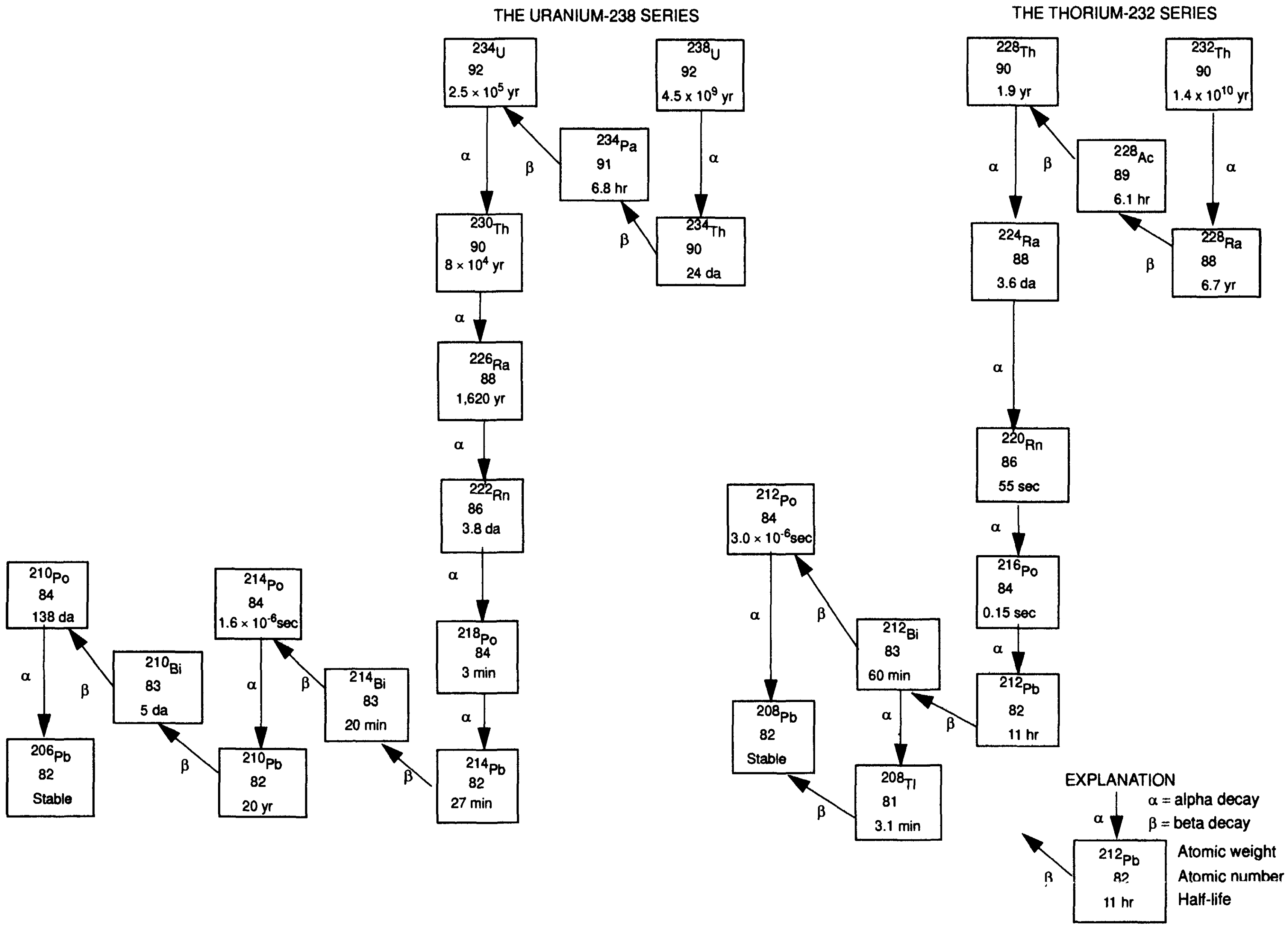
Ra-226, Ra-228, and Rn-222 are naturally occurring radionuclides that belong to the U-238 and Th-232 decay series (fig. 5). U-238 and Th-232 are the most abundant naturally occurring isotopes of U and Th and are the primary parents of the radioactive-decay series that ends in the stable isotopes lead-206 (Pb-206) and lead-208 (Pb-208), respectively. U-238 and Th-232 have long half-lives and, therefore, decay slowly. Other radionuclides in the decay series have half-lives many orders of magnitude shorter and decay rapidly. Ra-226 and Rn-222 belong to the U-238 series and Ra-228 belongs to the Th-232 series. A short-lived Rn isotope, Rn-220, also belongs to the Th-232 series, but its activity is difficult to measure because of its short half-life of 55.6 seconds.

Radioactive decay proceeds with alpha- or beta-particle emission and accompanying release of energy through gamma-ray and other electromagnetic radiation. Alpha particles are heavy, high-energy particles that do not travel far because matter impedes their progress and absorbs the particles' energy. Alpha particles are composed of two protons and two neutrons and are emitted from the nucleus of a radionuclide undergoing alpha decay. Beta particles are lighter, lower-energy particles that travel greater distances than alpha particles and, like alpha particles, can transfer kinetic energy to matter. Beta particles are electrons (or positrons) that are derived from the transformation of a neutron to a proton (or proton to neutron) during beta- (or beta+) decay. During radioactive decay, each radionuclide emits gamma rays of a specific energy and wavelength. Gamma radiation is not as effectively blocked by matter as are alpha and beta particles.

The activity of a radionuclide is a measure of the mass amount of the radionuclide and the rate of its decay. Activity is defined as being equal to $n \cdot \lambda$, where n is the number of atoms of the radionuclide and λ is the decay constant. The decay constant, λ, is equal to the natural log of 2 divided by the half-life of the radionuclide.

U-238 and Th-232 have fixed mass and activity ratios with their decay products in a closed system. A closed system can be defined as a given volume of solid, such as rock, or of a solid and liquid, such as rock and water, where no net gain or loss of radioactive decay products occurs by transport in or out of the system. Within a decay series, if no intermediate decay product is lost from the system, secular equilibrium is reached after a period dependent on the half-lives of isotopes in the series (approximately 10 half-lives of longest-lived intermediate radionuclide of the decay series). Secular equilibrium describes a state in which activities of all members of a decay series are equal, and mass ratios are fixed at some constant value. In an open system, transport of some decay products or parent radionuclides out of the system occurs, and secular equilibrium no longer prevails. Many ground-water systems are open systems at the local scale.

Differences in the chemical properties of radionuclides within a decay series may result in partitioning of the radionuclides within a closed physical-chemical system. If the system is open, partitioning of radionuclides may result in transport out of the system. Each isotope is chemically like any other isotope of the same element; conditions favoring mobility of U, for example, would equally favor mobility of U-238, U-234, and U-235. Physical mechanisms associated with radioactive decay, however, may cause one isotope to move in or out of a system more easily than another. For example, alpha recoil of the product nucleus in alpha decay (Friedlander and others, 1981) may promote ejection of U-234 from a solid (crystal structure or disordered surface condition).



[U, uranium; Th, thorium; Pa, protactinium; Ra, radium; Po, polonium; Pb, lead; Bi, bismuth; Ac, actinium; Tl, thallium]
[yr, year; da, day; hr, hour; min, minute; sec, second]

Figure 5. Uranium-238 and thorium-232 decay series (From U.S. Environmental Protection Agency, 1981).

Generally, U, Th, and Ra are soluble under different geochemical conditions. U is most soluble in oxidizing waters in the +6 oxidation state (especially as a uranyl complex UO_2^+) and in the +8 oxidation state (uranyl carbonates at pH greater than 8) (Langmuir, 1978). Th only is found in the +4 oxidation state and has low solubility, but it is soluble in strongly acidic waters (Langmuir and Herman, 1980). Ra only is found in the +2 oxidation state and is most mobile in reducing, Cl-rich ground water with elevated TDS (Tanner, 1964). Solubility of U and Th is strongly enhanced by complexation; the extent of Ra complexation is not well known (Langmuir and Riese, 1985).

Sources in the Rocks of the Chickies Quartzite

Solid-phase analysis of the Chickies Quartzite was conducted to determine sources of Ra and Rn in the ground water of the formation. Natural-gamma-ray geophysical logs were run in recently drilled wells to determine the vertical distribution of radioactivity in the formation and to identify radioactive zones or strata. Most logged wells were drilled during the study and, when possible, well cuttings were collected at 5-ft intervals. Water from most of these wells was later sampled for laboratory analysis of chemical constituents, including Ra and U. Gamma-ray logs were used to select well-cutting samples for solid-phase analyses. Rock samples of the conglomerate, quartzite, and slate lithologies were collected at several quarries and road cuts and from cuttings of recently drilled wells. Results of rock-sample analyses for total Th and U; Ra-226, Ra-228, and some other radionuclides in the U-238 and Th-232 decay series; and potential mineral hosts for U and Th are discussed below.

Natural-gamma-ray logs were run in 31 wells penetrating the Chickies Quartzite, underlying Precambrian crystalline rocks, and Antietam Quartzite and Harpers Phyllite. The wells penetrating the Chickies Quartzite represent the conglomerate and quartzite lithologies in the western and central areas and include one well in the Hellam Hills in York County; 1 well on Gap Hill in Lancaster County; 14 wells on Welsh Mountain in Lancaster and Chester Counties; and 5 wells, in the Barren Hills in Chester County (pl. 1). Natural-gamma-ray and caliper logs for all 31 wells are presented in the appendix.

Generally, the magnitude and distribution of natural-gamma-ray activity is related to lithology. The lowest measured natural-gamma-ray activity is associated with clean, white, pale pink, and gray quartzite that crops out in the Welsh Mountains and Barren Hills and corresponds to the quartz arenite facies of Hyde (1971). The maximum measured natural-gamma-ray activity is associated with the conglomerate that crops out in the Hellam Hills in York County and the Barren Hills in Chester County. Examples of the relations between lithology and gamma-ray logs are shown in figures 6-9.

The gamma-ray logs for wells drilled into the white, pale gray, and pink quartzite (CH-3166, LN-1702, LN-1703, and upper sections of CH-3213, CH-3219, and CH-3315) show gamma activities of about 50 cps (counts per second) and little variability. The gamma-ray logs for wells drilled into gray and dark-gray quartzite (CH-3160, CH-3305, and lower sections of CH-3213, CH-3219, and CH-3315) and in rusty-colored quartzite (CH-3189 and LN-1716) show gamma activities up to 250 cps, which are higher than “cleaner” quartzites. A down-section increase in gamma activity is shown on the log for well CH-3219 drilled into light and dark quartzite (fig. 6).

Natural-gamma-ray logs of the conglomerate include wells CH-3131, CH-3133, and YO-1172 and the upper sections of CH-3122 and CH-3188. Figure 7 shows that natural-gamma-ray logs of wells in the conglomerate (such as CH-3133 and YO-1172) have rock that contains higher background and peak radioactivity than clean, white, pink and pale gray quartzite (such as wells LN-1702 and CH-3166). Geophysical logging of well CH-3122 (fig. 8) identified increased gamma activity near the contact between the Chickies Quartzite and the underlying mafic gneiss. The lithologic log of the well describes a comparatively dark quartzite and conglomeratic quartzite containing small blue pebbles near the contact. Subsequent logging of wells LN-1713 (fig. 8) and LN-1715 located near the Chickies

Quartzite-crystalline rock contact on Welsh Mountain in Lancaster County also indicated some increase in gamma activity near the contact, suggesting that the conglomerate is more radioactive than the overlying, cleaner quartzite. The magnitude of peak gamma activity in well CH-3122 at a depth of about 210 ft, the largest peak observed, is more than twice that of the peak in well LN-1713. The logs of well CH-3188 (fig. 8), which penetrates the contact between the Chickies Quartzite and underlying crystalline rock, show a smaller increase in gamma activity near the contact, suggesting the concentration of gamma emitting material is variable. Lateral and vertical variability of radioactive and other minerals in the Chickies Quartzite reflects the original depositional variability of the sedimentary-rock precursor.

Natural-gamma-ray logs of wells drilled into the Harper's Phyllite and Antietam Quartzite in York County (YO-1169, YO-1170, and YO-1171) show that these rocks contain background and peak radioactivity similar to the dark gray quartzite of the Chickies Quartzite (fig. 9).

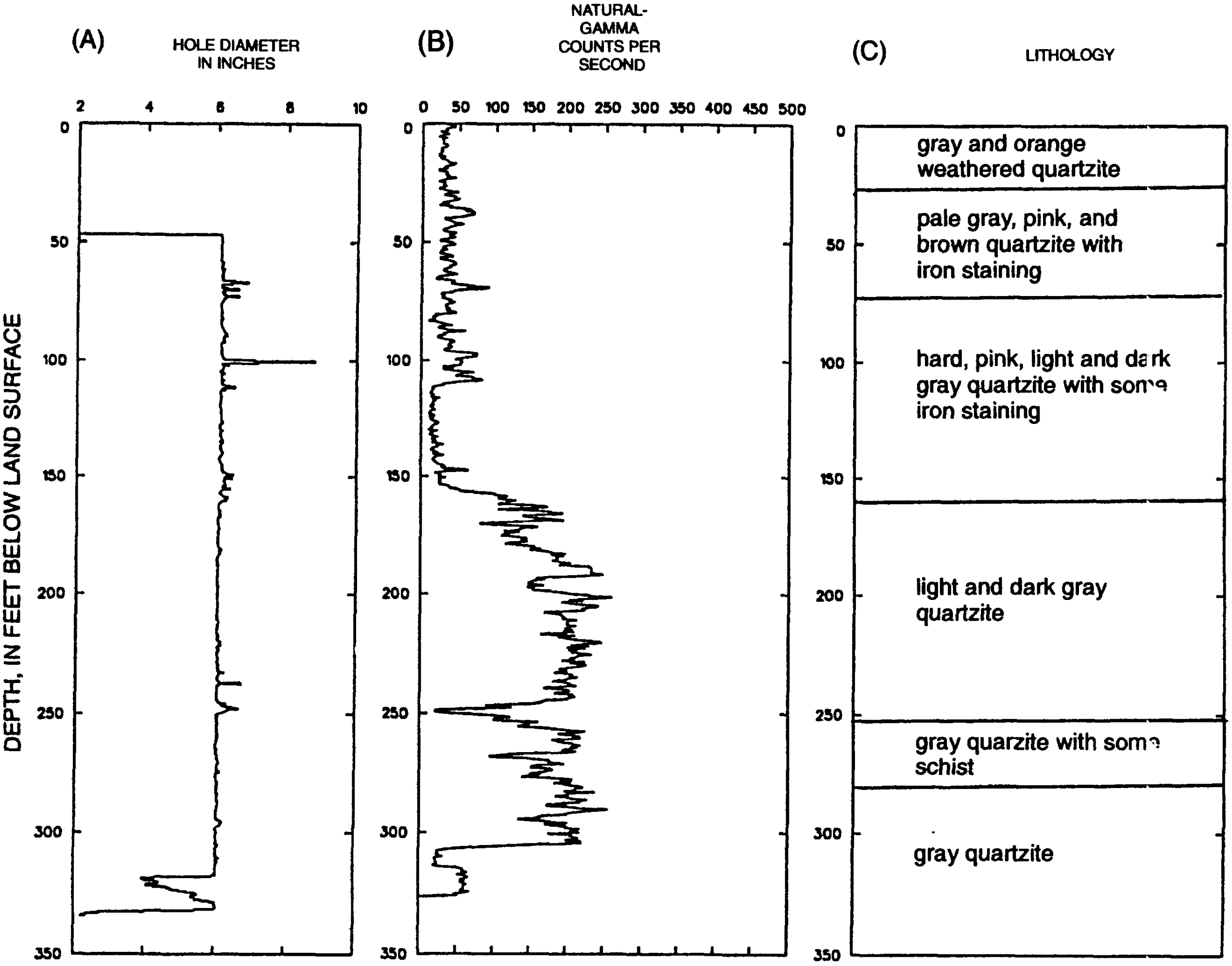


Figure 6. Caliper (A), natural-gamma-ray (B), and lithologic (C) logs for well CH-3219.

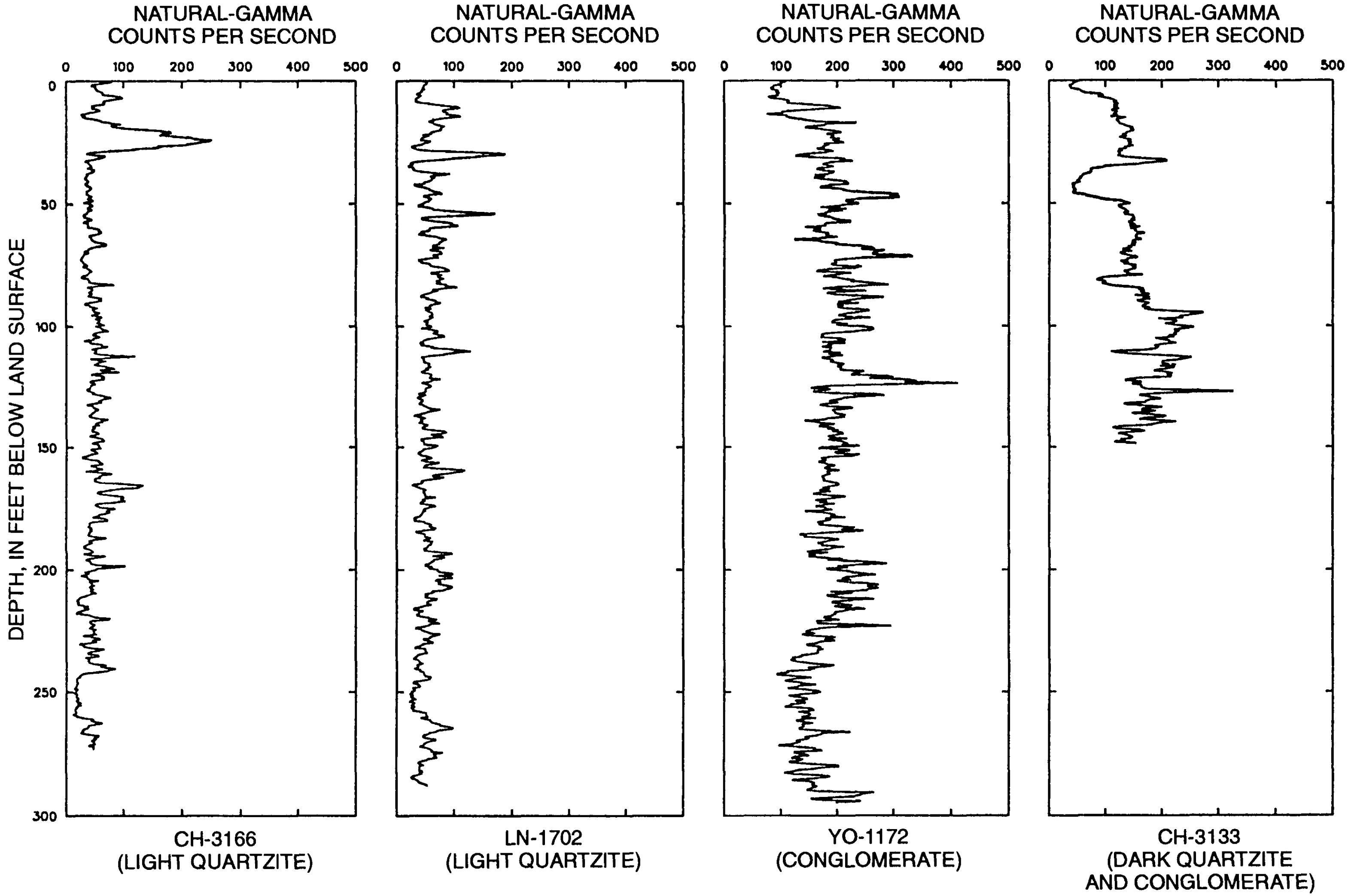


Figure 7. Natural-gamma-ray logs for wells drilled into light-colored quartzite, dark-colored quartzite, and conglomerate of the Chickies Quartzite.

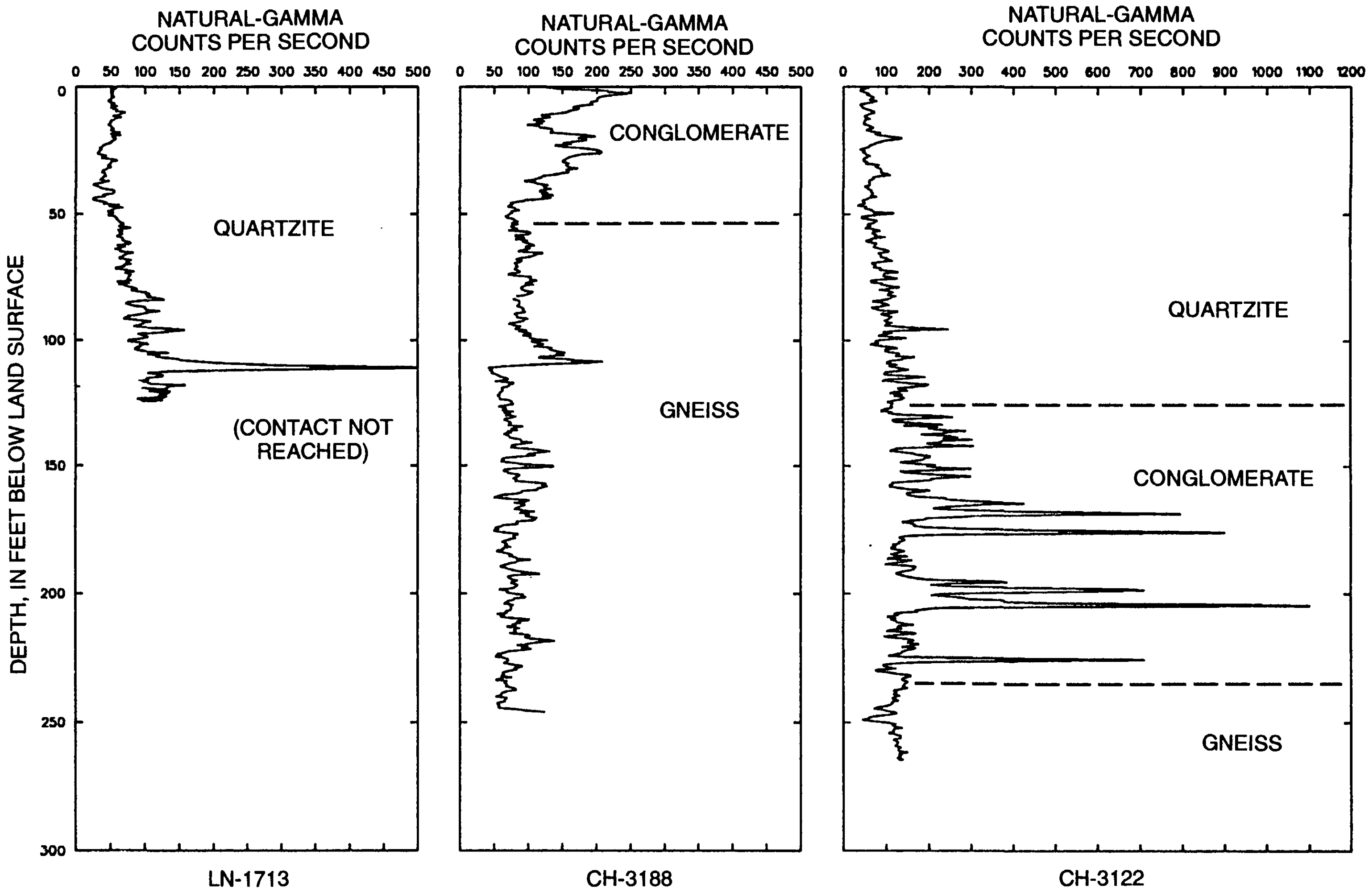


Figure 8. Natural-gamma-ray logs for wells LN-1713, CH-3122, and CH-3188 drilled at the Chickies Quartzite contact with underlying Precambrian crystalline-rock units.

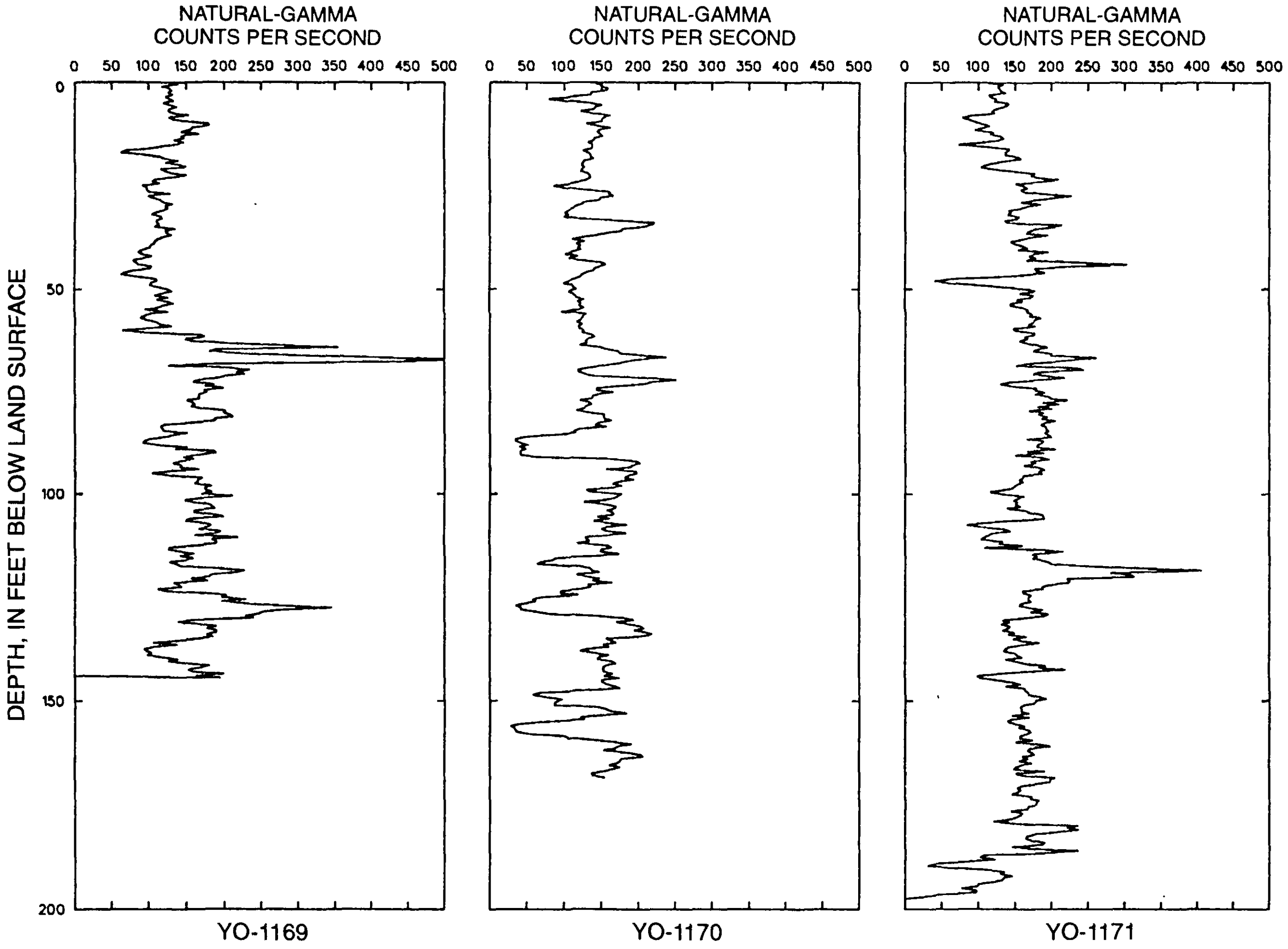


Figure 9. Natural-gamma-ray logs of wells drilled into the Harpers Phyllite and Antietam Quartzite (YO-1169, YO-1170, and YO-1171). Lithology is dark gray quartzite and phyllite.

Radioactive Elements and Isotopes

Elevated activities of Ra and Rn in ground water may be associated with enriched concentrations of U, Th, or Ra in the mineral grains or matrix of the solid phase. In sandstone and quartzite, U and Th are contained in detrital primary minerals and in secondary minerals. Detrital U- and Th-bearing primary minerals from crystalline source rocks, especially resistates such as zircon and monazite, may be concentrated in rocks by sedimentary processes. Primary minerals form by crystallization during cooling of igneous melts and during metamorphism. Secondary minerals form by precipitation from aqueous solutions containing dissolved components of primary minerals. The initial U, Th, and Ra content of rocks can be altered by subsequent diagenetic, metamorphic, and weathering processes that leach or deposit those elements. Migration of U, Th, and Ra causes enrichment or depletion of these elements in some rocks or zones within rocks.

Among sedimentary rocks, U, Th, and Ra contents are greater on the average in shales than in limestones, sandstones, and quartzites (table 7), although U and Th enrichment is possible in all of these rock types (Durrance, 1986). Precambrian source rocks may have contained more U than do average rocks of younger ages (Durrance, 1986). Precambrian source rocks for the Chickies Quartzite could have included igneous, metamorphic, and sedimentary rocks, and reworked unconsolidated sediments.

Table 7. Average uranium and thorium content of the earth's crust and some sedimentary and igneous rocks (from Durrance, 1986, p. 31-33)

[ppm, parts per million]

	Th (ppm)	U (ppm)	Th/U [1] mass ratio	Th/U [2] activity ratio
Earth's crust	8.5	2.7	3.2	1.1
Sandstone	1.7	.45	3.8	1.3
Shale	12	3.7	3.2	1.1
Limestone	1.7	2.2	.8	.3
Basalt	4	1	4.0	1.3

[1] Mass ratio calculated from average Th and U values.

[2] Activity ratio calculated by use of the approximation that the activity of 9 ppm Th = 1 pCi/g and the activity of 3 ppm U = 1 pCi/g, assuming most Th is Th-232 and most U is U-238.

Uranium and thorium

Rock samples of the Chickies Quartzite were analyzed for U and Th to determine the concentrations of U and Th in the formation and the relation between U and Th concentrations in the rock and Ra-226, Ra-228, and Rn-222 activities in the ground water. Analyses for activities of radionuclides in the U-238 and Th-232 decay series, including Ra-226 and Ra-228, may indicate whether or not secular equilibrium is maintained, the degree of secular disequilibrium, and whether preferential leaching or accumulation of radionuclides is suggested.

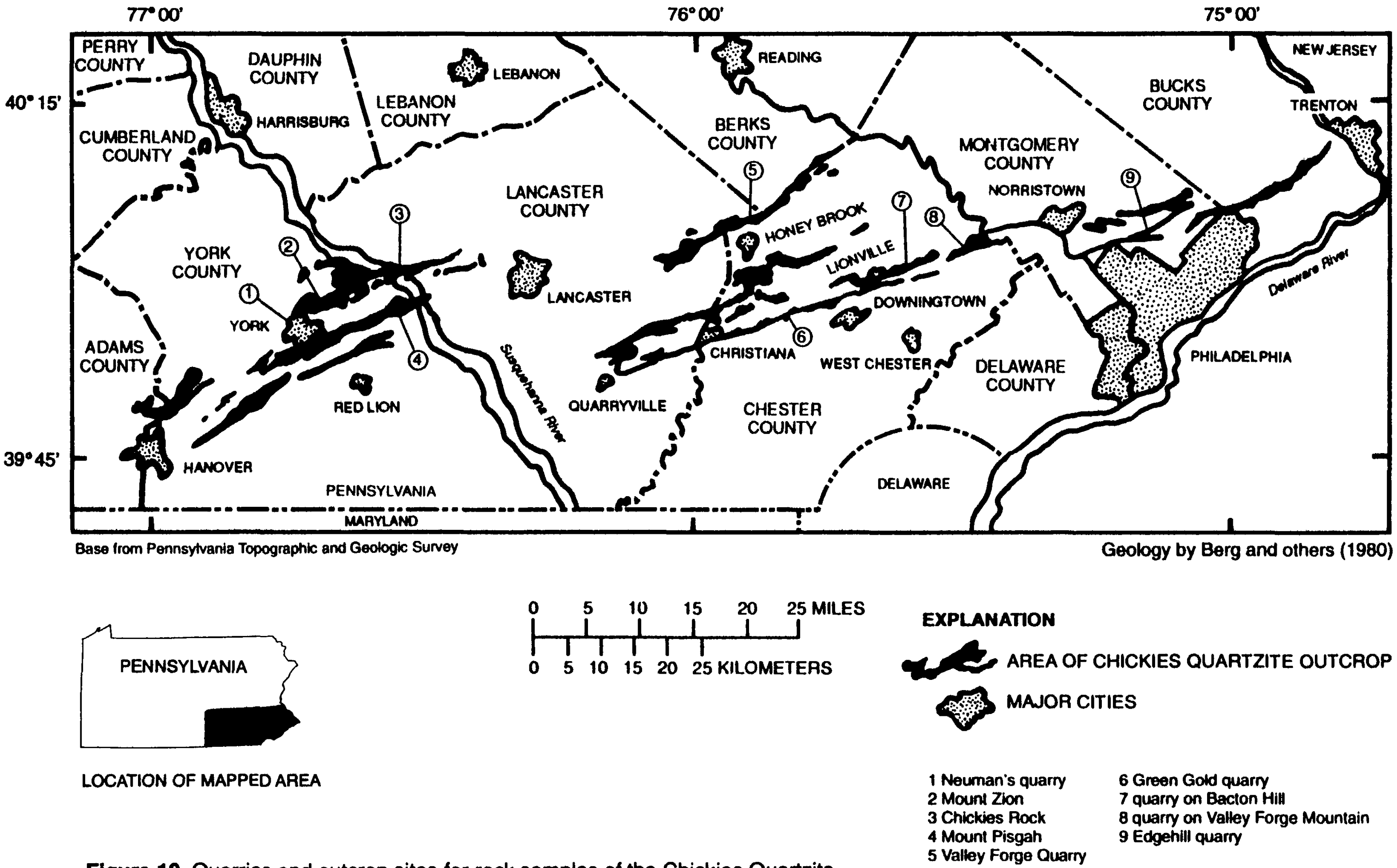
Rock samples and well cuttings analyzed for U and Th were collected in different geographic areas and are from outcrops and subsurface rocks of different lithologies of the Chickies Quartzite and adjacent geologic units. Sample locations of seven rock samples from six quarries in the quartzite and five hand samples from four outcrops of the quartzite, conglomerate, and slate lithologies of Chickies Quartzite are shown in figure 10. Well cuttings are from 18 wells drilled into the Chickies Quartzite, underlying crystalline rock and overlying phyllite and quartzite in the central and western areas of outcrop (pl. 1). Because well-cutting samples were not selected randomly and the limited number of sample sites and samples per site and lithology, rock samples may not be representative of the formations and provide only reconnaissance data on U and Th content.

Forty-one samples of well cuttings from 18 wells were analyzed, including samples from several different depths in 10 wells. Eight wells were drilled into the quartzite lithology and six were drilled into the conglomerate lithology of the Chickies Quartzite, one was drilled through the Chickies Quartzite into underlying crystalline rock, and three were drilled into the Antietam Quartzite and Harpers Phyllite. Well cuttings generally are a composite sample of a 5-ft drilling interval. Most cuttings were selected from zones where geophysical logs showed elevated gamma activity. For comparison, a few samples from zones with low gamma-ray activity also were analyzed.

All of the 12 quarry samples are quartzite or sericitic quartz schist. Two quarries in Chester County, the Valley Forge quarry in Honeybrook and the Green Gold quarry in Parkesburg, are active; the others are inactive. Samples from the Valley Forge quarry-screen pile are assumed to be representative of the bulk composition of the formation in the quarry area. All other quarry and rock samples were single hand samples and may not be representative of the formation at the site.

The concentrations of U and Th in rock samples and well cuttings of the Chickies Quartzite and adjacent geologic units are given in table 8 and are summarized for the Chickies Quartzite samples in table 9. The highest Th and U concentrations analyzed in samples of the Chickies Quartzite are from zones of peak gamma activity associated with conglomerate near the crystalline-rock contact in well CH-3122 (fig. 11) and were 61 ppm Th and 8.1 ppm U. The lowest Th and U concentrations are from a zone of low gamma activity associated with light quartzite in well CH-3315 (fig. 11) and were 2.2 ppm Th and 0.8 ppm U. The U and Th concentrations in quartzite and conglomerate rock samples from the Chickies Quartzite are greater than those concentrations for average sandstones; and the U and Th concentrations in the slate lithology samples of the Chickies Quartzite are similar to those in an average shale (table 7).

Analyses of the quarry, rock, and well-cutting samples suggest that U content of the lithologies of the Chickies Quartzite in all areas varies less than the Th content, especially in the conglomerate. Some samples of the conglomerate are enriched in Th with respect to U, as indicated by Th concentrations and Th/U activity ratios greater than the mean crustal average (table 7). Elevated Th concentrations in sandstones may be associated with the presence of heavy minerals, such as monazite (Durrance, 1986). Average Th/U activity for rocks with crustal abundance of U and Th is about 1.1, although estimates range as great as 1.6 (Mason, 1958); most samples of the Chickies Quartzite have Th/U activity ratios in this range. Generally, the Th/U mass and activity ratio is greatest in the conglomerate, comparatively less in the slate, and least in the quartzite. In the quartzite lithology, the dark quartzite and sericitic quartz schist samples have a higher Th/U mass ratio than clean quartzite.



Base from Pennsylvania Topographic and Geologic Survey

Geology by Berg and others (1980)

Figure 10. Quarries and outcrop sites for rock samples of the Chickies Quartzite.

Table 8. Uranium and thorium content of well cuttings and rock samples determined by neutron activation analysis

[ppm, parts per million; Ꞓc, Chickies Quartzite; Ꞓah, Harper's Phyllite and Antietam Quartzite, undivided; Yhma, mafic gneiss; --, no data]

Well number	Depth of sample (feet	Th (ppm)	U (ppm)	Th/U mass ratio	Geologic unit	Lithology
Well cuttings						
CH-3122	105	9.3	6.8	1.4	Ꞓc	conglomerate
CH-3122	175	31	5.2	6.0	Ꞓc	conglomerate
CH-3122	205	43	6.6	6.5	Ꞓc	conglomerate
CH-3122	210	61	8.1	7.5	Ꞓc	conglomerate
CH-3122	235	6.8	2.1	3.2	Ꞓc	conglomerate
CH-3122	265	.5	.6	.8	Yhma	mafic gneiss
CH-3122	275	.4	2.3	.2	Yhma	mafic gneiss
CH-3131	135	12	4.3	2.8	Ꞓc	conglomerate
CH-3133	115	4.9	2.3	2.1	Ꞓc	conglomerate
CH-3133	135	11	2.9	3.8	Ꞓc	conglomerate
CH-3133	140	5.3	2.4	2.2	Ꞓc	conglomerate
CH-3133	145 - 150	5.6	2.3	2.4	Ꞓc	conglomerate
CH-3166	225 - 230	3.9	1.2	3.3	Ꞓc	quartzite (light)
CH-3189	75	13	3.2	4.1	Ꞓc	quartzite (rusty)
CH-3213	180 - 185	7.6	2.7	2.8	Ꞓc	quartzite (dark)
CH-3213	205 - 210	13	3.2	4.1	Ꞓc	quartzite (dark)
CH-3213	210 - 215	16	4.3	3.7	Ꞓc	quartzite (dark)
CH-3219	90 - 95	4	1.4	2.9	Ꞓc	quartzite (light)
CH-3219	205 - 210	13	3.2	4.1	Ꞓc	quartzite (dark)
CH-3219	295 - 300	10	3.4	2.9	Ꞓc	quartzite (dark)
CH-3305	125 - 130	10	3.7	2.7	Ꞓc	quartzite (dark)
CH-3305	135 - 140	7.6	2.6	2.9	Ꞓc	quartzite (dark)
CH-3315	100	2.2	.8	2.8	Ꞓc	quartzite light)
CH-3315	170	15	3.8	4.0	Ꞓc	quartzite (dark)
CH-3315	200	11	3.6	3.1	Ꞓc	quartzite (dark)
CH-4146	--	15	4.0	3.8	Ꞓc	conglomerate
LN-1702	221 - 226	4.8	1.8	2.7	Ꞓc	quartzite (light)
LN-1713	115	13	3	4.3	Ꞓc	conglomerate
LN-1713	120	5.4	1.9	2.8	Ꞓc	conglomerate
LN-1715	110 - 115	6.2	6.2	1	Ꞓc	conglomerate
LN-1715	120 - 125	7.5	2.6	2.9	Ꞓc	conglomerate
LN-1716	55	13	3.9	3.3	Ꞓc	quartzite (rusty)
LN-1716	98	13	4.5	2.9	Ꞓc	quartzite (rusty)
YO-1169	70 - 75	31	5.7	5.4	Ꞓah	quartzite-phyllite
YO-1170	105 - 110	13	3.6	3.6	Ꞓah	quartzite-phyllite
YO-1171	125 - 130	20	4.5	4.4	Ꞓah	quartzite-phyllite
YO-1172	130 - 135	20	2.6	7.7	Ꞓc	conglomerate
YO-1172	200 - 205	10	2.2	4.6	Ꞓc	conglomerate
YO-1172	210 - 215	10	2.2	4.6	Ꞓc	conglomerate
YO-1172	215 - 220	16	4	4	Ꞓc	conglomerate
YO-1172	260 - 265	10	1.7	5.9	Ꞓc	conglomerate

Table 8. Uranium and thorium content of well cuttings and rock samples determined by neutron activation analysis --Continued

Sample location	Th (ppm)	U (ppm)	Th/U mass ratio	Geologic unit	Lithology
Quarry rocks and hand samples					
Valley Forge Quarry	8.2	3.1	2.7	Ꞓc	quartzite (light)
Valley Forge Quarry	5.8	3.1	1.9	Ꞓc	quartzite (light)
Green-Gold Quarry	5.3	1.6	3.3	Ꞓc	sericitic schist
Neuman's Quarry	5.5	2.3	2.4	Ꞓc	quartzite (light)
Quarry on Bacton Hill	3.1	1.6	1.9	Ꞓc	quartzite (light)
Quarry near Valley Forge	5.8	2.8	2.1	Ꞓc	quartzite (light)
Quarry on Edgehill Rd.	9.6	1.7	5.7	Ꞓc	sericitic schist
Chickies Rock	3.9	1.2	3.3	Ꞓc	quartzite (light)
Mt. Zion	40	2.8	14	Ꞓc	conglomerate
Mt. Pisgah	14	2.8	5	Ꞓc	slate
Mt. Pisgah	13	3	4.3	Ꞓc	slate
Bacton Hill	29	2.7	11	Ꞓc	conglomerate

Table 9. Summary of uranium and thorium content of well cuttings and rock samples of the conglomerate, quartzite, and slate lithologies of the Chickies Quartzite

[ppm, parts per million]

Sample source	Number of samples	Th (ppm) Range Median	U (ppm) Range Median	Th/U mass ratio Range Median	Th/U activity ratio[1] Range Median
Well cuttings					
Quartzite (light)	4	2.2 - 4.8	0.8 - 1.8	2.7 - 3.3	0.9 - 1.1
		4.0	1.3	2.9	1.0
Quartzite (dark)	12	7.6 - 16	2.6 - 4.5	2.7 - 4.1	.9 - 1.4
		13	3.5	3.2	1.1
Conglomerate	20	4.9 - 60	1.7 - 8.1	1.0 - 7.7	.3 - 2.6
		10	2.8	3.9	1.3
Quarry rocks and hand samples					
Quartzite (light)	6	3.1 - 8.2	1.2 - 3.1	1.9 - 3.3	.6 - 1.1
		5.7	2.6	2.3	.8
(schist)	2	5.3 - 9.6	1.6 - 1.7	3.3 - 5.7	1.1 - 1.9
		7.4	1.7	4.5	1.5
Conglomerate	2	29 - 40	2.7 - 2.8	11 - 14	3.6 - 4.8
		35	2.8	13	4.0
Slate	2	13 - 14	2.8 - 3.0	4.3 - 5.0	1.4 - 1.7
		14	2.9	4.7	1.6

[1] Activity ratio calculated by use of the approximation that the activity of 9 ppm Th = 1 pCi/g and the activity of 3 ppm U = 1 pCi/g.

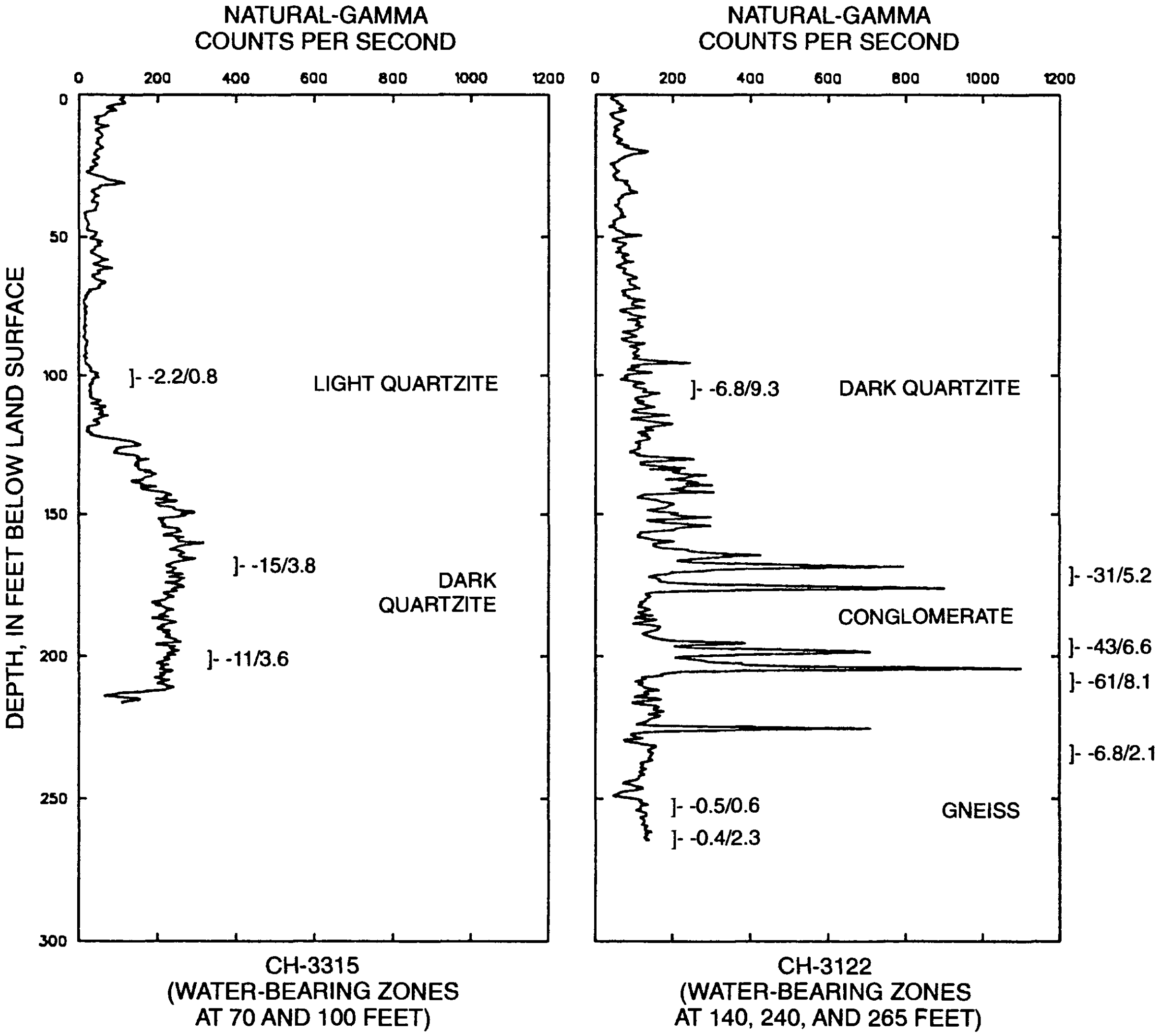


Figure 11. Natural-gamma-ray logs of wells CH-3315 and CH-3122. Annotated values are thorium/uranium content in parts per million for well cuttings from indicated depth intervals.

For comparison, well cuttings from geologic units adjacent to the Chickies Quartzite were analyzed (table 8). Low U and Th concentrations were measured in well cuttings of mafic gneiss (well CH-3122 at depths of 265 and 275 ft), the underlying crystalline rock in the Barren Hills of the central area; the low concentrations are consistent with the average for mafic rocks (basalt, table 7). The U and Th content of the Harpers Phyllite and Antietam Quartzite well cuttings from York County (YO-1169, YO-1170, and YO-1171) are as great or greater than content of the Chickies Quartzite.

U-238 and Th-232 decay series radionuclides

Secular equilibrium can be determined by comparing the activities of members within the U-238 or Th-232 decay series. In the absence of secular equilibrium, inferences may be drawn about the losses from or gains to the solid phase in the aquifer. In a natural ground-water system, loss of radionuclides from the rock can occur by alpha recoil, dissolution of minerals, and radon gas emanation.

The first radionuclide in the U-238 decay series measured by gamma-ray spectrometry is Th-234, the product of U-238 alpha decay (fig. 5). No significant losses from a system are expected to occur between U-238 and Th-234; therefore, activities of U-238 estimated from total U concentration and activities of Th-234 should be equal. Comparison of Ra-226 and Th-234 activities should indicate if Ra-226 or intermediate U-234 has been lost from the rock. The first radionuclide in the Th-232 decay series measured by gamma-ray spectrometry is actinium-228 (Ac-228), the product of Ra-228 beta decay (fig. 5). The activity of Ac-228, the short-lived daughter of Ra-228, is a good estimator of Ra-228 activity. Comparison of Ac-228 and Th-232 activity estimated from total Th concentration may indicate whether or not Ra-228 has been lost from the rock.

A total of 17 well-cutting samples from 10 wells were analyzed by gamma-ray spectrometry (table 10) to determine the activity of some members of the U-238 and Th-232 decay series. K-40 activity is also reported and contributes to the total gamma activity measured by geophysical logging. Total U and Th concentrations were determined by neutron activation analysis for all 17 samples (table 10). For some of the samples, estimates for U-238 and Th-232 activities from total U and Th concentrations are lower than those extrapolated from Th-234 and Ac-228 activities determined by gamma-ray spectrometry. Uncertainties and bias of each method and underlying assumptions are beyond the scope of this report.

Table 10. Solid-phase activities of uranium-238 and thorium-232 series radionuclides and potassium-40 determined by gamma-ray spectrometry of well-cutting samples from the Chickies Quartzite

[pCi/g, picocuries per gram; <, less than]

Well number	Depth of sample (feet)	U-238 series					Th-232 series				K-40
		U-238 [1]	Th-234	Ra-226	Pb-214	Bi-214	Th-232 [1]	Ac-228	Pb-212	Tl-208	
CH-3122	175	1.7	3.0	2.4	1.6	1.4	3.4	3.8	3.4	3.3	14
CH-3122	235	.7	<1.0	1.9	.85	.54	.8	1.4	1.2	.77	16
CH-3122 [2]	265	.2	< .5	< .7	.27	.34	.1	< .2	.65	< .1	43
CH-3131	135	1.4	<2.0	2.6	1.6	1.3	1.3	2.0	1.7	1.5	16
CH-3133	135	1.0	<1.0	<2.0	1.3	.99	1.2	1.9	2.0	1.3	5.3
CH-3133	145-150	.8	< .9	<1.0	.76	.62	.6	.95	.85	.69	24
CH-3189	75	1.1	<2.0	<2.0	.92	1.1	1.4	1.6	1.8	1.3	39
CH-3213	205-210	1.1	<2.0	2.2	.94	.8	1.4	1.9	1.7	1.5	49
CH-3213	210-215	1.4	2.9	2.2	1.3	1.1	1.8	1.8	1.7	1.5	59
CH-3219	205-210	1.1	2.0	2.0	1.5	1.1	1.4	2.6	1.7	1.6	82
CH-3219	295-300	.5	<2.0	<2.0	1.6	1.3	1.1	2.5	1.7	2.0	93
CH-3315	170	1.3	1.6	2.1	1.3	1.1	1.7	2.1	2.1	1.7	73
YO-1169	70- 75	1.9	2.9	2.7	1.7	1.4	3.4	3.6	3.1	3.1	32
YO-1171	125	1.5	1.7	2.7	1.4	1.3	2.2	2.7	2.7	2.4	32
YO-1172	130-135	.9	< .9	1.6	.89	.64	2.2	2.4	2.2	2.2	23
YO-1172	200-205	.7	< .7	1.3	.75	.65	1.1	1.4	1.3	1.2	14
YO-1172	210-215	.7	< .6	1.2	.62	.52	1.1	1.3	1.0	1.0	14

[1] U-238 and Th-232 activities calculated from mass of U and Th (determined by neutron activation analysis) by use of the approximation that 1 pCi/g U-238 = 3 ppm U and 1 pCi/g Th-232 = 9 ppm Th.

[2] Mafic gneiss.

Comparison of Ra-226 and Ac-228 activities with U-238 and Th-232 activities calculated from masses of U and Th, respectively, and comparison of Ra-226 with Th-234 activities indicates no apparent loss of Ra from the solid phase; however, differences in accuracy and magnitude of errors in analytical methods may not permit exact comparison by ratio of radionuclides in a series. Generally, activities of Pb-214 in the U-238 series and Pb-212 in the Th-232 series are less than activities of Rn-226 and Ac-228, respectively. Both Pb-214 and Pb-212 occur after Rn-222 and Rn-220 in their respective series (fig. 5). The relatively low Pb-214 and Pb-212 activities may reflect loss of Rn gas from the solid phase.

The maximum K-40 activity was measured for well cuttings of light-colored quartzites (wells CH-3213, CH-3219, and CH-3315). The minimum K-40 activity was measured in well cuttings of mafic gneiss (well CH-3122 at a depth of 265 ft) and conglomerates (wells CH-3122, CH-3131, CH- 3133, and YO-1172). Potassium feldspar is a possible source of K-40 in the light-colored quartzites.

Six well-cutting samples were analyzed for Ra-226 and Ra-228 activities (table 11). The samples were from zones of high, moderate, and low gamma activity in three wells drilled within one half-mile of each other into the conglomerate and quartzite lithologies of the Chickies Quartzite. The Th and U concentrations in these six well-cutting samples also were determined by neutron activation analysis (table 8). One sample (CH-3133 at depth of 135 ft) was analyzed by gamma-ray spectrometry as well.

Activities of Ra-226 and Ra-228 are from 7 to nearly 100 percent less than those calculated for U-238 and Th-232 (table 11); these lower activities suggest that Ra-226 and Ra-228 may have been lost from the rock through natural processes. Although the mean percentage lost is about the same for Ra-226 and Ra-228, the proportion of Ra-226 lost is less variable than the proportion of Ra-228 lost from the rock samples; the variance of percentage of Ra-226 lost is significantly less than for Ra-228 as determined statistically by the nonparametric squared ranks test (Conover, 1980). The difference in the losses of Ra-226 and Ra-228 from the solid phase may reflect different mineral hosts or loss mechanisms for Th-232 and U-238 decay series radionuclides. Although the Th/U mass ratios and approximately equivalent activity ratios of rock samples for the Chickies Quartzite are within the range of <1.0 to 14.2 (table 9) and <0.3 to 4.7, respectively, observed activity ratios of the Th and U daughter products (Ra-228/Ra-226) in the aqueous phase may be different because leaching rates for the two Ra isotopes differ.

Table 11. Radium-226 and radium-228 activities, calculated uranium-238 and thorium-232 activities, and percent radium-226 and radium-228 loss for six well-cutting samples from the Chickies Quartzite

[pCi/g, picocuries per gram; --, no data]

Well number	Depth of sample (feet)	U-238 [1](pCi/g)	Ra-226	Percent Ra-226 loss	Th-232 (pCi/g)	Ra-228 (pCi/g)	Percent Ra-228 loss	U-238/Th-232 activity ratio	Ra-228/Ra-226 activity ratio
CH-3122	105	2.3	1.11	52	1.0	0.32	68	0.4	0.3
CH-3122	205	2.2	1.70	21	4.8	4.46	7	2.2	2.6
CH-3122	210	2.7	1.54	43	6.8	4.60	32	2.5	3.0
CH-3133	135	1.0	.42	58	1.2	0	100	--	--
CH-3133	140	.8	.45	44	.6	.47	22	.8	1.0
CH-3213	180 - 185	.8	.44	45	.9	.42	53	1.1	1.0

[1] U-238 and Th-232 activities calculated from mass of U and Th (determined by neutron activation analysis) by use of the approximation that 1 pCi/g U-238 = 3 ppm U and 1 pCi/g Th-232 = 9 ppm Th.

Radioactive Minerals

U- and Th-bearing heavy minerals, such as zircon and monazite, in the Chickies Quartzite are potential sources of Ra and Rn in the ground water. Generally, zircon can contain up to 13.1 percent Th and 2.7 percent U, and monazite can contain up to 26.5 percent Th and 0.1 percent U (Frondel and others, 1967; Durrance, 1986). Other possible sources are secondary minerals that may be the product of primary mineral weathering or such minerals as iron or other metal oxides that adsorb or incorporate U, Th, or Ra.

Heavy-mineral separations of well cuttings from wells YO-1172, CH-3122, and LN-1715 yielded magnetite, zircon, rutile, monazite, titanite, iron oxides, and some unidentified minerals. Zircon crystals with dark, metamict cores (fig. 12) were identified in well cuttings from well CH-3122 (Gil Wizwall, West Chester University, oral commun.). Metamict cores are indications of radiation damage from U or Th decay in the crystal lattice.

Figure 12. Photomicrograph of zircon with metamict core from well CH-3122 cuttings. Reflected light 10× magnification. Photograph by David A. Sinson of West Chester University.

Radioactive minerals emit radiation that exposes photographic film, and a "picture" of the radioactivity, or autoradiograph, can be used to locate sources of radioactivity in a rock sample or thin section. Autoradiographs of a few thin sections of mounted heavy mineral separates and well cuttings were prepared by Linda C. Gunderson of the USGS. Point sources of radiation were found on the thin sections, indicating radioactivity was contained in and on edges of minerals and not disseminated in the matrix. The autoradiograph of well cuttings and heavy minerals from well CH-3122 shows that the heavy minerals are radioactive and that some radioactivity is associated with opaque minerals that surround larger mineral grains (fig. 13). The radioactivity at the edges of mineral grains could be from U, Th, or Ra in secondary minerals, such as iron oxides, that accumulate during weathering processes.

These heavy resistate minerals in the Chickies Quartzite are from Precambrian rocks that also probably were sources for the zircons in other rocks in southeastern Pennsylvania. Detrital zircons in the Devonian Catskill Formation in east-central Pennsylvania are reported to contain up to about 0.17 percent Th and 1.2 percent U (Tole, 1979).

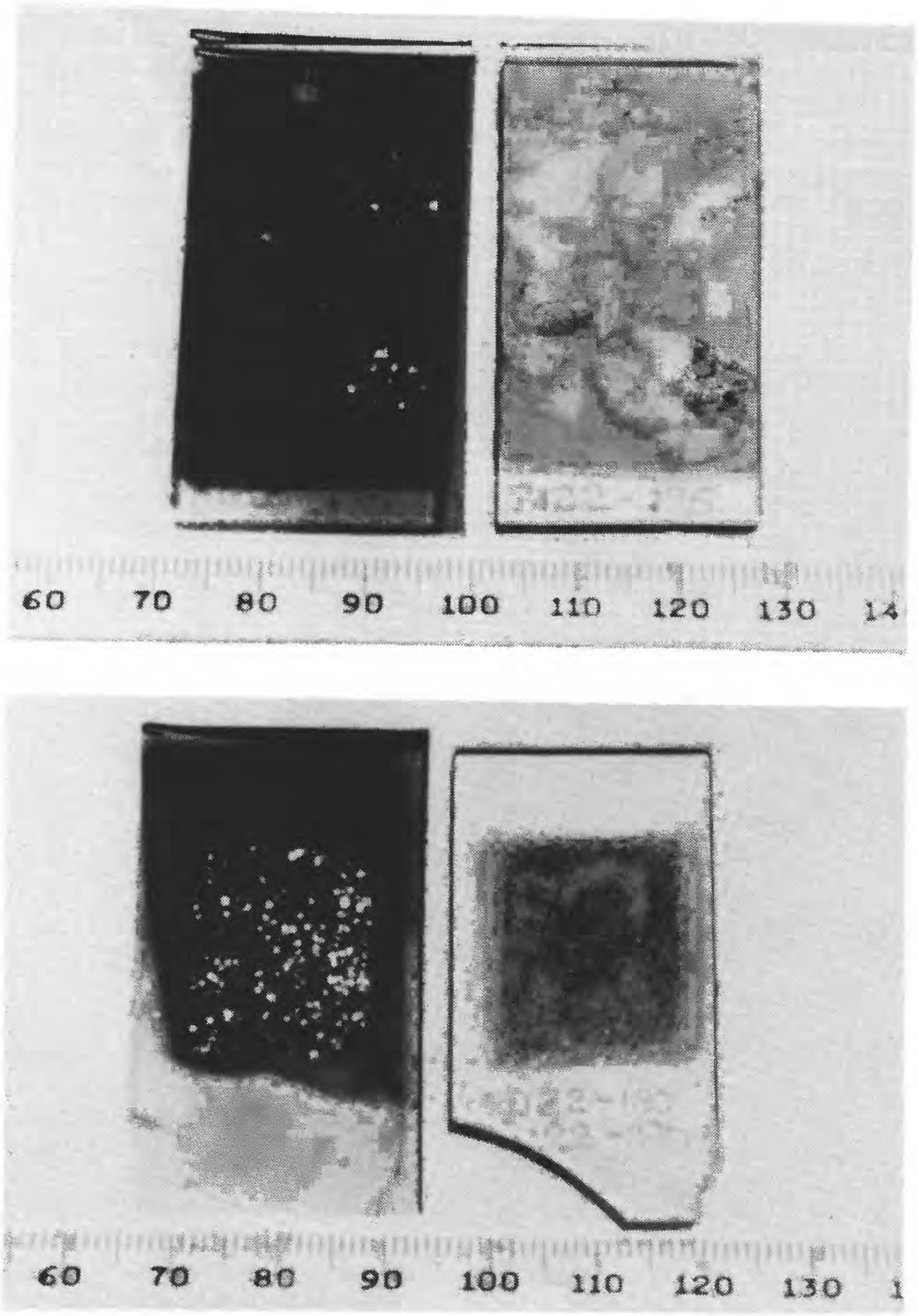


Figure 13. Autoradiographs (left) and thin sections (right) of heavy-mineral separates from well CH-3122 cuttings. Light areas of autoradiographs indicate radioactivity. Minerals are from well cuttings from (a) 175 feet and (b) 180 feet below land surface. Scale is in centimeters. Photographs by Linda C. Gunderson, U.S. Geological Survey.

Distribution of Radium and Radon in Ground Water

The range and median of Ra-226, Ra-228, combined Ra-226 and Ra-228, and Rn-222 activities, gross alpha- and gross beta-particle activity, Ra-228/Ra-226 activity ratios, and U concentrations in ground water from 160 wells penetrating the Chickies Quartzite are listed in table 12. Activities of Ra-226, Ra-228, and Rn-222 range over two orders of magnitude. Ra-228 activity exceeds Ra-226 activity in about 92 percent of the water samples from the Chickies Quartzite. The median Ra-228/Ra-226 activity ratio of 2.4 in ground water in the Chickies Quartzite is greater than the ratio of 1.1 for mean crustal abundance of U and Th (table 7).

Cumulative frequency distributions of Ra-226, Ra-228, and Rn-222 (figs. 14 and 15) are useful for estimating the likelihood of observing activities of a given magnitude of these radionuclides in ground water in the Chickies Quartzite. Forty-seven percent of the 160 samples contained combined Ra-226 and Ra-228 activities greater than 5 pCi/L, the USEPA MCL for Ra in drinking water.

Table 12. Range and median values of radiochemical constituents for water samples from 160 wells in the Chickies Quartzite

[pCi/L, picocuries per liter; µg/L, micrograms per liter; alpha, gross alpha-particle activity; beta, gross beta-particle activity; <, less than]

Constituent or property	Number of samples	Range	Median
Radiochemical consitituents			
Ra-226 (pCi/L)	160	< 0.1 - 41	1.2
Ra-228 (pCi/L)	160	<1.0 - 160	2.6
Alpha (pCi/L as U-nat)	160	< .1 - 171	4.5
Beta (pCi/L as Cs-137)	160	1.0 - 230	7.0
Rn-222 (pCi/L)	160	114 - 32,300	2,400
U (µg/L)	160	< .05 - 6.6	.09
Calculated values			
Ra-226 + Ra-228 (pCi/L)	160	<1.2 - 172	4.2
Ra-228/Ra-226 [1]	100	.37 - 30	2.4

[1] Activity ratio calculated only where both Ra-226 and Ra-228 activities are above lowest reporting level.

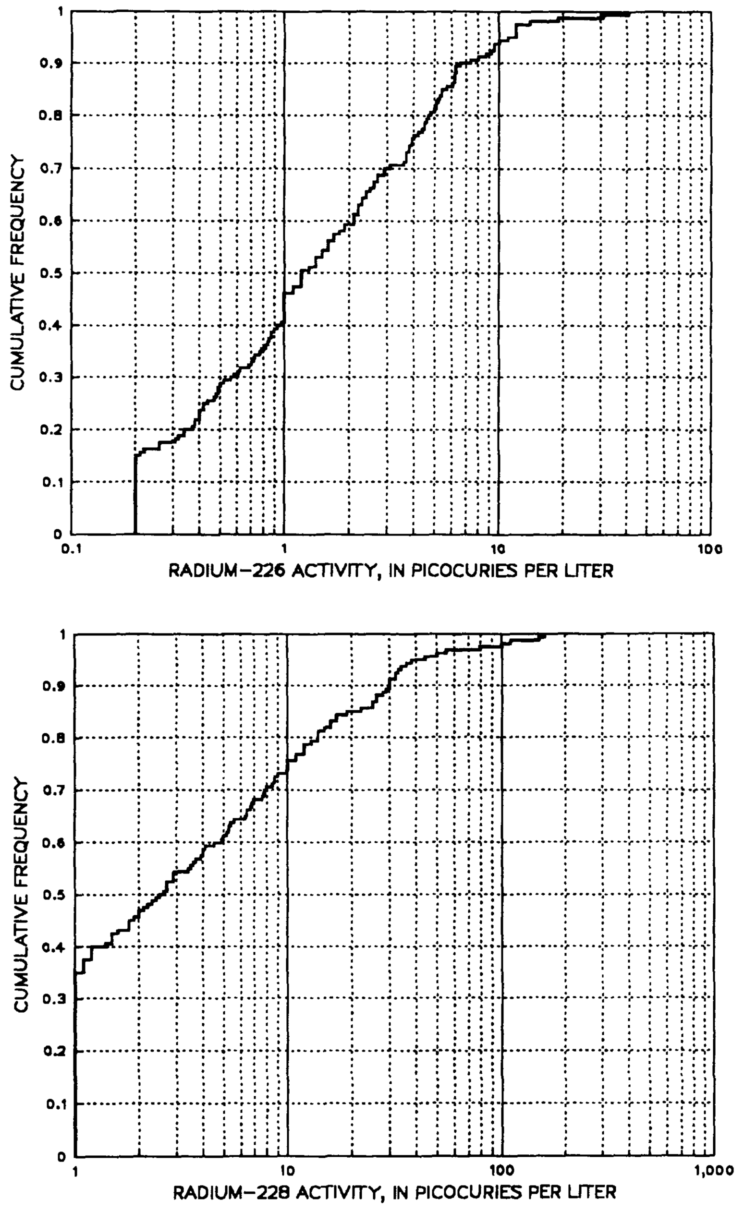


Figure 14. Cumulative frequency of radium-226 and radium-228 activities in ground water in the Chickies Quartzite. Total number of samples is 160.

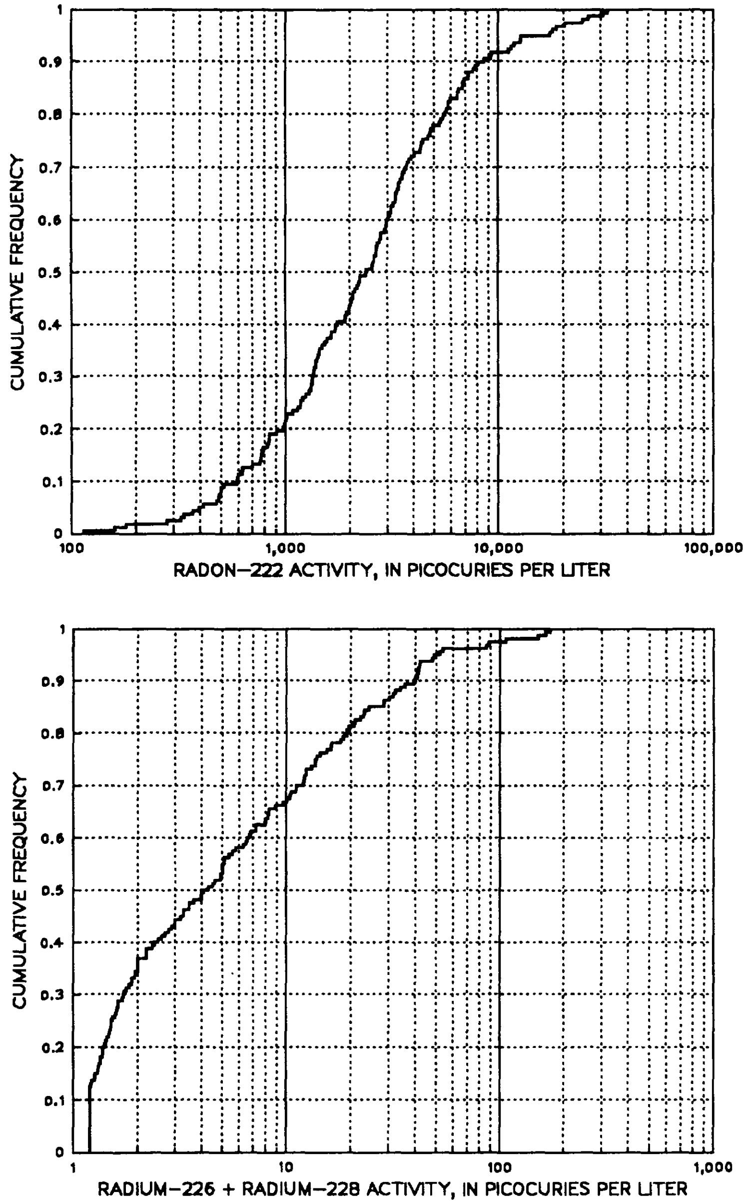


Figure 15. Cumulative frequency of radon-222 and the sum of radium-226 and radium-228 activities in ground water in the Chickies Quartzite. Total number of samples is 158 for radon-222 and 160 for radium-226 + radium-228.

Spatial Distribution

Ra and Rn activities in ground water are not evenly distributed over the area of outcrop of the Chickies Quartzite, although elevated Ra activities were measured in ground water throughout the entire area. Spatial distributions of Ra and Rn in ground water are controlled by geologic and hydrologic factors that may cause regional patterns. The geographic distribution of Ra and Rn activity in ground water from sampled wells penetrating the Chickies Quartzite, grouped into the eastern, central, and western areas, is given in table 13 and shown in boxplots in figures 16 and 17. The distribution of Ra and Rn activity by county is given in table 14.

Ground-water samples from the central area of the Chickies Quartzite have the greatest median activities of Ra-226, Ra-228, combined Ra-226 and Ra-228, and Rn-222 and the greatest percentage of combined Ra-226 and Ra-228 activities that exceed 5 pCi/L (table 13). Ground water in both the eastern and western areas had similar median activities that are lower than the median activities in the central area for Ra-226, Ra-228, and combined Ra-226 and Ra-228. Ground-water samples from the western and central areas have a greater median Rn-222 activity than those of the eastern area. The median Ra-228/Ra-226 activity ratios are greater in the eastern and central areas than those in the western area and are especially high in Chester County.

Ra activities exceeding 5 pCi/L were detected in ground-water samples from the Chickies Quartzite in York, Lancaster, Chester, and Bucks Counties (table 14). Elevated Ra activities were not detected in ground-water samples from Montgomery and Berks Counties; however, this may be the result of the small number of samples collected in these counties. The maximum median activities for Ra-226, Ra-228 and combined Ra-226 and Ra-228 are in ground water in Chester and Lancaster Counties. Ground water in Berks, Bucks, Montgomery, and York Counties have similar median activities that are less than the median activities of ground water in Chester and Lancaster Counties for Ra-226, and Ra-228, and combined Ra-226 and Ra-228. Median Rn-222 activities are greatest in ground water in Chester, Lancaster, and York Counties.

Table 13. Distribution of radium and radon-222 activities in ground water of the Chickies Quartzite by geographic area

[<, less than; pCi/L, picocuries per liter]

	Area		
	East	Central	West
Sum of Ra-226 and Ra-228 activities			
Number of samples	9	113	38
Minimum (pCi/L)	<1.2	<1.2	<1.2
Maximum (pCi/L)	54	172	42
Median (pCi/L)	1.4	6.5	1.6
Sum of Ra-226 and Ra-228 activities exceeding 5 pCi/L			
Number of samples	2	65	8
Percent of samples in area	22	58	21
Ra-226 activitiy			
Number of samples	9	113	38
Minimum (pCi/L)	<.1	<.2	<.2
Maximum (pCi/L)	3.8	41	12
Median (pCi/L)	.4	2.1	.5
Ra-228 activity			
Number of samples	9	113	38
Minimum (pCi/L)	<1.0	<1.0	<1.0
Maximum (pCi/L)	50	160	30
Median (pCi/L)	<1.0	4.0	<1.0
Ra-228/Ra-226 activity ratio			
Number of samples	3	84	13
Minimum	1.9	.6	.9
Maximum	13	30	9
Median	2.8	2.7	1.7
Rn-222 activity			
Number of samples	9	111	38
Minimum (pCi/L)	160	110	180
Maximum (pCi/L)	3,500	32,300	20,300
Median (pCi/L)	1,600	2,600	2,300

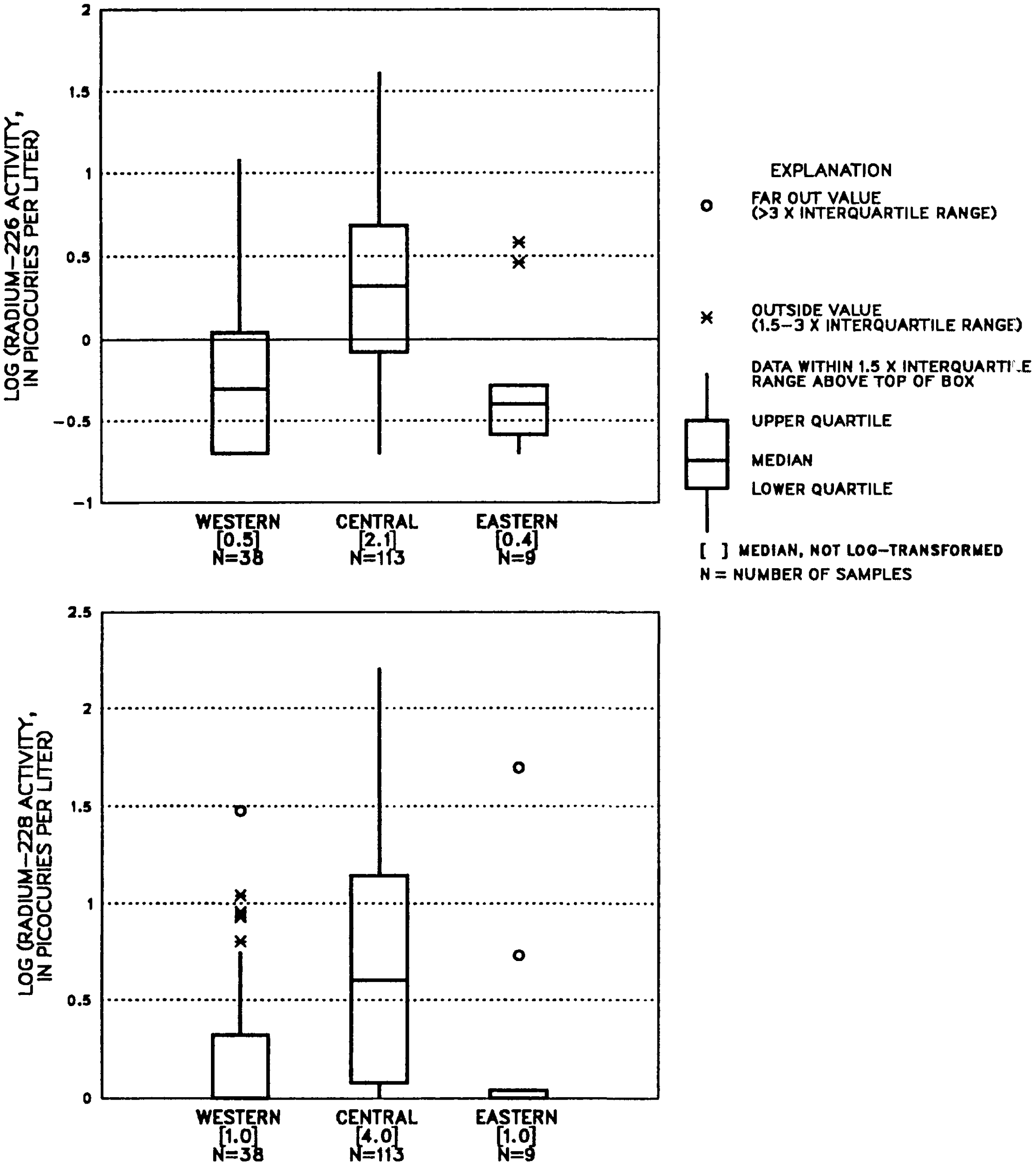


Figure 16. Distribution of radium-226 and radium-228 in ground water from the eastern, central, and western areas of outcrop of the Chickies Quartzite. Lower limit of detection is 0.2 picocuries per liter for radium-226 and 1.0 picocuries for radium-228.

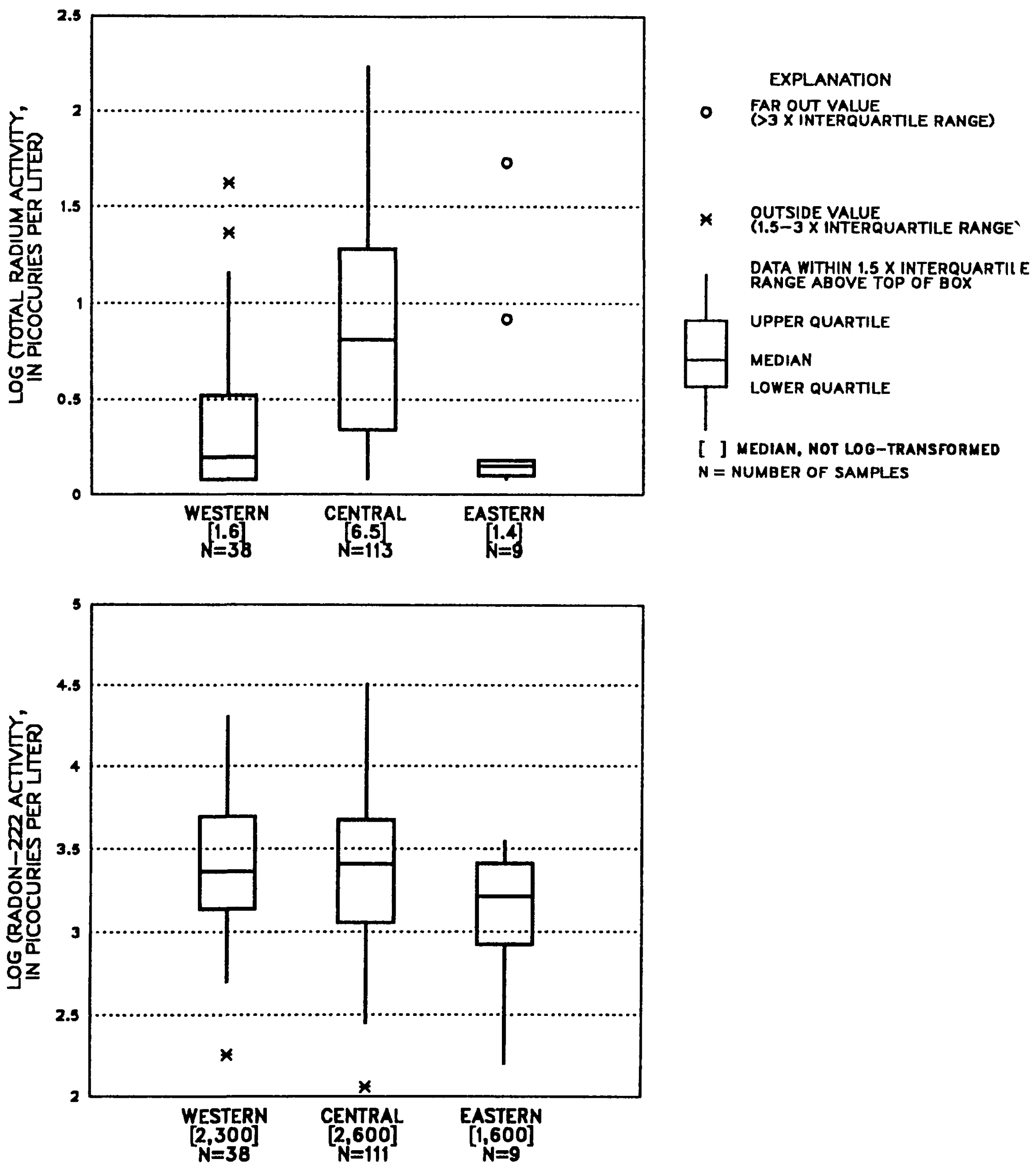


Figure 17. Distribution of radon-222 and the sum of radium-226 and radium-228 in ground water from the eastern, central, and western areas of outcrop of the Chickies Quartzite. Lower limit of detection is 1.2 picocuries per liter for radium-226 + radium-228.

Table 14. Distribution of radium and radon-222 activities in ground water of the Chickies Quartzite by county

[--, no data; <, less than; pCi/L, picocuries per liter]

	County					
	Berks	Bucks	Chester	Lancaster	Montgomery	York
Sum of Ra-226 and Ra-228 activities						
Number of samples	1	5	73	42	4	35
Minimum (pCi/L)	3.2	1.3	1.2	1.2	1.2	1.3
Maximum (pCi/L)	--	54	172	151	1.5	42
Median (pCi/L)	--	1.4	6.6	4.6	1.4	1.4
Sum of Ra-226 and Ra-228 activities exceeding 5 pCi/L						
Number of samples	0	2	45	20	0	8
Percent of samples in county	0	40	62	48	0	23
Ra-226 activity						
Number of samples	1	5	73	42	4	35
Minimum (pCi/L)	1.0	.3	.2	.2	.2	.2
Maximum (pCi/L)	--	3.8	31	41	.5	12
Median (pCi/L)	--	.4	2.1	1.7	.3	.4
Ra-226 activity						
Number of samples	1	5	73	42	4	35
Minimum (pCi/L)	2.2	1.0	1.0	1.0	1.0	1.0
Maximum (pCi/L)	--	50	160	110	1.1	30
Median (pCi/L)	--	1.0	4.1	3.2	1.0	1.0
Ra-228/Ra-226 ratio						
Number of samples	1	2	54	31	1	11
Minimum	2.2	1.9	.6	.7	--	.9
Maximum	--	13	30	15	--	9.0
Median	--	7.5	3.0	2.0	2.8	1.8
Rn-222 activity						
Number of samples	1	5	71	42	4	35
Minimum (pCi/L)	114	760	280	475	159	180
Maximum (pCi/L)	--	3,500	32,300	24,600	2,700	20,300
Median (pCi/L)	--	1,600	2,200	2,700	1,700	2,400

Factors affecting spatial distribution

The distribution of Ra-226, Ra-228, and Rn-222 activities in ground water of the Chickies Quartzite was examined by use of nonparametric statistics with respect to lithology, ground-water chemistry, aquifer and well-construction characteristics, and topographic setting. Statistically significant correlations between Ra, Rn-222, and physical and chemical factors are discussed and related to the hydrogeologic setting. The differences in distribution of Ra and Rn activities reflect differences in rock composition, including variable Th and U distributions indicative of different source areas and depositional environments. Reactions with other chemical constituents along ground-water flow paths also affect the distribution of Ra and Rn activities in the ground water.

Lithology.--The nonparametric Kruskal-Wallis one-way analysis of variance (ANOVA) with rank transformed data was used to determine whether the mean rank of Rn-222, Ra-226, and Ra-228 activities in ground water in the three mapped lithologies (conglomerate, quartzite, and slate) are significantly different at the 95-percent-confidence interval. If any difference was significant, a nonparametric multiple comparison test (MCT) was used to determine which lithologic-group mean rank was different. Corrections for tied ranks in this test were made (Conover, 1980, p. 230). Differences in mean ranks for the slate should be interpreted with caution because the small sample size may not accurately represent that lithology.

The Kruskal-Wallis test for Ra-226, Ra-228, and Rn-222 was significant at the 95-percent confidence level (p-values < 0.05), indicating that the mean rank of activities was not the same for all of the lithologies. The MCT was then performed on subsets to determine which lithologies were different. For Ra-226, the Kruskal-Wallis p-value was 0.002 for all three lithologies. The MCT test showed that the mean ranks for the quartzite and the conglomerate (p-value = 0.67) were the same, and the mean ranks for the quartzite and slate were different (p-value = 0.001). For Ra-228, the Kruskal-Wallis p-value was 0.002 for all three lithologies. The MCT showed that the mean ranks for quartzite and conglomerate were the same (p-value = 0.64), and the mean ranks for the quartzite and slate were different (p-value = 0.001). For Rn-222, the Kruskal-Wallis p-value was 0.005 for all three lithologies. The MCT test showed that the mean ranks for the quartzite and slate were the same (p-value = 0.50), and the mean ranks for the quartzite and conglomerate were different (p-value = 0.003). Thus, the mean rank of Ra-226 and Ra-228 activity in ground water is greater for the conglomerate and quartzite than for the slate, and the mean rank of Rn-222 activity in ground water is greater for the conglomerate than for the quartzite and slate. Median ground-water Ra-226 and Ra-228 activities increase from the slate (median is less than level of detection) to the conglomerate and quartzite (fig. 18). Median ground-water Rn-222 activity increases from the slate to the quartzite to the conglomerate (fig. 18).

Differences in Ra and Rn-222 activities in ground water (fig. 18) in the three lithologies could be explained by differences in U, Th, and Ra concentrations and (or) mode of occurrence in the aquifer material. Loomis (1987, p. 33) found that the average Rn concentration in ground water in the Piedmont of North Carolina was consistent with the relative abundance of U in rocks, and that aquifer lithology was a useful predictor of Rn concentration in ground water. The relative magnitudes of median Rn-222 activity in ground water from the three lithologies suggest that the U concentration is progressively greater from the slate to the quartzite to the conglomerate. However, the limited number of rock analyses (tables 8 and 9) do not indicate mode difference in U concentrations in the three lithologies. Distribution of Rn-222's parent, Ra-226, within the aquifer is controlled by the presence of parent U-bearing minerals and of Ra-bearing minerals in the aquifer; U and Ra can be adsorbed on edges of mineral (clays and Fe and Mn oxides) or incorporated into the crystal structure of a mineral U (in zircon) or Ra (in barite).

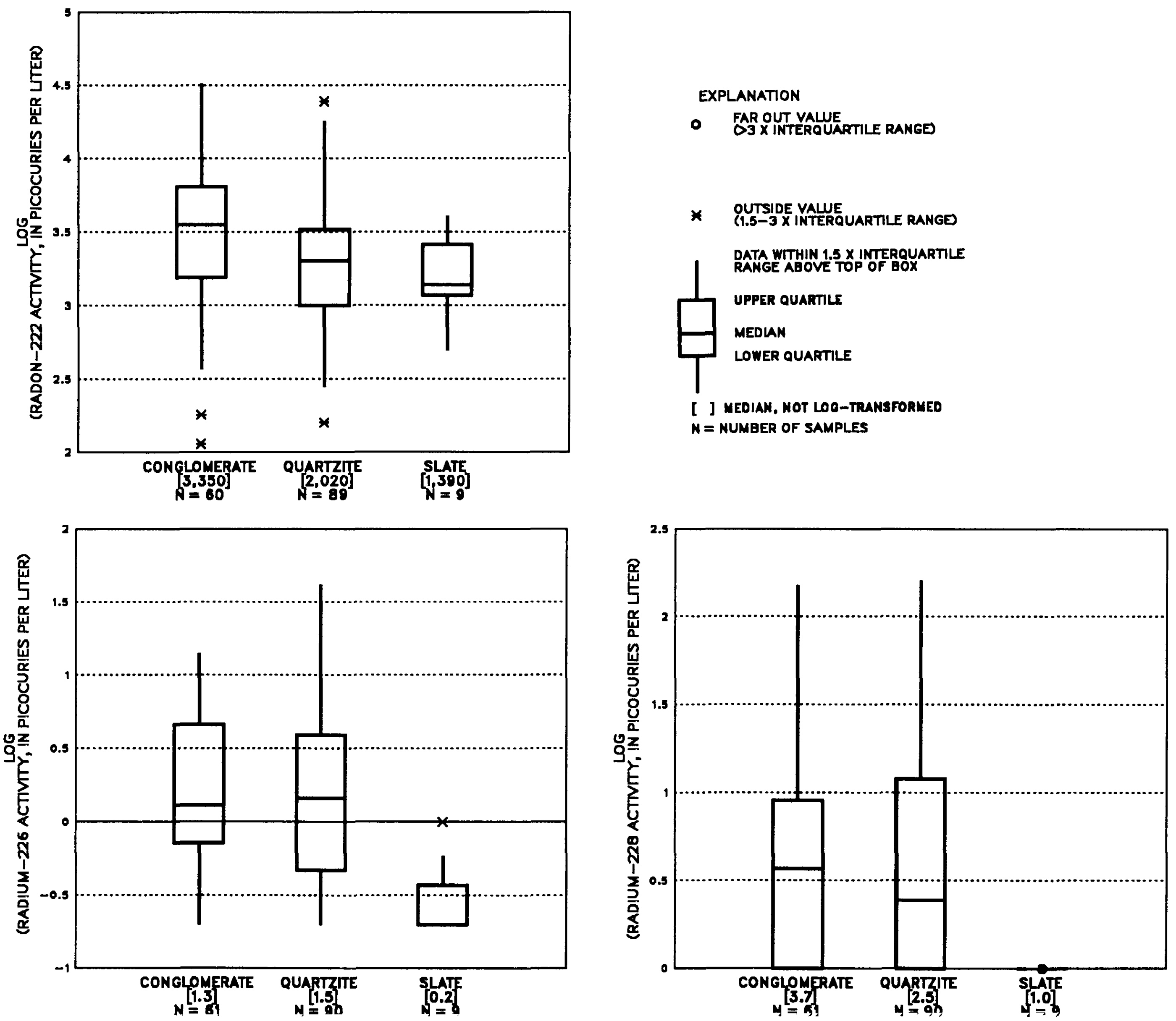


Figure 18. Distribution of radium-226, radium-228, and radon-222 in ground water from the conglomerate, quartzite, and slate lithologies of the Chickies Quartzite. Lower limit of detection is 0.2 picocuries per liter for radium-226 and 1.0 picocuries per liter for radium-228.

Chemistry of ground water.--Differences in Ra-226 and Ra-228 activities in ground water of the Chickies Quartzite are related to ground-water chemistry and to the U and Th content of the rocks. The general chemical character of ground water associated with elevated Ra activities is displayed on piper diagrams showing relative concentrations of major cations and anions in milliequivalent percents for ground-water samples that contain total Ra activities greater than or equal to 5 pCi/L and less than 5 pCi/L (fig. 19). A comparison of the piper diagrams (fig. 19) indicate that elevated Ra activities are associated with relatively greater concentrations of Na, K, SO_4, Mg, and Cl + NO_3, and relatively lower concentrations of Ca and HCO_3.

Statistically significant correlations between chemical constituents and the activities of Ra-226, Ra-228, and Rn-222 in the ground water were determined by use of Spearman's rho rank correlation test. Because the MCT analyses indicate that the conglomerate and quartzite contain ground water with activities of Ra different from ground water in the slate, correlations for Ra isotopes included only the data from ground water in the conglomerate and quartzite, which are assumed to be representative of a single population. Results of the two-tailed Spearman's rho correlation test at the 95-percent-confidence interval are given in table 15.

The correlations indicate that elevated Ra-226 and Ra-228 activities are strongly inversely related to pH, alkalinity, and SiO_2 concentration, and strongly positively related to DOC, Ba, SO_4, Mn concentrations and specific conductance. Weak, but significant, positive correlations were noted between Ra and Cl, NO_3, Na, Mg, K, U, and TDS concentrations. Both Ra-226 and Ra-228 correlate with the same constituents and properties, and, therefore, correlations are discussed for Ra in general, unless otherwise specified. Ra-226 and Ra-228 activities also strongly correlate with each other; each isotope has the identical chemical properties of Ra. Because of variable Ra-228/Ra-226 activity ratios related to variable distribution of Th and U in the aquifer, the r_s measuring correlation between Ra-226 and Ra-228 is less than 1.0.

Alpha-particle activity correlates more strongly with Ra-226 than Ra-228 activity, and beta-particle activity correlates more strongly with Ra-228 activity than Ra-226 activity. The magnitude and order of the alpha- and beta-particle correlations with Ra-226 and Ra-228 is expected because Ra-226 is an alpha-particle emitter and Ra-228 is a beta-particle emitter. Alpha-particle and beta-particle activities are good predictors of Ra-226 and Ra-228 activities, respectively.

Ra-226 of the U-238 decay chain and Ra-228 of the Th-232 decay chain correlates positively, but weakly, with U. Ra-226 and parents, U-238 and U-234, may enter ground water from the same source area in the aquifer but be separated in the aqueous phase because of differences in chemical behavior between Ra and U. U, unlike Ra, correlates positively with Ca and alkalinity (r_s = 0.38 and 0.22, respectively). U commonly forms anion complexes, especially in oxidizing solutions, whereas Ra commonly exists as a free cation (Riese, 1982). U forms carbonate complexes, and U mobility is enhanced in the presence of HCO_3 (Chatham and others, 1981) in neutral or alkaline waters, whereas Ra is most mobile in acidic waters. Sorption of U onto Fe-oxides is greatest at pH near 5 (Ames and others, 1983), which is close to the median pH for ground water from the quartzite and conglomerate.

Ra-226 does not appear to be in secular equilibrium with its parent U-234. For two samples with sufficient concentrations of U for detection of isotopic U, U-234 and U-238 analyses were performed. U isotopic disequilibrium in water caused by fractionation between solid and aqueous phases can occur by a number of mechanisms, including alpha recoil (Osmond and Lowart, 1976). Water from well YO-1179 contained 12 pCi/L Ra-226 and 0.67 μg/L U, comprised of 0.2 pCi/L each of U-238 and U-234. Water from well LN-1725 contained 41 pCi/L Ra-226 and 0.74 μg/L U, comprised of 0.2 pCi/L U-238 and 0.3 pCi/L U-234. In these two samples, activity of Ra-226 is two orders of magnitude greater than the activity of its parent in solution. Activities of relatively shorter-lived isotopes may increase in ground water more rapidly than longer-lived isotopes of the same decay series in aquifers where the radioactivity of the rock matrix is high, but the rock is resistant to solution (Durrance, 1986), such as the Chickies Quartzite.

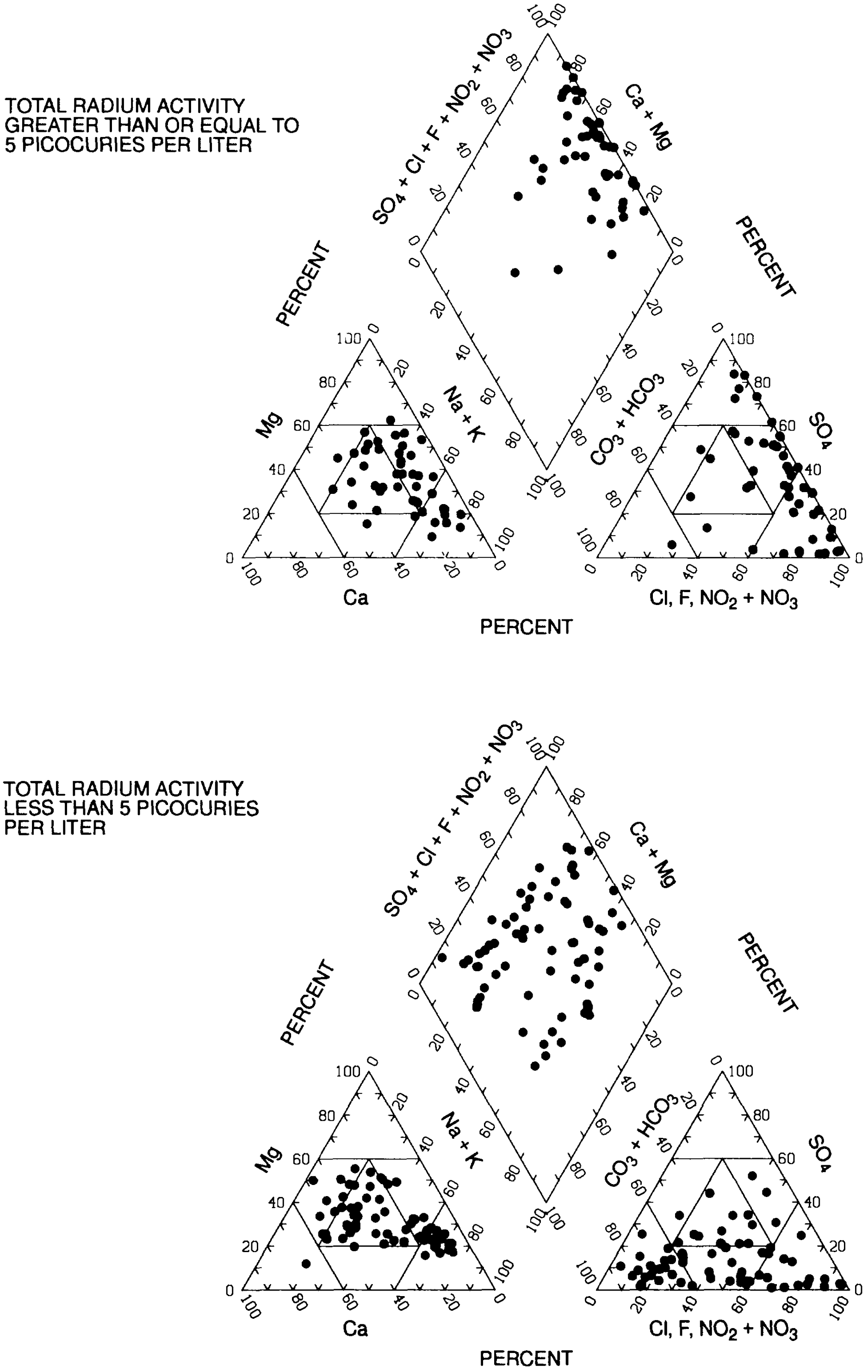


Figure 19. Piper diagrams comparing chemical character of ground water with and without elevated radium activities from wells in the Chickies Quartzite. Percentage of ions in milliequivalents.

Table 15. Correlations among activities of radium-226 and radium-228 and chemical constituents and properties significant at the 95-percent confidence interval for ground-water samples from 160 wells in the Chickies Quartzite

[r_s, Spearman rho correlation coefficient; alpha, gross alpha-particle activity; beta, gross beta-particle activity]

Ra-226		Ra-228	
Chemical constituent or property	r_s	Chemical constituent or property	r_s
Correlation coefficient p-values less than 0.0001			
Total Ra [1]	0.93	Total Ra [1]	0.97
Alpha	.91	Beta	.88
Ra-228	.85	Alpha	.87
Beta	.85	Ra-226	.85
pH	-.68	pH	-.67
Ba	.62	DOC	.67
DOC	.60	Ba	.60
Alkalinity	-.60	Alkalinity	-.59
SiO_2	-.51	SiO_2	-.54
Mn	.49	SO_4	.43
SO_4	.37	Mn	.42
Specific conductance	.33	Specific conductance	.34
Correlation coefficient p-values greater than or equal to 0.0001; p-value in parenthesis ( ) following coefficient			
PO_4	-0.41 (.0019)	PO_4	-0.45 (.0005)
NO_3	.39 (.0034)	NO_3	.30 (.0272)
B	.36 (.0058)	B	.35 (.0075)
Cl	.29 (.0003)	Cl	.29 (.0003)
F	.29 (.0003)	F	.28 (.0004)
TDS	.26 (.0006)	TDS	.28 (.0004)
Mg	.26 (.0013)	Mg	.26 (.0014)
K	.24 (.0030)	Na	.24 (.0028)
Na	.23 (.0040)	U	.20 (.0132)
U	.09 (.0176)	K	.16 (.0497)

[1] Total radium activity equals combined activities of radium-226 and radium-228.

Ra-226 does not correlate with its daughter, Rn-222, in solution. Elevated Rn-222 activity in ground water is expected where Ra-226 is concentrated in aquifer materials and not necessarily where Ra-226 is dissolved and, therefore, actively being leached from the aquifer materials. Ra-226 is not in secular equilibrium in solution with daughter Rn-222. The activity of Ra-226 is as much as five orders of magnitude less than that of Rn-222 in ground water in the Chickies Quartzite.

The negative relation of Ra with pH (fig. 20) shows pH is a strong control on Ra activities. All ground-water samples from the Chickies Quartzite with pH less than 4.7 have combined activities of Ra-226 and Ra-228 greater than 5 pCi/L (fig. 21). Low pH decreases adsorption of Ra and other cations onto SiO_2, kaolinite (Riese, 1982), and other mineral surfaces, such as Fe and Mn hydroxides.

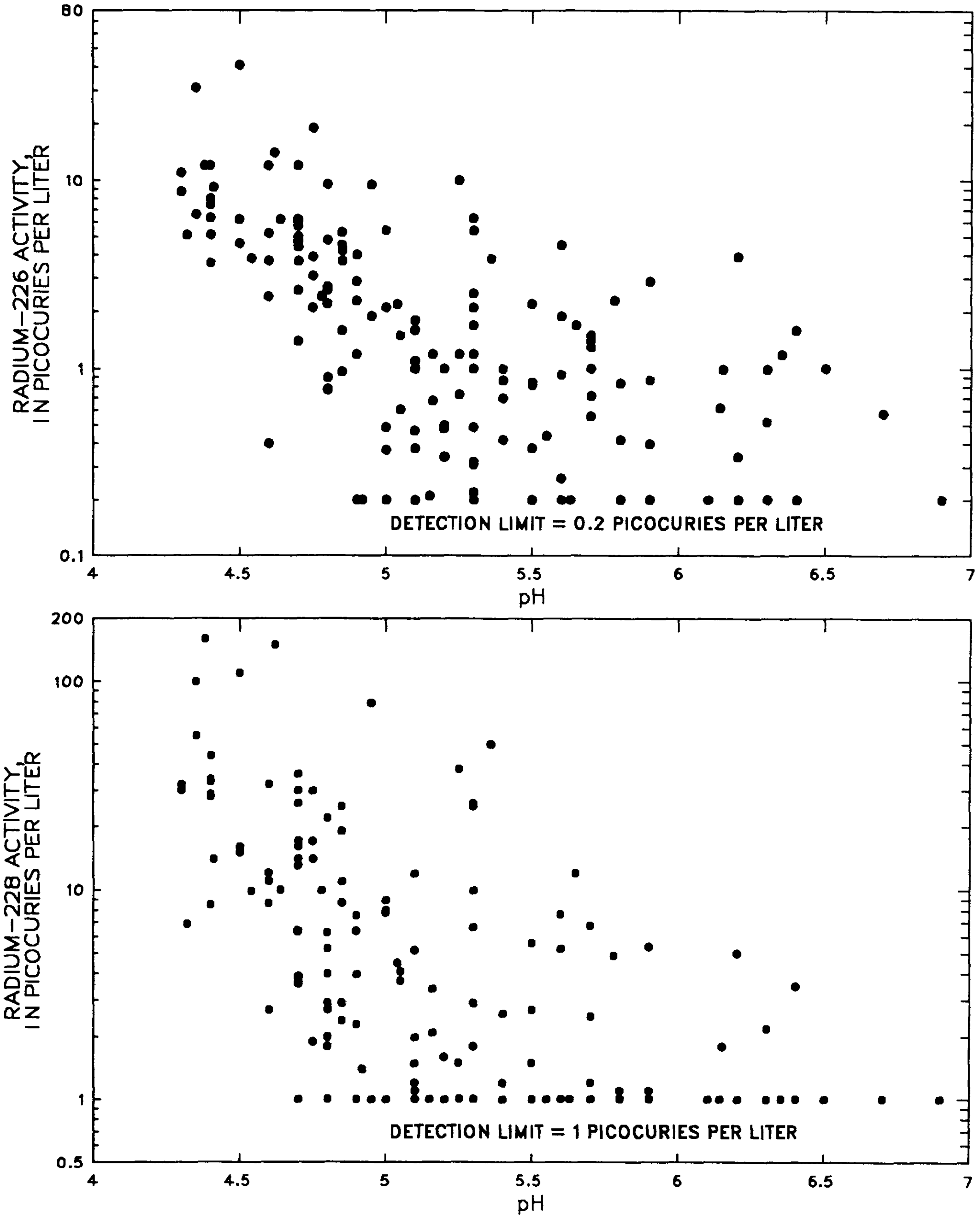


Figure 20. Relation between pH and radium-226 and radium-228 for ground water from the quartzite and conglomerate lithologies of the Chickies Quartzite. [pCi/L, picocuries per liter]

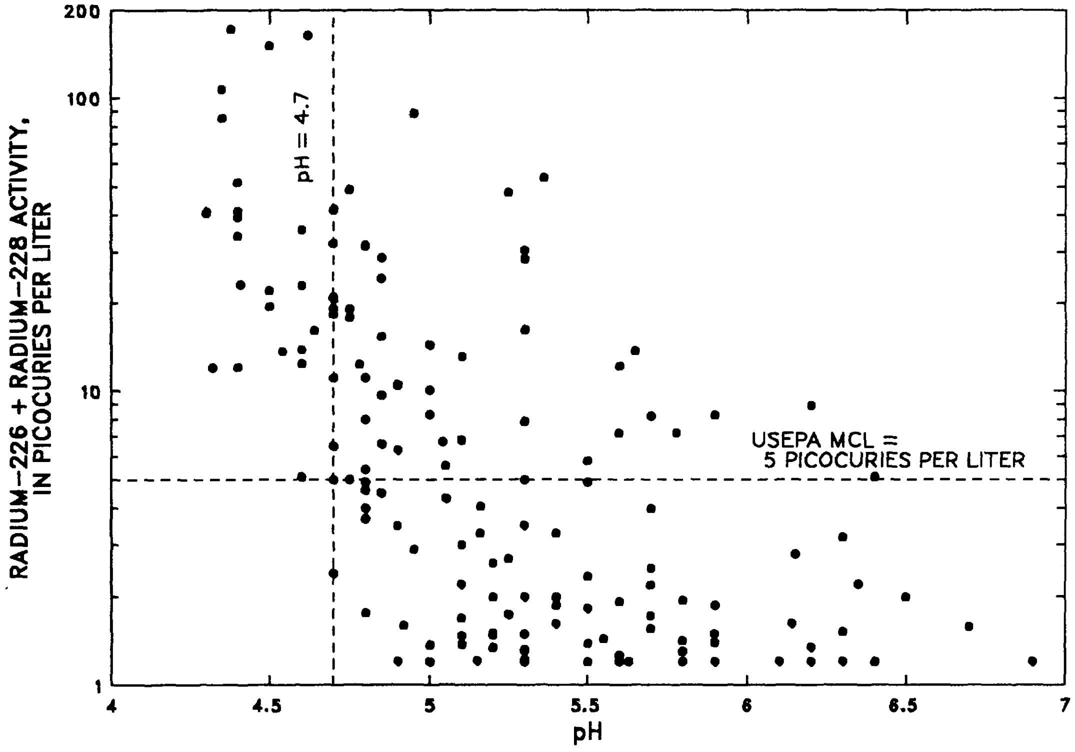


Figure 21. Relation between the sum of radium-226 plus radium-228 and pH for ground water in the Chickies Quartzite. [USEPA MCL, U.S. Environmental Protection Agency Maximum Contaminant Level; pCi/L, picocuries per liter]

Because pH is an important geochemical control in general, negative correlations are expected between Ra and constituents that correlate positively with pH. Ra correlates negatively with alkalinity and SiO_2 because both correlate positively with pH (r_s= 0.65 and 0.55, respectively) (table 6).

Maximum activities of Ra are observed in samples containing DOC concentrations above the median and having pH below the median (fig. 22). DOC concentrations, like Ra, also correlate negatively (r_s= -0.53) with lower pH (table 6). The relation between decreasing pH and increasing DOC may indicate decreased adsorption and slow degradation of DOC in acidic ground water (Thurman, 1985) or recharge from low pH, DOC-rich waters of meteoric origin. Because natural DOC is commonly composed of organics acids that have equilibrium dissociation constants (pKa's) in the pH range of 3 to 5 (Lasaga, 1984), DOC may contribute to the acidity of the ground water. However, high DOC concentrations appear to be associated with high Ra isotope activities independent of pH (fig. 22). Dissolved organic acids may enhance Ra mobility by complexation (Schubert and others, 1950). Thurman (1985) estimated that 1 mg/L DOC has about 1 microequivalent of metal-binding capacity, although that capacity generally decreases with decreasing pH because of hydrogen-ion competition for binding sites. The degree of ion complexation varies depending on pH, relative binding capacities, specific complexing agents, and competing ions present (Stumm and Morgan, 1970). Thus, Ra ions may be preferably complexed by organic acids even at low pH despite the abundance of competing cations (sample median is 0.8 milliequivalents).

Ba is one of the heavier alkaline earth elements like Ra, and, consequently, Ba and Ra can exhibit similar chemical behavior that is reflected in the strong positive correlation between Ba and Ra. Ba also correlates positively (in decreasing order) with DOC, NO_3, specific conductance, Cl, Mn, Mg, K, Na, and SO_4 and negatively with pH and alkalinity (table 6). The correlations for Ba are similar in magnitude to those for Ra. Relations between Ba and SO_4 and Ra-226 and Ra-228 are shown in figure 23. The correlations among Ba, Ra, SO_4, DOC, specific conductance, and pH suggest that precipitation and (or) coprecipitation of Ra as the relatively insoluble Ba and Ra sulfates [log Ksp = -10 and -11.4, respectively (Riese, 1982)] do not limit dissolved Ra activities in ground waters in the Chickies Quartzite, especially where these waters have a low pH (less than 5.0), have concentrations of DOC greater than 1 mg/L, and a relatively high specific conductance. Even where the ground water appears to be oversaturated with respect to Ba and Ra sulfates in water, the activities of Ra-226 and Ra-228 may remain elevated. Riese (1982) states that Ra activity will be limited by precipitation of $RaSO_4$ only in waters with extremely elevated concentrations of SO_4 or extremely elevated concentrations of Ra. In the Chickies Quartzite, most elevated activities of Ra are found in ground-water samples that appear to be theoretically oversaturated with $BaSO_4$ (log of the product of median concentrations is -9.57, which approximates the log solubility product, Ksp).

The relations among pH, Ra, Ba, and SO_4 could be the result of pyrite oxidation and dissolution, a process that decreases ground-water pH, increases desorption of Ba and Ra from cation-binding minerals, and increases dissolution of Ba- and Ra-bearing minerals. SO_4 correlates negatively, but weakly, with pH (r_s = -0.17), suggesting that pyrite may be a source of sulfate ions. The oxidation of dissolved ferrous Fe and precipitation of $Fe(OH)_3$ following pyrite dissolution in oxygen-rich ground water causes further acidification. Oxidation of dissolved ferrous Fe is suggested by the negative correlations of total Fe with dissolved oxygen (r_s = -0.21). The lack of significant correlations between dissolved or total Fe, and SO_4 (table 6) may be caused by other controlling reactions or sources of Fe and SO_4. For example, atmospheric deposition (acid rain) or fertilizer are sources of SO_4 unaccompanied by Fe. Minerals such as biotite and ilmenite are sources of Fe with no SO_4. Ra also complexes with SO_4 (Langmuir and Riese, 1985), a process that increases Ra solubility.

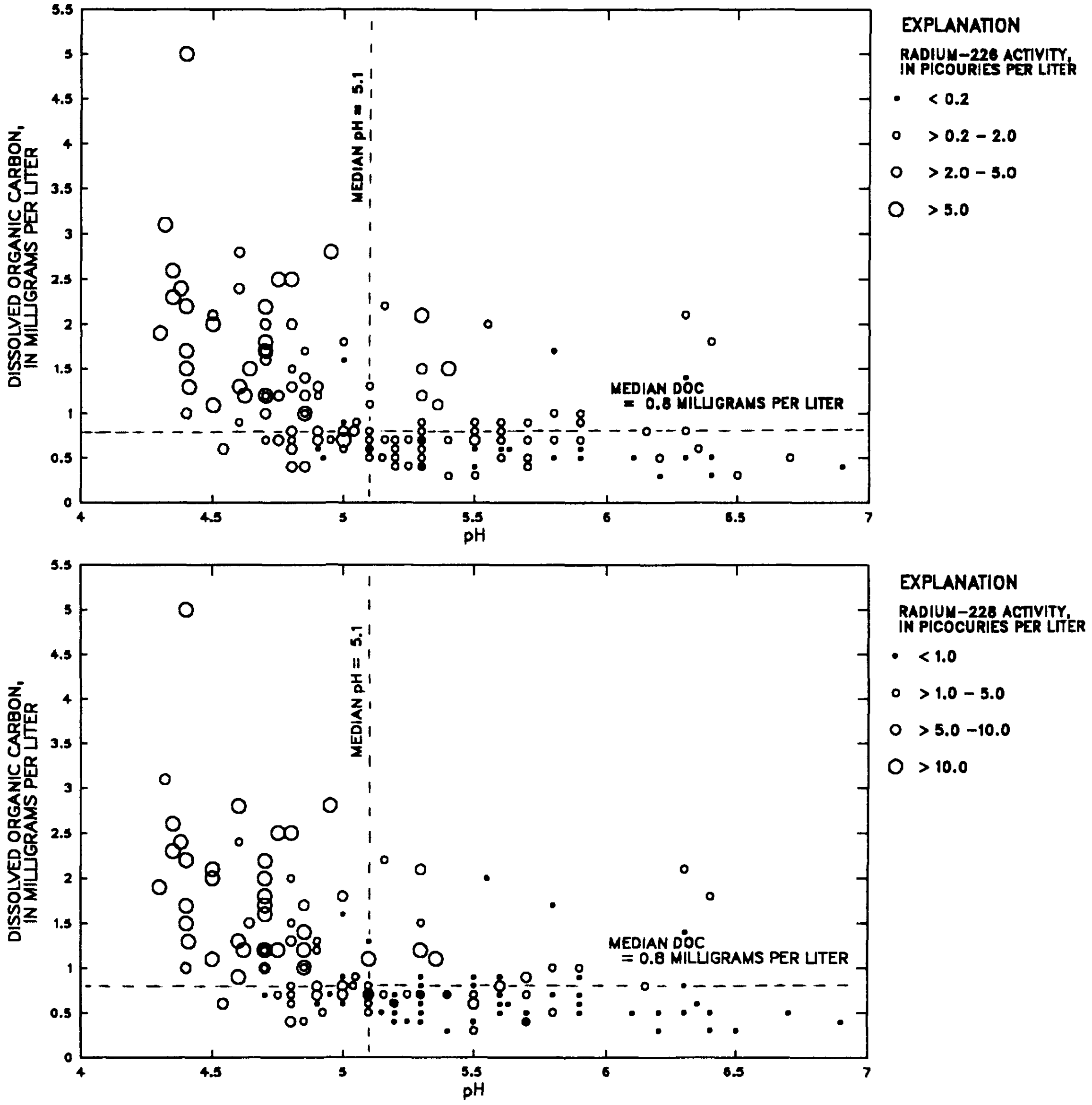


Figure 22. Relation among dissolved organic carbon, pH, radium-226, and radium-228 in ground water from the Chickies Quartzite.

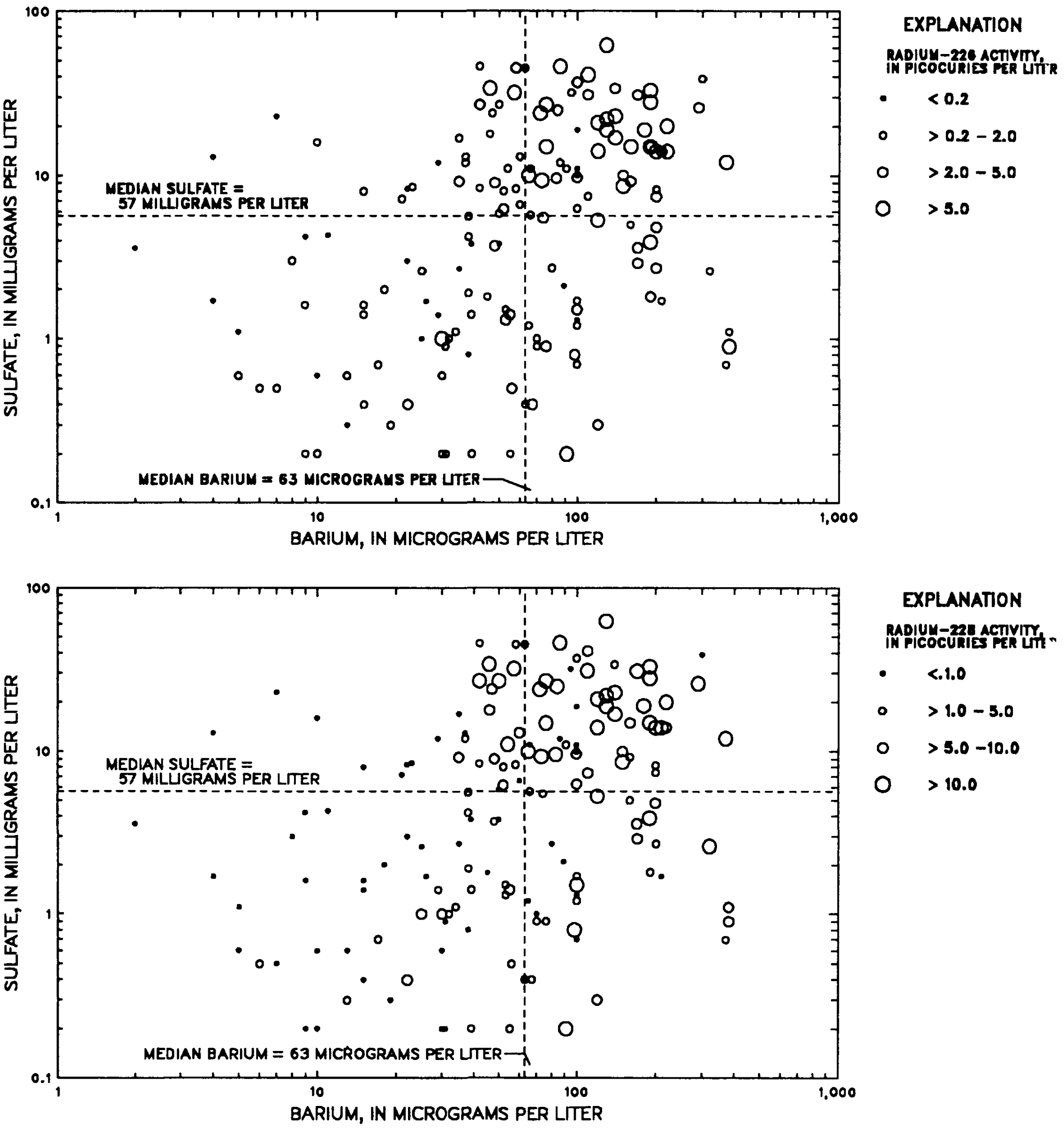


Figure 23. Relation among barium, pH, sulfate, radium-226, and radium-228 in ground water from the Chickies Quartzite.

The positive correlation between Ra and Mn and negative correlation between Mn and pH (r_s = -0.26) indicate that the mobility of Mn, like Ra, increases as pH decreases. Mn also correlates with DOC (r_s = 0.33). Mn is soluble in its reduced form, and DOC can act as a reducing agent. Dissolution of some Mn-bearing minerals, including Mn oxides, in reducing, low pH water may be accompanied by concurrent release of Ra that otherwise might be adsorbed by Mn oxides and hydroxides.

Ra correlates positively with specific conductance, Cl, and TDS. Ra solubility may be greater in water with higher specific conductance because ion solubility tends to increase with increases in specific conductance and ionic strength and because increasing concentrations of competing ions limits adsorption. In laboratory experiments, leaching of Ra from U and Th ores was enhanced by increasing concentrations of NaCl, and the leaching was further enhanced by lowering pH; Na-Ra ion exchange was interpreted to be part of the process (Dickson, 1985). However, elevated Ra activities are found only in high specific-conductance waters of low pH (low alkalinity) because pH appears to be the dominant control on Ra sorption in the Chickies Quartzite, as indicated by the relative strength of correlations between Ra and pH and between Ra and specific conductance. Ra also forms complexes with Cl (Langmuir and Riese, 1985), as it does with SO_4, that may increase Ra solubility.

Thus, the general ground-water chemistry associated with elevated Ra for 160 ground-water samples from the Chickies Quartzite is as follows, where the ground water: (1) has relatively low pH and elevated concentrations of DOC; (2) can contain relatively higher concentrations (above the median) of Ba and SO_4; (3) has relatively high specific conductance; (4) has low alkalinity; and (5) also may contain elevated concentrations of NO_3, NaCl, or other constituents from septic systems, road salt, or fertilizers. This type of ground water could have had a short residence time in the aquifer or retain the chemical character of recharge water because of the unreactive nature of the bedrock.

Distribution of pH, DOC, Ba, and SO_4, the chemical property and constituents with the strongest statistical correlations to Ra, are shown, by lithology, in boxplots (fig. 24) to determine whether geochemical environments favorable to Ra mobility are more common in a particular lithology. Ground water from the conglomerate and quartzite is more acidic and contains greater concentrations of DOC, Ba, SO_4 (fig. 24), Ra-226, and Ra-228 than the ground water from the slate. None of the nine ground-water samples from the slate contained elevated Ra, although the small number of samples may not be representative of ground water in the lithlogy as a whole.

Spearman's rho correlation test was used to determine the chemical constituents and physical properties that correlated with Rn-222 in ground water. Because the MCT indicated that the quartzite and slate represent a different population than the conglomerate, data for the slate and the quartzite were combined. Results of the Spearman's rho correlation tests (table 16) show that correlations among Rn-222 and chemical constituents and physical properties differ between the two lithologic groups. Only the inverse correlation with SO_4 is shared by the all lithologies (table 16). Sulfate positively correlates with Ra. Sulfate may directly enhance Ra mobility or may be in the low pH waters associated with elevated Ra such that Ra is not sorbed as well in the presence of elevated SO_4. Rn-222 concentrations in ground water may be lower where Ra is mobile. The different significant correlations suggest different geochemical controls on Rn-222 in the quartzite than the conglomerate, despite similar ground-water chemistry.

The correlation analysis for the conglomerate shows that Rn-222 activity is inversely correlated with concentrations of dissolved Fe. The relatively greater concentrations of dissolved Fe may reflect a relatively greater abundance of Fe-bearing minerals (pyrite or biotite) associated with U-bearing minerals in the solid phase. U and Ra sorb onto Fe-oxides and biotite (Ames and Walker, 1983b; Ames and others, 1983). Rn-222 is negatively correlated with Ba, SO_4, DOC, TDS, and specific conductance; these chemical constituents and property all are positively correlated with Ra. The chemical environment associated with Rn-222 is opposite of the chemical environment that favors Ra mobility.

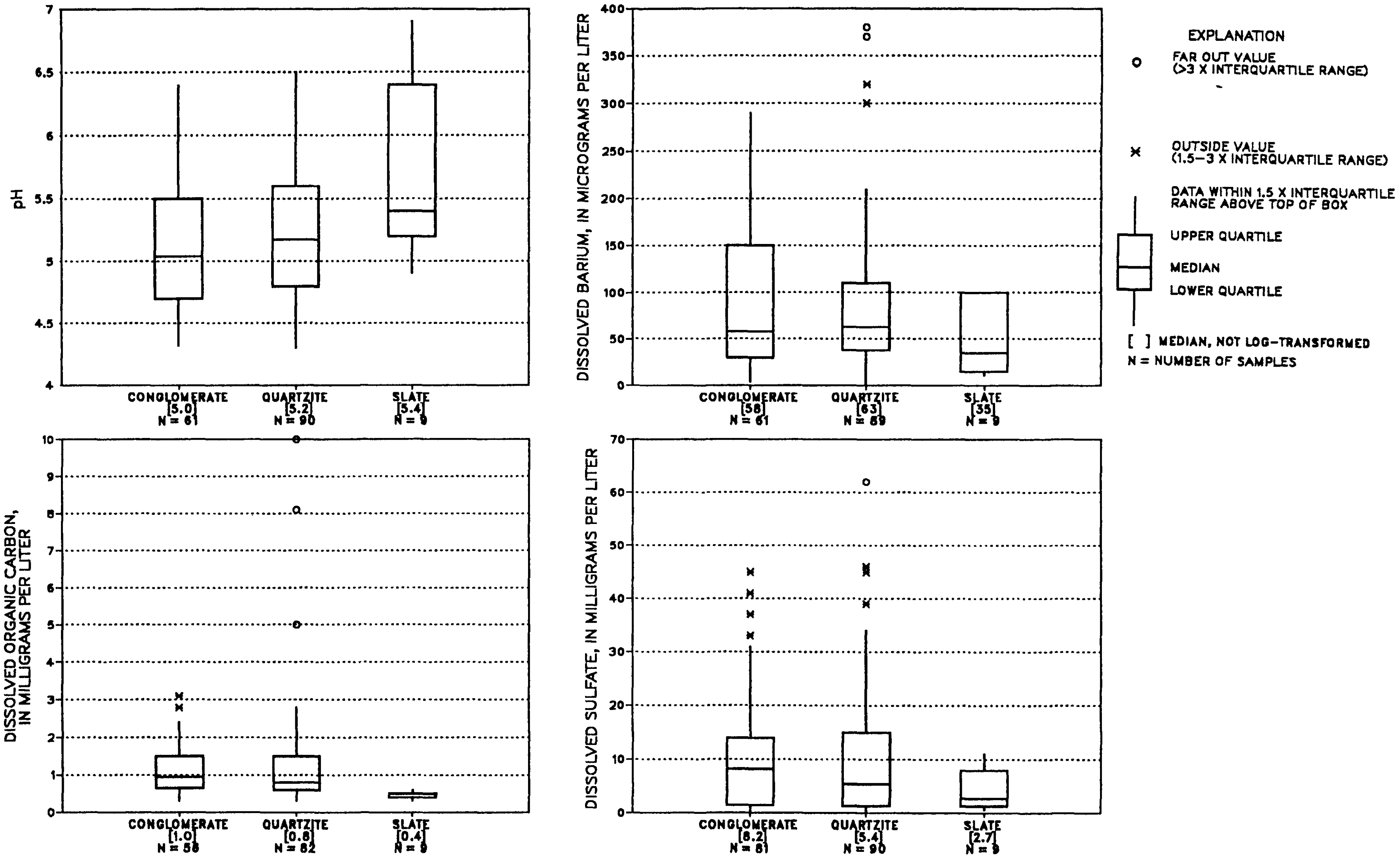


Figure 24. Distribution of pH, dissolved organic carbon, sulfate, and barium in ground water from the conglomerate, quartzite, and slate lithologies of the Chickies Quartzite. Detection limits were 0.1 mg/L for dissolved organic carbon, 2.0 µg/L for barium, and 0.2 µg/L for sulfate.

Table 16. Correlations between radon-222 and chemical constituents and properties significant at the 95-percent-confidence interval for ground-water samples from 160 wells in the Chickies Quartzite

[r_s, Spearman rho correlation coefficient]

Conglomerate			Quartzite and slate		
Chemical constituent or property	r_s	p-value	Chemical constituent or property	r_s	p-value
Fe, dissolved	-0.42	0.0009	NO_3	0.45	0.0091
Ba	-.36	.0051	K	.38	.0001
SO_4	-.32	.0120	SO_4	-.27	.0081
DOC	-.29	.0306	SiO_2	.23	.0220
TDS	-.29	.0260	F	-.23	.0236
Specific conductance	-.27	.0367			

For the quartzite and slate, the strongest positive correlation is between NO_3 and Rn-222 (table 16). Elevated activities of Rn-222 in ground water could be present where the aquifer is susceptible to contamination by septic systems, fertilizers, or other sources of NO_3 through relatively rapid infiltration of surface water; the conditions for rapid infiltration can include a relatively large rock-water surface-area ratio related to extensive fracturing or weathering that yields relatively large Rn-222 concentrations. The positive correlation between Rn-222 and SiO_2 and negative correlation between Rn-222 and SO_4 are opposite those of Ra and are indicative of a geochemical environment that does not favor Ra mobility. The positive correlations between Rn-222 and K and between Rn-222 and SiO_2 also suggest that Rn-222 is associated with areas of the quartzite containing more K-bearing silicates, such as muscovite, that can sorb U and Ra (Ames and others, 1983a, 1983b).

Because Rn-222 in ground water has a short half life, it does not travel far from its source (King and others, 1982). Elevated Rn-222 activity in ground water can occur where Ra-226 (and U) is relatively concentrated in or on aquifer materials. The general ground-water chemistry associated with elevated Rn-222 activity in the Chickies Quartzite is relatively low concentrations of SO_4, and Fe and relatively high concentrations of SiO_2, K, and U. The general ground-water chemistry indicates that higher Rn-222 activity is found where Ra-226 is likely to be concentrated in aquifer materials.

Aquifer and well-construction characteristics.--The concentrations of Ra and Rn in ground water are controlled partly by the rock-water ratio and rate of flushing or ground-water movement. Spearman's rho correlation test was used to determine if significant correlations exist between Ra-226, Ra-228, and Rn-222 activity and aquifer and well-construction characteristics. Tested variables include topographic setting (hillside or hilltop), well depth, reported casing length, well yield, specific capacity, and depth to water below land surface.

Significant negative correlations were found only between Ra activity and both specific capacity ($r_s = -0.37$ for both Ra-226 and Ra-228) and casing length ($r_s = -0.26$ for Ra-226 and -0.32 for Ra-228). No significant correlations were found between Rn-222 and aquifer and well-construction characteristics. Wells with a low specific capacity penetrate rock containing few fractures that are small and not well connected; therefore, the rock has low overall hydraulic conductivity and the Ra in solution has little chance of being diluted.

Casing commonly is set slightly below the depth where competent bedrock is encountered in drilling; therefore, the length of casing commonly indicates the depth of weathering or depth to competent bedrock. Casing length correlates positively with SiO_2 and alkalinity; the concentrations of these constituents that negatively correlate with Ra increase by chemical weathering. Casing length correlates negatively with DOC, Cl, Na, Mg, and SO_4; the concentrations of these chemical constituents that correlate positively with Ra decrease with increasing length of casing. The correlations among these chemical constituents, casing length, and Ra suggest that elevated Ra in ground water is associated with areas of the aquifer that have undergone relatively less extensive chemical weathering. Also, leaching of U, Th, and Ra occur during weathering of the bedrock (Michel and others, 1978); thus, the depth of weathering can indicate the extent to which sources of Ra in the rock are depleted in the zone flushed during recharge.

Hydrogeologic setting

The chemical composition of ground water, which includes dissolved Ra and Rn, reflects the hydrogeologic setting and is related to aquifer mineralogy, the origin of the ground water, and the chemical and physical changes that occur during ground-water flow. The hydrogeologic setting of the Chickies Quartzite is controlled by lithology; the quartzite lithology commonly caps ridges, and the underlying conglomerate crops out just below one side of the ridge crest. The overlying Harpers Phyllite and Antietam Quartzite crops out downslope on the other side of the crest. The strike of the Chickies Quartzite is roughly parallel to the ridge line.

Sets of wells located on transects perpendicular and parallel to strike were sampled to investigate changes in water chemistry caused by lithologic changes and ground-water flow across and along strike. Changes in water quality in a series of wells located along a down-gradient transect in a fractured-rock aquifer can progress along the vertical and horizontal flow paths. Transects perpendicular to strike included wells in adjacent aquifers to investigate ground-water transport of Ra and Rn across lithologic units. The detection of Ra-226 and Ra-228 in springs CH-SP-33 and BK-SP-21 (table 22) shows that Ra can be transported in ground water to surface discharge points. Transects were selected on the basis of availability of wells, geology, and known elevated Ra activities in ground water in the vicinity.

Schematic hydrogeologic sections showing chemical characteristics of Ra and Rn-222 activities and pH in well water, well depth, altitudes of land surface and the water table, and lithology for transects perpendicular and parallel to strike are discussed below to illustrate general conditions. The Ra and Rn-222 activities in ground water from individual wells in any hydrogeologic setting may not conform to general patterns because of local variability of controlling factors discussed in the preceding sections.

Transects perpendicular to strike.--Five transects perpendicular to strike that include wells near or in the crystalline rocks are located on Welsh Mountain and Mine Ridge in Lancaster County and in the Barren Hills southeast of Honeybrook in Chester County (fig. 25).

Generally, the transects show that water from wells drilled at the ridge crest has relatively greater Ra activities, lower Rn-222 activities, and lower pH than water from wells on slopes. Correlation between Ra and Rn-222 activities and topographic setting (hilltop or slope) was not statistically significant for the categories tested, although low pH correlated with hilltop wells. Water from wells located downgradient and at or near the contact between the Chickies Quartzite and underlying crystalline rocks commonly contained relatively low total Ra activities, elevated Rn-222 activities, and had a higher pH than water from ridge-crest wells. Ground water from wells on slopes correlated positively with SiO_2 and alkalinity.

Lithologic comparisons generally indicate that ground water in the conglomerate, which is nearest the crystalline-rock contact, contains more Rn-222 than ground water in the quartzite. This relation may reflect the higher U content of the conglomerate. The flow path, as well as lithology, can be an important factor controlling Ra and Rn-222 activity and pH in ground water sampled progressively downgradient from the ridge crest. Chemical reactions, such as dissolution of minerals, can increase pH and decrease sorption causing changes in water chemistry along a flow path from recharge at ridge crests to discharge at Chickies Quartzite-crystalline rock contacts.

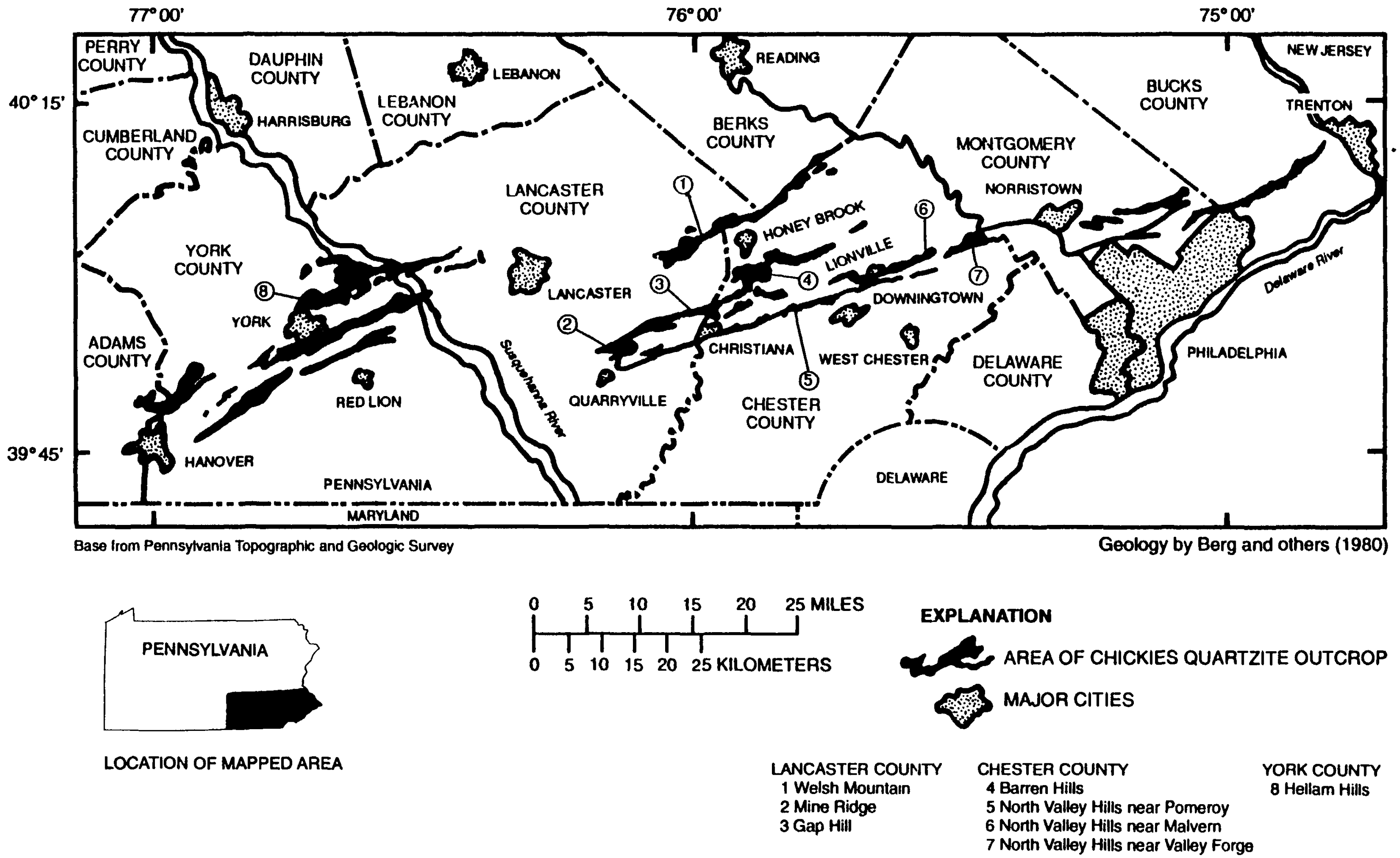
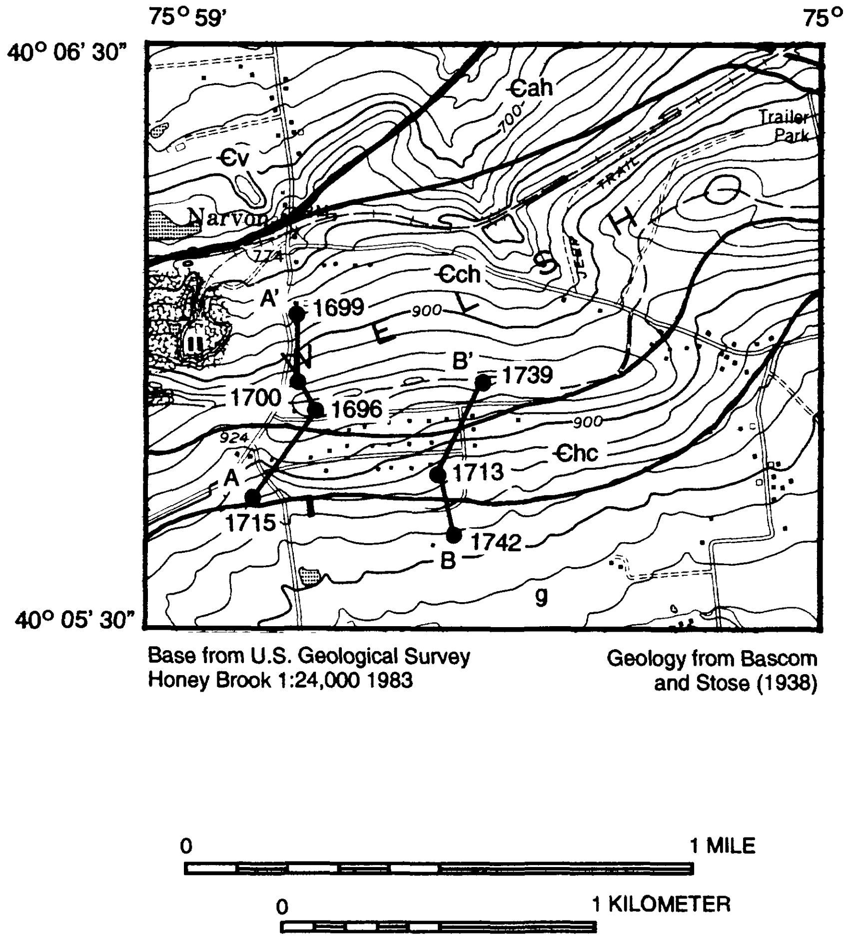


Figure 25. Location of transects of sampled wells.

Two closely spaced transects are on Welsh Mountain near Narvon, Lancaster County (fig. 26). One transect includes three wells and runs nearly perpendicular from the contact with the Precambrian crystalline rocks to the ridge crest (fig. 27). The other transect, located about 0.25 mi to the west along strike (fig. 27), includes four wells and also runs perpendicular to strike from the conglomerate north to the mid-section of overlying quartzite lithology. Water-level measurements indicate that the ground-water divide is located at the ridge crest; ground water flows to the north and the south from the ridge crest.

Ra activities are greatest and Rn-222 activities and pH are lowest in water from wells at the ridge crest compared to wells on slopes. The Rn-222 activities in water from wells downslope from the ridge crest could be caused by high U content of the aquifer as inferred from gamma-ray logs of wells near the crystalline rock contact (see logs of LN-1713 and LN-1715, in appendix). Ra-226 is immobilized by precipitation and (or) adsorbtion as the pH increases downgradient in the aquifer. Because pH is an important control on Ra mobility, the relatively greater Rn-222 activities in water from downslope wells can reflect immobilization of Ra that originated upgradient in the acidic recharge zone on ridge crests.

These general conditions are also seen in other transects perpendicular to strike that include wells in adjacent sedimentary rocks (fig. 25). Generally, water from wells on ridge crests in the Chickies Quartzite contains higher total Ra activities and has a lower pH than water from downgradient wells in the Chickies Quartzite and overlying sedimentary rocks. Rn-222 activities in water from wells in the Chickies Quartzite are similar to those in water from wells in the Harpers Phyllite and Antietam Quartzite but greater than those in water from wells in carbonate rocks. Rn-222 in the ground water in the Harpers Phyllite and Antietam Quartzite is derived from U in the aquifer materials and (or) from the precipitation or adsorption of dissolved Ra originating in the Chickies Quartzite. The median U concentration (3.6 ppm) for three rock samples of Harpers Phyllite and Antietam Quartzite is as great or greater than median U concentrations for samples of the Chickies Quartzite (tables 8 and 9). The low Ra activities in water samples from wells in carbonate rocks indicates that Ra is not mobile or that little Ra is present in aquifer materials. The low Rn-222 activities in water from the carbonate rocks reflects low U concentration in aquifer materials and (or) dilution of Rn-222 in carbonate aquifers with comparatively high hydraulic conductivity.



Base from U.S. Geological Survey
Honey Brook 1:24,000 1983

Geology from Bascom
and Stose (1938)

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

Ꞓah	HARPERS PHYLLITE AND ANTIETAM QUARTZITE, undivided
Ꞓch	CHICKIES QUARTZITE - quartzite
Ꞓhc	CHICKIES QUARTZITE - conglomerate
g	GNEISS
Cv	VINTAGE DOLOMITE

● 1696	WELL AND IDENTIFICATION NUMBER
A A'	LINE OF CROSS SECTION
▬ ▬	FAULT, dashed where infered
——	CONTACT - accuracy not stated

Figure 26. Geology and location of selected wells, Welsh Mountain, Lancaster County.

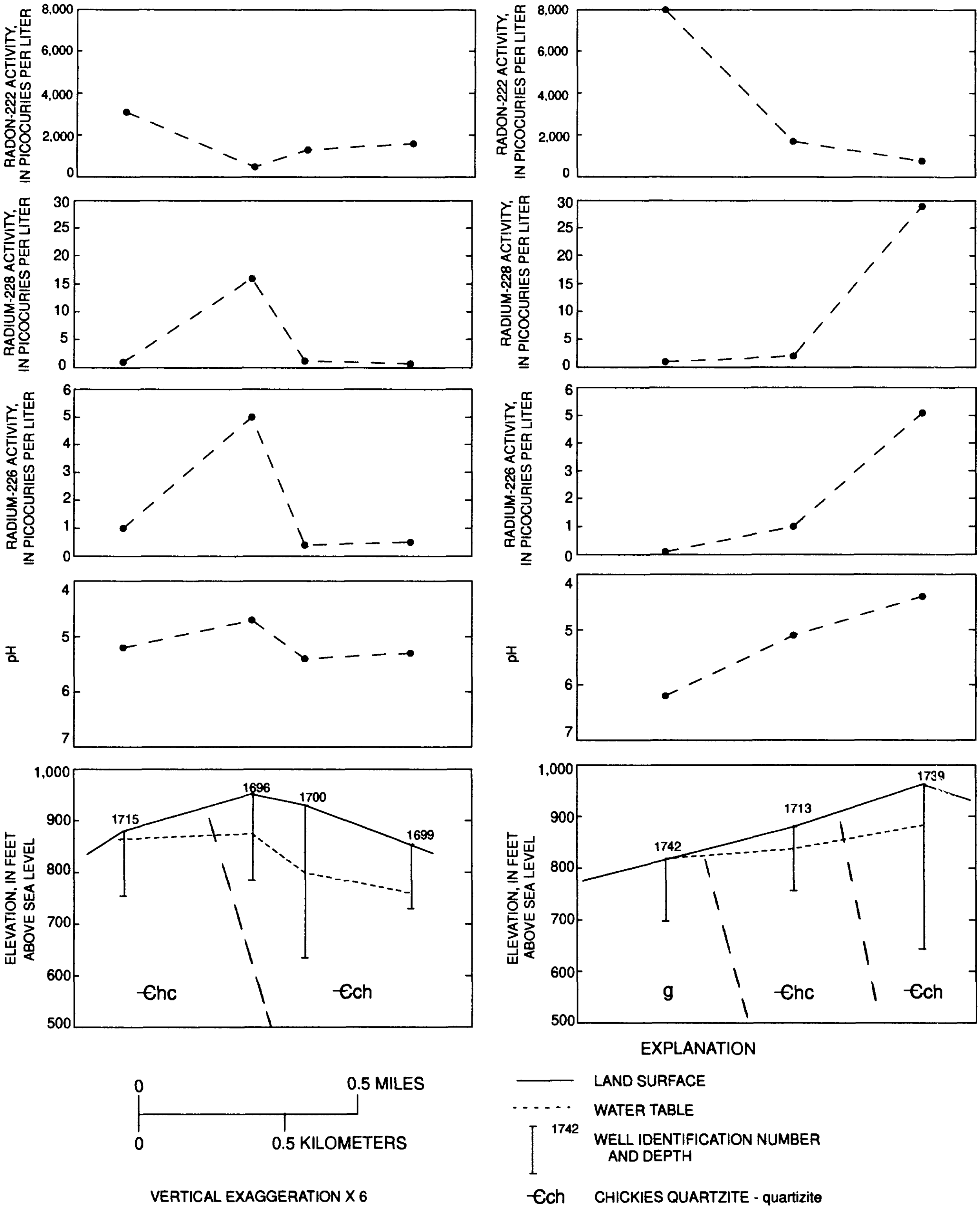
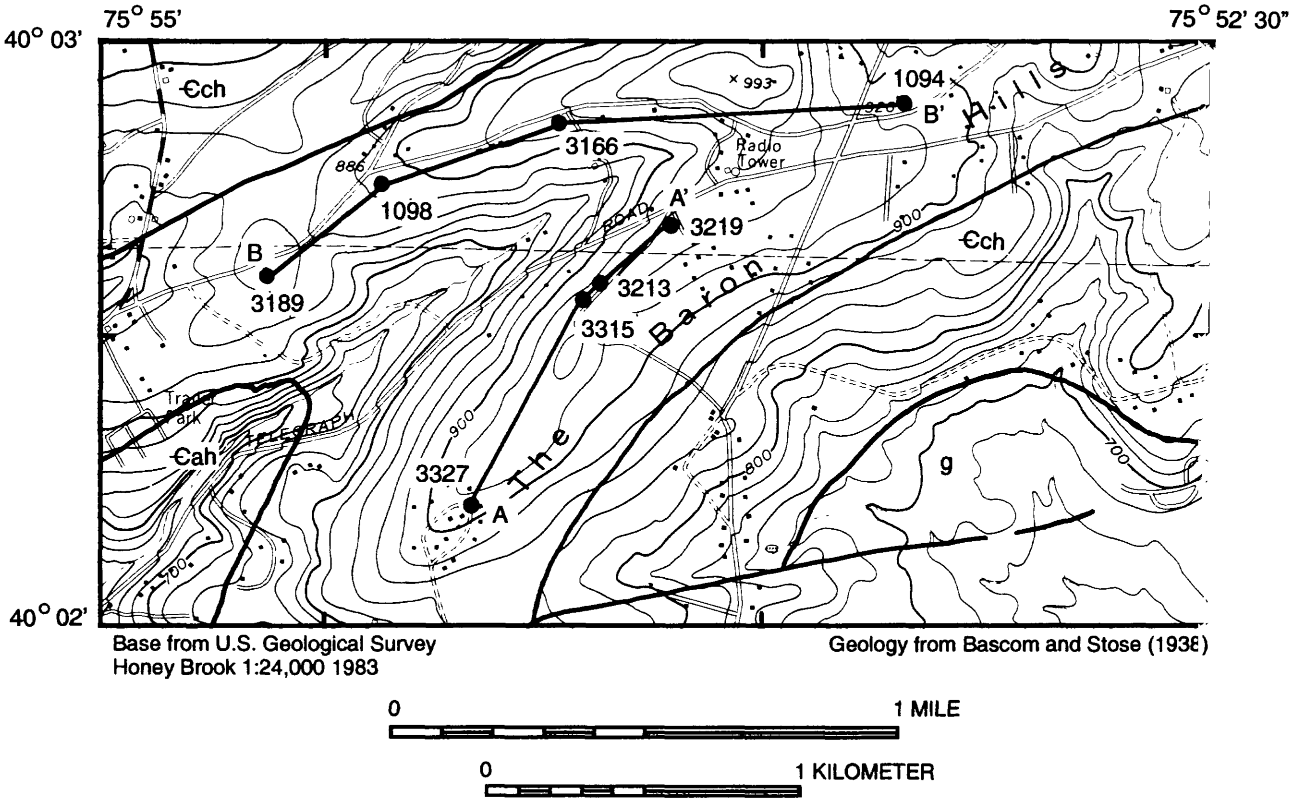


Figure 27. Radium and radon activities and pH in ground water and schematic geologic sections perpendicular to strike, Welsh Mountain, Lancaster County.

Transects parallel to strike.--Five transects parallel to strike that include wells on ridge crests are located on Mine Ridge in Lancaster County west of Gap, in the Barren Hills in Chester County southeast of Honeybrook, and in the North Valley Hills in Chester County north of Malvern and near Valley Forge (fig. 25). Generally, the transects show that Ra and Rn-222 activities and pH in water from wells along the ridge crest are similar as a result of similar aquifer composition and hydrologic conditions along strike. Rn-222 activities appear to vary less in water from wells along a ridge crest than in water from wells on slopes. On Mine Ridge, the contact between the conglomerate and quartzite lithologies underlies the crest, and there activities of Rn-222 are greater in wells on the crest than slopes. One of these transect areas is described below.

Two sets of wells were sampled along strike in the Barren Hills, Chester County (figs. 28 and 29). Both sets of wells are drilled near the ridge crest where the altitude of the land surface and the water table changes little along the transect. Water from wells CH-3327, CH-3315, CH-3213, and CH-3219 along transect A-A′ (fig. 29) contain Ra activities greater than 20 pCi/L. Water samples from wells CH-3189, CH-1098, CH-3166, and CH-1094 along transect B-B′ (fig. 29) contain Ra activities less than 10 pCi/L. Both sets of wells are in similar hydrogeologic settings. Water from wells within in each set contains a similar range of Ra and Rn-222 activities for that set. The difference in the range of Ra activity between the sets of wells probably reflects differences in the U and Th content of the aquifer.



Base from U.S. Geological Survey
Honey Brook 1:24,000 1983

Geology from Bascom and Stose (1938)

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

-Єah	HARPERS PHYLLITE AND ANTIETAM QUARTZITE, undivided	● 3189	WELL AND IDENTIFICATION NUMBER
		A ___ A'	LINE OF CROSS SECTION
-Єch	CHICKIES QUARTZITE - quartzite	▬ ▪	FAULT, dashed where infered
-Єhc	CHICKIES QUARTZITE - conglomerate	——	CONTACT - accuracy not stated
g	GNEISS		

Figure 28. Geology and locations of selected wells, Barren Hills, Chester County.

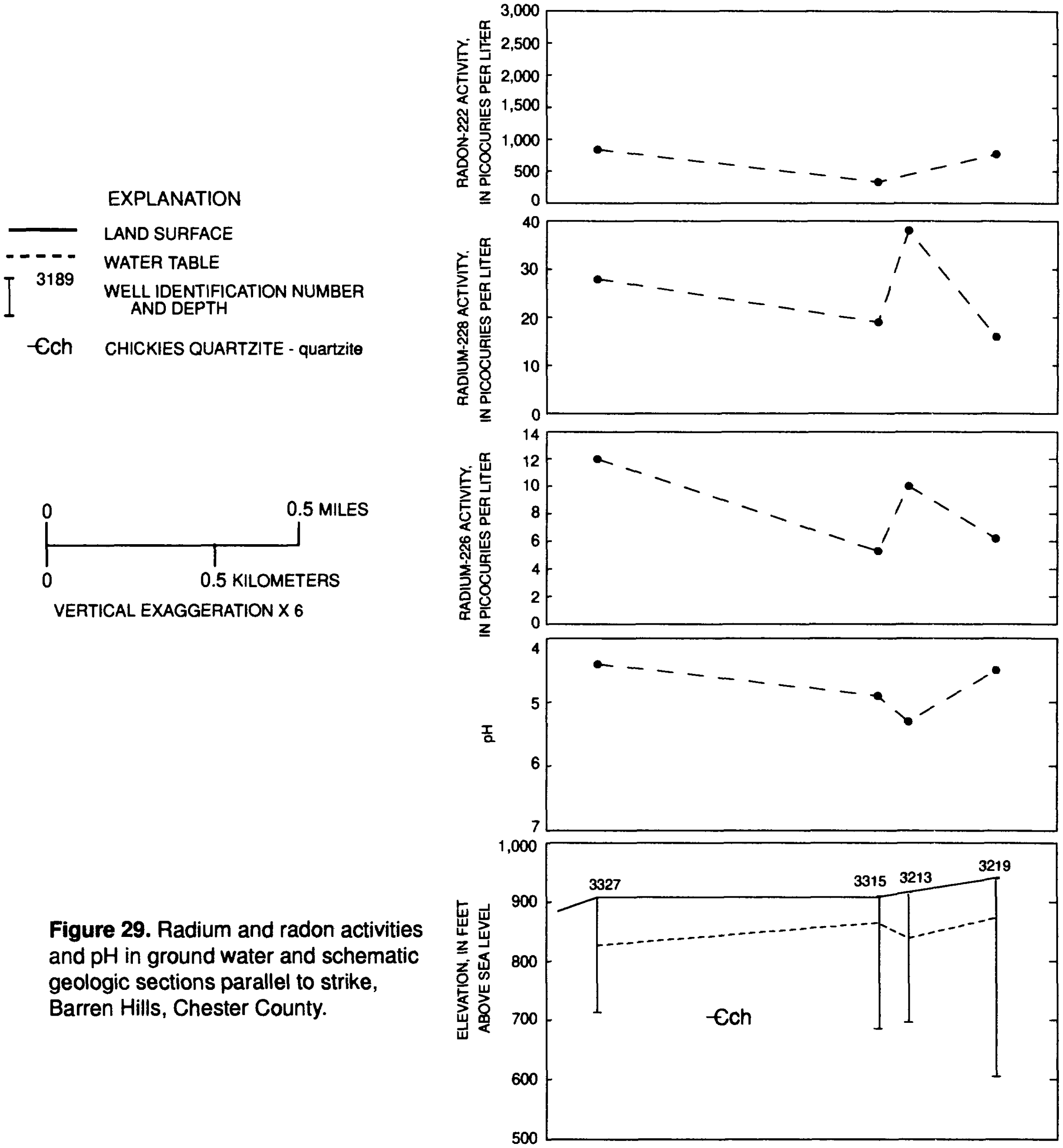
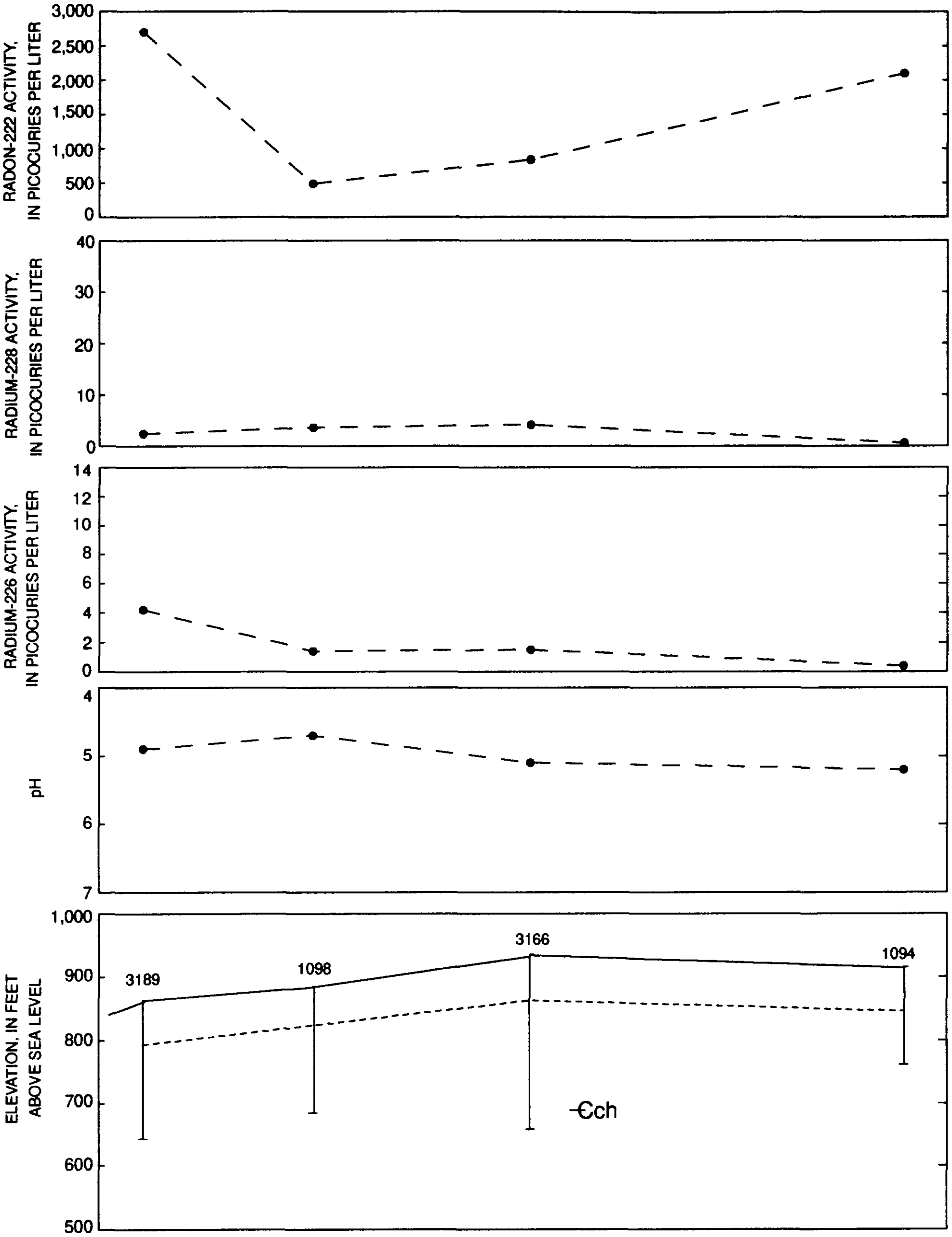


Figure 29. Radium and radon activities and pH in ground water and schematic geologic sections parallel to strike, Barren Hills, Chester County.

Local variability.--Ra and Rn-222 activities and water chemistry differ locally as well as regionally. Water from nearby wells with similar depths does not necessarily contain similar Ra and Rn-222 activities. Local variability represents departures from general patterns described in the discussions on transects. The transects generally show elevated Ra activities and low pH in water from ridge crest wells; elevated Rn-222 activities generally are found in water from wells drilled into the conglomerate lithology and from wells drilled on slopes. Factors unique to each well that affect local variability of Ra, Rn-222, and water chemistry include well characteristics (depth, yield, specific capacity, location of water-bearing zones, and casing length), position in the flow path, and aquifer mineralogy and lithology. Fracture patterns also differ, exposing different sections of the lithologies to ground-water flow.

Six sets of closely spaced wells with similar geologic and hydrologic settings were sampled to investigate the local variability of water chemistry. Each set includes two to three wells sampled on the same day. The wells are in Welsh Mountain and Gap Hill in Lancaster County, and in the North Valley Hills near Malvern in Chester County (fig. 25). Selected data for these wells are given in table 17.



Three closely spaced wells (LN-1738, LN-1740, and LN-1741) located on a ridge crest on Welsh Mountain were sampled. Water samples from these wells show that ground-water chemistry, including radium activities, may be similar if the water is derived from similar depths but can differ by depth from well to well in a small area. The results also show that not all water from wells on ridge crests in the Chickies Quartzite contains elevated Ra activities. Water samples from wells LN-1740 and LN-1741 come from at least one water-bearing zone of similar depth, have a similar chemical character (pH of 5.3, similar specific conductance, and low DOC, Ba, and SO_4 concentrations), and low Ra and Rn-222 activities (table 17). Well LN-1738, which is located nearby, is drilled deeper and taps deeper water-bearing zones than wells LN-1740 and LN-1741. Water from well LN-1738 has only slightly higher Rn-222 activities, but is more acidic and has a higher specific conductance, higher DOC, Ba, and SO_4 concentrations, and higher Ra activities than water from the other two wells. Because the Rn-222 activities are similar in samples from this group of wells, chemical factors probably account for the observed differences in radium activities more than other factors, such as the distribution of U in aquifer materials or well characteristics.

Table 17. Activities of radium-226, radium-228, and radon-222 and concentrations of selected chemical constituents and properties in water from six sets of wells drilled in close proximity in the Chickies Quartzite. Counting or analytical error values for each sample give counting or analytical uncertainty at the 2σ or 95-percent-confidence level. Location of wells shown on plate 1.

[<, less than; pCi/L, picocuries per liter; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; ft, feet; gal/min, gallons per minute; σ, sigma; CE, counting error; --, no data]

Well number	Well depth (ft)	Reported yield (gal/min)	Depth of water-bearing zones (ft)	Date sampled	Ra-226 (pCi/L)	Ra-226, 2-σ CE (pCi/L)	Ra-228 (pCi/L)	Ra-228, 2-σ CE (pCi/L)	Rn-222 (pCi/L)	pH	DOC (mg/L)	Ba (µg/L)	SO_4 (µg/L)	Specific conductance (µS/cm)
Welsh Mountain														
LN-1738	407	2	300/375	09-02-88	3.9	0.7	14	2.8	2,000	4.8	1.2	210	14	47
1740	325	2	130/210/298	09-02-88	.3	.06	< 1.0	--	1,300	5.3	.4	13	.6	15
1741	150	20	92/134	09-02-88	.2	.04	< 1.0	--	1,500	5.3	.5	9	<.2	16
LN-1686	275	15	106/257	12-03-86	1.0	.5	1.6	--	24,500	5.2	.6	39	.3	18
1701	220	15	170/196/198	08-23-88	.87	.09	.8	.04	5,300	5.9	.9	21	1.4	54
LN-1736	230	20	110/180	08-17-88	.61	.3	3.7	1.3	770	5.1	.8	58	8.3	45
1737	280	3	130/260	08-17-88	2.2	.4	2.7	1.3	2,800	5.5	.9	56	.5	43
Gap Hill														
LN-1697	70	--	--	07-13-87	6.6	.7	100	10	600	4.4	2.6	97	< .2	187
1698	217	--	--	07-13-87	6.3	.6	33	1.0	1,000	4.4	2.2	190	33	214
LN-1725	175	15	108/167	08-05-88	41	.05	100	20	12,700	4.5	2.0	130	19	165
1726	175	6	76/160	08-05-88	6.2	1.6	13	3.1	4,300	4.7	2.2	120	5.3	54
North Valley Hills														
CH-3132	143	5	65/132	09-03-87	31	2.0	55	6.0	1,400	4.7	2.3	190	28	304
3128	165	6	77/156	09-03-87	11	1.0	30	3.0	1,100	4.7	--	140	23	68

Wells LN-1686 and LN-1701, located on a slope on Welsh Mountain, are about 300 ft apart and have the same reported yield, but the depths of water-bearing zones differ (table 17). Both wells have elevated Rn-222 activities and similar, moderate radium activities, yet water from well LN-1686 has more than five times the Rn-222 activity than does the water from well LN-1701 (table 17). Despite the proximity and similarity of the two wells, factors affecting Rn-222 activities appear to differ by individual water-bearing zones in the aquifer. These differences in Rn-222 activities in ground water probably reflect differences in the concentration of U and Ra-226 sources and(or) emanation rates from host minerals near the wells, because other physical factors, such as well yield (a measure of aquifer porosity) and hydrologic setting, for the two wells are similar.

Water from wells LN-1736 and LN-1737, located near a ridge crest on Welsh Mountain, has similar chemistry, contains similar Ra-228 activities, but different Ra-226 and Rn-222 activities. Water from well LN-1737 contains a higher Ra-226 activity, despite having higher pH, and a higher Rn-222 activity than water from well LN-1736 nearby. This suggests that the aquifer may contain similar amounts of Th, but more U and(or) Ra-226 in aquifer materials in the immediate area of well LN-1737 than in the area near LN-1736.

Differences in Rn-222, Ra-226, and Ra-228 activities were measured in water from two pairs of closely spaced wells near the ridge crest on Gap Hill. Water from wells LN-1697, LN-1698, LN-1725, and LN-1726 has a relatively similar chemical character (low pH, high specific conductance, except for well LN-1726, and high DOC concentrations) that apparently favors Ra mobility, and elevated activities of Ra-226 and Ra-228 were measured in each water sample (table 17). The differences in Ra-228, Ra-226, and Rn-222 activities in water from these wells probably reflect differences in aquifer mineralogy, including locally variable distribution of both Th and U.

Elevated Ra activities were measured in water from two wells (CH-3128, CH-3132) with low pH and relatively high DOC and SO_4 concentrations, located near a ridge crest in the North Valley Hills (table 17). The wells differ only slightly in depth, yield, and depth of water-bearing zones, and water from the wells contains similar Rn-222 activities. Although radium activities are elevated in water from both wells, water from well CH-3132 contains substantially more radium-226 and radium-228 than water from well CH-3128. This set of wells shows that elevated Ra in a range of concentrations is found in ground water with characteristics favoring Ra mobility and that differences in the radium activities can be greater than the differences in Rn-222 activities in closely spaced wells with similar construction and hydraulic characteristics.

Thus, results of sampling closely spaced wells show that the chemical character of ground water commonly is similar in one area, but Ra and Rn-222 activities can range over two orders of magnitude. Ra activities of similar magnitude tend to be found in water from wells in similar hydrogeologic settings, although elevated Ra activities are not necessarily present in ground water with geochemical conditions favorable for Ra mobility. Rn-222 activity in ground water differs from well to well, but commonly is similar in water from wells in similar hydrogeologic settings. Ra and Rn-222 activities in ground water may be unpredictable in fractured-rock aquifers with variable U and Th distribution, variable mineralogy (caused by sedimentary facies changes), variable hydraulic conductivity, fracture spacing, and complex flow paths. Ra and Rn-222 generally do not travel in ground water far from sources because of the short-half life of Rn-222 and rapid sorption of Ra from aqueous phase onto aquifer materials (King and others, 1982).

Distributions in Adjacent Geologic Units

Ground water from a total of 28 wells in geologic units adjacent to the Chickies Quartzite was sampled to determine the radiochemical activities of these formations, the relative magnitude of Ra and Rn activities, and the possible effect of migration of Ra-rich waters from the Chickies Quartzite. Water samples were taken from wells penetrating the Harpers Phyllite and Antietam Quartzite, carbonate rocks and crystalline rocks immediately adjacent to and downgradient from the Chickies Quartzite (within 1 mi of the contact). The crystalline-rock units include felsic, intermediate, and mafic gneiss. The carbonate units are the Ledger Dolomite, Conestoga Limestone, and Vintage Dolomite. Range and median values of Ra-226, Ra-228, and Rn-222 activities and U concentrations in water samples are given in table 18.

Of the adjacent units, only water samples from wells penetrating the Harpers Phyllite and Antietam Quartzite contained Ra activities greater than 5 pCi/L. Ground water in these units is acidic (median is 5.3; pH range is 4.9 to 6.6). The median and range of Rn-222 activities in ground water in the Harpers Phyllite and Antietam Quartzite (median is 2,300 pCi/L; range is 228-25,300 pCi/L) is about equal to that of the Chickies Quartzite (median is 2,400 pCi/L; range is 114-

32,300 pCi/L). Ra enrichment of ground water in adjacent units by migration of Ra in ground water from the Chickies Quartzite is not indicated by the data. The analysis of cuttings from wells drilled in Harpers Phyllite and Antietam Quartzite indicate that U and Th concentrations in these rocks are similar to U and Th concentrations in the Chickies Quartzite (table 9), and, therefore, the sources of Ra and Rn-222 in ground water in the Harpers Phyllite and Antietam Quartzite are minerals in these units.

The low Ra and Rn-222 activities in the ground water in carbonate rocks may reflect geochemical conditions unfavorable for Ra mobility (median pH 7.3; range 7.0 to 7.8), low U and Th content of aquifer materials, and possibly dilution because of higher permeability. Slightly greater concentrations of U are observed in the ground water in carbonate rocks than in the ground water in other rocks because the mobility of U tends to increase in high pH, bicarbonate-rich waters.

The 10 water samples from the crystalline rocks are grouped into water samples from either felsic or basic rocks for comparison because of the small sample size for individual rock units. U and Th content of felsic rocks generally is greater than that of mafic rocks (table 7). For the wells sampled, ground water in felsic rocks has a lower pH (median 5.5) than ground water in mafic rocks (median 6.4). The highest Ra and Rn-222 activities and U concentrations in water from a well in crystalline rock were detected in amphibolite facies of a felsic and intermediate gneiss (CH-3117).

In addition to wells that penetrate only adjacent geologic units, wells drilled through the contact between the Chickies Quartzite and adjacent geologic units also were sampled. Elevated Ra activities were not detected in water from wells drilled through the Chickies Quartzite into other geologic units. Water samples from well MG-1003, which probably penetrates the Ledger Dolomite, and wells CH-3122, CH-3135, and LN-1742, which penetrate Precambrian crystalline rocks, have a relatively high pH which reduces Ra mobility. Rn-222 activities in these water samples range from 76 pCi/L for well MG-1003 to 9,200 pCi/L for well CH-3122; the Rn-222 activity partly depends on the U content of the contributing aquifers. Some of the highest Rn-222 activities (up to 30,000 pCi/L) in the Chickies Quartzite were detected in water samples from wells (CH-3122, CH-3328, and CH-3337) drilled near the contact with mafic rocks; these elevated Rn-222 activities are probably caused by high U content of the Chickies Quartzite near the contact but could reflect increased precipitation of Ra at the contact with the mafic rocks, which have a higher pH ground water than does the Chickies Quartzite.

Table 18. Radium-226, radium-228, and radon-222 activities and uranium concentrations in ground water from geologic units adjacent to the Chickies Quartzite

[pCi/L, picocuries per liter; µg/L, micrograms per liter; --, insufficient data to calculate median]

	Harpers Phyllite and Antietam Quartzite, undivided	Carbonate rocks	Crystalline rocks	
			felsic	basic
Number of samples	13	5	8	2
Ra-226 (pCi/L)				
Minimum	< .2	< .2	< .2	< .2
Maximum	2.9	1.0	1.1	.6
Median	.3	< .2	< .2	--
Ra-228 (pCi/L)				
Minimum	<1.0	[1] <1.0	<1.0	<1.0
Maximum	12	--	1.7	<1.0
Median	<1.0	--	<1.0	--
Total Ra (pCi/L)				
Minimum	<1.2	<1.2	<1.2	<1.2
Maximum	14.9	<2.0	2.8	<1.6
Median	1.4	<1.2	<1.2	--
Rn-222 (pCi/L)				
Minimum	230	65	140	1,600
Maximum	25,300	520	8,200	8,000
Median	2,300	366	900	--
U (mg/L)				
Minimum	< .05	< .05	< .05	< .01
Maximum	1.8	2.4	1.7	.25
Median	< .05	.36	< .05	--

[1] Ra-228 activity in all samples was less than detection limit.

Distribution in Other Quartzites in the Piedmont

Other quartzites in Pennsylvania have acidic ground water that is part of a geochemical environment supportive of elevated Ra activities. Data from other quartzites that crop out in the Piedmont are discussed below to compare to data for the Chickies Quartzite. The Hardyston Quartzite is reported to contain monazite, a Th-rich mineral, as an "unusually common accessory" (Smith, 1974; Aaron, 1969) and to have radioactive minerals in a thin bed near the base of the unit (Smith, 1975). The presence of Th- and U-bearing minerals in the aquifer matrix indicates that ground water in the Hardyston Quartzite could contain elevated Ra activities where geochemical conditions favor Ra mobility. Th-rich aquifer materials are associated with elevated Ra-228 activities in ground water.

One water sample was collected from a randomly selected well (BK-1288) that penetrates the Hardyston Quartzite on Buckingham Mountain in Bucks County. The sample contained 1.7 pCi/L Ra-226 and 3.6 pCi/L Ra-228 (5.3 pCi/L total Ra), 12,000 pCi/L Rn-222, and 0.14 μg/L U. These activities and concentration are above the median but within the range for Chickies Quartzite ground-water samples.

The Setters Quartzite and the Peters Creek Schist (a quartzite schist) are Paleozoic or older, and are not clean quartzites like the Chickies Quartzite. Both units crop out south of the Chickies Quartzite and are associated with Wissahickon and Octoraro Schists. Ground-water samples from the Setters Quartzite and Peters Creek Schist in Chester County were analyzed for Ra-226, Ra-228, Rn-222 activities, and U concentration (Sloto, 1989). Water from some wells in both the Precambrian Setters Quartzite and Peters Creek Schist contained some low, but detectable, activities of Ra-22[illegible] and Ra-228. The ground-water samples from the Peters Creek Schist contained relatively elevated activities of Rn-222 (up to 9,100 pCi/L, with a median of 5,800 pCi/L). Probable sources of Th and U in the Setters Quartzite and Peters Creek Schist are minerals such as monazite and zircon that have been identified in the Wissahickon Schist (Dryden and Dryden, 1964). In comparison to the Chickies Quartzite, Ra mobility in the ground water of these aquifers may by limited by relatively less acidic or neutral pH, greater abundance of sorption sites, and (or) other unfavorable geochemical conditions.

Temporal Variability

Ra-226, Ra-228, and Rn-222 activities and chemistry can vary in the water from a well through time. In order to determine if Ra-226, Ra-228, and Rn-222 activities changed over time, 3 wells from different areas of the Chickies Quartzite (BK-1202, CH-3219, and YO-1148) were sampled twice, 1 well (CH-1616) 3 times, and 1 well (CH-3335) 14 times. Wells BK-1202 and CH-3219 are drilled into the quartzite lithology and well YO-1148 is drilled into the conglomerate lithology of the Chickies Quartzite. Wells CH-1616 and CH-3335 are near each other and drilled in the conglomerate lithology. Water from wells sampled two or three times was analyzed for major and minor ions, Ra-226, Ra-228, Rn-222, and U. Water from well CH-3335 was analyzed each time for Ra-226, Ra-228, Rn-222 activities, once for major and minor ions, and 10 times for Cl, SO_4, NO_3, and NH_4. Ra and Rn-222 activities and selected chemical constituents and properties in water from wells CH-1616, CH-3219, and BK-1202 are given in table 19. Complete chemical and radiochemical analyses for all wells are presented in tables 21 and 22, respectively.

Ra and Rn-222 activities in well-water samples fluctuate over periods of months; measured fluctuations range up to 40 percent of the lowest Rn-222 activity and more than 100 percent of the lowest activities for Ra-226 and Ra-228. Increases in Rn-222 activities are not necessarily accompanied by increases or decreases in Ra in ground water. The smallest observed change (8 percent) in Rn-222 activity was in water from well CH-1616, which was sampled three times in about 1 year. The largest observed change (40 percent) was in water from well YO-1148, which was sampled in the winter and summer. Another well, BK-1202, was also sampled in the winter and summer, but Rn-222 activity differed by only 9 percent. Water from wells in different hydrogeologic settings probably differ in the extent of temporal fluctuations in Ra and Rn-222 activities; temporal variability may be caused by seasonal changes in water levels, recharge, and biological activity, or by other changes, including withdrawal rates.

Table 19. Activities of radium-226, radium-228, and radon-222 and concentrations of selected dissolved constituents and properties of water from wells in the Chickies Quartzite sampled more than once. Counting or analytical error values for each sample give counting or analytical uncertainty at the 2σ or 95-percent-confidence level.

[pCi/L, picocuries per liter; mg/L, milligrams per liter; μS/cm, microsiemens per centimeter at 25 degrees Celsius; U, uranium; μg/L, micrograms per liter; σ, sigma; CE, counting error; AE, analytical error; --, no data]

Well number	Date sampled	Ra-226 (pCi/L)	Ra-226 2-σ CE (pCi/L)	Ra-228 (pCi/L)	Ra-228 2-σ CE (pCi/L)	Rn-222 (pCi/L)	U (μg/L)	U 2-σ AE (mg/L)	pH	DOC (mg/L)	Ba (mg/L)	Specific conductance (μS/cm)
BK-1202	12-31-86	3.8	0.5	50	2.0	2,600	0.33	0.05	5.4	1.1	<100	58
	05-07-87	5.7	.6	66	2.0	2,800	.39	.06	4.9	--	58	75
CH-1265	11-21-86	2.7	.5	2.7	.7	370	.18	.03	--	--	--	--
	05-06-87	2.0	.2	2.4	.5	--	.23	.03	--	--	--	--
CH-1616	11-12-86	2.7	.6	17	3.0	3,400	.30	.05	5.3	1.2	42	203
	08-11-87	2.9	.1	25	1.0	--	< .05	--	5.0	1.0	40	230
	10-23-87	4.1	.4	29	3.0	3,700	.87	.01	5.1	--	40	242
CH-3219	06-16-87	4.6	.8	13	2.7	671	--	--	5.4	1.4	53	44
	08-23-87	6.2	1.0	16	3.1	772	.02	.01	4.5	1.1	65	44
YO-1148	12-09-86	5.4	.6	9	.9	20,300	.86	.13	5.0	.7	30	48
	07-22-87	2.1	.1	4	.7	28,500	.79	.12	5.1	.8	15	35

Ra-226, Ra-228, and Rn-222 activities in water samples from well CH-3335 exhibit a seasonal rise and decline that is inversely related to the seasonal rise and decline of the water table and the SO_4 concentrations. Ra-226 activities ranged from 4.4 to 15.3 pCi/L, Ra-228 activities ranged from 64 to 160 pCi/L, and Rn-222 activities ranged from 2,800 to 7,900 pCi/L (table 22). Ra-226, Ra-228, and Rn-222 activities; pH, SO_4, and NH_4 concentration; and depth to water in well CH-3335 are shown in figure 30 for September 1988 through November 1989. The lowest Ra and Rn-222 activities occur during April-June when the water table is highest, concentrations of SO_4 are greatest (up to 31 mg/L), and concentrations of NH_4 are lowest (below level of detection) (tables 21 and 22). These low Ra and Rn-222 activities may reflect dilution by recharge of meteoric origin. Increased SO_4 and decreased NH_4 concentrations in ground water indicate more oxidizing conditions that are consistent with recharge through shallow fractures. Increased SO_4 concentrations in ground water can be associated with SO_4-enriched recharge, where sources are acid rain and SO_4 accumulated in the unsaturated zone during dry periods. Precipitation collected in 1979-86 in Chester County west of well CH-3335 contained SO_4 concentrations of up to 10 mg/L.

The inverse temporal relation between Ra and SO_4 for water from well CH-3335 is opposite to the positive correlation shown by statistical analysis of data for 160 wells sampled once. However, concentrations of SO_4 in water from well CH-3335 (median concentration is 24 mg/L) are relatively elevated compared to all 160 wells (median of 5.7 mg/L). Some ground water with elevated Ra activity (well LN-1697; for example, see table 17) do not contain an elevated SO_4 concentration; this suggests that the chemical relation between Ra and SO_4 is not as strong as it is between Ra and other controlling factors, such as pH.

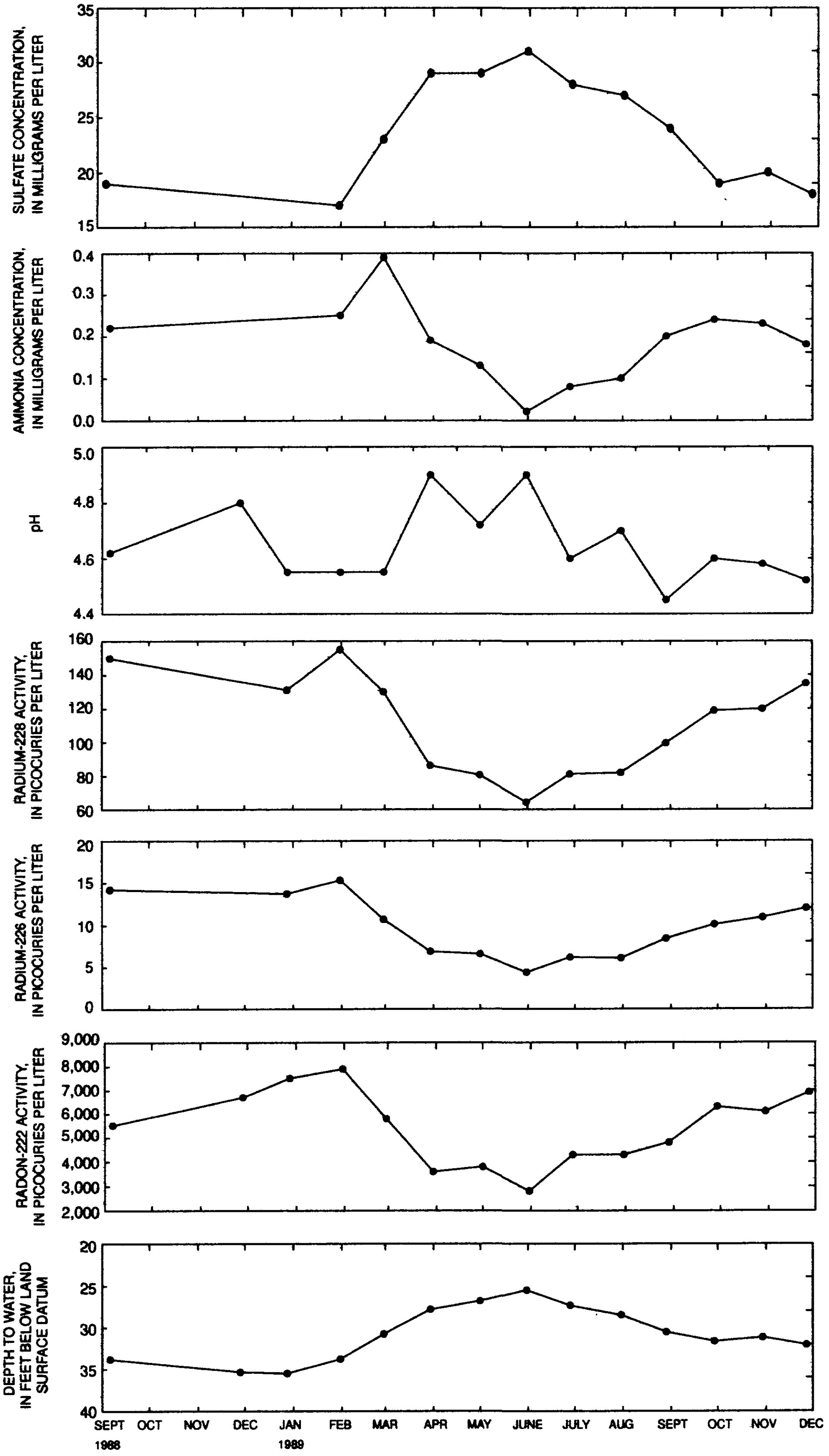


Figure 30. Relations among radon-222, radium-226, and radium-228 activities; pH; sulfate and ammonia concentrations; and depth to water in well CH-3335, September 1988 to November 1989.

Conceptual Model of Radium and Radon in Ground Water

Elevated Ra activities in ground water are found in a geochemical environment that favors Ra mobility. Ground-water chemistry depends on both geologic and hydrologic controls that include aquifer lithology and mineralogy, and flow paths. Primary sources of Ra in ground water are U- and Th-bearing minerals in the aquifer matrix. The abundance of U and Th in rocks is not as important as geochemical controls in determining Ra activities in ground water. Elevated activities of Ra-226 and Ra-228 are found in ground water in rocks that are not especially enriched in U, Th, and Ra because geochemical controls, such as pH, limit solubility.

Elevated Ra in ground water in the Chickies Quartzite is associated with low pH waters. Differences in pH partly reflects differences in mineralogy between the facies or lithologies of the Chickies Quartzite. Dissolution of silicate minerals is an acid-neutralizing process that raises the pH of ground water. Silicate minerals are more abundant in the feldspathic arenites and wackes than in the quartz arenites and conglomerates of the Chickies Quartzite described by Hyde (1971). Elevated Ra commonly is found in the most acidic ground water in the quartzite and conglomerate lithologies (quartz arenite and conglomerate facies), and is less commonly detected in the less acidic ground water in feldspathic arenites of the quartzite lithology. Elevated Ra was not detected in the water in the slate lithology that has the least acidic (most neutral) pH of the Chickies Quartzite aquifer lithologies.

The spatial distribution of elevated Ra in ground water generally corresponds to the distribution of lithologies. The quartz arenite and conglomerate facies crop out in the central and western areas, feldspathic arenites and wackes in the south-central and eastern areas, and the slate in the south-central area of the Chickies Quartzite, southeastern Pennsylvania (Hyde, 1971; Stose and Stose, 1944). Lithology can be used as a predictor of elevated Ra in ground water. Elevated Ra-228 in ground water has been predicted for arkosic sandstone and sandstone aquifers with high TDS concentrations in the eastern Piedmont (Hess and others, 1985; Michel, 1988). The Chickies Quartzite was classified as arkosic by Engelder (1976).

Ground water in the Chickies Quartzite contains Ra-228 activities that exceed Ra-226 activities. The Ra-228 and Ra-226 activities in ground water indicate a relatively greater abundance of Th than U in the aquifer. Geologic controls on the distribution of Ra-226 and Ra-228 in the ground water of the Chickies Quartzite may include differences in mineral phases for U and Th in the rocks. The Ra-228/Ra-226 activity ratios are greater in the ground water than the rocks, suggesting preferential dissolution or desorption of Ra-228 from Th-bearing host minerals relative to the release of Ra-226 from U-bearing minerals, or more Th-enrichment relative to U in the rocks than was detected in this study.

The hydrologic setting of the Chickies Quartzite, a ridge-forming, water-table aquifer, also is a control on ground-water chemistry and Ra. From the transect data, it appears that water drilled on ridge crests contains the greatest measured activities of Ra. Ridge crest wells are recharged directly from acidic precipitation. Wells on slopes are supplied from direct acidic recharge that has undergone little chemical evolution and by ground water that is more chemically evolved and has increased pH through weathering of silicate minerals and other reactions. Ra is leached in acidic ground water from aquifer minerals beneath the ridge crests and is transported downgradient where Ra sorbs to mineral surfaces in contact with waters that are less acidic than upgradient. The quartzite lithology appears to be more resistant to erosion than the conglomerate lithology of the Chickies Quartzite, because it commonly underlies hilltops where recharge occurs; in this recharge area, ground water chemical evolution may be least advanced (lowest pH) because the ground-water is nearest the origin of its flow path and because of the sparsity of easily dissolved silicate minerals in the quartzite lithology.

Rn-222 in ground water, because of its short half-life, directly reflects the Ra-226 and U content of the aquifer materials for aquifers with similar porosity, permeability and Rn-222 emanation rates. The hydrologic properties of the conglomerate, quartzite and slate lithologies of the Chickies Quartzite appear to be similar, as determined from well characteristics. However, the conglomerate may contain more U than does the quartzite or the slate, and therefore, has ground water with the maximum Rn-222 activities of the Chickies Quartzite lithologies.

If transport of Ra from ridge crest to slope occurs, then elevated Rn-222 activities could be expected in ground water from wells on slopes. The transects show that maximum Rn-222 activities are in water from wells on slopes and near the Chickies Quartzite-crystalline rock contact, which partly reflects the higher U content in these rocks. However, Rn-222 activities are also commonly elevated in water from wells on slopes in the upper section of the quartzite, suggesting that Ra is retained on aquifer materials rather than mobile in ground water beneath slopes. No significant transport of Ra or Rn-222 into units adjacent to the Chickies was found.

Removal of Radium and Radon From Water Supplies

Elevated Ra activities in ground water of the Chickies Quartzite could pose a health risk to users. Alternative water supplies or treatment of water are necessary if activities exceed the USEPA MCL for Ra in drinking water. Zapecza and Szabo (1986) summarize water treatment for Ra, Rn, and U, and describe a number of methods to reduce or eliminate those constituents in water. The USEPA has documented procedures for removing of Ra from community water supplies (U.S. Environmental Protection Agency, 1983; Mangelson, 1988; Valentine and others, 1988)—procedures that may be applicable to the few public supply wells in the Chickies Quartzite.

Treatment of water containing dissolved or suspended Ra and Rn could result in the concentration of Ra, Rn, and decay products in filters, ion-exchange columns, treatment tanks, or waste effluent discharged during treatment processes. Safe disposal of radioactive waste effluent or treatment materials is a consideration in selecting a treatment process.

SUMMARY

The Chickies Quartzite is a minor water-table aquifer in southeastern Pennsylvania. It is recharged primarily by precipitation, and ground water is soft, dilute, and acidic. The Chickies Quartzite is Lower Cambrian in age and consists of a basal conglomerate, quartzite, and slate. It forms narrow ridges and crops out discontinuously over 112 mi^2 in the Piedmont Physiographic Province.

Combined activities of radium-226 (Ra-226) and radon-228 (Ra-228) greater than 5 pCi/L (picocuries per liter) were detected in water samples from 47 percent of 160 wells penetrating the Chickies Quartzite. Elevated Ra activities were detected throughout the formation. Activities up to 41 pCi/L for Ra-226, 160 pCi/L for Ra-228, and 32,300 pCi/L for radon-222 (Rn-222) were measured. Ra-228 activity exceeded Ra-226 activity in most ground-water samples. The median Ra-228/Ra-226 activity ratio was 2.4 for ground-water samples from 100 wells.

Nonparametric Spearman rho correlations between Ra activities and chemical constituents and properties show that low pH and high dissolved organic carbon (DOC) correlate most strongly with elevated Ra. pH is the strongest control on Ra mobility. DOC and constituents, such as sulfate (SO_4), that correlated positively with elevated Ra may enhance Ra mobility in low pH waters. Rn-222 activity does not correlate with its parent isotope, Ra-226, in ground water. Rn-222 correlates inversely with SO_4.

The magnitudes of Ra-226, Ra-228, and Rn-222 activities differ in the ground water from the three lithologies—conglomerate, quartzite, and slate—of the Chickies Quartzite, reflecting variable geochemical controls on solubility, adsorption, and varying uranium (U) and thorium (Th) content. Ra-226 and Ra-228 activities are significantly greater in ground water in the conglomerate and quartzite than in the slate. Ground water in the conglomerate and quartzite is more acidic (median pH of 5.0 and 5.2, respectively) than ground water in the slate (median pH of 6.4). Rn-222 activity in ground water is significantly greater in the conglomerate than ground water in the slate and quartzite. Median Rn-222 activity in ground water generally increases progressively from the slate to the quartzite to the conglomerate, suggesting that the U content of the solid phase may increase from the slate to the quartzite to the conglomerate, although other controls on Rn-222, such as aquifer porosity and Rn-222 emanation rates, also are important.

Ra activity in ground water is related to U and Th sources in the aquifer and to a geochemical environment that promotes Ra mobility. Rn-222 activity is related to U and Ra-226 sources in the aquifer. Variable distribution of U and Th within the conglomerate and quartzite is indicated by natural-gamma-ray logs. U and Th concentrations in rock samples were similar to those reported for average shales and sandstones. The conglomerate contains zones of Th and U enrichment. Ra-228/Ra-226 activity ratios are greater in ground water than calculated Th-232/U-238 ratios in rock samples of the quartzite and conglomerate, suggesting preferential leaching of Ra-228 from aquifer solids.

Ra-228, Ra-226, and Rn-222 activities differ locally and temporally. Temporal variability appears to be seasonal. Ra activities commonly are elevated in water from wells on ridge crests. Rn-222 activities commonly are elevated in water from wells on slopes and wells near the contact between the Chickies Quartzite and underlying crystalline rock.

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GLOSSARY

Activity.--Number of atoms of a radioactive element multiplied by the decay constant of the element.

Alpha decay.--The radioactive decay of an unstable isotope during which an alpha particle is emitted and the atomic number is decreased by two.

Alpha particle.--Particle composed of two protons and two neutrons (helium nucleus).

Beta decay.--The radioactive decay of an unstable isotope during which a beta particle is emitted and the atomic number is increased or decreased by one.

Beta particle.-- An electron (or positron) that is derived from the transformation of a neutron to proton (or proton to neutron).

Curie.--Unit of measure of radioactivity based on the decay rate of Ra-226 that has a half-life of 1,620 years; 1 gram of Ra-226 generates 1 Curie.

Decay constant.-- Lambda = $\frac{\ln(2)}{t_{1/2}}$, where lambda is the decay constant and $t_{1/2}$ is the half-life.

Gamma ray.--High energy electromagnetic radiation emitted spontaneously in some radioactive decay processes.

Gross-alpha and gross-beta activity.--The total amount of alpha- or beta-particle activity detected from all radionuclides present in a sample. Gross-alpha and beta activities are relative measurements that do not identify specific radionuclides, and that depend upon the counter efficiency, self-absorption of activity by the solids, counting time, energy of alpha and beta particles, in growth of daughter products, and counter calibration standards. For gross-beta activity, the standard commonly is Cs-137; for gross alpha, the standard may be uranium of natural isotopic composition or Am-241. In a water sample, the gross-alpha and beta activity of the solid residue remaining after evaporation is counted.

Half-life.-- The time required for an amount of a radioactive element to decay to one half that amount.

Isotopes.--Atoms with the same number of protons but different number of neutrons (elements with different atomic weights).

Picocurie.-- 10^{-12} Curies is equivalent to 3.7×10^{-2} nuclear disintegrations per second or about 2.2 nuclear disintegrations per minute.

Radionuclide.--A radioactive species of atom characterized by the number of protons and neutrons in its nucleus.

Table 20. Records of wells and springs

USGS well or spring number: Springs are designated by the prefix, SP; all other numbers refer to wells.

Township or borough: Name refers to township unless noted as Boro for Borough.

Driller license number: 0032, William W. Reichart; 0110, Brown Bros. Drilling Inc.; 0111, Anthony Dominiani Jr.; 0154, Leroy Myers; 0188, C.S. Garber and Sons Inc.; 0198, Eichelberger Well Drilling; 0211, Weldo W. Funt; 0248, Thomas G. Keyes; 0249, Ridpath and Potter Company Inc.; 0274, H.K. Honberger and Sons; 0297, Artesian Well Drilling Co.; 0308, Petersheim Bros.; 0317, Walter Knies; 0356, A.C. Reider and Son, Inc.; 0383, Young Bros.; 0384, E.J. Myers and Sons; 0399, John O'Donnell and Son; 0514, F.L. Bollinger and Sons; 0741, James P. Kohler; 0904, Brookover Well Drilling Co.; 1083, Kenneth L. Madron; 1258, Floyd R. Sensenig; 1290, B.L. Myers; 1308, Robert E. Matteson; 1365, Alfred G. Gurley; 1381, J and J Well Drilling; 1457, Bonnie J. Myers; 1515, John W. Wilwert; 1539, Sensenig and Weaver Well Drilling; 1551, Mays Well Drilling; 1609, Edward Powell Well Drilling; 1628, B.L. Myers Bros. Inc.; 1706, Chapman Construction Inc.

Use of site: U, unused; W, withdrawal; O, observation.

Use of water: H, domestic; I, irrigation; P, public supply; U, unused.

Topographic setting: H, hilltop; S, slope; V, valley; W, upland draw.

Aquifer codes: 367CNSG, Conestoga Limestone; 377LDGR, Ledger Dolomite; 377VNTG, Vintage Dolomite; 377ANTM, Antietam Quartzite; 377HRPR, Harpers Phyllite; 377CCKS, Chickies Quartzite; 377HRDS, Hardyston Quartzite; 400FLCGP, Felsic gneiss, granulite facies; 400FMFG, Felsic and mafic gneiss; 400FCIGA, Felsic and intermediate gneiss, amphibolite facies; 400BMFGA, Banded mafic gneiss, amphibolite facies; 400FLCGG, Felsic gneiss, granulite facies; 000GBBR, Gabbro and gabbroic gneiss.

Altitude of land surface is estimated from topographic maps. Datum is National Geodetic Vertical Datum of 1929.

Water level is in feet below land surface.

Table 20. Records of wells and springs

USGS well number or spring	Location Latitude (degrees)	Location Longitude (degrees)	Township or borough	Owner	Driller license number	Year drilled	Primary Use of site	Primary Use of water	Altitude of land surface (feet)	Topo-graphic setting	Hydro-geologic unit
BE- 1440	401159	0754635	Union	French Creek State Park	--	--	O	U	710	H	377CCKS
BK- 396	400814	0750034	L. Southampton	Somerton Springs Pool	0399	1927	U	U	180	W	377CCKS
1200	400924	0745535	Middletown	Rush, Richard	0111	1980	W	H	57	S	377CCKS
1201	400916	0745605	Middletown	Orfe, Francis	0111	1979	W	H	40	S	377CCKS
1202	401223	0744942	L. Makefield	Ferri, David	0111	1985	W	H	140	S	377CCKS
1227	401222	0745027	L. Makefield	Hildebrand, J.	0111	1983	W	H	182	H	400FLCGP
1228	401211	0745013	L. Makefield	Groome	--	--	W	H	170	S	377CCKS
1288	401920	0750158	Buckingham	Barford, Thomas	--	1967	W	H	410	H	377HRDS
SP21	401229	0744943	L. Makefied	Ferri, David	--	--	U	U	140	S	377CCKS
CH- 293	400422	0753128	Tredyffrin	Cedar Hollow Water Assoc	0297	1927	W	P	340	S	377CCKS
333	400504	0752904	Schuylkill	Cappelli, P.	0248	1977	W	H	545	S	377CCKS
417	395728	0755707	W. Sadsbury	Simmons, G.	1539	1986	W	H	720	H	377CCKS
418	400740	0755230	W. Nantmeal	Roberts, George	1365	1978	W	H	810	H	377CCKS
427	400837	0755107	W. Nantmeal	Filmore, Robert	--	1977	W	H	770	S	377HRPR
505	400535	0752847	Schuylkill	McMaster, G.	--	--	W	H	420	S	377CCKS
693	400614	0754154	West Vincent	Laloup, Andrew	0188	1973	W	H	650	S	377CCKS
703	400854	0755017	West Nantmeal	Miller, Jeff	0904	1987	W	H	718	S	377HRPR
945	395918	0755002	Valley	Hines, Norman	--	--	W	H	470	S	377CCKS
992	395808	0755303	Sadsbury	Doratt, Shirley	0154	1949	W	H	615	S	377HRPR
1089	400909	0755038	Elverson Boro	Fry, Edward	0308	1984	W	H	675	S	377CCKS
1090	400108	0755458	West Caln	Funk, Jim	0904	1979	W	H	800	S	377CCKS
1091	400030	0755542	West Caln	Loggins, Lawrence	0308	1975	W	H	878	H	377CCKS
1092	400335	0754905	W. Brandywine	Urban, Joe	--	--	W	H	730	S	377CCKS
1093	400225	0753814	W. Whiteland	Mattioni, Amberto	1365	--	W	H	450	S	377CCKS
1094	400254	0755313	West Caln	Bryan, Joseph	--	1981	W	H	916	H	377CCKS
1095	395817	0755313	Sadsbury	Wolf, Lentha	0319	1978	W	H	635	S	377CCKS
1096	400206	0755337	West Caln	Gregor, Adam	1308	1987	W	H	760	S	377CCKS
1097	400214	0755551	West Caln	Batdorf, Vernon	0319	1978	W	H	742	H	377ANTM
1098	400246	0755423	West Caln	Supplee, Elam	0308	1977	W	H	885	S	377CCKS
1099	400927	0754927	Elverson	Austin, Jeff	--	1974	W	H	610	S	400FLCGG
1213	400224	0754055	Uwchlan	Fetteroft, Ken	0248	1971	W	H	615	S	377CCKS
1217	400216	0754056	Uwchlan	Copp, Karen	0248	1972	W	H	555	S	377CCKS
1265	400708	0755506	Honey Brook	Samuels, F.	0308	1968	W	H	910	S	377CCKS
1286	400359	0755146	Honey Brook	Blake, Ramous	0308	1968	W	U	760	S	377CCKS
1296	400338	0755144	Honey Brook	Morris, T.	0308	1971	W	H	820	S	377CCKS
1367	400300	0755237	W. Caln	Francis, D.	0308	1972	W	H	856	S	377CCKS
1376	400016	0755211	West Caln	Ferguson, Charles	0904	1971	W	H	684	S	377CCKS

Table 20. Records of wells and springs--Continued

Depth of well (feet)	Casing		Depth to water-bearing zone(s) (feet)	Water level (feet)	Date water level measured	Reported yield (gal/min)	Measured yield			Field water quality			USGS well number or spring
	Depth (feet)	Diameter (inches)					Specific capacity [(gal/min)/ft]	Discharge (gal/min)	Pumping period (hours)	Date measured	Specific conductance (µS/cm)	pH (standard units)	
--	--	--	--	--	--	--	--	--	--	12-22-86	145	6.3	1440-BE
318	--	--	--	--	07-07-47	--	1.7	100	8.0	12-21-86	251	6.2	396-BK
125	52	6	60/115	26.10	12-21-86	--	.50	10	2	12-21-86	275	5.8	1200
40	37	6	32	10.00	04-08-79	--	2.5	25	2	12-31-86	298	5.0	1201
165	30	6	15/ 35/ 50	1.30	12-31-86	--	.06	8	.3	12-31-86	58	5.4	1202
165	63	6	80/118/142	14.20	06-22-87	--	.56	25	2	06-22-87	145	6.6	1227
--	--	--	--	--	--	--	--	--	--	06-27-87	343	6.0	1228
109	--	--	86/108	74.40	09-03-88	--	.34	12	4	09-03-88	92	5.1	1288
--	--	--	--	--	--	--	--	--	--	05-27-87	105	4.9	SP21
90	--	--	--	19.00	04-01-27	--	.55	96	--	11-13-86	340	6.4	293-CH
265	48	6	--	50.40	11-15-86	--	.01	4	1	11-15-86	189	4.8	333
160	35	6	--	50.60	11-24-86	20	--	--	--	11-24-86	77	5.2	417
140	82	6	100/135	93.60	12-05-86	15	--	--	1	12-05-86	41	4.9	418
--	--	--	--	--	--	--	--	--	--	12-05-86	19	5.2	427
--	--	--	--	45.50	05-08-87	--	--	--	--	05-08-87	125	5.9	505
145	83	6	--	60.00	11-07-73	--	.70	60	--	05-29-87	64	5.9	693
208	45	6	80	82.30	06-05-87	--	.01	2	2	06-05-87	160	6.1	703
80	--	--	--	36.10	11-14-63	--	--	--	--	11-13-86	93	5.5	945
125	120	6	60/ 85/125	8.00	05-27-64	30	--	--	--	05-27-64	200	5.6	992
140	120	4	115/120	90.90	06-12-87	--	1	40	.5	06-12-87	145	5.3	1089
63	21	6	49	29.00	06-17-87	--	.99	20	--	06-17-87	76	4.7	1090
153	39	6	--	45.00	12-11-75	--	.25	5	--	06-18-87	39	4.8	1091
95	--	--	--	40.00	06-23-87	12	--	--	--	06-23-87	62	5.0	1092
150	43	6	118/126	59.80	06-26-87	--	.33	5	.7	06-26-87	193	5.6	1093
155	--	--	--	70.00	06-26-87	22	--	--	--	06-26-87	10	5.2	1094
150	63	6	95/141	--	--	10	--	--	--	07-28-87	163	4.7	1095
120	42	6	35/ 69	29.90	07-29-87	10	--	--	--	07-29-87	15	5.0	1096
200	21	6	146/188	82.00	08-04-87	6	--	--	--	08-04-87	121	4.9	1097
200	40	6	55/150/185	--	--	--	1.8	9	--	08-05-87	70	4.7	1098
--	--	--	--	24.00	08-06-87	--	--	--	--	08-08-87	100	5.1	1099
70	40	6	53	29.00	01-01-74	--	.44	15	1.0	07-02-87	203	5.3	1213
120	75	6	50	18.00	02-01-74	--	.14	15	1.0	06-30-87	114	5.6	1217
110	86	6	95/102	--	--	25	--	--	--	11-21-86	229	4.8	1265
182	35	6	160/175/182	72.7	12-01-86	5	--	--	--	12-01-86	200	4.6	1286
123	40	6	50/ 65/115	--	--	15	--	--	--	09-02-87	118	4.8	1296
280	63	6	273	--	--	25	--	--	--	08-05-87	70	4.5	1367
75	21	6	68/ 71	35.00	09-20-71	--	.75	18	2.0	09-04-87	131	4.8	1376

Table 20. Records of wells and springs--Continued

USGS well number or spring	Location		Township or borough	Owner	Driller license number	Year drilled	Primary		Altitude of land surface (feet)	Topographic setting	Hydrogeologic unit
	Latitude (degrees)	Longitude (degrees)					Use of site	Use of water			
CH-1616	400329	0753622	Charlestown	Bacton Hill Church	0308	1973	W	H	615	S	377CCKS
1617	400338	0753527	Charlestown	Moffett, F.	0248	1973	W	H	680	S	377CCKS
1618	400417	0753411	Charlestown	Chalupa, William	0308	1972	W	H	613	S	377CCKS
2113	400120	0754144	E. Caln	Northwood Cemetery	0904	1966	W	U	467	S	377CCKS
2115	400046	0754440	Caln	Darlington, Edward	0904	1967	W	H	415	S	400BMFGA
2410	400301	0755451	West Caln	Baldwin Clement	0384	1978	W	H	910	H	377CCKS
2417	400117	0755415	West Caln	Snyder, E.	--	--	W	H	815	H	377CCKS
2418	400340	0755012	West Brandywine	Hooper, Robert	--	1980	W	H	770	H	377CCKS
2828	395750	0755302	Sadsbury	Watts, R.	1083	1981	W	H	496	V	367CNSG
2847	400320	0753553	Charlestown	Magargee, Steven	0248	--	W	H	648	S	377CCKS
2998	400611	0755438	Honeybrook	Stoltzfus, John	--	1963	W	H	701	S	400FLCGG
3076	400221	0755304	West Caln	Warren, William	--	--	W	H	839	S	377CCKS
3079	400454	0752817	Tredyffrin	Linton, Otto	0248	1978	W	H	350	S	377HRPR
3086	400439	0753325	Charlestown	Faggioli, Dorando	0904	1978	W	H	480	S	400FCIGA
3087	400325	0753555	Charlestown	Sorgenfrei, Mal	1609	1983	W	H	705	H	377CCKS
3088	400305	0753651	Charlestown	Wallin, Mark	1628	1986	W	H	680	H	377CCKS
3089	400222	0754418	E. Brandywine	Phipps, Daniel	0188	1975	W	H	495	S	400FCIGA
3090	400202	0754419	E. Brandywine	Hopewell U. Meth. Church	1457	1978	W	H	418	S	400FCIGA
3091	400419	0753420	Charlestown	Rossiter, Barry	0248	1981	W	H	575	S	377CCKS
3111	400315	0753540	E. Whiteland	Wiley, Frank	0904	1982	W	H	570	S	377CCKS
3112	400508	0752919	Schuylkill	Snyder, Marshall	0248	1981	W	H	610	H	377CCKS
3113	400507	0752907	Tredyffrin	Generotti, Bruce	0248	1979	W	H	438	S	377CCKS
3114	400408	0753415	Charlestown	Capetola, E.	0188	1979	W	H	630	H	377CCKS
3117	400148	0754301	E. Brandywine	Chatfield, William	0317	1983	W	H	495	S	400FCIGA
3122	400206	0755336	West Caln	Gregor and Comb	--	1987	W	H	755	S	377CCKS
3123	400227	0755229	West Caln	Ickes, Larry	--	--	W	H	783	S	377CCKS
3124	400315	0755230	West Caln	Bireley, Craig	--	1984	W	H	832	H	377CCKS
3125	400224	0754327	E. Brandywine	Arthers, Raymond	0904	1979	W	H	580	H	377CCKS
3126	400218	0754240	E. Brandywine	Clayton, Edward	0248	1979	W	H	385	S	377CCKS
3127	400232	0754107	Uwchlan	Staurowsky, Phillip	0248	1983	W	H	520	S	377CCKS
3128	400419	0753358	Charlestown	Busaglia, Carl	0904	1979	W	H	645	H	377CCKS
3131	400207	0755337	West Caln	Barrage	0308	1987	W	H	762	S	377CCKS
3132	400418	0753400	Charlestown	Persico, Frank	0904	1979	W	H	645	H	377CCKS
3133	400217	0755343	West Caln	Gregor, Lawrence	0308	1987	W	H	840	S	377CCKS
3135	400358	0753503	Charlestown	Hoy, Thomas	0904	1986	W	H	600	S	377CCKS
3136	400318	0753526	E. Whiteland	Turner, Thomas	0248	--	W	H	465	S	377HRPR

Table 20. Records of wells and springs--Continued

	Casing						Measured yield			Field water quality			
Depth of well (feet)	Depth (feet)	Diameter (inches)	Depth to water-bearing zone(s) (feet)	Water level (feet)	Date water level measured	Reported yield (gal/min)	Specific capacity [(gal/min)/ft]	Discharge (gal/min)	Pumping period (hours)	Date measured	Specific conductance (μS/cm)	pH (standard units)	USGS well number *or spring*
130	79	6	86/115	--	--	35	--	--	--	10-23-87	240	5.1	1616-CH
194	50	6	117/139/158/180	30.6	06-03-87	--	0.06	6	1.0	06-03-87	116	4.7	1617
240	96	6	240	--	--	4	--	--	--	05-22-87	164	4.6	1618
155	35	6	135/148	63.00	11-01-66	--	.56	32	4.0	11-10-86	157	5.7	2113
137	12	6	70/ 97/123	64.00	06-01-67	--	.15	8	6.0	11-10-86	127	6.6	2115
145	20	6	22/ 70	52.90	07-24-80	10	--	--	--	11-20-86	139	5.8	2410
--	--	--	--	--	--	--	--	--	--	08-27-80	--	7.1	2417
--	--	--	--	32.43	11-22-86	--	--	--	--	11-22-86	27	5.4	2418
146	86	6	95/120	32.95	07-29-87	20	--	--	--	07-29-87	677	7.0	2828
123	89	6	92/101	60.00	09-05-87	--	.21	15	1	09-05-87	49	4.8	2847
73	--	--	--	--	--	--	--	--	--	07-16-87	340	5.4	2998
--	--	--	--	--	--	--	--	--	--	07-16-87	160	4.8	3076
182	146	6	158	61.10	07-27-87	--	.11	12	1	07-27-87	103	6.6	3079
125	55	6	97/116	38.60	08-07-87	--	.56	23	3	08-07-87	175	5.6	3086
160	21	6	84/ 95/125/143	47.00	08-13-87	--	.13	10	3	08-13-87	82	4.3	3087
280	168	6	180	--	--	2	--	--	--	08-13-87	33	5.4	3088
210	55	6	100/190/200	46.20	08-12-87	--	.11	5	.5	08-12-87	95	6.5	3089
170	20	6	30	35.30	08-12-87	8	--	--	1	08-12-87	130	5.6	3090
100	20	6	37/ 75	50.70	08-11-87	--	.15	10	1	08-11-87	118	4.7	3091
146	20	6	133	30.30	08-26-87	--	.08	7	4	08-26-87	36	4.9	3111
263	24	6	183	70.00	08-28-87	--	.02	4	1	08-28-87	214	4.4	3112
220	20	6	100	15.00	03-01-79	--	.02	4	1	08-28-87	219	5.6	3113
248	60	6	136/191/242	105.00	08-29-87	--	--	--	--	08-29-87	--	4.7	3114
100	40	6	65/ 91	--	--	45	--	--	--	08-31-87	77	5.3	3117
270	56	6	140/240/265	37.00	09-04-87	18	--	--	--	09-04-87	70	6.1	3122
--	--	--	--	66.50	09-02-87	--	--	--	--	09-02-87	42	5.0	3123
185	42	6	--	41.20	09-02-87	8	--	--	--	09-02-87	38	4.6	3124
103	44	6	58/ 85	35.90	09-01-87	--	.34	11	4	09-01-87	271	4.3	3125
100	46	6	--	49.80	09-01-87	--	.16	8	1	09-01-87	16	5.3	3126
81	27	6	30/ 50	10.00	10-00-83	35	--	--	1	09-01-87	165	5.3	3127
165	40	6	77/156	97.70	09-03-87	--	.05	6	4	09-03-87	68	4.3	3128
155	58	6	110	52.00	09-04-87	15	--	--	--	09-04-87	16	5.2	3131
143	21	6	65/132	58.00	03-26-79	--	.08	5	4	09-03-87	304	4.3	3132
155	98	6	100	9.95	10-21-87	--	--	--	--	10-21-87	19	4.8	3133
291	44	6	80/ 90	66.80	09-05-87	--	.08	2	4	09-05-87	152	5.1	3135
200	--	--	--	--	--	--	--	--	--	09-08-87	150	4.9	3136

Table 20. Records of wells and springs--Continued

USGS well number or spring	Location Latitude (degrees)	Location Longitude (degrees)	Township or borough	Owner	Driller license number	Year drilled	Primary Use of site	Primary Use of water	Altitude of land surface (feet)	Topo-graphic setting	Hydro-geologic unit
CH-3160	400404	0755156	Honeybrook	Evans, Wayne	1628	1987	W	H	700	S	377CCKS
3166	400253	0755358	West Caln	McCumsky, Ed	1628	1987	W	H	935	H	377CCKS
3168	400109	0754320	E. Brandywine	D'Ginto, Roy	0904	1978	W	H	490	S	377CCKS
3189	400236	0755440	West Caln	Myers, Craig	1308	1987	W	H	863	S	377CCKS
3213	400238	0755353	West Caln	Herr	1308	1987	W	H	917	S	377CCKS
3214	400370	0755502	West Caln	Klingensmith, David	1290	1979	W	H	812	S	377CCKS
3215	400332	0753615	Charlestown	Piombino, Brenda	--	--	W	H	625	S	377CCKS
3219	400243	0755343	West Caln	Brass, Robert	0308	1987	W	H	940	S	377CCKS
3301	395914	0755538	Sadsbury	White, Kirk	1290	--	W	H	690	S	400FMFG
3315	400238	0755356	West Caln	Stasny, John	1308	1988	W	H	910	S	377CCKS
3325	395920	0755755	W. Sadsbury	Castelli, Pat	--	--	W	H	791	H	377CCKS
3326	400005	0755415	West Caln	Mouday, Joseph	0319	1987	W	H	770	H	377CCKS
3327	400212	0755411	West Caln	Baldwin, A.	1290	1977	W	P	908	S	377CCKS
3328	400105	0755348	West Caln	Cresmer, Bernadette	0904	1980	W	H	728	S	377CCKS
3329	400251	0755312	West Caln	Sarmento, Peter	1628	1985	W	H	925	H	377CCKS
3330	400010	0755650	W. Sadsbury	Mabry, Kenneth	--	1965	W	H	857	H	377CCKS
3331	400507	0752924	Schuylkill	Osinski	--	1957	W	H	615	H	377CCKS
3332	400125	0755602	West Caln	Bednar, Paul	0904	--	W	H	660	S	377ANTM
3333	400457	0753002	Tredyffrin	Trimble, John	0188	1960	W	H	589	H	377CCKS
3334	400510	0752925	Schuylkill	Pyle, Ed	0248	1983	W	H	585	S	377CCKS
3335	400332	0753618	Charlestown	Murphy, Jim	1290	1982	W	H	610	S	377CCKS
3336	400454	0753046	Charlestown	Chambers, Laurence	1628	1986	W	H	500	S	377CCKS
3337	400232	0755257	West Caln	Fling, Brian	1308	1986	W	H	760	S	377CCKS
3338	400421	0753400	Charlestown	Benton, Mike	0904	--	W	H	625	S	377CCKS
3339	400348	0753515	Charlestown	Klagholz, Michael	1609	1986	W	H	620	S	377CCKS
SP33	400458	0752850	Tredyffrin	Linton, Otto	--	--	W	R	420	S	377HRPR
LN-1684	400621	0755747	Caernarvon	Swisher, Evelyn	1539	1985	W	H	915	S	377CCKS
1685	395939	0755830	Salisbury	Hodges, Bob	0308	1980	W	H	800	S	377CCKS
1686	400432	0760053	Salisbury	Kiser, Dale	0319	1981	W	H	978	S	377CCKS
1687	400534	0760109	E. Earl	Shriver, Joseph	0308	1978	W	H	825	S	377CCKS
1688	395732	0760609	Paradise	Wertz, Gerald	0274	1986	W	H	818	H	377CCKS
1689	395638	0760806	Eden	Riehl, Jesse S.	0110	1986	W	H	900	S	377CCKS
1690	400313	0763052	W. Hempfield	Divet, L.	--	--	W	H	540	H	377CCKS
1691	400301	0762759	W. Hempfield	Bennett, William	0319	--	W	H	680	H	377CCKS
1692	395607	0760456	Bart	Prugh, John	0110	1980	W	H	670	S	377CCKS
1693	395910	0760146	Salisbury	Byrd, Michael W.	MYER	1970	W	H	580	S	377CCKS

Table 20. Records of wells and springs--Continued

Depth of well (feet)	Casing		Depth to water-bearing zone(s) (feet)	Water level (feet)	Date water level measured	Reported yield (gal/min)	Measured yield			Field water quality			USGS well number or spring
	Depth (feet)	Diameter (inches)					Specific capacity [(gal/min)/ft]	Discharge (gal/min)	Pumping period (hours)	Date measured	Specific conductance (µS/cm)	pH (standard units)	
330	72	6	90/285	32.80	09-16-87	7	--	--	--	08-22-88	37	5.1	3160-CH
277	99	6	125/245	71.90	09-18-87	2	--	--	--	10-19-87	23	5.0	3166
188	38	6	171	79.60	09-29-87	--	0.02	3	--	09-29-87	114	4.7	3168
220	60	6	110	70.00	08-30-88	10	--	--	--	08-30-88	37	4.9	3189
221	47	6	105	77.80	10-21-87	2	--	--	--	10-21-87	116	5.3	3213
70	42	6	50/ 55/ 60	36.70	10-22-87	30	--	--	1	10-22-87	226	4.6	3214
109	--	--	--	--	--	--	--	--	--	10-23-87	465	5.3	3215
335	60	6	155/290/300/315	66.00	06-16-88	--	.03	4	.5	06-16-88	44	5.4	3219
175	--	--	--	40.20	06-16-88	--	--	--	--	06-16-88	34	5.2	3301
225	26	6	70/100	44.90	09-01-88	3	--	--	--	09-01-88	58	4.8	3315
--	--	--	--	46.20	08-16-88	--	--	--	--	08-16-88	130	4.6	3325
200	74	6	--	47.50	08-16-88	4	--	--	--	08-16-88	92	6.3	3326
195	21	6	95/120	80.50	08-26-88	3	--	--	1	08-26-88	77	4.4	3327
--	--	--	--	--	--	--	--	--	--	08-26-88	53	5.3	3328
175	34	6	70/ 80	31.00	08-22-88	8	--	--	--	08-22-88	36	4.9	3329
87	35	6	--	15.00	00-00-87	40	--	--	--	08-23-88	57	4.7	3330
120	--	--	--	--	--	--	--	--	--	08-23-88	245	4.4	3331
--	--	--	--	53.40	08-30-88	--	--	--	--	08-30-88	150	5.6	3332
--	--	--	--	--	--	--	--	--	--	09-06-88	75	4.8	3333
243	121	6	145/190/218	68.30	09-06-88	20	--	--	--	09-06-88	49	5.1	3334
150	20	6	66/130	33.80	09-06-88	20	--	--	--	09-06-88	370	4.6	3335
280	84	6	90/200	46.60	09-06-88	8	--	--	--	09-06-88	105	5.9	3336
120	78	6	85	28.60	09-08-88	8	--	--	--	09-08-88	29	5.7	3337
143	42	6	135	45.50	09-08-88	--	.07	6	4	09-08-88	160	4.5	3338
220	98	6	65/127/192	69.90	09-09-88	--	.07	9	3	09-09-88	110	5.2	3339
--	--	--	--	--	--	--	--	--	--	07-27-87	102	5.4	SP33
300	60	6	260	85.00	10-28-85	--	.01	2	4.7	11-21-86	16	5.6	1684-LN
140	40	6	45/ 80/125/130	40.00	07-00-80	14	--	--	--	12-03-86	633	6.2	1685
275	102	6	106/257	12.20	12-03-86	15	--	--	--	12-03-86	18	5.2	1686
270	60	6	--	79.00	12-03-86	--	.05	3	--	12-03-86	46	4.8	1687
142	20	6	--	52.20	12-04-86	--	.10	10	1	12-04-86	341	4.4	1688
400	80	6	193	54.80	12-08-86	--	.00	<1	1.0	12-08-86	171	5.7	1689
144	--	--	--	--	--	--	--	--	--	12-08-86	166	5.1	1690
275	--	--	--	86.80	12-12-86	--	--	--	--	12-12-86	151	6.4	1691
105	67	6	75/ 95	50.40	12-30-86	--	.50	15	.7	12-30-86	118	5.8	1692
120	90	--	--	19.80	12-30-86	7	--	--	--	12-30-86	60	5.6	1693

Table 20. Records of wells and springs--Continued

USGS well number or spring	Location		Township or borough	Owner	Driller license number	Year drilled	Primary		Altitude of land surface (feet)	Topo-graphic setting	Hydro-geologic unit
	Latitude (degrees)	Longitude (degrees)					Use of site	Use of water			
LN-1694	400443	0760101	East Earl	Giza, David	0319	1979	W	H	1020	H	377CCKS
1695	395920	0755845	Salisbury	Elmer, Harold	0308	1982	W	H	845	H	377CCKS
1696	400549	0755841	Salisbury	Martin, Nevin	1258	1979	W	H	950	H	377CCKS
1697	395936	0755823	Salisbury	Hershey, Everett	--	--	W	H	865	H	377CCKS
1698	395937	0755817	Salisbury	Martin, Eugene	0308	--	W	H	862	H	377CCKS
1699	400601	0755841	Caernarvon	Clevely, Robert	1258	--	W	H	855	S	377CCKS
1700	400555	0755840	Caernavon	Oestereich, Mary Ann	1628	1978	W	H	930	S	377CCKS
1701	400433	0760054	Salisbury	Barrows, William	0308	1984	W	H	990	S	377CCKS
1713	400547	0755820	Salisbury	Platt, George	1539	1988	W	H	880	H	377CCKS
1714	395907	0755923	Sadsbury	Jordan, Ronald	1628	1987	W	H	720	S	377CCKS
1715	400544	0755845	Salisbury	Blume, Ryan	0319	1988	W	H	880	S	377CCKS
1716	395927	0755931	Salisbury	Stoltzfus, Nathan	0319	1988	W	H	715	S	377CCKS
1717	395718	0760644	Paradise	Forrester, Cecil	0319	1985	W	H	790	H	377CCKS
1718	395753	0760712	Paradise	Reese, Robert	0308	1986	W	H	600	S	377ANTM
1719	395642	0760805	Eden	Duffy, Robert	--	--	W	H	917	H	377CCKS
1720	395731	0760659	Paradise	Hess, Gary	0319	1977	W	H	780	S	377HRPR
1721	395808	0760401	Paradise	Beiler, Clair	0110	1986	W	H	818	H	377CCKS
1722	395834	0760426	Paradise	Loney, John	0308	1986	W	H	680	S	377CCKS
1723	395824	0760413	Paradise	Wohlert, Paul	--	1972	W	H	750	S	377CCKS
1724	395617	0760810	Eden	Dunn, Cindy	0319	1986	W	H	820	S	377CCKS
1725	395925	0755835	Salisbury	Bidwell, Randy	0319	1986	W	H	875	H	377CCKS
1726	395922	0755836	Salisbury	Johnson, Henry	0319	1986	W	H	885	H	377CCKS
1727	395637	0760843	Strasburg	Knerr, Fritz	0319	1985	W	H	845	H	377CCKS
1728	400334	0762801	W. Hempfield	Scantling, Walter	0319	1985	W	H	620	H	377CCKS
1730	395809	0760732	Paradise	Boyd, Dennis	0110	1975	W	H	490	S	367CNSG
1731	395618	0760147	Sadsbury	Lapp, Benjamin	0319	1986	W	H	615	H	377CCKS
1732	400416	0760018	Salisbury	Shaub, Mary Lou	0308	--	W	H	910	S	377CCKS
1733	400547	0760121	East Earl	Shirk, Larry	1539	1986	W	H	753	S	377ANTM
1734	395917	0755923	Salisbury	Sosko, Ken	0319	1970	W	H	795	H	377CCKS
1735	400435	0760127	East Earl	Sensenig, Gary	0319	1979	W	H	960	S	377CCKS
1736	400658	0755546	Caernarvon	Krieger, Thomas	1290	1988	W	H	922	S	377CCKS
1737	400654	0755546	Caernarvon	Smith, Brad	1290	1988	W	H	900	S	377CCKS
1738	400617	0755745	Caernarvon	Zimmerman, Tammy	0308	1986	W	H	960	S	377CCKS
1739	400554	0755815	Salisbury	Senn, Bruce	0308	1988	W	H	962	H	377CCKS
1740	400605	0755755	Caernarvon	Hicks, Roger	0319	1986	W	H	925	H	377CCKS
1741	400606	0755748	Salisbury	Heagy, Jeff	0319	1987	W	H	925	S	377CCKS

Table 20. Records of wells and springs--Continued

Depth of well (feet)	Casing		Depth to water-bearing zone(s) (feet)	Water level (feet)	Date water level measured	Reported yield (gal/min)	Measured yield			Field water quality			USGS well number or spring
	Depth (feet)	Diameter (inches)					Specific capacity [(gal/min)/ft]	Discharge (gal/min)	Pumping period (hours)	Date measured	Specific conductance (µS/cm)	pH (standard units)	
200	111	6	120/147	--	--	7	--	--	--	12-30-86	42	5.1	1694-LN
160	82	6	110/130/140	68.90	12-30-86	--	0.25	20	0.5	12-30-86	63	4.9	1695
--	--	--	--	74.80	07-08-87	--	--	--	--	07-08-87	67	4.7	1696
70	--	--	--	--	--	--	--	--	--	07-27-87	187	4.3	1697
217	--	--	--	--	--	--	--	--	--	07-13-87	214	4.4	1698
125	--	--	--	94.20	07-14-87	30	--	--	--	07-14-87	12	5.2	1699
295	145	6	175/280	130.00	07-15-87	4	--	--	--	07-15-87	12	5.4	1700
220	100	6	170/196/198	46.40	07-15-87	--	.10	15	.5	07-15-87	54	5.8	1701
123	88	6	90	41.80	06-27-88	40	--	--	--	09-01-88	49	5.1	1713
270	30	6	--	15.80	08-25-88	2	--	--	--	08-25-88	103	5.0	1714
125	62	6	38/ 66/ 80/110	15.80	08-27-88	30	--	--	--	08-27-88	21	5.2	1715
175	85	6	95/155/175	55.00	07-18-88	10	--	--	--	08-25-88	30	5.1	1716
150	72	6	103/137	31.10	08-03-88	7	--	--	--	08-03-88	320	4.7	1717
120	40	6	90/100	39.80	08-03-88	--	.07	4	.5	08-03-88	250	5.3	1718
--	--	--	--	--	--	--	--	--	--	08-03-88	71	4.8	1719
300	21	6	--	42.90	08-04-88	1	--	--	--	08-04-88	120	5.1	1720
135	86	6	115/130/134	38.10	08-04-88	--	1.5	15	1.0	08-04-88	215	4.9	1721
273	40	6	59/135	55.50	08-04-88	--	.04	4	.5	08-04-88	119	5.8	1722
215	--	--	--	--	--	--	--	--	--	08-04-88	105	5.0	1723
250	41	6	--	71.00	08-05-88	3	--	--	--	08-05-88	115	5.3	1724
175	51	6	108/167	--	--	15	--	--	--	08-05-88	165	4.5	1725
175	60	6	76/160	69.40	08-05-88	6	--	--	--	08-05-88	54	4.7	1726
250	80	6	110/142/235	83.80	08-08-88	5	--	--	--	08-08-88	49	5.4	1727
250	102	6	125/230	--	--	6	--	--	1	08-08-88	80	5.7	1728
112	--	--	--	2.75	08-13-88	--	--	--	--	08-13-88	420	7.7	1730
228	75	6	98/160	30.00	08-13-88	2	--	--	--	08-13-88	190	5.7	1731
213	41	6	--	49.20	08-15-88	--	--	--	--	08-15-88	110	4.4	1732
135	80	6	105/120	74.30	08-15-88	18	--	--	5	08-15-88	46	5.3	1733
90	40	6	--	--	--	10	--	--	--	08-25-88	175	4.7	1734
100	41	6	--	39.10	08-15-88	20	--	--	--	08-17-88	68	4.8	1735
230	100	6	110/180	36.40	08-17-88	20	--	--	--	08-17-88	45	5.0	1736
280	125	6	130/260	34.70	08-17-88	3	--	--	--	08-17-88	43	5.5	1737
407	60	6	300/375	125.00	09-02-88	2	--	--	.5	09-02-88	--	4.7	1738
318	40	6	96/185/274	78.60	09-01-88	--	.02	4	.5	09-01-88	77	4.4	1739
325	100	6	130/210/298	85.00	09-02-88	2	--	--	--	09-02-88	17	5.3	1740
150	77	6	92/134	70.90	09-02-88	20	--	--	--	09-02-88	17	5.3	1741

Table 20. Records of wells and springs--Continued

USGS well number or spring	Location Latitude (degrees)	Location Longitude (degrees)	Township or borough	Owner	Driller license number	Year drilled	Primary Use of site	Primary Use of water	Altitude of land surface (feet)	Topo-graphic setting	Hydro-geologic unit
LN-1742	400538	0755818	Salisbury	Boyce, Dale	1539	1988	W	H	818	S	000GBBR
MG- 399	400755	0751033	U Dublin	Manufacturers G & C Club	0249	1954	W	H	350	S	377CCKS
1000	400908	0750537	U Moreland	DeFlavis, David	--	--	W	H	340	H	377CCKS
1001	400745	0751120	U Dublin	Neuman, Richard	--	--	W	H	240	S	377CCKS
1002	400701	0751353	Whitemarsh	Ft. Washington State Park	0514	1958	U	U	215	S	377LDGR
1003	400703	0751508	Whitemarsh	Ahner, William	--	--	W	H	235	H	377LDGR
1004	400647	0751717	Plymouth	Souder, Bruce (tenant)	--	--	W	H	230	H	377CCKS
YO- 88	400033	0763923	Springettsbury	York County Planning	0356	1971	W	P	800	W	377CCKS
351	395236	0765439	Jackson	Hartman, Charles	0383	1965	W	H	785	H	377CCKS
371	395058	0765018	N. Codorus	Smith, George H.	0383	1967	W	H	823	H	377CCKS
650	395717	0763454	Lower Windsor	Ball, Elizabeth	--	--	W	H	695	H	377CCKS
792	400152	0763908	Hellam	York Rifle Range Assoc.	--	1964	W	H	685	H	377CCKS
1148	400023	0763919	Springettsbury	Loucks, Ronald	0198	1980	W	H	810	S	377CCKS
1149	400155	0763432	Hellam	Lauchman	0741	1979	W	H	565	H	377CCKS
1150	400007	0763200	Lower Windsor	Keller, Donald	--	--	W	H	650	S	377CCKS
1151	395236	0764655	N. Codorus	Grammer, Alan	1551	1980	W	H	700	S	377CCKS
1152	395103	0765651	Heidelberg	Withers, Donald	0032	1979	W	H	1190	H	377CCKS
1153	395245	0765409	Jackson	Heiser, William	0198	1985	W	H	785	H	377CCKS
1154	395833	0763710	Springettsbury	Koller, Timothy	0741	1985	W	H	600	S	377CCKS
1155	395049	0765830	Heidelberg	Andes, Frank	0741	1984	W	H	765	S	377CCKS
1156	395251	0765428	Jackson	Lain, Kevin	0211	1981	W	H	710	S	377CCKS
1157	400025	0764015	Springettsbury	Mummert, Marlyn	--	--	W	H	840	H	377CCKS
1158	395211	0765021	N. Codorus	Paonessa, Samuel	--	--	W	H	640	H	377CCKS
1159	395419	0764643	N. Codorus	Hartman, Wayne	--	--	W	H	610	H	377CCKS
1160	395516	0764452	Spring Garden	Ryan, E.W.	1515	1980	W	H	430	S	377HRPR
1161	395938	0763331	Hellam	Keller, Scott	0741	1984	W	H	710	S	377CCKS
1162	400103	0763919	Hellam	Beaverson, Richard	--	--	W	H	570	S	377HRPR
1163	400243	0763242	Hellam	Hovis, Raymond	0356	1978	W	H	700	H	377CCKS
1164	400022	0763914	Springettsbury	Emswiler, Charles	0356	1986	W	H	780	S	377CCKS
1165	400020	0763912	Springettsbury	Boll, H.	0356	1947	W	H	730	S	377CCKS
1166	400039	0764124	Springettsbury	Beaverson, Richard	0356	1954	W	H	470	S	377CCKS
1167	400004	0763910	Springettsbury	Fetrow, Russell	0356	1950	W	H	585	S	377HRPR
1168	395957	0763904	Springettsbury	Bates, Douglas	--	--	W	H	475	S	377VNTG
1172	400023	0763919	Springettsbury	Loucks, Ronald	0356	1988	W	H	816	S	377CCKS
1175	400245	0763225	Hellam	Evans, Warren	0356	1978	W	H	640	S	377CCKS
1176	400026	0764134	Springettsbury	Oberdick, Michael	0741	1987	W	H	530	S	377CCKS

Table 20. Records of wells and springs--Continued

Depth of well (feet)	Casing		Depth to water-bearing zone(s) (feet)	Water level (feet)	Date water level measured	Reported yield (gal/ min)	Measured yield			Field water quality			USGS well number or spring
	Depth (feet)	Diameter (inches)					Specific capacity [(gal/ min)/ft]	Dis-charge (gal/ min)	Pumping period (hours)	Date measured	Specific conductance (µS/cm)	pH (standard units)	
120	81	6	--	-1.00	09-02-88	40	--	--	--	09-02-88	55	6.2	1742-LN
400	--	--	--	72.00	04-08-54	73	--	--	--	07-01-87	329	6.3	399-MG
--	--	--	--	--	--	--	--	--	--	12-19-86	186	6.3	1000
--	--	--	--	13.50	12-29-86	--	--	--	--	12-29-86	204	6.3	1001
170	140	4	--	80.00	10-06-58	--	1	25	92	01-08-87	351	7.5	1002
180	--	--	--	--	--	--	--	--	--	01-09-87	626	7.3	1003
--	--	--	--	--	--	--	--	--	--	01-13-87	335	5.9	1004
110	30	6	90	--	--	90	--	--	--	07-21-89	39	5.9	88-YO
110	--	--	--	50.00	06-01-65	--	15	15	1.0	08-10-88	85	5.0	351
100	30	6	58/ 88	46.00	08-01-70	20	--	--	--	12-23-86	78	5.2	371
101	--	--	--	--	--	--	--	--	--	08-11-88	115	5.0	650
170	26	6	--	91.00	07-01-71	--	.25	10	--	12-22-86	31	5.5	792
162	42	4	--	62.00	12-09-86	--	--	--	--	12-09-86	48	5.0	1148
160	70	6	85/145	81.30	12-09-86	15	--	--	--	12-09-86	116	6.1	1149
--	--	--	--	--	12-09-86	--	--	--	--	12-09-86	63	6.2	1150
160	42	6	95/140	86.90	12-10-86	10	--	--	--	12-10-86	264	6.7	1151
500	23	6	115/360	80.00	06-01-79	1	--	--	--	12-10-86	91	6.4	1152
245	105	6	114/141/197/231	99.80	12-10-85	--	.07	15	.5	12-10-86	174	6.5	1153
140	40	6	90/125	25.20	12-11-86	15	--	--	--	12-11-85	85	5.4	1154
160	60	6	9/140/155	--	--	15	--	--	--	12-11-86	52	6.1	1155
100	40	6	68/ 86	--	--	--	.18	12	2	12-11-86	47	5.5	1156
--	--	--	--	--	--	--	--	--	--	12-22-86	136	4.7	1157
--	--	--	--	--	--	--	--	--	--	12-23-86	173	4.9	1158
249	--	--	--	29.10	12-23-86	--	--	--	--	12-23-86	238	6.4	1159
145	26	6	45/ 90/125	31.00	06-01-80	--	.04	5	2	12-23-86	168	6.2	1160
300	40	6	65/150	26.90	12-24-86	4	--	--	--	12-24-86	15	6.9	1161
70	--	--	--	--	--	--	--	--	--	07-21-87	80	5.2	1162
230	121	6	--	--	--	4	--	--	--	07-21-87	26	5.3	1163
350	18	6	--	67.40	07-22-87	--	--	--	--	07-22-87	65	5.8	1164
126	13	6	65	13.00	10-00-47	<1	--	--	--	07-22-87	145	4.8	1165
99	25	6	--	58.20	07-22-87	6	--	--	--	07-23-87	200	4.4	1166
125	20	6	--	48.80	07-23-87	--	--	--	--	07-23-87	128	5.6	1167
70	--	--	--	--	--	--	--	--	--	07-23-87	250	7.3	1168
300	20	6	200/220	52.80	08-11-88	5	--	--	--	08-11-88	30	5.2	1172
230	126	6	--	82.00	08-08-88	--	--	--	--	08-08-88	24	5.5	1175
240	60	6	126/185/227	63.00	08-09-88	7	--	--	--	08-09-88	89	5.3	1176

Table 20. Records of wells and springs--Continued

USGS well number or spring	Location Latitude (degrees)	Location Longitude (degrees)	Township or borough	Owner	Driller license number	Year drilled	Primary Use of site	Primary Use of water	Altitude of land surface (feet)	Topographic setting	Hydrogeologic unit
YO-1177	400053	0763924	Springettsbury	Landis, Leonard	1706	1988	W	H	662	S	377CCKS
1178	400233	0763708	Hellam	Ruppert, Donna	0356	1986	W	H	751	S	377CCKS
1179	400202	0763547	Hellam	Myers, Henry	0741	1986	W	H	770	H	377CCKS
1180	395123	0765656	Heidelberg	Wright, W.	0211	1981	W	H	1210	H	377CCKS
1181	395317	0765509	Jackson	Niner, Jean	1381	1978	W	H	825	H	377CCKS
1182	395235	0764737	N. Codorus	Miller, Daniel	0383	1984	W	H	723	H	377CCKS
1183	395926	0763323	L. Windsor	Hamilton, Richard	--	1979	W	H	720	H	377CCKS
1184	400106	0763633	Hellam	Carroll, Roy	--	1986	W	H	710	S	377CCKS
1185	400207	0763724	Hellam	Barbor, G.	1515	1981	W	H	985	H	377CCKS
1186	400025	0764010	Springettsbury	Mcclain, Linda	--	1980	W	H	881	H	377CCKS

Table 20. Records of wells and springs--Continued

	Casing						Measured yield			Field water quality			
Depth of well (feet)	Depth (feet)	Diameter (inches)	Depth to water-bearing zone(s) (feet)	Water level (feet)	Date water level measured	Reported yield (gal/min)	Specific capacity [(gal/min)/ft]	Discharge (gal/min)	Pumping period (hours)	Date measured	Specific conductance (µS/cm)	pH (standard units)	USGS well number or spring
--	--	--	--	50.70	08-09-88	--	--	--	--	08-09-88	41	5.9	1177-YO
160	52	6	--	39.20	08-09-88	3	--	--	--	08-09-88	34	5.1	1178
300	40	6	210/290	61.00	08-09-88	5	--	--	--	08-09-88	122	4.7	1179
220	27	6	128/185	96.60	08-10-88	--	0.08	10	1	08-10-88	38	5.5	1180
--	--	--	--	50.10	08-10-88	--	--	--	--	08-10-88	58	5.6	1181
167	34	6	73/158	80.20	08-10-88	4	--	--	--	08-10-88	45	5.3	1182
230	--	--	--	--	--	--	--	--	--	08-11-88	180	5.7	1183
180	--	--	115	24.20	09-07-88	--	--	--	--	09-07-88	93	4.6	1184
160	37	6	120/145	95.00	07-00-81	--	.17	9	2.5	09-07-88	50	4.8	1185
--	--	--	--	--	--	--	--	--	--	09-07-88	50	4.9	1186

Table 21. Physical properties and chemical analyses for major ions, selected minor ions, nutrients, and dissolved organic carbon in ground water in the Chickies Quartzite and adjacent geologic units. Geologic unit codes are explained at beginning of table 20.

[°C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; --, no data]

USGS well number	Geologic unit	Date	pH (standard units)	Temperature, water (°C)	Specific conductance (µS/cm)	Oxygen, dissolved (mg/L)	Alkalinity field (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dis solved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl	Sulfate, dissolved (mg/L as SO_4)
BE- 1440	377CCKS	12-22-86	6.3	10.0	145	3.3	28	5.6	2.0	3.6	1.2	5.9	8.2
BK- 396	377CCKS	12-21-86	6.2	12.5	251	4.8	36	25	7.0	8.6	2.0	27	17
1200	377CKKS	12-21-86	5.8	11.5	275	4.6	26	17	7.8	21	2.7	37	32
1201	377CCKS	12-31-86	5.8	13.0	298	4.6	27	20	9.0	15	3.5	36	39
1202	377CCKS	12-31-86	5.4	10.8	58	7.0	10	1.0	2.8	2.9	1.2	8.2	1.5
	377CCKS	05-07-87	4.9	13.5	75	8.8	4	1.0	2.6	3.4	1.4	9.0	< .20
1227	400FLCGP	06-22-87	6.6	13.0	145	<.1	60	11	4.8	5.3	4.9	4.5	6.0
1228	377CCKS	06-22-87	5.9	14.0	343	.3	48	25	8.1	17	5.1	56	4.8
1288	377HRDS	09-03-88	5.1	12.0	92	9.0	7	2.5	3.1	5.1	5.3	8.8	6.5
SP21	377CCKS	05-07-87	4.9	11.5	105	--	2	--	--	--	--	--	--
CH- 293	377CCKS	11-13-86	6.4	11.5	340	6.6	84	27	14	19	1.6	28	46
333	377CCKS	11-15-86	4.8	11.5	189	6.1	4	9.7	7.8	8.3	2.2	6.5	62
417	377CCKS	11-24-86	5.2	11.5	77	5.2	6	2.2	2.5	3.8	3.5	7.8	2.7
418	377CCKS	12-05-86	4.9	11.5	41	6.2	10	.50	.70	2.7	2.5	4.9	1.4
427	377HRPR	12-05-86	5.2	11.0	19	9.0	3	.40	.50	1.2	.70	2.8	.40
505	377CCKS	05-08-87	5.9	12.0	125	8.8	24	12	3.1	4.4	1.9	10	12
693	377CCKS	05-29-87	5.9	14.0	64	8.0	20	7.0	2.0	2.4	1.0	8.2	.60
703	377HRPR	06-05-87	6.1	12.0	160	7.6	28	12	6.2	5.8	3.2	13	5.6
945	377CCKS	11-13-86	5.5	14.0	93	5.2	20	4.0	4.4	2.7	3.4	4.3	13
992	377HRPR	07-28-87	5.0	13.0	265	.7	8	7.1	6.7	22	5.0	15	13
1089	377CCKS	06-12-87	5.3	12.0	145	7.3	14	4.4	3.5	12	3.9	21	.70
1090	377CCKS	06-17-87	4.7	12.0	76	--	1	1.8	3.0	4.4	1.5	9.0	9.6
1091	377CCKS	06-18-87	4.8	12.0	39	5.1	6	.47	1.0	3.8	2.0	5.8	3.7
1092	377CCKS	06-23-87	5.0	13.5	62	8.4	6	.44	1.3	8.6	1.6	7.3	7.4
1093	377CCKS	06-26-87	5.6	13.0	193	8.0	11	5.4	4.7	19	3.7	34	8.3
1094	377CCKS	06-26-87	5.2	11.5	10	11.3	--	.10	.37	1.5	.80	2.4	< .20
1095	377CCKS	07-28-87	4.7	13.5	163	7.3	3	3.7	6.6	11	3.3	12	7.4
1096	377CCKS	07-29-87	4.9	11.5	15	10.2	6	.46	.45	1.5	1.4	1.9	.30
1097	377ANTM	08-04-87	4.9	13.0	121	8.7	4	4.5	5.6	4.7	3.8	6.8	4.9
1098	377CCKS	08-05-87	4.7	11.5	70	10.0	4	.64	2.7	2.4	1.4	5.4	5.6
1099	400FLCGG	08-06-87	5.1	13.5	100	--	27	7.3	3.3	3.6	3.6	8.6	8.6
1213	377CCKS	07-02-87	5.3	12.5	203	7.3	27	8.0	10	2.2	11	8.7	37

Table 21. Physical properties and chemical analyses for major ions, selected minor ions, nutrients, and dissolved organic carbon in ground water in the Chickies Quartzite and adjacent geologic units. Geologic unit codes are explained at beginning of table 20--Continued

Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Iron, total recoverable (µg/L as Fe)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Barium, dissolved (µg/L as Ba)	Boron, dissolved (µg/L as B)	Solids, residue at 180 °C dissolved (mg/L)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)	Carbon, organic, dissolved (mg/L as C)	USGS well number
<0.10	6.6	2,800	2,600	400	200	--	85	--	--	--	--	2.1	1440-BE
< .10	24	80	8	3	35	--	156	--	--	--	--	.5	396-BK
.10	12	2,600	75	11	95	--	147	--	--	--	--	.7	1200
<.10	21	50	20	< 10	300	--	187	--	--	--	--	.7	1201
<.10	3.4	3,000	2,600	60	100	--	35	--	--	--	--	1.1	1202
<.10	6.8	920	730	25	58	--	40	--	--	--	--	--	
.30	33	5,600	5,000	250	94	--	97	--	--	--	--	2.0	1227
.20	20	1,400	180	160	200	--	205	--	--	--	--	--	1228
.10	14	20	13	23	110	10	77	<0.010	<0.010	3.00	0.002	.8	1288
--	--	--	--	--	--	--	--	--	--	--	--	--	SP21
<.10	12	30	11	< 1	42	--	206	--	--	--	--	1.8	293-CH
.10	8.8	1,300	73	190	130	--	109	--	--	--	--	2.5	333
<.10	10	170	5	22	80	--	46	--	--	--	--	.6	417
<.10	9.0	10	5	15	55	--	25	--	--	--	--	.8	418
<.10	6.4	10,000	13	4	13	--	10	--	--	--	--	.7	427
<.10	18	40	5	12	29	--	80	--	--	--	--	.6	505
.20	18	80	6	2	10	--	48	--	--	--	--	.5	693
.10	21	1,300	13	7	35	--	112	--	--	--	--	.5	703
<.10	8.7	80	16	11	37	--	51	--	--	--	--	.9	945
.10	8.3	20	12	410	180	--	152	--	--	--	--	1.5	992
<.10	12	< 10	5	34	370	--	76	--	--	--	--	.7	1089
.20	6.7	60	8	120	83	--	41	--	--	--	--	1.6	1090
.10	10	2,800	60	25	48	--	29	--	--	--	--	.6	1091
.10	8.3	5,000	120	20	110	--	43	--	--	--	--	1.8	1092
.10	12	100	16	6	22	--	99	--	--	--	--	.6	1093
.10	6.0	240	520	20	10	--	10	--	--	--	--	.7	1094
.10	9.8	1,000	22	86	200	--	108	--	--	--	--	1.0	1095
.10	8.0	80	5	3	13	--	12	--	--	--	--	.5	1096
.10	11	< 10	10	23	36	--	87	--	--	--	--	.6	1097
.10	7.1	51,000	57	8	38	--	37	--	--	--	--	1.2	1098
.10	15	--	36	7	--	--	78	--	--	--	--	--	1099
.20	7.0	40	15	79	100	--	125	--	--	--	--	1.5	1213

Table 21. Physical properties and chemical analyses for major ions, selected minor ions, nutrients, and dissolved organic carbon in ground water in the Chickies Quartzite and adjacent geologic units. Geologic unit codes are explained at beginning of table 20--Continued

USGS well number	Geologic unit	Date	pH (standard units)	Temperature, water (°C)	Specific conductance (µS/cm)	Oxygen, dissolved (mg/L)	Alkalinity field (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dis solved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
CH-1217	377CCKS	06-30-87	5.6	14.0	114	8.8	13	9.6	2.5	6.8	2.5	8.7	6.6
1265	377CCKS	11-21-86	4.8	11.5	229	2.3	8	3.2	4.6	26	2.1	58	1.8
1286	377CCKS	12-01-86	4.6	11.5	200	6.0	2	2.5	2.5	29	4.6	44	2.6
1296	377CCKS	09-02-87	4.8	13.0	118	9.5	6	2.2	1.8	13	4.3	24	10
1367	377CCKS	08-05-87	4.5	13.0	70	9.1	< 1	1.7	3.1	4.3	2.4	8.2	.30
1376	377CCKS	09-04-87	4.8	12.0	131	3.2	6	3.6	3.2	13	2.1	13	11
1616	377CCKS	11-12-86	5.3	12.0	203	5.1	8	6.6	5.4	22	1.6	35	27
	377CCKS	08-11-87	5.0	12.5	230	--	8	7.0	5.6	22	1.3	35	27
	377CCKS	10-23-87	5.1	12.0	242	6.4	7	6.8	5.5	23	1.3	36	26
1617	377CCKS	06-03-87	4.7	13.0	116	8.2	4	5.2	3.5	7.5	1.1	14	25
1618	377CCKS	05-22-87	4.6	13.5	164	7.4	2	3.5	6.8	7.5	4.8	17	26
2113	377CCKS	11-10-86	5.7	12.4	157	6.1	24	7.8	3.3	13	1.6	16	27
2115	400BMFGA	11-10-86	6.6	11.5	127	10.6	26	13	5.0	3.9	2.2	2.3	21
2410	377CCKS	11-20-86	5.8	11.7	139	7.0	24	6.3	4.3	11	1.2	23.	.90
2417	377CCKS	08-26-88	5.1	12.0	25	9.6	4	.27	.45	2.2	1.1	2.6	.40
2418	377CCKS	11-22-86	5.4	11.5	27	7.7	10	.50	.80	2.2	1.5	3.3	1.1
2828	367CNSG	07-29-87	7.0	13.0	677	6.6	214	92	12	25	3.0	26	33
2847	377CCKS	09-05-87	4.8	12.0	49	8.0	5	1.5	1.8	4.0	2.4	7.6	.90
2998	400FLCGG	07-16-87	5.4	12.5	340	8.0	14	33	10	11	3.0	60	3.0
3076	377CCKS	07-16-87	4.8	11.0	160	6.8	3	5.2	4.8	8.9	3.5	14	3.6
3079	377HRPR	07-27-87	6.6	13.5	103	< .1	40	3.6	4.0	2.9	3.0	2.0	9.8
3086	400FCIGA	08-07-87	5.7	11.5	175	8.6	18	14	4.5	8.0	2.1	27	4.8
3087	377CCKS	08-13-87	4.3	12.5	82	--	0	3.4	3.0	1.6	1.4	3.2	24
3088	377CCKS	08-13-87	5.5	11.5	33	--	14	.98	1.2	2.1	2.7	2.7	1.8
3089	400FCIGA	08-12-87	6.5	12.5	95	--	34	9.1	3.8	4.5	1.9	2.0	3.0
3090	400FCIGA	08-12-87	5.6	11.5	130	--	13	10	4.0	6.6	1.5	9.6	24
3091	377CCKS	08-11-87	4.7	11.0	118	--	2	3.7	4.2	7.2	2.6	13	21
3111	377CCKS	08-26-87	4.9	12.0	36	--	6	1.0	1.2	4.2	1.3	7.1	4.2
3112	377CCKS	08-28-87	4.4	12.5	214	--	0	6.2	1.7	23	1.6	20	34
	377CCKS	08-01-89	4.3	13.0	150	7.2	0	--	--	--	--	12	25
3113	377CCKS	08-28-87	5.6	12.0	219	--	36	.67	2.0	1.7	1.2	4.2	9.0

Table 21. Physical properties and chemical analyses for major ions, selected minor ions, nutrients, and dissolved organic carbon in ground water in the Chickies Quartzite and adjacent geologic units. Geologic unit codes are explained at beginning of table 20--*Continued*

Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Iron, total recoverable (µg/L as Fe)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Barium, dissolved (µg/L as Ba)	Boron, dissolved (µg/L as B)	Solids, residue at 180 °C dissolved (mg/L)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)	Carbon, organic, dissolved (mg/L as C)	USGS well number
0.10	22	90	15	6	60	--	91	--	--	--	--	0.9	1217-CH
<.10	7.1	1,600	1,700	38	190	--	113	--	--	--	--	2.0	1265
<.10	9.0	180	20	95	320	--	116	--	--	--	--	.9	1286
.10	9.6	700	100	20	150	--	74	--	--	--	--	1.3	1296
.10	7.4	30	12	32	120	--	42	--	--	--	--	.6	1367
.10	7.0	80	9	290	91	--	70	--	--	--	--	1.5	1376
<.10	5.7	290	130	40	42	--	117	--	--	--	--	1.2	1616
.10	5.8	80	70	41	40	--	116	--	--	--	--	1.0	
.10	5.7	140	95	43	40	--	112	--	--	--	--	--	
.10	6.5	310	140	100	84	--	59	--	--	--	--	1.7	1617
.30	9.3	330	610	200	290	--	88	--	--	--	--	2.8	1618
.10	4.7	4,600	280	39	50	--	87	--	--	--	--	--	2113
<.10	19	4,000	19	3	39	--	89	--	--	--	--	.9	2115
<.10	16	210	68	14	76	--	85	--	--	--	--	--	2410
<.10	7.9	90	10	4	15	<10	17	< 0.010	< 0.010	0.590	0.001	.7	2417
<.10	8.8	1,200	51	11	34	--	16	--	--	--	--	.7	2418
.10	13	110	6	2	23	--	388	--	--	--	--	.8	2828
<.10	9.7	340	73	17	70	--	39	--	--	--	--	.7	2847
.10	19	30	10	11	120	--	298	.020	< .010	14.0	<.010	--	2998
.20	9.7	20	11	440	170	--	85	--	--	--	--	--	3076
.20	19	11,000	10,000	880	20	--	54	--	--	--	--	.6	3079
.10	18	180	8	7	100	--	126	--	--	--	--	.7	3086
.20	5.8	40	9	140	72	--	47	--	--	--	--	1.9	3087
.10	10	19,000	2,500	180	45	--	20	--	--	--	--	.8	3088
.10	21	5,300	4	8	60	--	67	--	--	--	--	.3	3089
.10	19	< 10	< 3	2	47	--	83	--	--	--	--	.9	3090
.20	8.0	< 10	< 3	85	120	--	68	--	--	--	--	1.8	3091
<.10	7.3	480	< 3	24	38	--	28	--	--	--	--	1.2	3111
.20	4.4	740	7	77	46	--	107	--	--	--	--	5.0	3112
--	--	--	90	60	--	--	110	< .010	< .010	2.90	--	--	
.10	8.2	--	200	47	48	--	23	--	--	--	--	10	3113

Table 21. Physical properties and chemical analyses for major ions, selected minor ions, nutrients, and dissolved organic carbon in ground water in the Chickies Quartzite and adjacent geologic units. Geologic unit codes are explained at beginning of table 20--Continued

USGS well number	Geologic unit	Date	pH (standard units)	Temperature, water (°C)	Specific conductance (µS/cm)	Oxygen, dissolved (mg/L)	Alkalinity field (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dis solved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
CH-3114	377CCKS	08-29-87	4.7	12.5	296	--	3	3.3	3.8	40	2.1	83	3.9
3117	400FCIGA	08-31-87	5.3	12.0	77	--	14	5.3	2.7	5.2	1.1	6.6	17
3122	377CCKS	09-04-87	6.2	11.0	70	--	26	6.5	1.9	2.2	3.6	2.3	1.9
3123	377CCKS	09-02-87	5.0	12.0	42	--	7	1.9	2.6	2.2	1.2	3.2	9.2
3124	377CCKS	09-02-87	4.6	12.0	38	--	3	5.9	5.7	7.7	1.4	9.7	45
3125	377CCKS	09-01-87	4.3	12.5	271	--	0	5.2	3.1	23	3.2	18	41
3126	377CCKS	09-01-87	5.3	12.0	16	--	7	.49	.49	1.3	2.2	2.1	1.7
3127	377CCKS	09-01-87	5.3	12.5	165	--	18	6.8	3.9	12	9.7	12	18
3128	377CCKS	09-03-87	4.3	12.5	68	--	0	2.6	2.4	1.6	.90	3.1	23
3131	377CCKS	09-04-87	5.2	11.5	16	--	7	.50	.42	1.7	1.7	1.8	.70
3132	377CCKS	09-03-87	4.4	12.0	304	--	0	5.9	6.2	33	1.9	42	28
3133	377CCKS	10-21-87	4.8	11.0	19	5.5	4	.31	.40	2.3	1.6	2.6	2.0
3135	377CCKS	09-05-87	5.1	11.5	152	7.5	10	6.2	3.3	14	1.7	29	1.0
3136	377HRPR	09-08-87	4.9	12.5	150	7.5	4	3.2	3.1	15	2.8	24	12
3160	377CCKS	08-22-88	5.1	13.0	37	6.6	7	.45	.59	3.3	1.6	6.0	1.4
3166	377CCKS	10-19-87	5.1	12.0	23	--	3	.53	.87	3.0	.70	6.0	.20
3168	377CCKS	09-29-87	4.8	12.5	114	9.4	--	5.4	4.6	3.3	2.7	5.6	31
3189	377CCKS	08-30-88	4.9	11.6	37	9.8	2.5	.33	1.1	2.1	1.9	3.1	.40
3213	377CCKS	10-21-87	5.3	11.5	116	9.0	7	5.9	3.5	7.3	2.2	7.5	22
3214	377CCKS	10-22-87	4.6	12.5	226	8.7	1	4.0	7.4	18	2.0	39	15
3215	377CCKS	10-23-87	5.3	12.5	465	7.8	18	7.1	8.0	52	3.3	100	14
3219	377CCKS	06-16-88	5.4	13.0	44	10.0	6	.44	1.6	1.6	--	--	--
	377CCKS	08-23-88	4.5	13.5	44	10.6	0	.58	2.1	.90	1.4	1.8	10
3301	400FMFG	06-16-88	5.3	11.5	34	8.1	11	1.5	1.4	1.9	.80	2.8	.80
3315	377CCKS	09-01-88	4.9	13.0	58	9.8	2	2.5	2.2	1.2	1.0	1.9	15
3325	377CCKS	08-16-88	4.6	12.0	130	7.2	1	5.1	5.5	3.3	3.1	6.0	14
3326	377CCKS	08-16-88	6.4	11.5	92	5.5	32	6.7	3.7	2.9	4.6	2.6	.60
3327	377CCKS	08-26-88	4.4	16.5	77	10.4	0	1.5	2.3	1.5	1.4	3.2	17
3328	377CCKS	08-26-88	5.3	13.0	53	8.0	6	1.8	1.4	4.0	1.5	6.0	< .20
3329	377CCKS	08-22-88	5.0	12.0	36	9.0	3	.59	1.0	2.6	3.1	5.5	2.6

Table 21. Physical properties and chemical analyses for major ions, selected minor ions, nutrients, and dissolved organic carbon in ground water in the Chickies Quartzite and adjacent geologic units. Geologic unit codes are explained at beginning of table 20--Continued

Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Iron, total recoverable (µg/L as Fe)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Barium, dissolved (µg/L as Ba)	Boron, dissolved (µg/L as B)	Solids, residue at 180 °C dissolved (mg/L)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)	Carbon, organic, dissolved (mg/L as C)	USGS well number
0.10	8.1	< 10	7	10	190	--	143	--	--	--	--	1.7	3114-CH
.10	18	2,600	220	16	66	--	54	--	--	--	--	1.5	3117
.10	11	850	190	33	38	--	45	--	--	--	--	.8	3122
.10	9.5	< 10	11	9	35	--	32	--	--	--	--	.8	3123
.10	8.0	--	27,000	170	58	--	84	--	--	--	--	2.4	3124
.50	6.8	50	72	46	110	--	143	--	--	--	--	31	3125
.10	9.4	< 10	<3	1	26	--	14	--	--	--	--	.7	3126
.10	9.9	80	15	48	46	--	86	--	--	--	--	--	3127
.20	5.8	< 10	7	140	140	--	40	--	--	--	--	--	3128
<.10	8.4	130	110	5	17	--	16	--	--	--	--	2.2	3131
.30	7.4	80	4	460	190	--	143	--	--	--	--	2.3	3132
.10	9.5	350	170	32	18	--	20	--	--	--	--	--	3133
.10	11	340	7	31	70	--	99	--	--	--	--	1.3	3135
.10	6.9	830	340	29	80	--	73	--	--	--	--	2.3	3136
.10	6.5	< 10	4	29	29	<10	27	< 0.010	< 0.010	0.290	0.002	.6	3160
.10	7.4	120	10	43	55	--	27	--	--	--	--	--	3166
.10	8.7	3,000	7	58	110	--	72	--	--	--	--	--	3168
.10	7.9	80	11	7	67	<10	27	< .010	< .010	1.70	.004	.4	3189
.10	8.4	410	20	79	130	--	74	--	--	--	--	--	3213
.10	9.0	10	11	32	160	--	111	--	--	--	--	--	3214
.10	7.3	46,000	88	34	200	--	215	--	--	--	--	--	3215
--	6.0	--	1,900	72	53	--	--	< .010	< .010	.230	< .001	1.4	3219
.10	5.8	700	180	56	65	<10	26	.020	< .010	.270	< .001	1.1	
.10	9.8	50	7	5	22	--	20	< .010	< .010	.110	< .001	1.4	3301
.10	5.9	410	16	91	76	<10	35	< .010	< .010	.280	< .001	1.0	3315
.10	7.8	40	24	270	220	10	78	< .010	< .010	6.00	< .001	1.5	3325
.10	14	23,000	4	65	5	<10	56	.010	< .010	.720	.009	.6	3326
.20	6.1	40	10	120	140	<10	35	.020	< .010	.540	< .001	1.5	3327
<.10	13	440,000	100	64	31	<10	41	< .010	< .010	1.40	< .001	.9	3328
<.10	6.6	260	22	14	25	<10	19	< .010	< .010	< .100	< .001	.7	3329

Table 21. Physical properties and chemical analyses for major ions, selected minor ions, nutrients, and dissolved organic carbon in ground water in the Chickies Quartzite and adjacent geologic units. Geologic unit codes are explained at beginning of table 20--Continued

USGS well number	Geologic unit	Date	pH (standard units)	Temperature, water (°C)	Specific conductance (µS/cm)	Oxygen, dissolved (mg/L)	Alkalinity field (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dis solved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
CH-3330	377CCKS	08-23-88	4.8	12.0	57	9.2	--	0.58	1.9	3.2	2.0	8.0	1.3
3331	377CCKS	08-23-88	4.4	14.0	245	7.4	0	15	3.2	14	4.0	22	27
3332	377ANTM	08-30-88	5.7	12.0	150	9.0	12	11	4.5	5.7	3.0	9.9	5.8
3333	377CCKS	09-06-88	4.9	12.5	75	6.0	4	1.1	2.9	2.8	3.9	4.8	15
3334	377CCKS	09-06-88	5.1	12.0	49	10.1	3	.82	2.3	1.9	1.1	3.1	11
3335	377CCKS	09-06-88	4.6	12.5	370	2.6	1	5.7	8.0	45	2.4	86	19
	377CCKS	01-31-89	4.6	11.5	370	1.4	1	--	--	--	--	92	17
	377CCKS	02-28-89	4.6	11.0	403	2.8	1	--	--	--	--	100	23
	377CCKS	03-30-89	4.9	11.0	409	3.4	4	--	--	--	--	95	29
	377CCKS	05-01-89	4.7	11.5	475	3.3	2	--	--	--	--	120	29
	377CCKS	05-31-89	4.9	12.0	408	6.0	3	--	--	--	--	94	31
	377CCKS	06-28-89	4.6	12.5	440	1.6	0	--	--	--	--	110	28
	377CCKS	07-31-89	4.7	12.0	477	2.6	2	--	--	--	--	120	27
	377CCKS	08-29-89	4.5	13.0	455	1.8	0	--	--	--	--	110	24
	377CCKS	09-29-89	4.6	12.0	422	.9	2	--	--	--	--	110	19
	377CCKS	10-30-89	4.6	12.0	418	2.2	1	--	--	--	--	110	20
	377CCKS	11-27-89	4.5	11.5	408	2.3	0	--	--	--	--	100	18
3336	377CCKS	09-06-88	5.9	11.5	105	6.4	36	9.3	3.8	5.7	1.3	5.4	3.0
3337	377CCKS	09-08-88	5.7	12.0	29	10.4	8	1.6	.61	1.8	1.2	2.2	1.6
3338	377CCKS	09-08-88	4.5	12.0	160	6.6	0	3.7	5.8	9.3	2.2	13	31
3339	377CCKS	09-09-88	5.3	11.5	110	8.1	8	3.3	3.3	9.5	2.0	17	5.7
SP33	377HRPR	07-27-87	5.4	20.0	102	8.0	9	--	--	--	--	--	--
LN-1684	377CCKS	11-21-86	5.6	9.5	16	8.5	6	.40	.20	.90	.90	1.0	1.1
1685	377CCKS	12-03-86	6.2	11.0	633	2.0	130	22	11	59	10	68	34
1686	377CCKS	12-03-86	5.2	11.5	18	8.0	5	.40	.30	1.1	2.1	1.4	1.4
1687	377CCKS	12-04-86	4.8	11.5	46	6.5	3	.60	.80	3.1	3.0	4.7	6.2
1688	377CCKS	12-04-86	4.4	12.0	341	7.0	0	33	8.8	7.9	1.4	18	46
1689	377CCKS	12-08-86	5.7	12.0	171	3.8	16	9.9	7.4	4.2	4.6	10	13
1690	377CCKS	12-08-86	5.1	10.5	166	7.7	6	6.0	3.3	15	5.1	26	5.0
1691	377CCKS	12-12-86	5.7	11.5	151	< .1	44	7.5	6.5	4.1	.90	9.3	8.5

Table 21. Physical properties and chemical analyses for major ions, selected minor ions, nutrients, and dissolved organic carbon in ground water in the Chickies Quartzite and adjacent geologic units. Geologic unit codes are explained at beginning of table 20--Continued

Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Iron, total recoverable (µg/L as Fe)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Barium, dissolved (µg/L as Ba)	Boron, dissolved (µg/L as B)	Solids, residue at 180 °C dissolved (mg/L)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)	Carbon, organic, dissolved (mg/L as C)	USGS well number
0.10	7.1	20	25	16	53	< 10	34	<0.010	<0.010	1.50	<0.001	0.7	3330-CH
.20	5.4	80	61	79	76	290	133	< .010	< .010	9.90	< .001	2.4	3331
.10	12	50	4	1	14	< 10	107	< .010	< .010	7.80	.031	.5	3332
.10	8.8	260	150	47	190	< 10	50	.030	< .010	.810	< .001	1.2	3333
<.10	8.0	390	250	22	54	< 10	32	< .010	< .010	<.100	< .001	1.1	3334
.10	7.4	10	6	70	180	10	198	.220	< .010	2.60	< .001	1.2	3335
--	--	--	--	--	--	--	--	.250	.010	2.40	--	--	
--	--	--	--	--	--	--	--	.390	< .010	2.50	--	--	
--	--	--	--	--	--	--	--	.190	< .010	2.70	--	--	
--	--	--	--	--	--	--	--	.130	< .010	2.60	--	--	
--	--	--	--	--	--	--	--	.020	< .010	1.90	--	--	
--	--	--	--	--	--	--	--	.080	< .010	2.60	--	--	
--	--	--	--	--	--	--	--	.100	< .010	2.90	--	--	
--	--	--	--	--	--	--	--	.200	< .010	2.90	--	--	
--	--	--	--	--	--	--	--	.240	< .010	2.80	--	1.2	
--	--	--	--	--	--	--	--	.230	< .010	3.00	--	1.1	
--	--	--	--	--	--	--	--	.180	< .010	2.80	--	1.2	
.10	21	<10	6	<1	22	< 10	78	.010	< .010	.260	.038	.5	3336
<.10	9.6	<10	10	2	9	< 10	13	.010	< .010	.110	.032	.5	3337
.20	7.8	12,000	29	160	170	< 10	78	.010	< .010	2.20	< .001	2.1	3338
<.10	11	6,700	44	36	66	10	64	< .010	< .010	1.20	< .001	.7	3339
--	--	--	--	--	--	--	--	--	--	--	--	--	SP33
<.10	8.0	10	22	<1	380	--	7	--	--	--	--	.8	1684-LN
<.10	4.8	1,400	150	400	140	--	299	--	--	--	--	8.1	1685
<.10	11	240	10	5	39	--	12	--	--	--	--	.6	1686
<.10	13	690	35	48	52	--	25	--	--	--	--	.4	1687
.10	5.3	40	9	41	86	--	185	--	--	--	--	1.7	1688
<.10	8.6	8,300	9	220	60	--	89	--	--	--	--	.9	1689
<.10	8.8	230	98	130	160	--	94	--	--	--	--	.8	1690
.10	17	8,600	850	340	23	--	59	--	--	--	--	.4	1691

Table 21. Physical properties and chemical analyses for major ions, selected minor ions, nutrients, and dissolved organic carbon in ground water in the Chickies Quartzite and adjacent geologic units. Geologic unit codes are explained at beginning of table 20--Continued

USGS well number	Geologic unit	Date	pH (standard units)	Temperature, water (°C)	Specific conductance (µS/cm)	Oxygen, dissolved (mg/L)	Alkalinity field (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dis solved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
LN-1692	377CCKS	12-30-86	5.8	10.0	118	9.2	50	6.2	4.0	5.0	2.3	10	1.7
1693	377CCKS	12-30-86	5.6	11.5	60	5.5	42	--	--	--	--	5.2	6.9
1694	377CCKS	12-30-86	5.1	10.0	42	7.8	4	.60	1.1	.90	1.2	1.9	6.3
1695	377CCKS	12-30-86	4.9	11.5	63	6.2	28	1.1	2.0	3.0	2.6	6.3	2.7
1696	377CCKS	07-08-87	4.7	14.5	67	9.4	< 1	.25	2.9	3.5	1.7	9.2	9.3
1697	377CCKS	07-13-87	4.4	13.0	187	10.3	0	8.4	5.7	6.0	2.9	8.2	< .20
1698	377CCKS	07-13-87	4.4	13.5	214	10.4	0	13	7.7	2.5	3.6	8.6	33
1699	377CCKS	07-14-87	5.3	11.5	12	10.2	6	.50	.33	.70	1.7	1.2	.30
1700	377CCKS	07-15-87	5.4	12.0	12	11.4	7	.50	.24	.80	1.8	.90	1.0
1701	377CCKS	07-15-87	5.9	15.0	54	10.5	9	.86	1.4	1.4	2.1	1.5	7.2
1713	377CCKS	09-01-88	5.1	12.5	49	8.8	5	.69	1.0	4.8	1.1	8.8	< .20
1714	377CCKS	08-25-88	5.0	13.0	103	9.4	3	3.8	5.6	2.5	2.0	8.0	9.2
1715	377CCKS	08-27-88	5.2	12.0	21	11.0	3	.26	.31	1.5	1.4	2.5	< .20
1716	377CCKS	08-25-88	5.1	12.0	30	9.8	5	.27	.52	2.0	2.3	2.7	.40
1717	377CCKS	08-03-88	4.8	13.0	320	6.2	4	9.5	12	23	5.7	42	12
1718	377ANTM	08-03-88	5.3	12.5	250	10.0	10	24	8.2	4.2	4.0	36	25
1719	377CCKS	08-03-88	4.9	14.0	71	8.5	1	1.6	2.6	4.7	2.7	7.3	.80
1720	377HRPR	08-04-88	5.2	12.5	120	4.5	10	8.2	5.9	5.8	2.0	11	1.8
1721	377CCKS	08-04-88	5.0	12.0	215	8.6	4	11	6.9	11	5.8	18	32
1722	377CCKS	08-04-88	5.8	12.0	119	8.5	18	12	3.1	3.2	3.8	3.8	23
1723	377CCKS	08-04-88	5.0	13.0	105	7.8	6	4.5	4.5	5.2	2.8	11	2.1
1724	377CCKS	08-05-88	5.3	12.5	115	6.0	6	4.5	7.0	4.0	4.7	8.2	.90
1725	377CCKS	08-05-88	4.5	12.0	165	<.1	0	10	6.8	3.0	2.2	5.6	19
1726	377CCKS	08-05-88	4.7	12.0	54	2.0	2	.92	2.4	1.9	2.5	4.8	5.3
1727	377CCKS	08-08-88	5.4	12.0	49	6.8	6	1.1	.87	3.1	1.5	5.8	1.2
1728	377CCKS	08-08-88	5.7	13.5	80	1.2	16	2.4	3.8	2.6	2.9	3.1	8.0
1730	367CNSG	08-13-88	7.8	15.0	420	6.0	148	45	26	4.5	1.3	12	19
1731	377CCKS	08-13-88	5.7	13.5	190	7.8	19	1	7.6	4.7	5.4	11	12
1732	377CCKS	08-15-88	4.4	12.0	110	10.3	0	2.2	2.8	7.1	2.6	12	15
1733	377ANTM	08-15-88	5.4	12.5	46	7.3	6	1.7	1.6	2.8	1.7	3.9	3.5

Table 21. Physical properties and chemical analyses for major ions, selected minor ions, nutrients, and dissolved organic carbon in ground water in the Chickies Quartzite and adjacent geologic units. Geologic unit codes are explained at beginning of table 20--Continued

Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Iron, total recoverable (µg/L as Fe)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Barium, dissolved (µg/L as Ba)	Boron, dissolved (µg/L as B)	Solids, residue at 180 °C dissolved (mg/L)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)	Carbon, organic, dissolved (mg/L as C)	USGS well number
<0.10	14	490	<10	<10	<100	--	76	--	--	--	--	1.0	1692-LN
<.10	12	50	--	--	--	--	43	--	--	--	--	.5	1693
<.10	5.9	180	250	30	100	--	23	--	--	--	--	.7	1694
<.10	7.5	1,200	<10	40	200	--	40	--	--	--	--	1.3	1695
.30	7.3	120	81	32	73	--	49	--	--	--	--	2.0	1696
.10	6.4	560	36	100	91	--	112	--	--	--	--	2.6	1697
.10	7.4	60	33	170	190	--	100	--	--	--	--	2.2	1698
.10	8.3	<10	<3	2	19	--	12	--	--	--	--	.6	1699
.10	8.8	330	1,100	29	32	--	12	--	--	--	--	.7	1700
.10	10	10,000	5,300	360	21	--	36	--	--	--	--	.9	1701
<.10	8.3	2,500	440	22	39	<10	33	<0.010	<0.010	0.580	<0.001	.5	1713
.10	8.0	640	5	26	160	<10	63	.020	< .010	4.20	< .001	.8	1714
<.10	8.6	20	48	7	30	<10	31	.020	< .010	.170	.001	.5	1715
.10	8.2	220	80	39	63	<10	23	.030	< .010	.740	.001	.6	1716
.10	7.9	13,000	100	280	370	50	194	1.40	.010	16.0	< .001	2.5	1717
.10	6.3	40	9	29	35	40	161	< .010	< .010	5.10	.030	1.9	1718
.10	7.7	550	27	60	98	20	56	< .010	< .010	4.60	< .001	1.4	1719
.10	8.0	520	4	43	43	30	88	< .010	< .010	9.20	.013	1.8	1720
.10	5.4	670	320	120	57	60	134	.030	< .010	7.40	< .001	2.8	1721
.10	11	50	6	25	7	<10	88	< .010	< .010	1.90	< .001	1.7	1722
.10	8.9	30	5	32	89	<10	71	.050	< .010	5.90	.007	1.6	1723
.10	11	380	200	68	380	<10	88	.040	< .010	9.80	< .001	2.1	1724
.20	6.8	70	7	26	130	<10	89	< .010	< .010	11.0	< .001	2.0	1725
.10	8.0	80	6	67	120	<10	33	< .010	< .010	1.50	.004	2.2	1726
<.10	7.5	11,000	2,200	82	65	<10	26	.080	.010	.830	< .001	.7	1727
.10	14	14,000	1,200	480	52	<10	49	.050	.020	1.10	< .001	.4	1728
.10	12	5,800	30	1	6	<10	233	< .010	< .010	6.80	.020	.5	1730
.10	12	6,900	17	23	37	<10	123	.010	< .010	7.40	< .001	.7	1731
.10	6.7	150	11	75	190	<10	50	< .010	< .010	1.50	< .001	1.3	1732
.10	11	<10	5	5	18	<10	29	< .010	< .010	.700	< .001	.8	1733

Table 21. Physical properties and chemical analyses for major ions, selected minor ions, nutrients, and dissolved organic carbon in ground water in the Chickies Quartzite and adjacent geologic units. Geologic unit codes are explained at beginning of table 20--Continued

USGS well number	Geologic unit	Date	pH (standard units)	Temperature, water (°C)	Specific conductance (µS/cm)	Oxygen, dissolved (mg/L)	Alkalinity field (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dis solved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
LN-1734	377CCKS	08-25-88	4.7	13.0	175	9.0	1	4.0	8.3	8.9	4.4	20	1.7
1735	377CCKS	08-17-88	4.8	12.0	68	11.0	1	1.3	1.2	6.6	1.4	11	5.5
1736	377CCKS	08-17-88	5.1	12.0	45	11.0	2	1.2	1.9	1.7	1.3	2.7	8.3
1737	377CCKS	08-17-88	5.5	12.0	43	9.2	8.0	1.0	.80	2.7	1.8	3.6	.50
1738	377CCKS	09-02-88	4.8	11.5	--	--	1	3.4	1.3	1.2	.70	1.7	14
1739	377CCKS	09-01-88	4.4	12.0	77	9.5	0	2.3	1.5	1.9	.90	3.5	20
1740	377CCKS	09-02-88	5.3	12.0	17	4.0	4	.23	.36	1.2	.80	1.8	.60
1741	377CCKS	09-02-88	5.3	12.0	17	9.0	2	.43	.35	1.3	.80	1.8	<.20
1742	000GBBR	09-02-88	6.2	12.0	55	9.0	21	4.9	2.0	3.0	1.2	1.9	1.4
MG- 399	377CCKS	07-01-87	6.3	12.0	329	7.7	54	22	13	14	3.4	45	16
1000	377CCKS	12-19-86	6.3	11.5	186	7.0	40	11	10	7.2	1.4	23	3.8
1001	377CCKS	12-29-86	6.3	11.5	204	4.0	52	18	7.0	4.1	2.2	14	19
1002	377LDGR	01-18-87	7.5	11.0	351	5.0	192	37	25	3.5	.70	4.5	11
1003	377LDGR	01-09-87	7.3	12.0	626	1.6	296	59	38	19	5.6	34	20
1004	337CCKS	01-13-87	5.9	11.5	335	6.6	40	23	9.6	16	6.2	36	45
YO- 88	377CCKS	07-21-87	5.9	14.0	39	9.4	17	3.0	1.6	1.8	1.0	2.3	.50
351	377CCKS	08-10-88	5.0	13.0	85	5.4	5	1.5	2.3	8.5	1.3	8.1	.80
371	377CCKS	12-23-86	5.2	12.0	78	7.6	4	3.0	4.0	4.2	1.2	4.9	.70
650	377CCKS	08-11-88	5.0	13.0	115	8.0	4	3.4	5.4	5.1	1.2	7.3	.60
792	377CCKS	12-22-86	5.5	11.0	31	5.6	10	5.7	.60	1.0	1.4	1.6	1.2
1148	377CCKS	12-09-86	5.0	9.0	48	4.6	3	1.3	1.4	4.2	1.6	7.0	1.0
	377CCKS	07-22-87	5.1	13.0	35	9.4	5	.83	.78	2.6	1.5	5.1	.50
1149	377CCKS	12-09-86	6.1	11.5	116	4.4	41	6.0	5.1	4.6	3.1	9.2	5.8
1150	377CCKS	12-09-86	6.2	11.5	63	6.1	22	4.1	3.5	1.5	.50	1.8	4.3
1151	377CCKS	12-10-86	6.7	13.0	264	1.5	114	26	14	7.8	.80	17	8.0
1152	377CCKS	12-10-86	6.4	12.0	91	4.5	37	5.2	6.3	3.3	.50	1.7	13
1153	377CCKS	12-10-86	6.5	12.0	174	<.1	110	17	6.0	4.6	1.5	7.0	12
1154	377CCKS	12-11-86	5.4	11.5	85	7.0	--	2.8	3.1	6.8	1.0	9.4	1.6
1155	377CCKS	12-11-86	6.1	10.5	52	4.1	30	2.0	2.0	6.1	.90	.30	3.6
1156	377CCKS	12-11-86	5.5	10.5	47	7.1	12	2.8	1.0	2.9	1.4	3.2	1.0

Table 21. Physical properties and chemical analyses for major ions, selected minor ions, nutrients, and dissolved organic carbon in ground water in the Chickies Quartzite and adjacent geologic units. Geologic unit codes are explained at beginning of table 20--Continued

Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Iron, total recoverable µg/L as Fe)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Barium, dissolved (µg/L as Ba)	Boron, dissolved (µg/L as B)	Solids, residue at 180 °C dissolved (mg/L)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)	Carbon, organic, dissolved (mg/L as C)	USGS well number
0.10	9.0	<10	9	130	210	<10	115	0.020	<0.010	8.90	0.004	0.7	1734-LN
.10	6.7	20	3	29	74	<10	35	--	--	--	<.001	.8	1735
<.10	7.6	90	54	13	58	<10	18	<.010	<.010	.520	<.001	.9	1736
.10	8.7	4,200	1,800	44	56	<10	31	.050	<.010	1.10	<.001	.7	1737
.10	5.5	10	10	150	210	<10	39	<.010	<.010	.190	<.001	1.2	1738
.10	5.9	40	7	320	220	<10	41	<.010	<.010	.410	<.001	1.5	1739
<.10	7.2	9,300	330	9	13	<10	23	<.010	<.010	.100	<.001	.4	1740
<.10	7.2	<10	15	3	9	<10	19	<.010	<.010	<.100	<.001	.5	1741
<.10	22	210	6	3	8	<10	36	<.010	<.010	.210	.024	.4	1742
.10	11	30	18	2	10	--	179	--	--	--	--	.8	399-MG
.10	23	970	7	10	39	--	103	--	--	--	--	.5	1000
<.10	8.3	4,900	2,000	20	100	--	112	--	--	--	--	1.4	1001
<.10	9.7	13,000	12	39	20	--	195	--	--	--	--	.8	1002
<.10	11	219	19	350	150	--	343	--	--	--	--	.8	1003
<.10	8.8	50	12	59	63	--	172	--	--	--	--	1.0	1004
.10	14	1,800	290	12	7	--	26	--	--	--	--	.7	88-YO
<.10	11	<10	5	10	38	20	56	<.010	<.010	4.30	.052	.9	351
<.10	11	10	<10	<10	100	--	52	--	--	--	--	.4	371
<.10	7.7	10	5	21	30	<10	72	<.010	<.010	8.10	.002	.6	650
<.10	8.0	2,600	130	20	<100	--	15	--	--	--	--	.3	792
<.10	7.1	1,000	40	14	30	--	25	--	--	--	--	.7	1148
.10	6.5	8,700	13	6	15	--	24	--	--	--	--	.8	
.20	21	4,300	5,800	870	50	--	63	--	--	--	--	--	1149
<.10	7.9	160	140	47	11	--	51	--	--	--	--	.3	1150
.10	21	1,200	220	230	15	--	143	--	--	--	--	.5	1151
.20	20	3,300	2,400	700	4	--	51	--	--	--	--	.3	1152
.20	28	9,700	9,500	610	86	--	92	--	--	--	--	.3	1153
<.10	9.1	10	9	42	15	--	43	--	--	--	--	.3	1154
.10	28	<10	7	<10	<2	--	39	--	--	--	--	.5	1155
<.10	14	10	4	1	25	--	33	--	--	--	--	.6	1156

Table 21. Physical properties and chemical analyses for major ions, selected minor ions, nutrients, and dissolved organic carbon in ground water in the Chickies Quartzite and adjacent geologic units. Geologic unit codes are explained at beginning of table 20--Continued

USGS well number	Geologic unit	Date	pH (standard units)	Temperature, water (°C)	Specific conductance (µS/cm)	Oxygen, dissolved (mg/L)	Alkalinity field (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dis solved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
YO-1157	377CCKS	12-22-86	4.7	12.0	136	3.6	6	4.4	3.8	11	1.8	13	9.7
1158	377CCKS	12-23-86	4.9	12.0	173	4.0	2	3.7	4.7	18	2.6	17	1.3
1159	377CCKS	12-23-86	6.4	11.0	238	4.3	48	19	9.0	8.5	.70	12	10
1160	377HRPR	12-23-86	6.2	10.5	168	8.3	16	9.0	6.7	2.3	1.1	2.7	27
1161	377CCKS	12-24-86	6.9	11.0	15	<.1	90	17	11	1.0	.30	2.8	11
1162	377HRPR	07-21-87	5.3	13.0	80	--	8	4.6	2.6	6.2	1.7	7.1	.50
1163	377CCKS	07-21-87	5.3	13.0	26	9.0	7	.54	.35	1.8	1.4	1.7	3.0
1164	377CCKS	07-22-87	5.8	14.0	65	7.1	20	5.0	3.3	2.2	.90	4.2	1.1
1165	377CCKS	07-22-87	4.9	15.0	145	6.0	4	8.2	4.8	8.2	1.7	12	24
1166	377CCKS	07-23-87	4.4	14.0	200	5.9	0	9.2	4.4	17	5.1	34	2.9
1167	377HRPR	07-23-87	5.6	13.5	128	7.0	16	8.4	4.2	5.6	3.7	8.3	6.4
1168	377VNTG	07-23-87	7.3	13.5	250	6.2	116	30	14	3.0	1.7	3.5	5.7
1172	377CCKS	08-11-88	5.2	13.0	30	9.0	6	1.3	.62	1.7	1.4	3.9	.50
1175	377CCKS	08-08-88	5.6	12.0	24	6.2	10	.66	.38	1.0	1.3	1.6	1.4
1176	377CCKS	08-09-88	5.3	14.5	89	10.2	5	4.2	2.7	4.4	2.1	7.5	11
1177	377CCKS	08-09-88	5.9	12.5	41	8.8	16	3.5	1.4	2.0	.80	1.3	1.7
1178	377CCKS	08-09-88	5.2	15.5	34	10.2	6	1.6	.83	1.5	2.1	3.6	.90
1179	377CCKS	08-09-88	4.7	12.5	122	--	2	3.4	2.3	11	2.8	22	8.6
1180	377CCKS	08-10-88	5.5	12.0	38	12.0	6	1.3	1.9	1.0	1.0	2.1	4.2
1181	377CCKS	08-10-88	5.6	14.0	58	6.0	11	3.7	2.0	2.6	1.1	3.1	3.8
1182	377CCKS	08-10-88	5.3	13.5	45	8.5	4	1.9	1.6	2.7	.90	2.7	2.7
1183	377CCKS	08-11-88	5.7	--	180	6.4	1	3.5	5.9	18	1.1	25	1.5
1184	377CCKS	09-07-88	4.6	14.0	93	7.0	1	2.7	2.3	4.4	2.9	6.6	14
1185	377CCKS	09-07-88	4.9	13.0	50	9.2	2	2.3	1.5	1.4	1.0	4.6	8.4
1186	377CCKS	09-07-88	4.9	12.5	50	0.2	3	1.4	1.1	3.8	1.0	7.7	.40

Table 21. Physical properties and chemical analyses for major ions, selected minor ions, nutrients, and dissolved organic carbon in ground water in the Chickies Quartzite and adjacent geologic units. Geologic unit codes are explained at beginning of table 20--Continued

Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Iron, total recoverable (μg/L as Fe)	Iron, dissolved (μg/L as Fe)	Manganese, dissolved (μg/L as Mn)	Barium, dissolved (μg/L as Ba)	Boron, dissolved (μg/L as B)	Solids, residue at 180 °C dissolved (mg/L)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)	Carbon, organic, dissolved (mg/L as C)	USGS well number
<0.10	6.8	120	150	100	100	--	79	--	--	--	--	1.0	1157-YO
<.10	8.9	50	40	50	100	--	103	--	--	--	--	.6	1158
<.10	19	260	130	20	100	--	140	--	--	--	--	.5	1159
<.10	8.4	70	20	<10	<100	--	76	--	--	--	--	.7	1160
.20	7.5	2,200	1,900	220	100	--	101	--	--	--	--	.4	1161
.10	12	20	5	5	25	--	65	--	--	--	--	.6	1162
.10	6.9	590	180	46	8	--	18	--	--	--	--	.4	1163
.10	8.1	20	<3	9	5	--	41	--	--	--	--	.5	1164
.10	7.5	40	22	70	47	--	84	--	--	--	--	1.7	1165
.10	8.8	20	17	44	170	--	122	--	--	--	--	1.0	1166
.10	18	240	21	9	5	--	92	--	--	--	--	.7	1167
.10	9.3	50	<3	<1	15	--	153	--	--	--	--	.5	1168
.10	7.2	60	<3	2	6	<10	24	0.010	<0.010	0.280	0.017	.7	1172
<.10	7.2	46,000	590	77	15	<10	18	.010	<.010	.140	<.001	2.0	1175
<.10	8.4	1,000	11	10	66	<10	49	.020	.010	2.70	.002	.8	1176
<.10	12	1,100	67	20	4	<10	26	<.010	<.010	<.100	.001	.5	1177
<.10	8.2	280	16	29	31	<10	27	.020	<.010	.780	<.001	.5	1178
<.10	7.5	40	12	27	150	<10	66	.010	<.010	.840	<.001	1.2	1179
.10	6.5	<10	4	6	9	<10	26	.020	<.010	.740	.019	.4	1180
.10	12	180	48	37	50	<10	39	.010	<.010	1.20	.024	.6	1181
<.10	9.8	110	49	23	35	<10	28	.010	<.010	1.70	.001	.4	1182
.10	7.2	20	6	97	53	<10	94	.010	<.010	6.70	<.001	.4	1183
<.10	7.4	160	5	57	120	20	44	<.010	<.010	1.80	.012	1.3	1184
<.10	6.1	240	5	27	42	<10	24	<.010	<.010	.570	<.001	1.0	1185
<.10	6.6	20	6	62	22	<10	42	<.010	<.010	.470	.009	.7	1186

Table 22. Chemical analyses of radionuclides in ground water in the Chickies Quartzite and adjacent geologic units. Geologic unit codes are explained at the beginning of table 20. Counting or analytical error values for each sample give counting or analytical uncertainty at the 2σ or 95-percent-confidence level.

[pCi/L, picocuries per liter; μg/L, micrograms per liter; -- no data; σ, sigma; CE, counting error; AE, analytical error]

USGS well number	Geologic unit	Date	Radon-222, total (pCi/L)	Radium-226, dissolved, radon method (pCi/L)	Radium-226, 2-σ CE (pCi/L)	Radium-228, dissolved (pCi/L as Ra-228)	Radium-228, 2-σ CE (pCi/L)	Uranium, natural, dissolved (μg/L as U)	Uranium, 2-σ AE (μg/L)
BE-1440	377CCKS	12-22-86	110	1.0	0.3	2.2	0.4	0.18	0.03
BK- 396	377CCKS	12-21-86	1,600	.34	.09	< .90	--	.22	.03
1200	377CCKS	12-21-86	900	.42	.12	< 1.0	--	.14	.02
1201	377CCKS	12-31-86	760	.26	.07	< .50	--	.34	.05
1202	377CCKS	12-31-86	2,600	3.8	.5	50	2.0	.33	.05
	377CCKS	05-07-87	2,800	5.7	.6	66	2.0	.39	.06
1227	400FLCGP	06-22-87	1,200	1.0	.1	1.6	.4	< .05	--
1228	377CCKS	06-22-87	3,500	2.9	.3	5.4	.5	< .05	--
1288	377HRDS	09-03-88	12,000	1.7	.3	3.6	1.5	.14	.02
SP21	377CCKS	05-27-87	--	3.8	.4	8.1	.8	.40	.06
CH- 293	377CCKS	11-13-86	3,000	1.6	.5	3.5	1.9	.30	.05
333	377CCKS	11-15-86	1,300	9.5	1.0	22	2.0	.30	.05
417	377CCKS	11-24-86	4,300	.48	.12	< 1.0	--	.17	.03
418	377CCKS	12-05-86	9,300	2.9	.5	7.6	1.9	.32	.05
427	377HRPR	12-05-86	270	.78	.48	1.8	.8	.16	.02
505	377CCKS	05-08-87	400	< .10	--	.60	.38	.21	.03
693	377CCKS	05-29-87	2,200	< .20	--	< .60	--	.26	.04
703	377CCKS	06-05-87	230	< .20	--	< 1.0	--	.14	.02
945	377CCKS	11-13-86	3,100	.82	.44	< 1.0	--	.15	.02
992	377HRPR	07-28-87	5,300	1.8	.1	2.0	.4	< .05	--
1089	377CCKS	06-12-87	3,600	1.7	.2	1.8	.4	< .05	--
1090	377CCKS	06-17-87	1,400	4.4	.4	14	1.0	< .05	--
1091	377CCKS	06-18-87	3,300	2.6	.3	< 2.0	--	< .05	--
1092	377CCKS	06-23-87	410	.49	.04	7.8	.5	< .05	--
1093	377CCKS	06-26-87	3,000	< .10	--	< .50	--	< .05	--
1094	377CCKS	06-26-87	2,100	.50	.01	.56	.03	< .05	--
1095	377CCKS	07-28-87	5,600	2.6	.1	3.9	.4	.18	.03
1096	377CCKS	07-29-87	4,800	< .20	--	1.4	.4	< .05	--
1097	377ANTM	08-04-87	2,800	.36	.09	< .80	--	< .05	--
1098	377CCKS	08-05-87	490	1.4	.1	3.6	.5	< .05	--
1099	400FLCGG	08-06-87	440	.15	--	.73	--	< .05	--
1213	377CCKS	07-02-87	1,200	2.1	.2	2.9	.7	.09	.01
1217	377CCKS	06-30-87	1,700	.93	.09	.70	.4	< .05	--

Table 22. Chemical analyses of radionuclides in ground water in the Chickies Quartzite and adjacent geologic units. Geologic unit codes are explained at the beginning of table 20. Counting or analytical error values for each sample give counting or analytical uncertainty at the 2σ or 95-percent-confidence level.--Continued

Gross alpha, dis-solved (pCi/L as U-Nat)	Gross alpha, 2-σ CE (pCi/L as U-Nat)	Gross alpha, dis-solved (μg/L as U-Nat)	Gross alpha, 2-σ CE (μg/L as U-Nat)	Gross beta, dis-solved (pCi/L as Cs-137)	Gross beta, 2-σ CE (pCi/L as CS-137)	Gross beta, dis-solved (pCi/L as Sr/Yt-90)	Gross beta, 2-σ CE (pCi/L as SR/YT-90)	USGS well number
5.2	2.0	--	--	7.0	1.0	--	--	1440-BE
< 2.0	--	--	--	3.6	1.0	--	--	396-BK
< 5.0	--	--	--	8.0	1.8	--	--	1200
< 2.0	--	--	--	4.3	1.1	--	--	1201
35	4.0	--	--	120	10	--	--	1202
45	6.0	--	--	150	20	--	--	
6.2	2.5	--	--	21	1.0	--	--	1227
5.0	2.6	--	--	21	2.0	--	--	1228
--	--	12	2.5	14	2.0	13	1.9	1288
10	2.0	--	--	18	2.0	--	--	SP21
1.8	1.6	--	--	7.7	1.2	--	--	293-CH
33	5.0	--	--	41	3.0	--	--	333
1.2	.9	--	--	5.0	.9	--	--	417
20	2.0	--	--	20	2.0	--	--	418
1.3	.8	--	--	2.9	.8	--	--	427
< 1.0	--	--	--	3.9	.9	--	--	505
< .7	--	--	--	3.3	.8	--	--	693
1.2	1.1	--	--	5.0	1.0	--	--	703
.9	.8	--	--	5.1	.9	--	--	945
2.9	1.9	--	--	9.3	1.3	--	--	992
3.2	1.6	--	--	7.5	1.1	--	--	1089
22	3.0	--	--	32	2.0	--	--	1090
4.1	1.4	--	--	4.6	.8	--	--	1091
7.1	1.9	--	--	17	1.0	--	--	1092
< 2.0	--	--	--	5.5	1.0	--	--	1093
1.5	.8	--	--	2.6	.7	--	--	1094
4.6	1.8	--	--	7.8	1.1	--	--	1095
< 1.0	--	--	--	4.6	.9	--	--	1096
< 1.0	--	--	--	5.1	1.0	--	--	1097
2.0	1.1	--	--	6.7	1.0	--	--	1098
< 1.0	--	--	--	3.9	--	--	--	1099
4.3	1.8	--	--	18	2.0	--	--	1213
1.4	1.1	--	--	3.9	.8	--	--	1217

Table 22. Chemical analyses of radionuclides in ground water in the Chickies Quartzite and adjacent geologic units. Geologic unit codes are explained at the beginning of table 20. Counting or analytical error values for each sample give counting or analytical uncertainty at the 2σ or 95-percent-confidence level.--Continued

USGS well number	Geo-logic unit	Date	Radon-222, total (pCi/L)	Radium-226, dis-solved, radon method (pCi/L)	Radium-226, 2-σ CE (pCi/L)	Radium-228, dis-solved (pCi/L as Ra-228)	Radium-228, 2-σ CE (pCi/L)	Uranium, natural, dis-solved (μg/L as U)	Uranium, 2-σ AE (μg/L)
CH-1265	377CCKS	11-21-86	370	2.7	0.5	2.7	0.7	0.18	0.03
	377CCKS	05/06/87	--	2.0	.2	2.4	.5	.23	.03
1286	377CCKS	12-01-86	3,300	.40	.13	12	1.0	.18	.03
1296	377CCKS	09-02-87	2,000	4.8	.1	6.3	1.0	.24	.04
1367	377CCKS	08-05-87	7,300	3.8	.1	9.9	.7	.35	.05
1376	377CCKS	09-04-87	5,800	.90	.1	4.0	.8	.06	.01
1616	377CCKS	11-12-86	3,400	2.5	.6	26	3.0	.30	.05
	377CCKS	08-11-87	--	2.9	.1	25	1.0	< .05	--
	377CCKS	10-23-87	3,700	4.1	.4	29	3.0	.87	.01
1617	377CCKS	06-03-87	280	3.7	1.0	17	1.0	.25	.04
1618	377CCKS	05-22-87	1,900	3.7	1.0	32	2.0	.21	.03
2113	377CCKS	11-10-86	2,200	1.7	.5	12	3.0	.22	.03
2115	400BMFGA	11-10-86	1,600	< .60	--	<1.0	--	.25	.04
2410	377CCKS	11-20-86	8,600	2.3	.5	4.9	2.9	.15	.03
2417	377CCKS	08-26-88	3,600	.47	.08	<1.0	--	< .01	--
2418	377CCKS	11-22-86	1,300	< .70	--	2.6	.8	.12	.02
2828	367CNSG	07-29-87	520	.33	.08	< .50	--	2.4	.4
2847	377CCKS	09-05-87	3,700	.78	.01	2.9	.4	.08	.01
2998	400FLCGG	07-16-87	2,100	< .20	--	< .70	--	< .05	--
3076	377CCKS	07-16-87	7,800	2.4	.1	10	1.0	.12	.02
3079	377HRPR	07-27-87	1,100	.64	.01	< .90	--	< .05	--
3086	400FCIGA	08-07-87	470	< .20	--	< .60	--	< .05	--
3087	377CCKS	08-13-87	360	8.7	.2	32	2.0	< .05	--
3088	377CCKS	08-13-87	7,300	.38	.07	< .70	--	< .05	--
3089	400FCIGA	08-12-87	140	< .10	--	< .90	--	< .05	--
3090	400FCIGA	08-12-87	2,100	< .20	--	< .70	--	< .05	--
3091	377CCKS	08-12-87	--	6.1	.1	26	2.0	6.6	1.0
3111	377CCKS	08-26-87	970	1.2	.1	2.3	.6	< .05	--
3112	377CCKS	08-28-87	590	8.0	.2	44	2.0	< .05	--
	377CCKS	06-01-89	750	--	--	--	--	--	--
3113	377CCKS	08-28-87	1,300	4.5	.1	7.7	1.2	1.1	.02
3114	377CCKS	08-29-87	590	5.7	.2	36	2.0	< .05	--

Table 22. Chemical analyses of radionuclides in ground water in the Chickies Quartzite and adjacent geologic units. Geologic unit codes are explained at the beginning of table 20. Counting or analytical errorvalues for each sample give counting or analytical uncertainty at the 2σ or 95-percent-confidence level.--Continued

Gross alpha, dis-solved (pCi/L as U-Nat)	Gross alpha, 2-σ CE (pCi/L as U-Nat)	Gross alpha, dis-solved (μg/L as U-Nat)	Gross alpha, 2-σ CE (μg/L as U-Nat)	Gross beta, dis-solved (pCi/L as Cs-137)	Gross beta, 2-σ CE (pCi/L as CS-137)	Gross beta, dis-solved (pCi/L as Sr/ Yt-90)	Gross beta, 2-σ CE (pCi/L as SR/YT-90)	USGS well number
6.2	2.4	--	--	6.6	1.6	--	--	1265-CH
2.1	1.8	--	--	5.7	1.1	--	--	
13	3.0	--	--	11	1.0	--	--	1286
13	3.0	--	--	12	1.0	--	--	1296
5.6	1.7	--	--	20	2.0	--	--	1367
3.2	1.5	--	--	8.8	1.1	--	--	1376
17	3.0	--	--	51	3.0	--	--	1616
9.8	2.9	--	--	59	3.0	--	--	
55	6.0	--	--	59	3.0	--	--	
17	3.0	--	--	33	2.0	--	--	1617
15	3.0	--	--	79	3.0	--	--	1618
5.7	1.8	--	--	25	3.0	--	--	2113
< 1.0	--	--	--	3.2	.9	--	--	2115
4.4	1.9	--	--	5.9	1.5	--	--	2410
--	--	2.2	0.8	2.5	.8	2.4	0.7	2417
1.3	1.0	--	--	2.2	1.2	--	--	2418
< 4.0	--	--	--	3.8	1.3	--	--	2828
1.7	1.0	--	--	6.9	.9	--	--	2847
< 2.0	--	--	--	5.4	1.0	--	--	2998
9.0	2.7	--	--	21	2.0	--	--	3076
< 1.0	--	--	--	3.6	.9	--	--	3079
< 2.0	--	--	--	1.4	.8	--	--	3086
23	3.0	--	--	49	2.0	--	--	3087
< 1.0	--	--	--	5.3	.8	--	--	3088
< 1.0	--	--	--	2.3	.8	--	--	3089
< 1.0	--	--	--	3.3	.9	--	--	3090
19	3.0	--	--	54	3.0	--	--	3091
2.8	1.1	--	--	4.5	.8	--	--	3111
27	4.0	--	--	82	3.0	--	--	3112
--	--	--	--	--	--	--	--	
6.2	2.3	--	--	15	1.0	--	--	3113
24	5.0	--	--	85	3.0	--	--	3114

Table 22. Chemical analyses of radionuclides in ground water in the Chickies Quartzite and adjacent geologic units. Geologic unit codes are explained at the beginning of table 20. Counting or analytical error values for each sample give counting or analytical uncertainty at the 2σ or 95-percent-confidence level.--Continued

USGS well number	Geologic unit	Date	Radon-222, total (pCi/L)	Radium-226, dissolved, radon method (pCi/L)	Radium-226, $2\text{-}\sigma$ CE (pCi/L)	Radium-228, dissolved (pCi/L as Ra-228)	Radium-228, $2\text{-}\sigma$ CE (pCi/L)	Uranium, natural, dissolved (μg/L as U)	Uranium, $2\text{-}\sigma$ AE (μg/L)
CH-3117	400FCIGA	08-31-87	8,200	1.1	0.1	1.4	0.4	1.7	0.3
3122	377CCKS	09-04-87	9,200	1.0	.1	1.8	1.0	.13	.02
3123	377CCKS	09-02-87	6,500	2.1	.1	8.0	1.1	.55	.08
3124	377CCKS	09-02-87	3,700	2.4	.3	2.7	.4	.07	.01
3125	377CCKS	09-01-87	630	5.1	.2	6.9	1.2	.10	.03
3126	377CCKS	09-01-87	6,900	< .20	--	< .80	--	< .05	--
3127	377CCKS	09-01-87	6,400	1.2	.1	6.7	.7	.09	.01
3128	377CCKS	09-03-87	1,100	11	1.0	30	3.0	< .05	--
3131	377CCKS	09-04-87	4,700	.68	.07	3.4	.7	.08	.01
3132	377CCKS	09-03-87	1,400	31	2.0	55	6.0	< .05	--
3133	377CCKS	10-21-87	4,400	.77	.09	< .80	--	< .05	--
3135	377CCKS	09-05-87	3,800	.38	.01	< .70	--	< .05	--
3136	377HRPR	09-08-87	790	2.9	.1	12	1.0	< .05	--
3160	377CCKS	08-22-88	1,700	.2	.04	1.5	.9	< .01	--
3166	377CCKS	10-19-87	840	1.5	.4	4.1	.7	< .05	--
3168	377CCKS	09-29-87	700	2.1	.1	17	2.0	< .05	--
3189	377CCKS	08-30-88	2,700	4.2	.7	2.4	.8	.03	.01
3213	377CCKS	10-21-87	--	10	1.0	38	3.0	.08	.01
3214	377CCKS	10-22-87	5,800	5.2	.5	8.7	.8	.11	.02
3215	377CCKS	10-23-87	630	5.4	.6	25	2.0	.08	.01
3219	377CCKS	06-16-88	670	4.6	.8	13	2.7	--	--
	377CCKS	08-23-88	770	6.2	1.0	16	3.1	.02	.01
3301	400FMFG	06-16-88	600	.03	.01	< 1.0	--	.01	.01
3315	377CCKS	09-01-88	330	5.3	.9	19	3.7	.04	.01
3325	377CCKS	08-16-88	1,300	6.2	1.1	10	2.1	.10	.01
3326	377CCKS	08-16-88	32,300	1.2	.19	<1.0	.6	1.0	.16
3327	377CCKS	08-26-88	840	12	2.1	28	5.4	.09	.01
3328	377CCKS	08-26-88	26,100	1.0	.17	< 1.0	--	.32	.05
3329	377CCKS	08-22-88	2,200	1.9	.3	< 1.0	--	.04	.01
3330	377CCKS	08-23-88	1,500	3.1	.52	1.9	1.3	.03	.01
3331	377CCKS	08-23-88	820	12	2.0	160	29	.07	.01

Table 22. Chemical analyses of radionuclides in ground water in the Chickies Quartzite and adjacent geologic units. Geologic unit codes are explained at the beginning of table 20. Counting or analytical error values for each sample give counting or analytical uncertainty at the 2σ or 95-percent-confidence level.--Continued

Gross alpha, dissolved (pCi/L as U-Nat)	Gross alpha, 2-σ CE (pCi/L as U-Nat)	Gross alpha, dissolved (μg/L as U-Nat)	Gross alpha, 2-σ CE (μg/L as U-Nat)	Gross beta, dissolved (pCi/L as Cs-137)	Gross beta, 2-σ CE (pCi/L as CS-137)	Gross beta, dissolved (pCi/L as Sr/ Yt-90)	Gross beta, 2-σ CE (pCi/L as SR/YT-90)	USGS well number
4.2	1.5	--	--	5.2	0.9	--	--	3117-CH
2.2	1.2	--	--	6.7	1.0	--	--	3122
6.0	1.6	--	--	17	1.0	--	--	3123
4.4	1.3	--	--	6.5	.9	--	--	3124
13	3.0	--	--	21	2.0	--	--	3125
1.3	.8	--	--	4.8	.8	--	--	3126
5.6	2.0	--	--	18	2.0	--	--	3127
32	4.0	--	--	54	2.0	--	--	3128
3.5	1.1	--	--	6.4	.9	--	--	3131
54	7.0	--	--	130	10	--	--	3132
1.9	.9	--	--	3.4	.7	--	--	3133
< 1.0	--	--	--	3.2	.8	--	--	3135
6.1	1.9	--	--	16	1.0	--	--	3136
--	--	0.8	0.6	2.1	.8	2.0	--	3160
4.9	1.3	--	--	6.4	.9	--	--	3166
12	2.0	--	--	29	2.0	--	--	3168
--	--	19	3.0	6.3	1.6	6.0	1.1	3189
55	6.0	--	--	58	3.0	--	--	3213
10	3.0	--	--	15	1.0	--	--	3214
26	5.0	--	--	47	3.0	--	--	3215
--	--	19	3.0	11	2.6	11	1.6	3219
--	--	49	6.1	30	6.4	28	3.3	
--	--	.4	.4	.9	.6	.93	.5	3301
--	--	53	6.6	39	4.7	37	4.5	3315
--	--	48	6.2	22	4.5	20	2.5	3325
--	--	13	2.5	16	3.3	14	1.9	3326
--	--	92	10	40	7.7	38	4.2	3327
--	--	8.8	1.9	10	1.7	9.8	1.6	3328
--	--	6.0	1.5	4.1	1.2	4.0	.9	3329
--	--	16	2.7	5.1	1.4	4.8	1.0	3330
--	--	250	25	230	44	190	36	3331

Table 22. Chemical analyses of radionuclides in ground water in the Chickies Quartzite and adjacent geologic units. Geologic unit codes are explained at the beginning of table 20. Counting or analytical error values for each sample give counting or analytical uncertainty at the 2σ or 95-percent-confidence level.--Continued

USGS well number	Geologic unit	Date	Radon-222, total (pCi/L)	Radium-226, dissolved, radon method (pCi/L)	Radium-226, 2-σ CE (pCi/L)	Radium-228, dissolved (pCi/L as Ra-228)	Radium-228, 2-σ CE (pCi/L)	Uranium, natural, dissolved (μg/L as U)	Uranium, 2-σ AE (μg/L)
CH-3332	377ANTM	08-30-88	25,800	0.08	0.02	1.3	0.8	<0.01	--
3333	377CCKS	09-06-88	2,800	3.7	.6	25	4.8	.17	0.03
3334	377CCKS	09-06-88	1,300	1.1	.2	12	2.6	.01	.01
3335	377CCKS	09-06-88	5,500	14	2.3	150	27	.21	.03
	377CCKS	11-28-88	6,700	--	--	--	--	--	--
	377CCKS	12-28-88	7,500	13.7	.1	130	1.0	--	--
	377CCKS	01-31-89	7,900	15.3	.1	160	2.0	--	--
	377CCKS	02-28-89	5,800	10.7	.1	130	1.0	--	--
	377CCKS	03-30-89	3,600	6.9	.1	86	1.0	--	--
	377CCKS	05-01-89	3,800	6.6	.1	81	1.0	--	--
	377CCKS	05-31-89	2,800	4.4	.1	64	1.0	--	--
	377CCKS	06-28-89	4,300	6.2	.1	81	1.0	--	--
	377CCKS	07-31-89	4,300	6.1	.1	82	1.0	--	--
	377CCKS	08-29-89	4,800	8.4	.1	100	1.0	--	--
	377CCKS	09-29-89	6,300	10.1	.1	120	1.0	--	--
	377CCKS	10-30-89	6,100	10.9	.1	120	1.0	--	--
	377CCKS	11-27-89	6,900	12	.1	140	1.0	--	--
3336	377CCKS	09-06-88	490	.06	.02	<1.0	--	< .01	--
3337	377CCKS	09-08-88	30,600	.72	.15	<1.0	--	.04	.01
3338	377CCKS	09-08-88	2,400	4.6	.8	15	3.0	.14	.02
3339	377CCKS	09-09-88	5,400	1.2	.2	1.5	.8	.10	.02
SP33	377HRPR	07-27-87	--	1.3	.4	2.7	.6	< .05	--
LN-1684	377CCKS	11-21-86	980	1.9	.4	5.3	2.2	.14	.02
1685	377CCKS	12-03-86	5,700	3.9	.6	5.0	1.5	.54	.08
1686	377CCKS	12-03-86	24,500	1.0	.5	1.6	.7	.31	.05
1687	377CCKS	12-04-86	7,600	2.7	.5	5.3	.9	.25	.04
1688	377CCKS	12-04-86	1,900	7.4	.7	34	4.0	.23	.03
1689	377CCKS	12-08-86	11,800	1.4	.4	6.8	2.2	.75	.11
1690	377CCKS	12-08-86	2,800	1.1	.4	1.1	.5	.50	.08
1691	377CCKS	12-12-86	510	.56	.39	< .50	--	.86	.13
1692	377CCKS	12-30-86	4,400	.84	.27	1.1	.5	.36	.05

Table 22. Chemical analyses of radionuclides in ground water in the Chickies Quartzite and adjacent geologic units. Geologic unit codes are explained at the beginning of table 20. Counting or analytical error values for each sample give counting or analytical uncertainty at the 2σ or 95-percent-confidence level.--Continued

Gross alpha, dis-solved (pCi/L as U-Nat)	Gross alpha, 2-σ CE (pCi/L as U-Nat)	Gross alpha, dis-solved (μg/L as U-Nat)	Gross alpha, 2-σ CE (μg/L as U-Nat)	Gross beta, dis-solved (pCi/L as Cs-137)	Gross beta, 2-σ CE (pCi/L as CS-137)	Gross beta, dis-solved (pCi/L as Sr/Yt-90)	Gross beta, 2-σ CE (pCi/L as SR/YT-90)	USGS well number
--	--	1.4	0.8	4.2	1.0	3.7	0.9	3332-CH
--	--	46	6.1	51	6.0	47	5.5	3333
--	--	16	2.8	24	3.0	23	3.0	3334
--	--	--	--	--	--	--	--	3335
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--	--	--	--	--	--	--	--	
--	--	--	--	--	--	--	--	
--	--	<.4	--	1.9	.8	1.6	.6	3336
--	--	5.4	1.5	9.7	2.3	9.3	1.4	3337
--	--	46	6.4	31	6.0	27	3.0	3338
--	--	5.5	1.7	6.7	1.3	6.0	1.1	3339
3.7	1.4	--	--	4.7	.9	--	--	SP33
2.7	1.2	--	--	3.0	1.2	--	--	1684-LN
7.5	3.9	--	--	24	2.0	--	--	1685
4.0	1.2	--	--	9.7	1.1	--	--	1686
4.8	1.4	--	--	7.5	1.0	--	--	1687
20	4.0	--	--	73	3.0	--	--	1688
4.5	2.0	--	--	12	1.0	--	--	1689
2.1	1.3	--	--	9.0	1.2	--	--	1690
<1.0	--	--	--	1.5	.8	--	--	1691
3.7	1.5	--	--	6.5	1.1	--	--	1692

Table 22. Chemical analyses of radionuclides in ground water in the Chickies Quartzite and adjacent geologic units. Geologic unit codes are explained at the beginning of table 20. Counting or analytical error values for each sample give counting or analytical uncertainty at the 2σ or 95-percent-confidence level.--Continued

USGS well number	Geo-logic unit	Date	Radon-222, total (pCi/L)	Radium-226, dis-solved, radon method (pCi/L)	Radium-226, 2-σ CE (pCi/L)	Radium-228, dis-solved (pCi/L as Ra-228)	Radium-228, 2-σ CE (pCi/L)	Uranium, natural, dis-solved (μg/L as U)	Uranium, 2-σ AE (μg/L)
LN-1693	377CCKS	12-30-86	3,400	0.26	0.06	< 0.50	--	0.40	0.06
1694	377CCKS	12-30-86	500	1.6	.3	5.2	0.5	.34	.05
1695	377CCKS	12-30-86	2,000	2.3	.3	4.0	.5	.33	.05
1696	377CCKS	07-08-87	480	5.0	.5	16	1.0	.06	.01
1697	377CCKS	07-13-87	600	6.6	.7	100	10	.27	.04
1698	377CCKS	07-13-87	1,000	6.3	.6	33	1.0	.16	.02
1699	377CCKS	07-14-87	1,600	.49	.07	.68	.39	< .05	--
1700	377CCKS	07-15-87	1,400	.42	.01	1.2	.4	< .05	--
1701	377CCKS	07-15-87	5,300	.87	.09	.75	.04	< .05	--
1713	377CCKS	09-01-88	1,700	1.0	.2	2.0	.9	.02	.01
1714	377CCKS	08-25-88	4,800	2.2	.4	4.5	1.3	.06	.01
1715	377CCKS	08-27-88	3,100	1.0	.2	<1.0	--	.04	.01
1716	377CCKS	08-25-88	3,200	1.8	.3	1.2	.7	.02	.01
1717	377CCKS	08-03-88	6,500	19	3	30	6.0	.31	.05
1718	377ANTM	08-03-88	1,300	.15	.03	<1.0	--	.01	--
1719	377CCKS	08-03-88	8,000	4.5	.7	11	2.3	.07	.01
1720	377HRPR	08-03-88	1,500	.25	.05	<1.0	--	< .01	--
1721	377CCKS	08-04-88	1,000	9.5	1.6	79	14	--	--
1722	377CCKS	08-04-88	2,700	.10	.02	<1.0	--	.04	.01
1723	377CCKS	08-04-88	2,700	.20	.04	<1.0	--	.03	.01
1724	377CCKS	08-05-88	2,600	6.3	1.1	10	2.5	.06	.01
1725	377CCKS	08-05-88	12,700	41	7	106	20	.74	.11
1726	377CCKS	08-05-88	4,300	6.2	1.0	13	3.1	.11	.02
1727	377CCKS	08-08-88	3,300	.87	.15	1.0	.6	.02	.01
1728	377CCKS	08-08-88	2,000	1.0	.17	1.2	.7	.03	.01
1730	367CNSG	08-13-88	65	.02	.01	<1.0	--	.15	.02
1731	377CCKS	08-13-88	17,900	1.5	.3	2.5	1.0	.58	.09
1732	377CCKS	08-15-88	3,300	9.2	1.6	14	2.8	.13	.02
1733	377ANTM	08-15-88	2,300	.06	.02	<1.0	--	< .01	--
1734	377CCKS	08-25-88	3,900	1.4	.2	<1.0	--	.06	.01
1735	377CCKS	08-17-88	2,100	2.2	.4	1.8	1.4	.04	.01
1736	377CCKS	08-17-88	770	.61	.11	3.7	1.3	.02	.01

Table 22. Chemical analyses of radionuclides in ground water in the Chickies Quartzite and adjacent geologic units. Geologic unit codes are explained at the beginning of table 20. Counting or analytical error values for each sample give counting or analytical uncertainty at the 2σ or 95-percent-confidence level.--Continued

Gross alpha, dis-solved (pCi/L as U-Nat)	Gross alpha, $2\text{-}\sigma$ CE (pCi/L as U-Nat)	Gross alpha, dis-solved (μg/L as U-Nat)	Gross alpha, $2\text{-}\sigma$ CE (μg/L as U-Nat)	Gross beta, dis-solved (pCi/L as Cs-137)	Gross beta, $2\text{-}\sigma$ CE (pCi/L as CS-137)	Gross beta, dis-solved (pCi/L as Sr/Yt-90)	Gross beta, $2\text{-}\sigma$ CE (pCi/L as SR/YT-90)	USGS well number
<0.8	--	--	--	3.4	0.7	--	--	1693-LN
7.7	1.8	--	--	14	1.0	--	--	1694
7.6	1.7	--	--	9.1	1.1	--	--	1695
11	2.0	--	--	33	2.0	--	--	1696
150	3.0	--	--	210	10	--	--	1697
36	5.0	--	--	79	3.0	--	--	1698
1.1	.6	--	--	2.1	.6	--	--	1699
1.7	.8	--	--	2.0	.6	--	--	1700
1.2	.9	--	--	5.6	.9	--	--	1701
6.1	1.6	--	--	3.4	1.0	3.2	0.8	1713
16	3.0	--	--	8.7	2.1	7.9	1.5	1714
6.3	1.6	--	--	4.6	1.0	4.4	1.0	1715
6.6	1.6	--	--	5.2	1.1	5.2	1.0	1716
110	13	--	--	56	11	43	10	1717
1.8	1.3	--	--	5.4	1.4	4.3	1.0	1718
31	4.0	--	--	23	4.6	16.	2.6	1719
1.1	.9	--	--	3.5	1.1	2.9	.8	1720
150	16	--	--	140	25	110	11	1721
1.2	.8	--	--	4.5	1.3	4.0	1.0	1722
1.6	.9	--	--	3.5	1.1	3.1	.8	1723
33	5.0	--	--	18	4.0	16	3.0	1724
250	25	--	--	160	31	130	13	1725
35	4.6	--	--	23	4.6	22	2.6	1726
6.5	1.6	--	--	4.6	1.2	4.3	.9	1727
--	--	8.3	1.9	5.7	1.5	5.3	1.2	1728
--	--	< .4	--	2.3	.9	1.8	.7	1730
--	--	20	3.5	18	2.6	16	2.2	1731
--	--	78	9.0	50	6.0	46	5.0	1732
--	--	.8	.6	3.1	1.0	2.9	.8	1733
--	--	5.9	1.7	6.6	1.7	5.5	1.1	1734
--	--	12	2.4	7.9	1.4	7.3	1.3	1735
--	--	7.3	1.8	4.7	1.3	4.6	1.0	1736

Table 22. Chemical analyses of radionuclides in ground water in the Chickies Quartzite and adjacent geologic units. Geologic unit codes are explained at the beginning of table 20. Counting or analytical error values for each sample give counting or analytical uncertainty at the 2σ or 95-percent-confidence level.--Continued

USGS well number	Geo- logic unit	Date	Radon-222, total (pCi/L)	Radium-226, dis- solved, radon method (pCi/L)	Radium-226, 2-σ CE (pCi/L)	Radium-228, dis- solved (pCi/L as Ra-228)	Radium-228, 2-σ CE (pCi/L)	Uranium, natural, dis- solved (μg/L as U)	Uranium, 2-σ AE (μg/L)
LN-1737	377CCKS	08-17-88	2,800	2.2	0.4	2.7	1.3	0.06	0.01
1738	377CCKS	09-02-88	2,000	3.9	.7	14	2.8	< .01	--
1739	377CCKS	09-01-88	770	5.1	1.0	29	5.7	.08	.01
1740	377CCKS	09-02-88	1,300	.32	.06	<1.0	--	.01	--
1741	377CCKS	09-02-88	1,500	.22	.04	<1.0	--	.11	.01
1742	000GBBR	09-02-88	8,000	.09	.02	<1.0	--	< .01	--
MG- 399	377CCKS	07-01-87	2,600	.52	.09	< .60	--	.09	.01
1000	377CCKS	12-19-86	840	< .20	--	<1.0	--	.14	.02
1001	377CCKS	12-29-86	160	< .20	--	.83	.45	.18	.03
1002	377LDGR	01-08-87	370	< .10	--	< .50	--	.36	.05
1003	377LDGR	01-09-87	86	<1.0	--	< .7	--	.42	.06
1004	337CCKS	01-13-87	2,700	.40	.07	1.1	.4	.38	.06
YO- 88	377CCKS	07-21-87	6,800	.40	.09	< .60	--	.06	.01
351	377CCKS	08-10-88	1,400	.17	.03	<1.0	--	.01	.01
371	377CCKS	12-23-86	1,200	.34	.07	< .60	--	.36	.05
650	377CCKS	08-11-88	4,000	.37	.06	<1.0	--	.01	.01
792	377CCKS	12-22-86	2,900	.85	.36	1.5	.4	.18	.03
1148	377CCKS	12-09-86	20,300	5.4	.6	9.0	.9	.86	.13
	377CCKS	07-22-87	28,500	2.1	.1	4.0	.7	.79	.12
1149	377CCKS	12-09-86	790	.62	.42	.70	--	.75	.11
1150	377CCKS	12-09-86	1,400	< .20	--	<1.0	--	.23	.03
1151	377CCKS	12-10-86	1,000	.58	.09	<1.0	--	.19	.03
1152	377CCKS	12-10-86	180	< .20	--	<1.0	--	.44	.07
1153	377CCKS	12-10-86	1,200	1.0	.4	< .70	--	.75	.11
1154	377CCKS	12-11-86	2,600	1.0	.4	< .90	--	.38	.06
1155	377CCKS	12-11-86	2,200	< .20	--	< .90	--	.86	.13
1156	377CCKS	12-11-86	3,000	< .20	--	5.6	1.8	.75	.11
1157	377CCKS	12-22-86	2,100	4.7	.2	6.4	1.9	.37	.06
1158	377CCKS	12-23-86	1,400	< .20	--	< .90	--	< .24	.04
1159	377CCKS	12-23-86	3,500	< .20	--	<1.0	--	.26	.04
1160	377HRPR	12-23-86	2,600	< .10	--	< .60	--	.18	.03
1161	377CCKS	12-24-86	500	< .10	--	<1.0	--	.19	.03

Table 22. Chemical analyses of radionuclides in ground water in the Chickies Quartzite and adjacent geologic units. Geologic unit codes are explained at the beginning of table 20. Counting or analytical error values for each sample give counting or analytical uncertainty at the 2σ or 95-percent-confidence level.--Continued

Gross alpha, dissolved (pCi/L as U-Nat)	Gross alpha, 2-σ CE (pCi/L as U-Nat)	Gross alpha, dissolved (µg/L as U-Nat)	Gross alpha, 2-σ CE (µg/L as U-Nat)	Gross beta, dissolved (pCi/L as Cs-137)	Gross beta, 2-σ CE (pCi/L as CS-137)	Gross beta, dissolved (pCi/L as Sr/Yt-90)	Gross beta, 2-σ CE (pCi/L as SR/YT-90)	USGS well number
--	--	15	2.6	5.8	1.5	5.5	1.1	1737-LN
--	--	26	3.8	20	4.5	19.	2.4	1738
--	--	54	6.6	42	8.0	39.	4.2	1739
--	--	2.0	--	1.9	--	1.8	--	1740
--	--	.9	.7	2.0	.07	1.9	.06	1741
--	--	2.3	1.0	4.2	1.0	3.8	.9	1742
2.2	1.8	--	--	5.1	1.1	--	--	399-MG
<2.0	--	--	--	2.5	.9	--	--	1000
<1.0	--	--	--	2.4	.9	--	--	1001
<3.0	--	--	--	1.3	.8	--	--	1002
<4.0	--	--	--	10	2.0	--	--	1003
<2.0	--	--	--	11	1.0	--	--	1004
<1.0	--	--	--	1.9	.7	--	--	88-YO
--	--	1.2	.8	2.7	.8	2.5	.7	351
< .9	--	--	--	2.1	.7	--	--	371
--	--	3.0	1.1	2.9	1.0	2.5	.7	650
2.4	.9	--	--	3.1	.7	--	--	792
9.6	2.0	--	--	21	2.0	--	--	1148
7.0	1.6	--	--	15	1.0	--	--	
1.4	1.2	--	--	4.3	1.0	--	--	1149
<1.0	--	--	--	1.2	.7	--	--	1150
<2.0	--	--	--	1.6	1.0	--	--	1151
<2.0	--	--	--	<1.0	--	--	--	1152
<2.0	--	--	--	3.7	1.0	--	--	1153
1.1	.9	--	--	2.1	.8	--	--	1154
< .9	--	--	--	1.3	.7	--	--	1155
< .8	--	--	--	2.9	.8	--	--	1156
17	3.0	--	--	23	2.0	--	--	1157
<1.0	--	--	--	4.6	1.0	--	--	1158
<2.0	--	--	--	2.3	.9	--	--	1159
<1.0	--	--	--	1.6	.7	--	--	1160
< .1	--	--	--	3.2	.9	--	--	1161

Table 22. Chemical analyses of radionuclides in ground water in the Chickies Quartzite and adjacent geologic units. Geologic unit codes are explained at the beginning of table 20. Counting or analytical error values for each sample give counting or analytical uncertainty at the 2σ or 95-percent-confidence level.--Continued

USGS well number	Geologic unit	Date	Radon-222, total (pCi/L)	Radium-226, dissolved, radon method (pCi/L)	Radium-226, 2-σ CE (pCi/L)	Radium-228, dissolved (pCi/L as Ra-228)	Radium-228, 2-σ CE (pCi/L)	Uranium, natural, dissolved (μg/L as U)	Uranium, 2-σ AE (μg/L)
YO-1162	377HRPR	07-21-87	2,400	0.45	0.09	< 0.60	--	< 0.05	--
1163	377CCKS	07-21-87	1,100	.73	.09	.66	0.04	< .05	--
1164	377CCKS	07-22-87	6,800	< .10	--	1.1	.4	< .05	--
1165	377CCKS	07-22-87	11,500	.97	.01	8.7	.9	.09	0.01
1166	377CCKS	07-23-87	5,000	3.6	.1	8.5	1.0	.20	.03
1167	377HRPR	07-23-87	3,500	< .20	--	< .50	--	< .05	--
1168	377VNTG	07-23-87	460	< .20	--	< .50	--	< .05	--
1172	377CCKS	08-11-88	12,700	1.2	.2	2.1	1.0	.06	.01
1175	377CCKS	08-08-88	1,600	.44	.08	<1.0	--	.01	.01
1176	377CCKS	08-09-88	2,400	.31	.05	<1.0	--	.01	.01
1177	377CCKS	08-09-88	3,100	.10	.02	<1.0	--	.01	.01
1178	377CCKS	08-09-88	1,400	.21	.04	<1.0	--	.01	.01
1179	377CCKS	08-09-88	6,000	12	2.0	30	6.0	.67	.10
1180	377CCKS	08-10-88	11,100	.18	.03	<1.0	--	.09	.01
1181	377CCKS	08-10-88	1,400	.19	.03	<1.0	--	.02	.01
1182	377CCKS	08-10-88	1,200	.07	.02	<1.0	--	.01	.01
1183	377CCKS	08-11-88	3,000	1.3	.2	1.2	.9	.01	.01
1184	377CCKS	09-07-88	18,600	12	2.0	11	2.0	.50	.10
1185	377CCKS	09-07-88	2,000	1.6	.3	2.9	.8	.03	.01
1186	377CCKS	09-07-88	17,400	4.0	.7	6.4	1.6	.43	.06

Table 22. Chemical analyses of radionuclides in ground water in the Chickies Quartzite and adjacent geologic units. Geologic unit codes are explained at the beginning of table 20. Counting or analytical error values for each sample give counting or analytical uncertainty at the 2σ or 95-percent-confidence level.--Continued

Gross alpha, dissolved (pCi/L as U-Nat)	Gross alpha, 2-σ CE (pCi/L as U-Nat)	Gross alpha, dissolved (μg/L as U-Nat)	Gross alpha, 2-σ CE (μg/L as U-Nat)	Gross beta, dissolved (pCi/L as Cs-137)	Gross beta, 2-σ CE (pCi/L as CS-137)	Gross beta, dissolved (pCi/L as Sr/Yt-90)	Gross beta, 2-σ CE (pCi/L as SR/YT-90)	USGS well number
<1.0	--	--	--	2.2	0.7		--	1162-YO
1.2	0.8	--	--	2.5	.7	--	--	1163
1.3	1.0	--	--	3.2	.8	--	--	1164
5.7	1.9	--	--	11	1.0	--	--	1165
5.4	2.1	--	--	18	2.0	--	--	1166
<1.0	--	--	--	5.5	1.0	--	--	1167
2.0	--	--	--	1.6	.9	--	--	1168
--	--	7.6	1.7	8.9	2.0	8.4	1.3	1172
--	--	1.8	.8	2.0	.8	2.0	.6	1175
--	--	2.5	1.0	4.6	1.0	4.2	.9	1176
--	--	1.0	.7	1.9	.8	1.8	.6	1177
--	--	1.4	.7	2.2	.7	2.1	.7	1178
--	--	120	13	79	9.0	70	8.0	1179
--	--	3.9	1.2	6.5	1.2	6.2	1.2	1180
--	--	1.4	.8	1.5	.7	1.4	.6	1181
--	--	< .4	--	1.1	.6	1.1	.5	1182
--	--	6.8	2.1	3.7	1.1	3.1	.8	1183
--	--	53	7.0	30	6.0	28	4.0	1184
--	--	8.4	1.8	7.1	1.7	6.7	1.2	1185
--	--	22	3.0	15	3.0	14	2.0	1186

APPENDIX--Caliper and natural gamma logs for wells in the Chickies Quartzite, southeastern Pennsylvania

GEOPHYSICAL LOGS

In the Barren Hills, Chester County, Pa.

Chickies Quartzite: Light- to dark-colored sandstone and quartzite; phyllitic quartzite; "Hellam conglomerate"

CH- 3122
3131
3133
3160
3166
3188
3189
3213
3219
3305
3315

On Welsh Mountain and Gap Hill, Lancaster County, Pa.

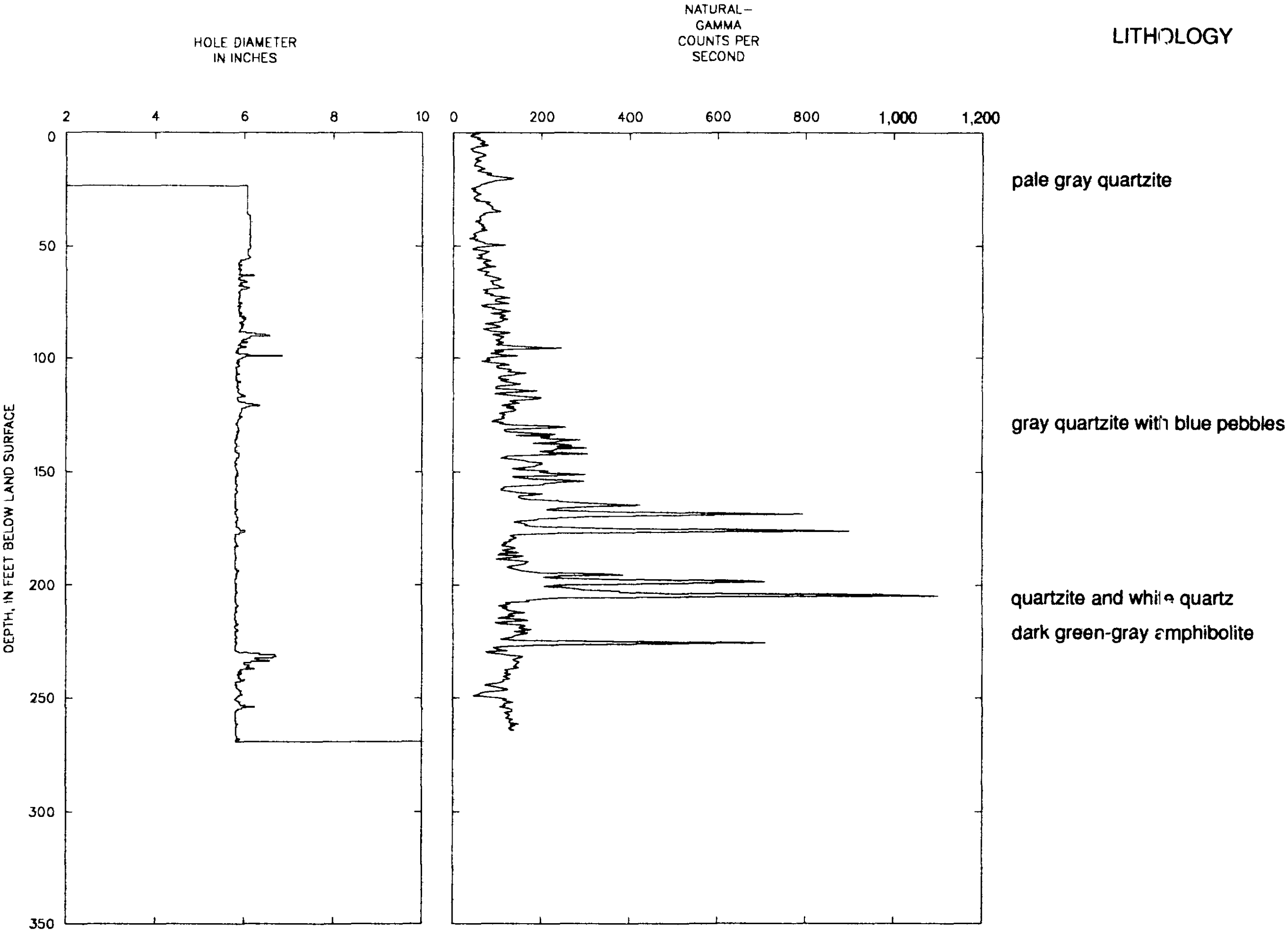
Chickies Quartzite: White to tan quartzite and sandstone; gray quartzite

LN- 1702
1703
1713
1715
1716

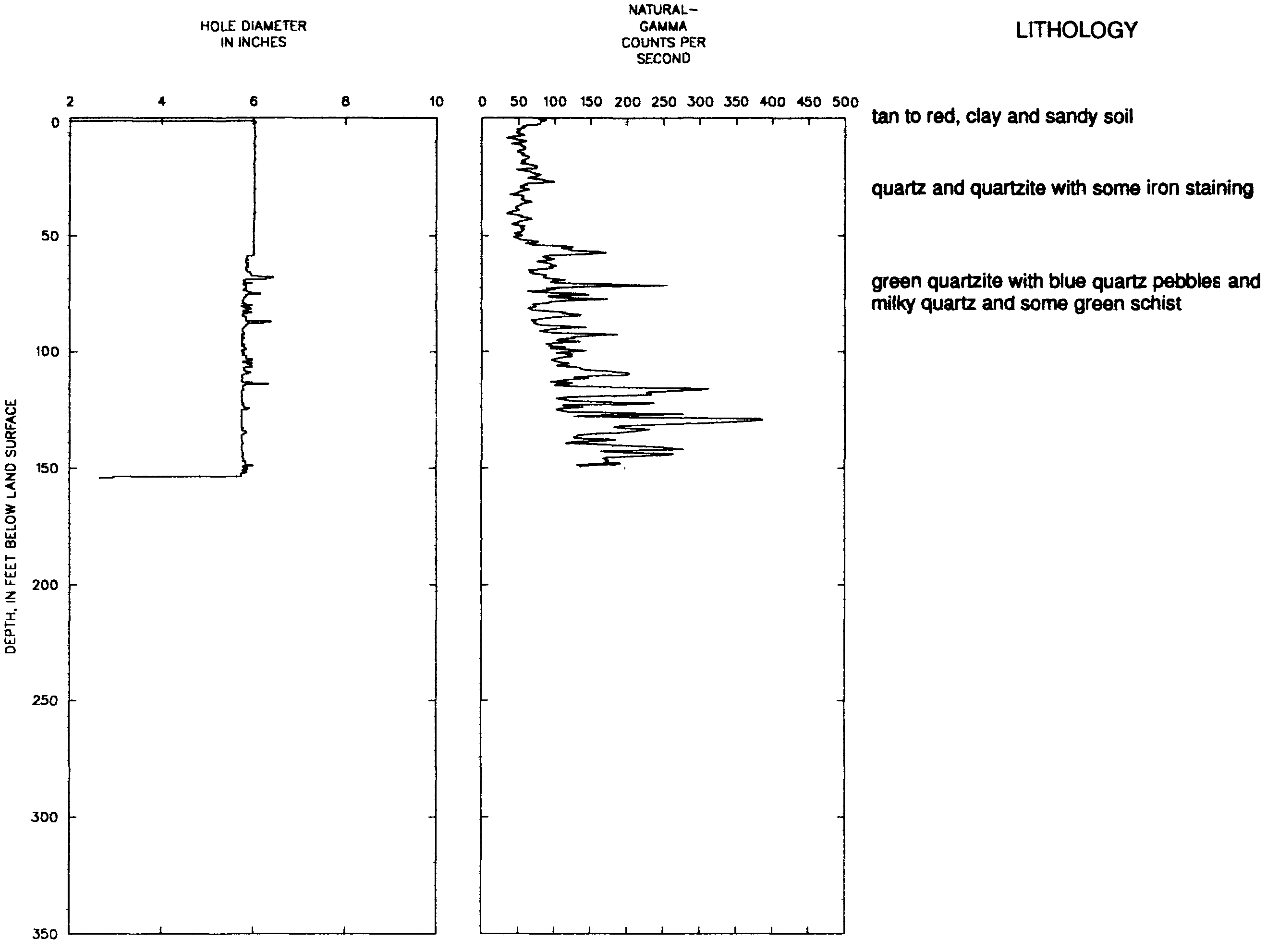
In the Hellam Hills, York County, Pa.

Chickies Quartzite: "Hellam conglomerate"

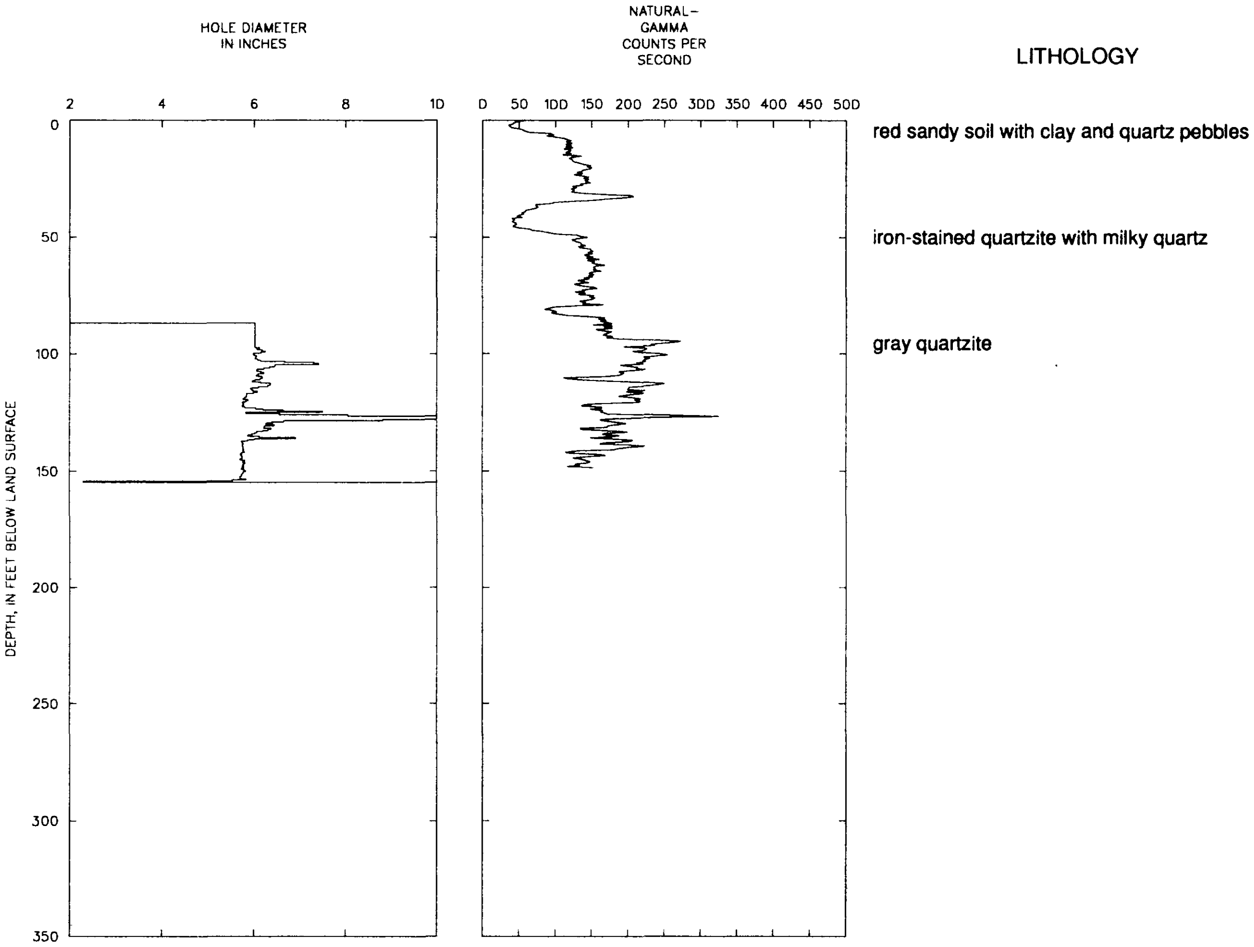
YO- 1172



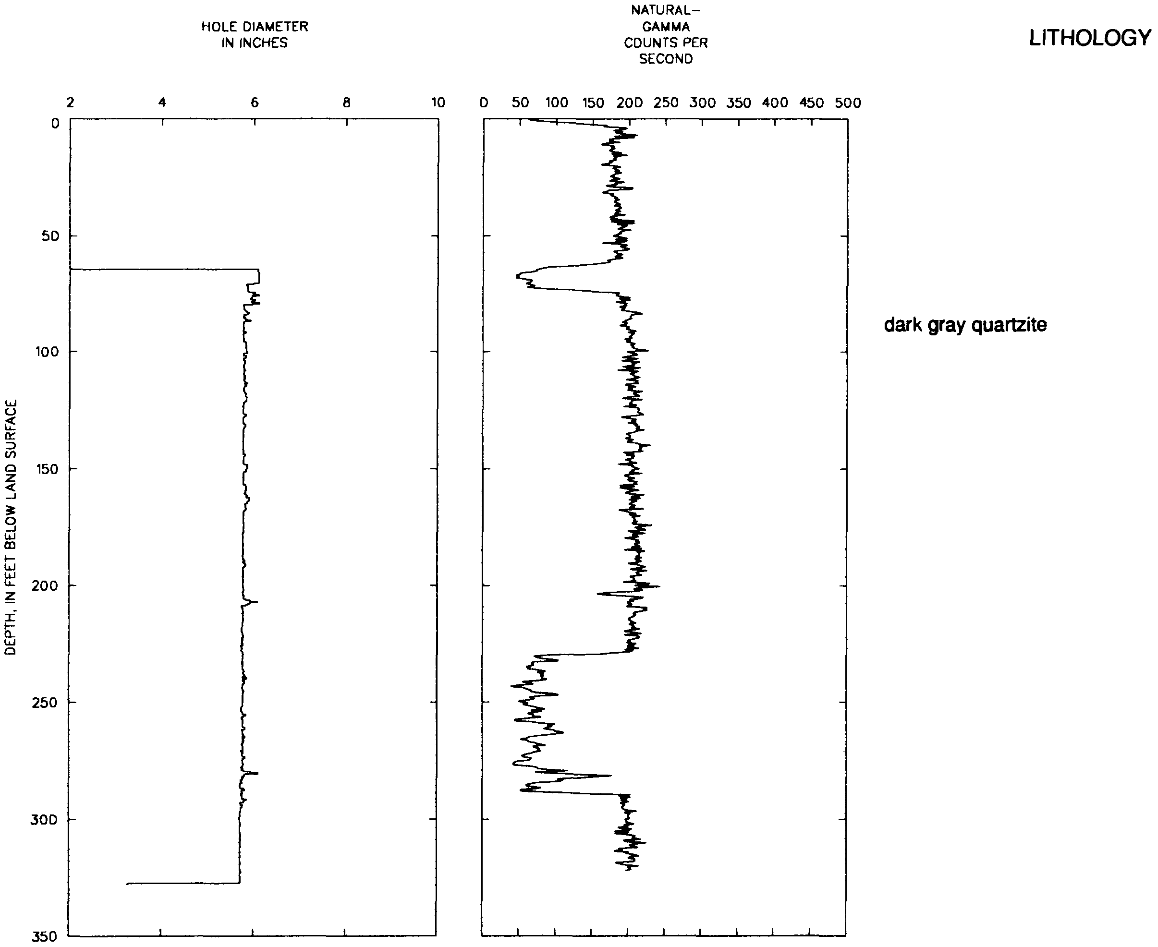
Caliper and natural gamma logs for well CH-3122 in the Chickies Quartzite, southeastern Pennsylvania.



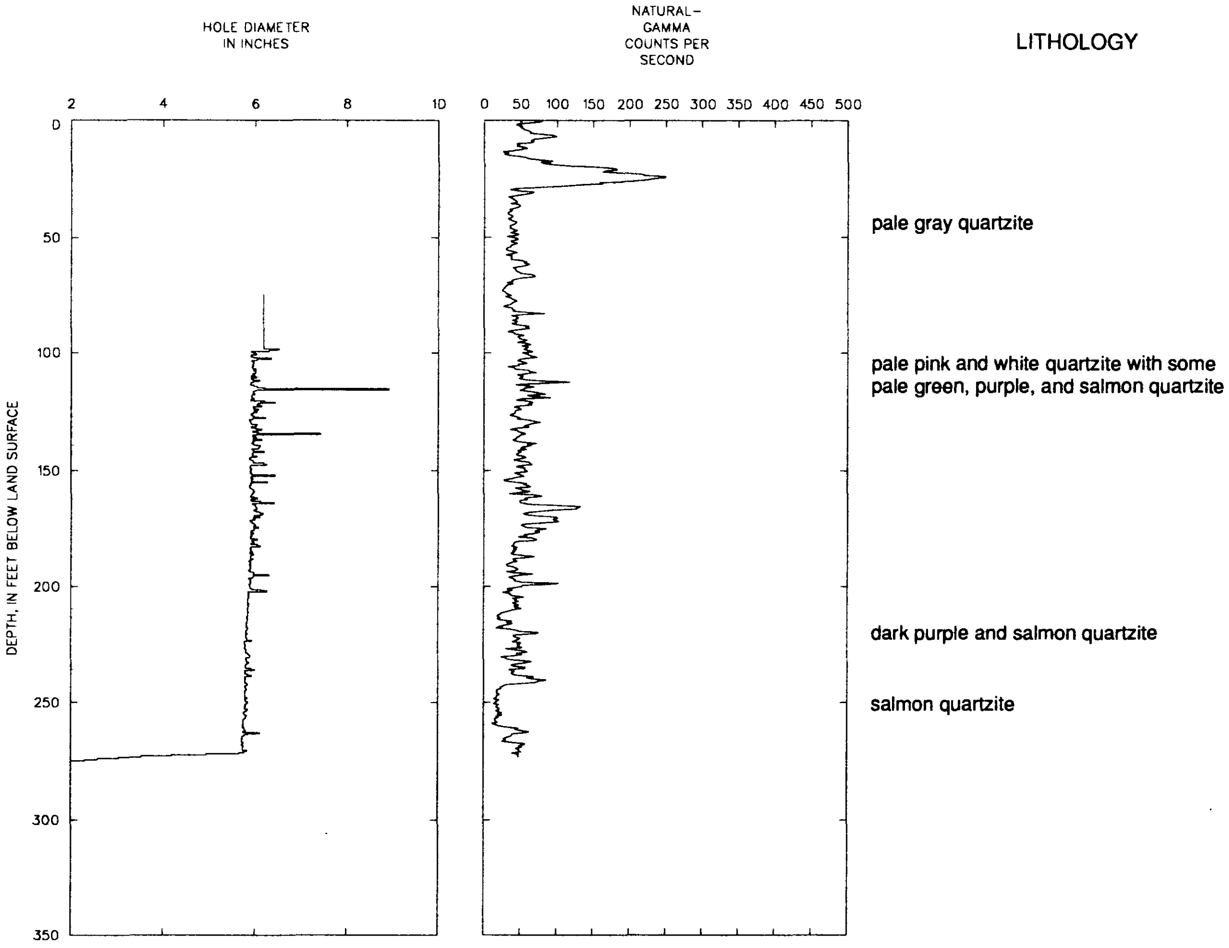
Caliper and natural gamma logs for well CH-3131 in the Chickies Quartzite, southeastern Pennsylvania.



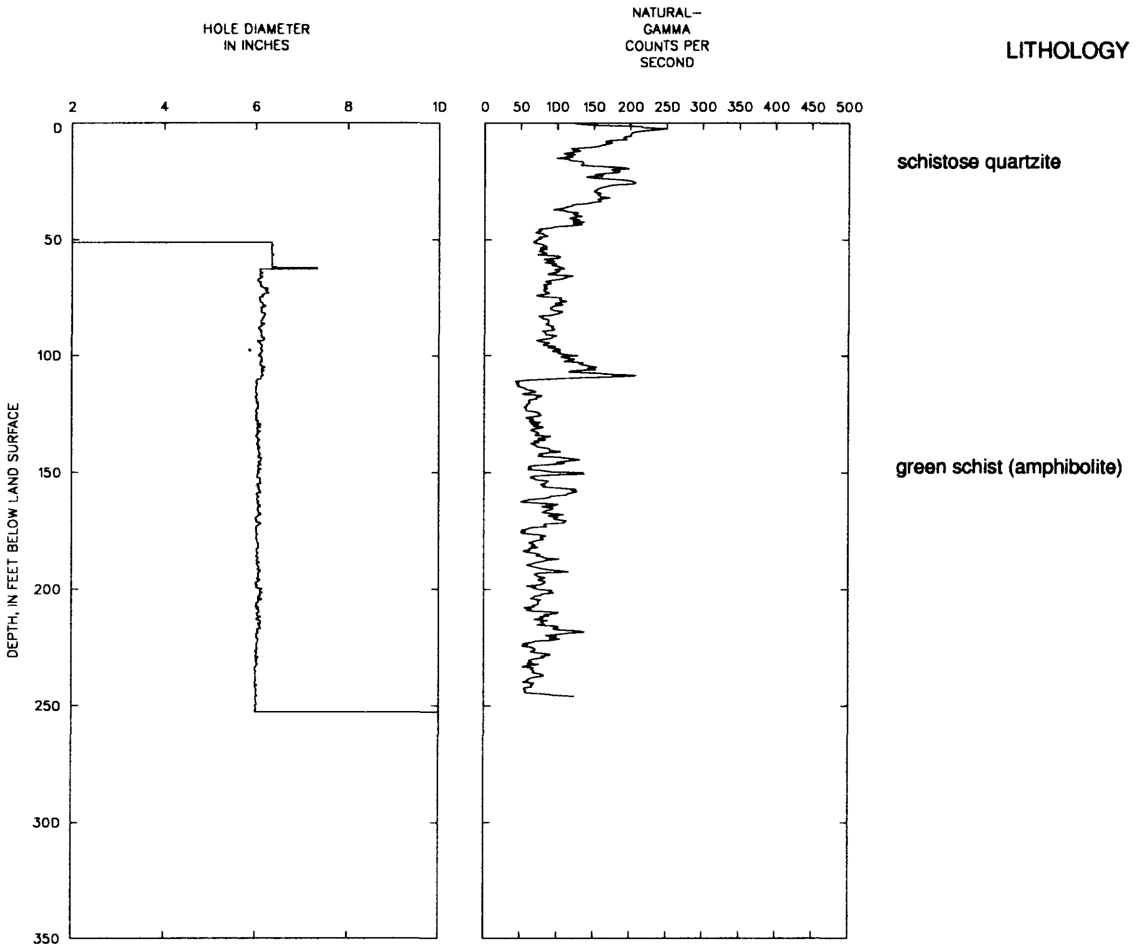
Caliper and natural gamma logs for well CH-3133 in the Chickies Quartzite, southeastern Pennsylvania.



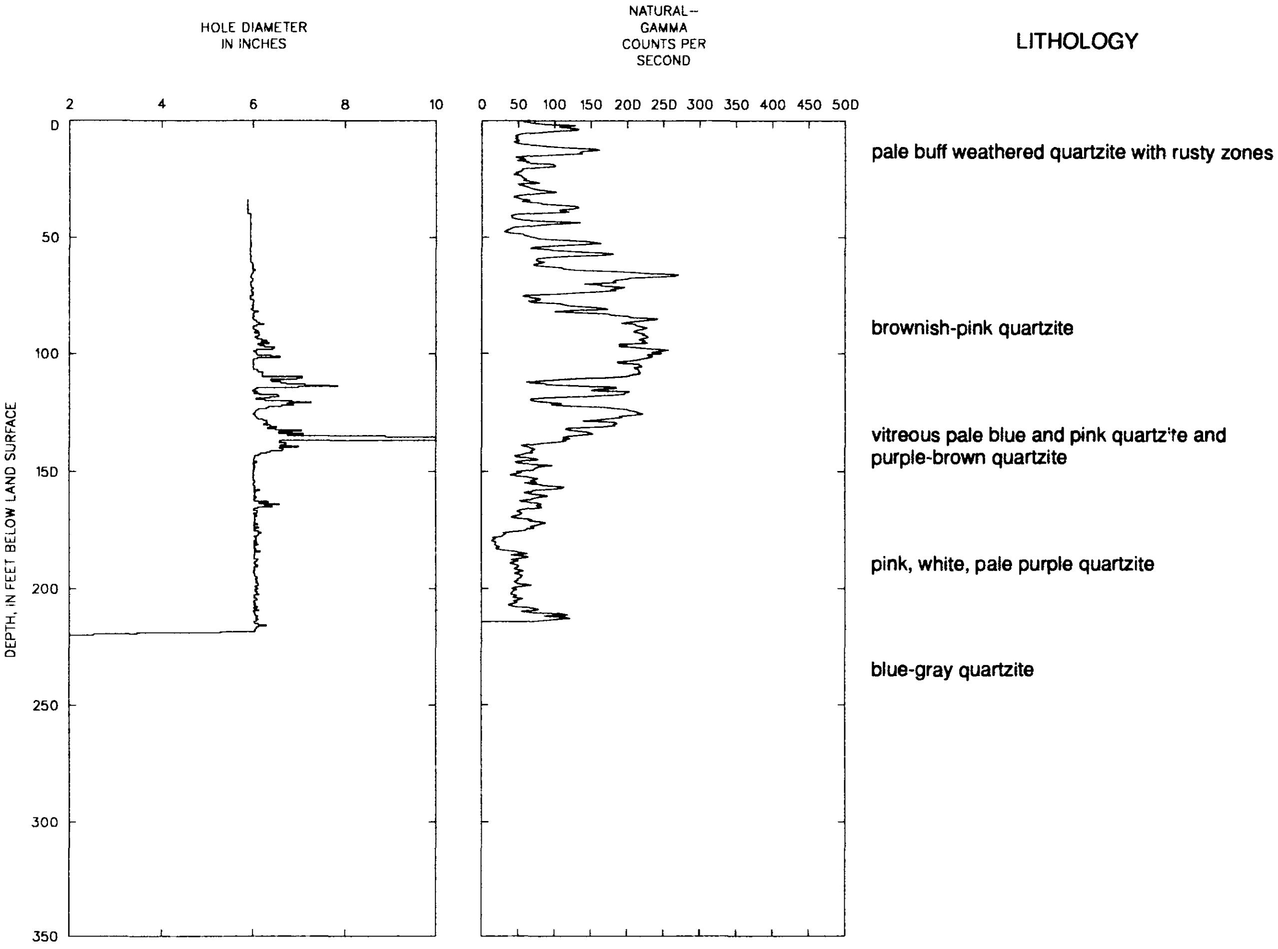
Caliper and natural gamma logs for well CH-3160 in the Chickies Quartzite, southeastern Pennsylvania.



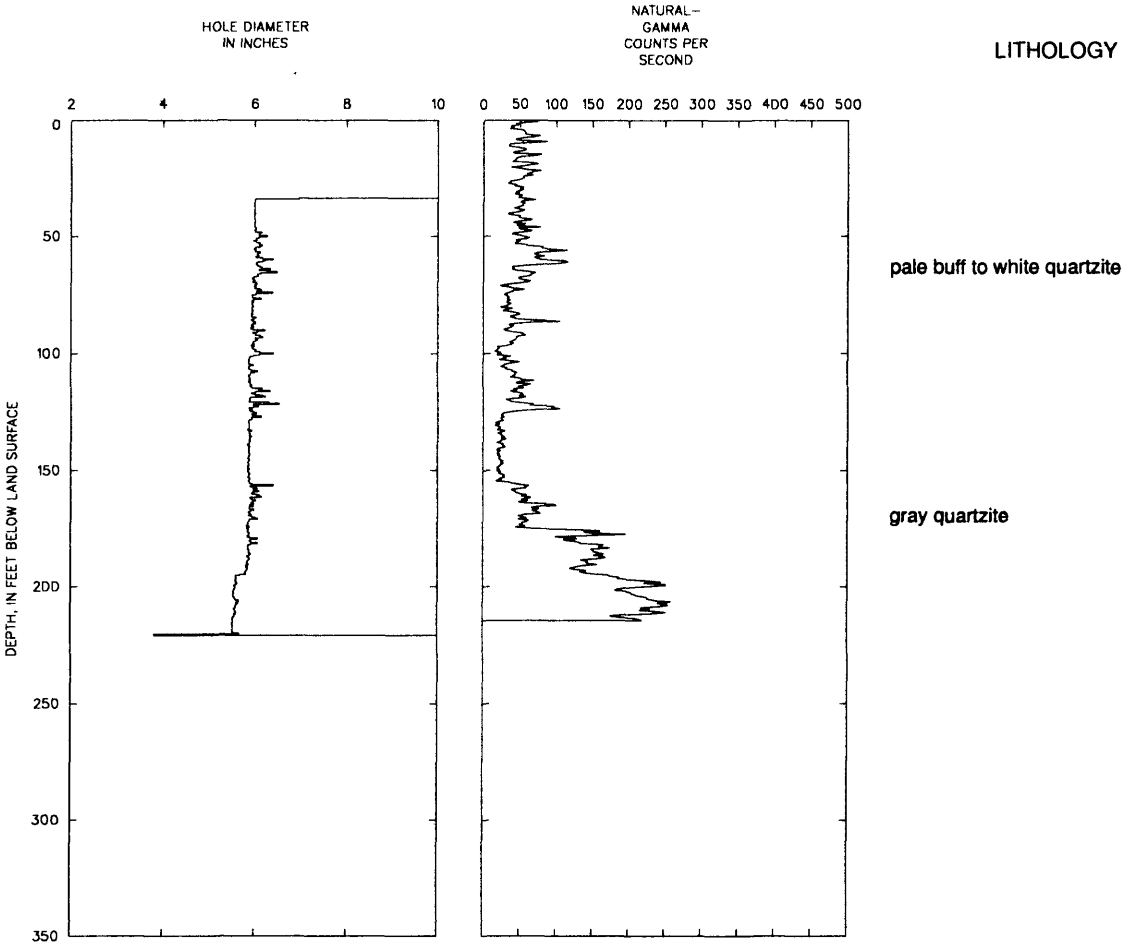
Caliper and natural gamma logs for well CH-3166 in the Chickies Quartzite, southeastern Pennsylvania.



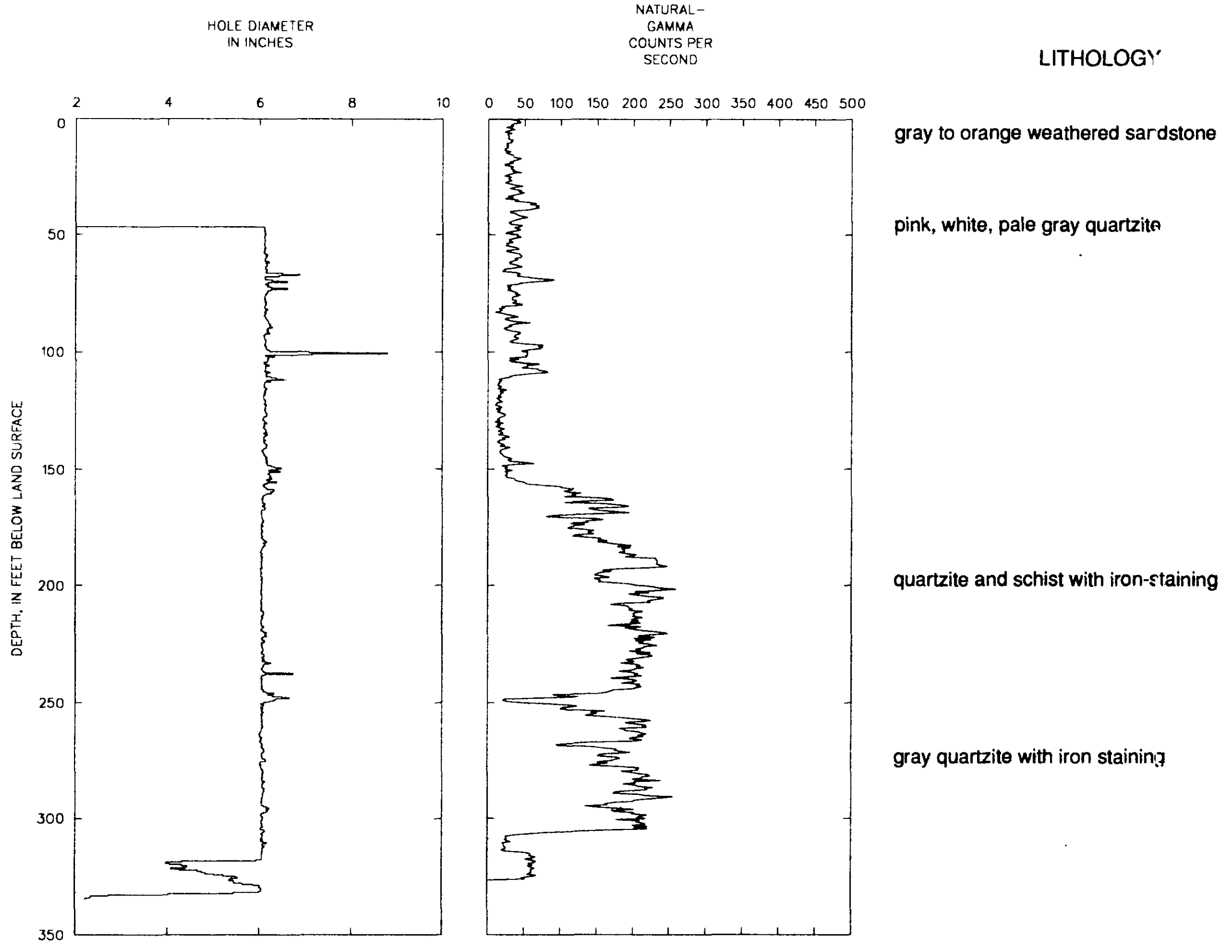
Caliper and natural gamma logs for well CH-3188 in the Chickies Quartzite, southeastern Pennsylvania.



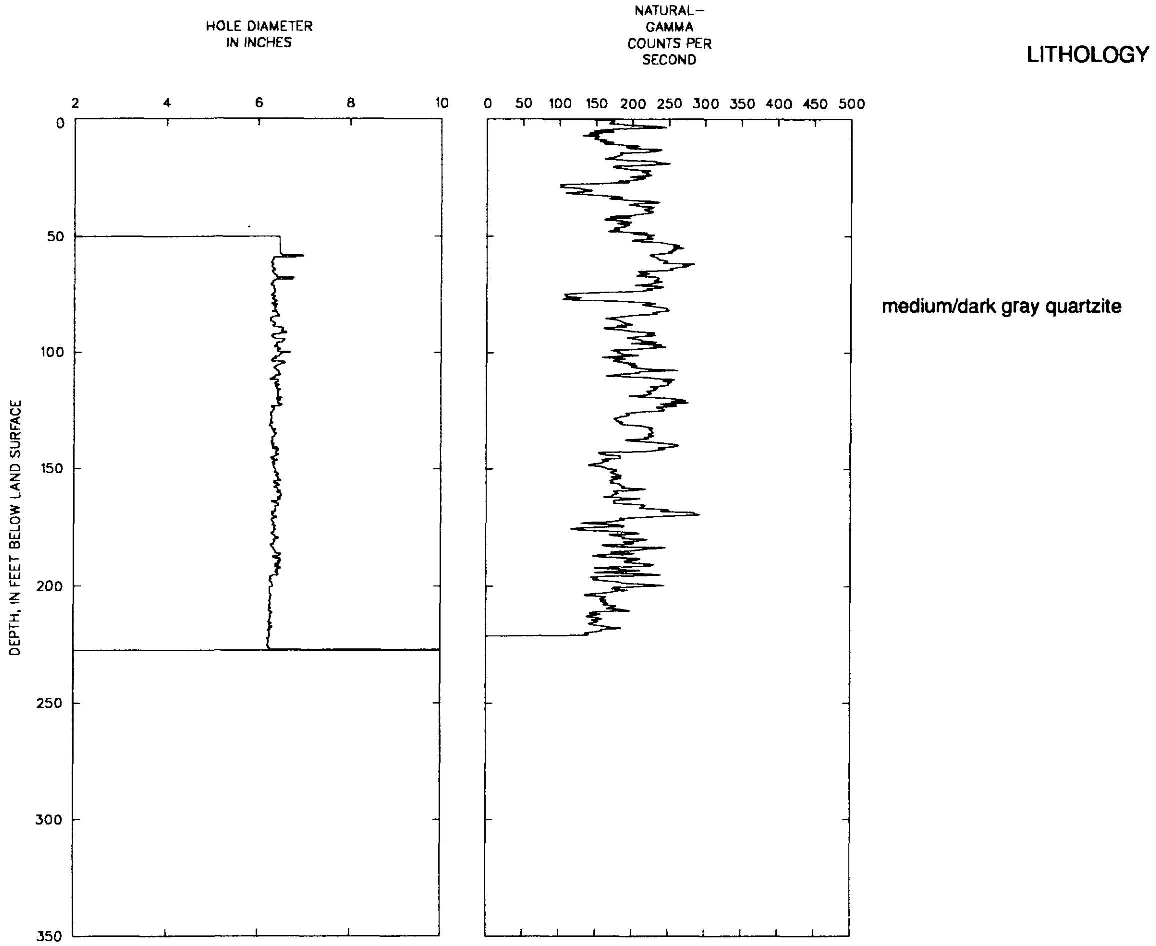
Caliper and natural gamma logs for well CH-3189 in the Chickies Quartzite, southeastern Pennsylvania.



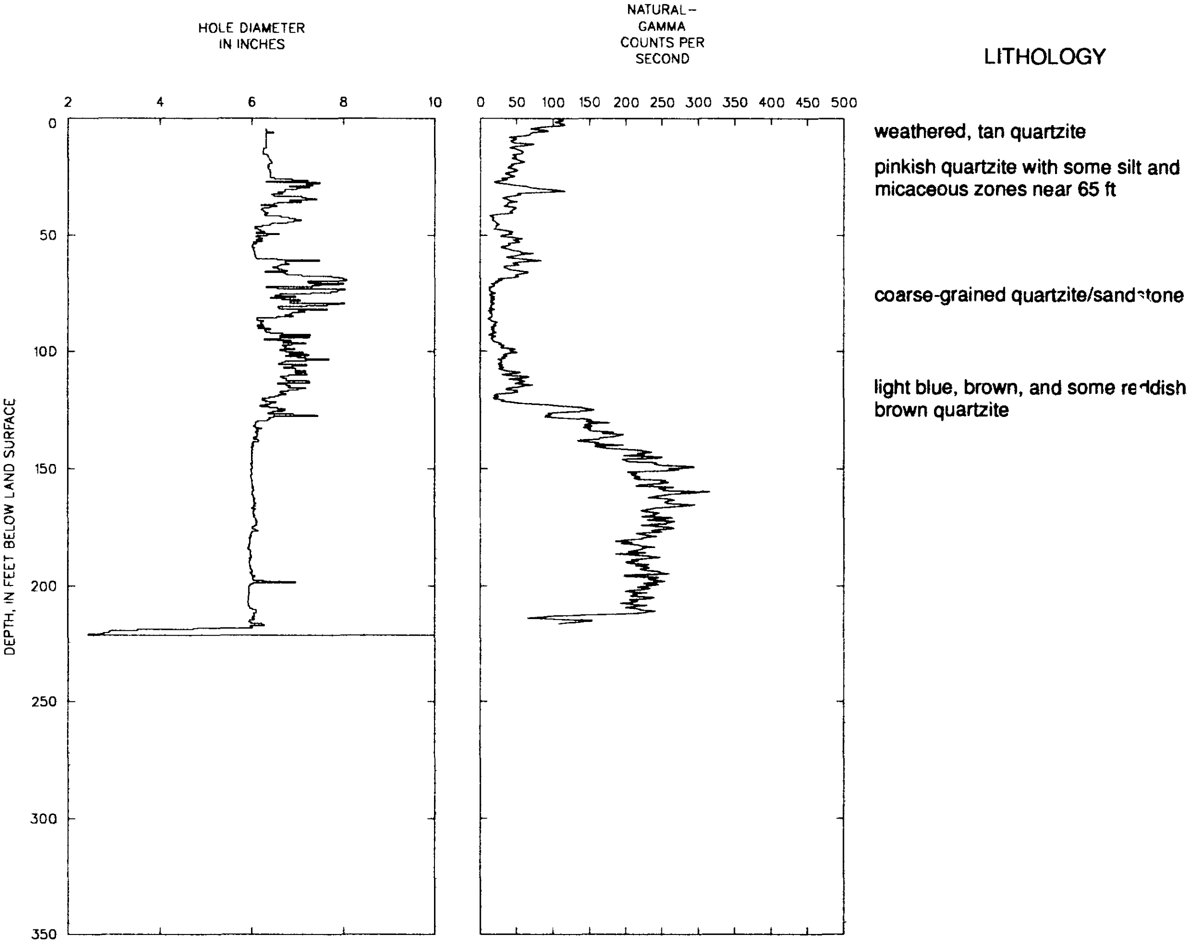
Caliper and natural gamma logs for well CH-3213 in the Chickies Quartzite, southeastern Pennsylvania.



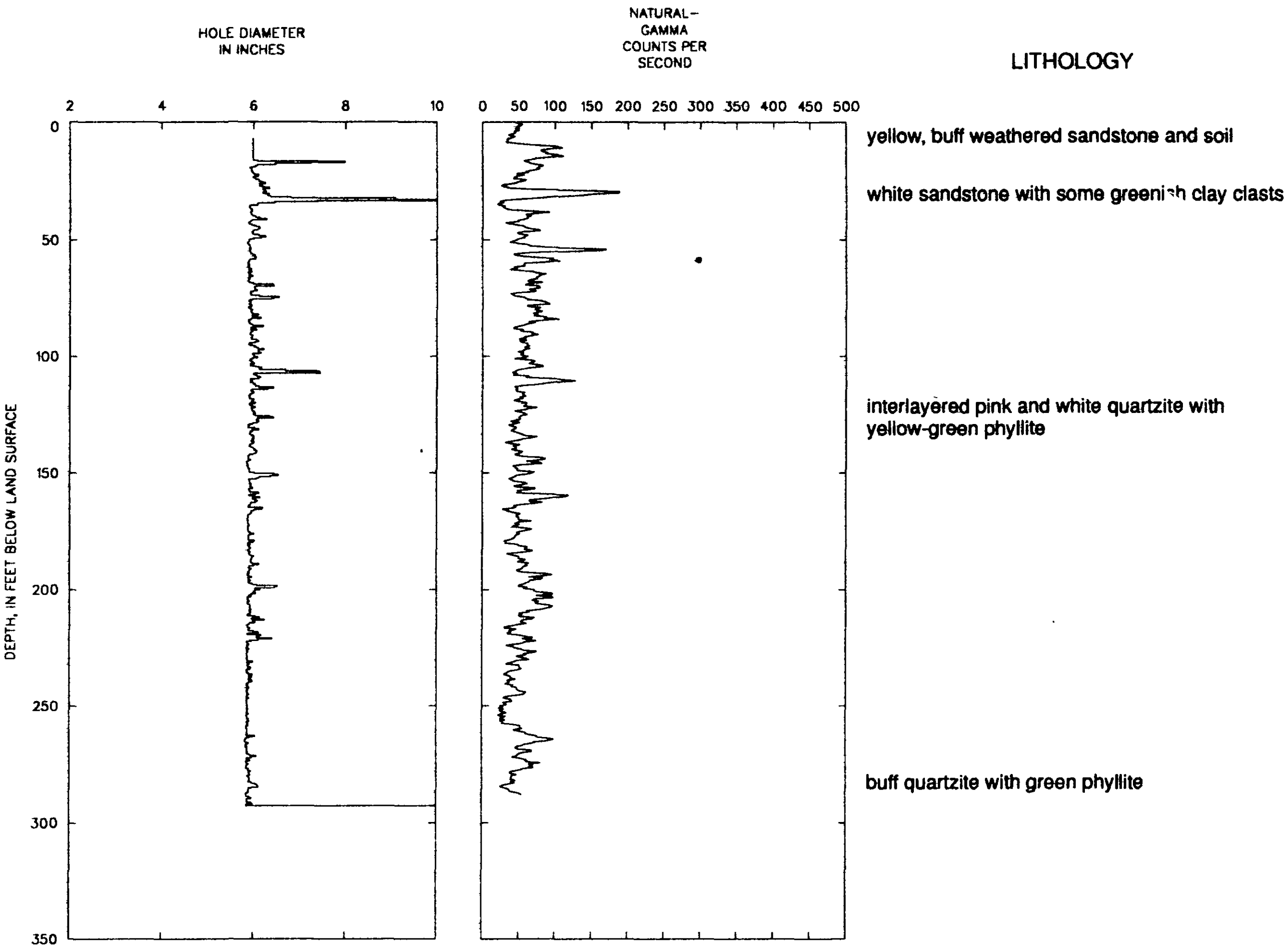
Caliper and natural gamma logs for well CH-3219 in the Chickies Quartzite, southeastern Pennsylvania.



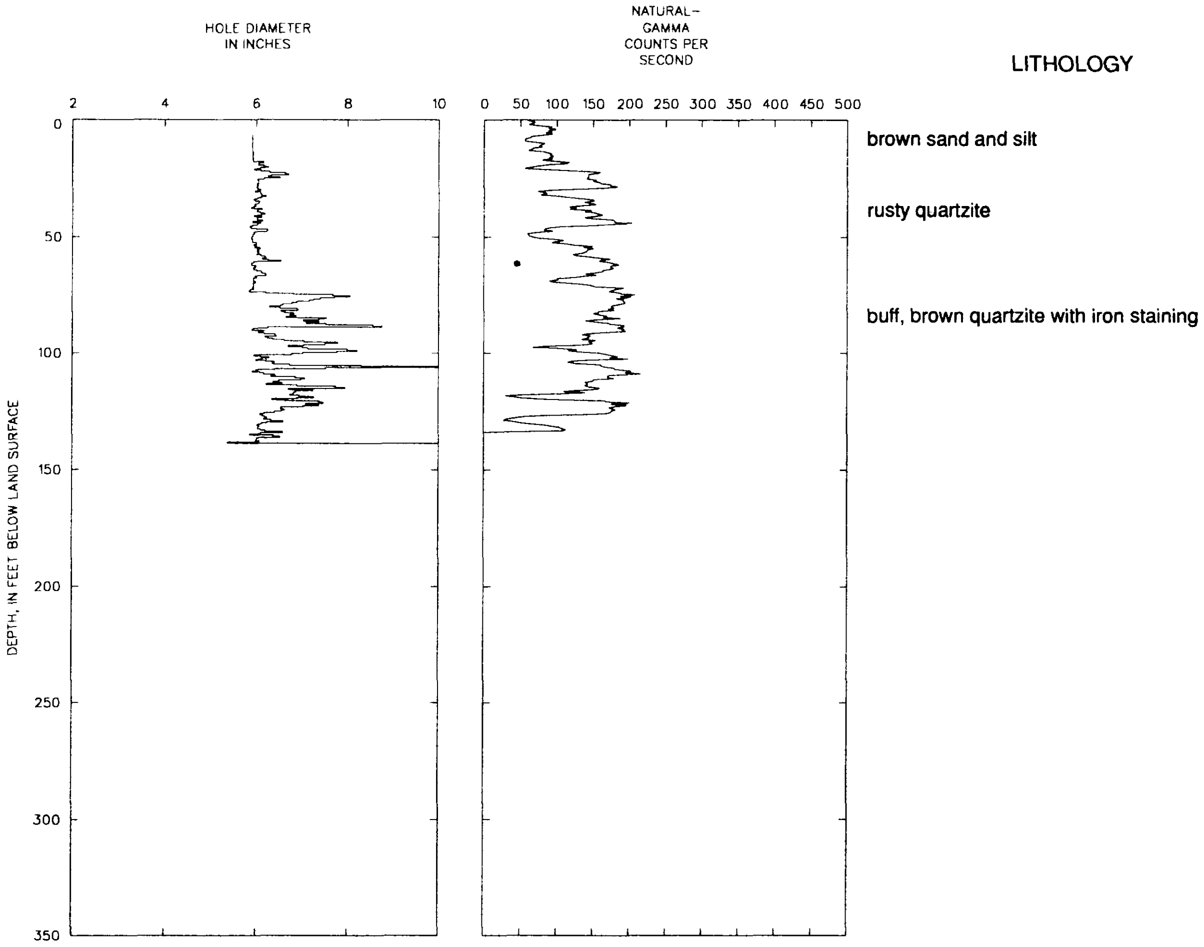
Caliper and natural gamma logs for well CH-3305 in the Chickies Quartzite, southeastern Pennsylvania.



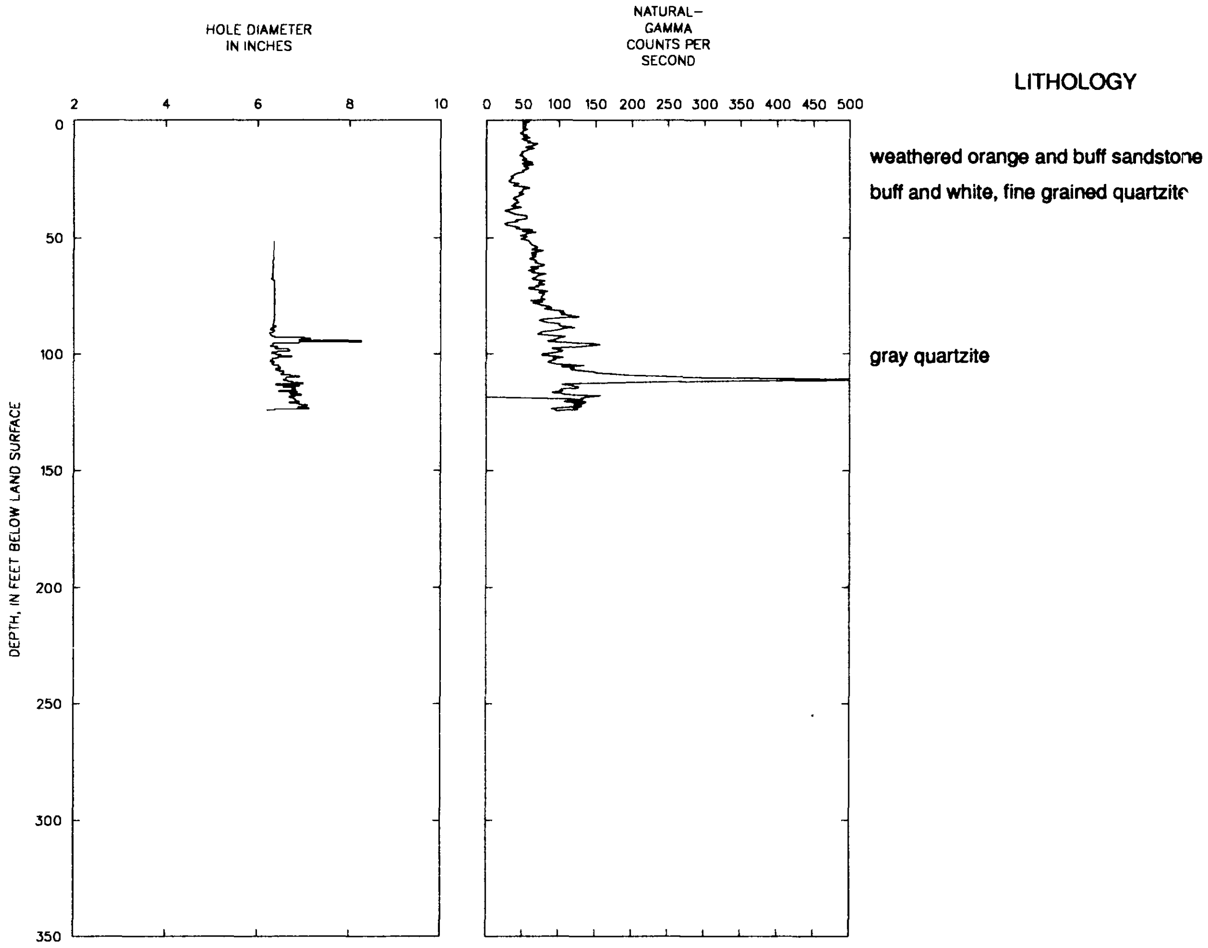
Caliper and natural gamma logs for well CH-3315 in the Chickies Quartzite, southeastern Pennsylvania.



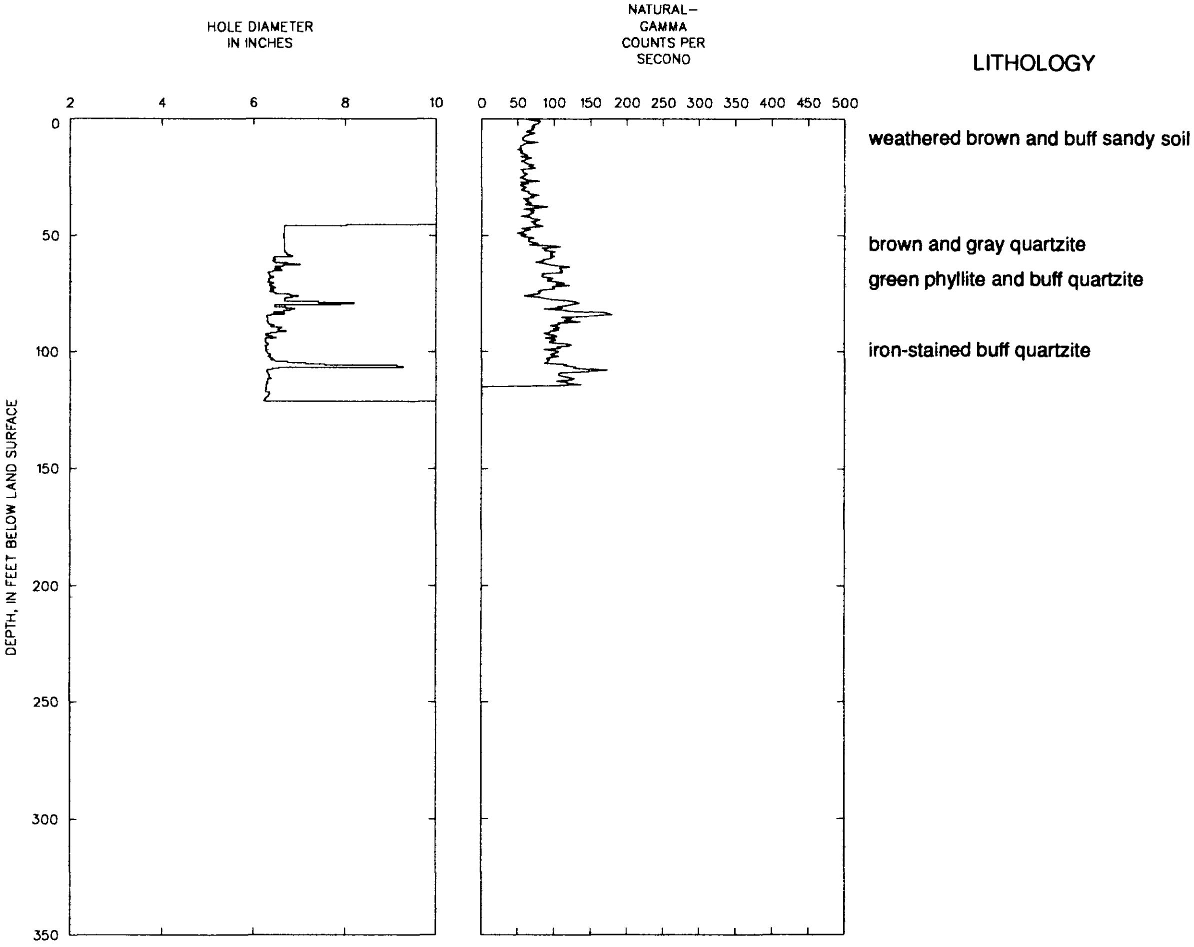
Caliper and natural gamma logs for well LN-1702 in the Chickies Quartzite, southeastern Pennsylvania.



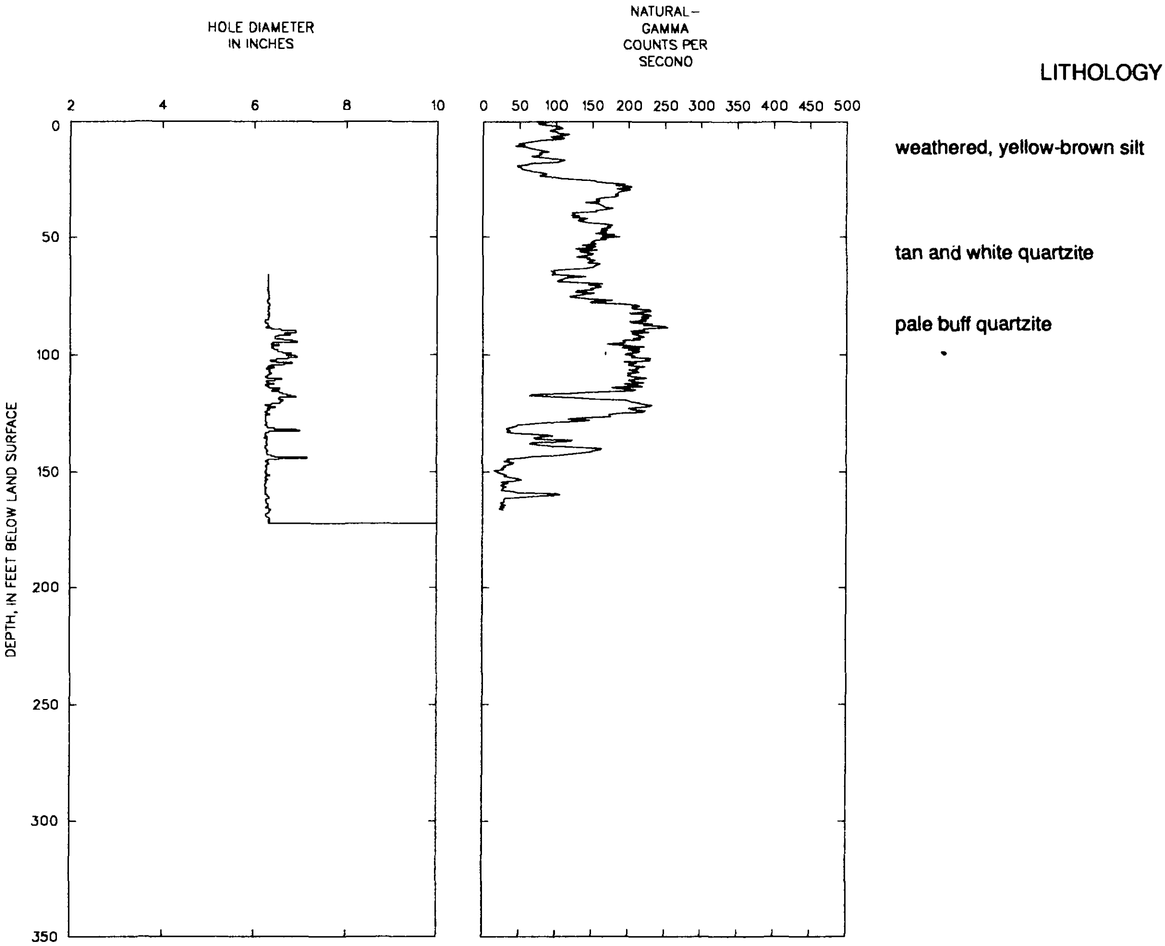
Caliper and natural gamma logs for well LN-1703 in the Chickies Quartzite, southeastern Pennsylvania.



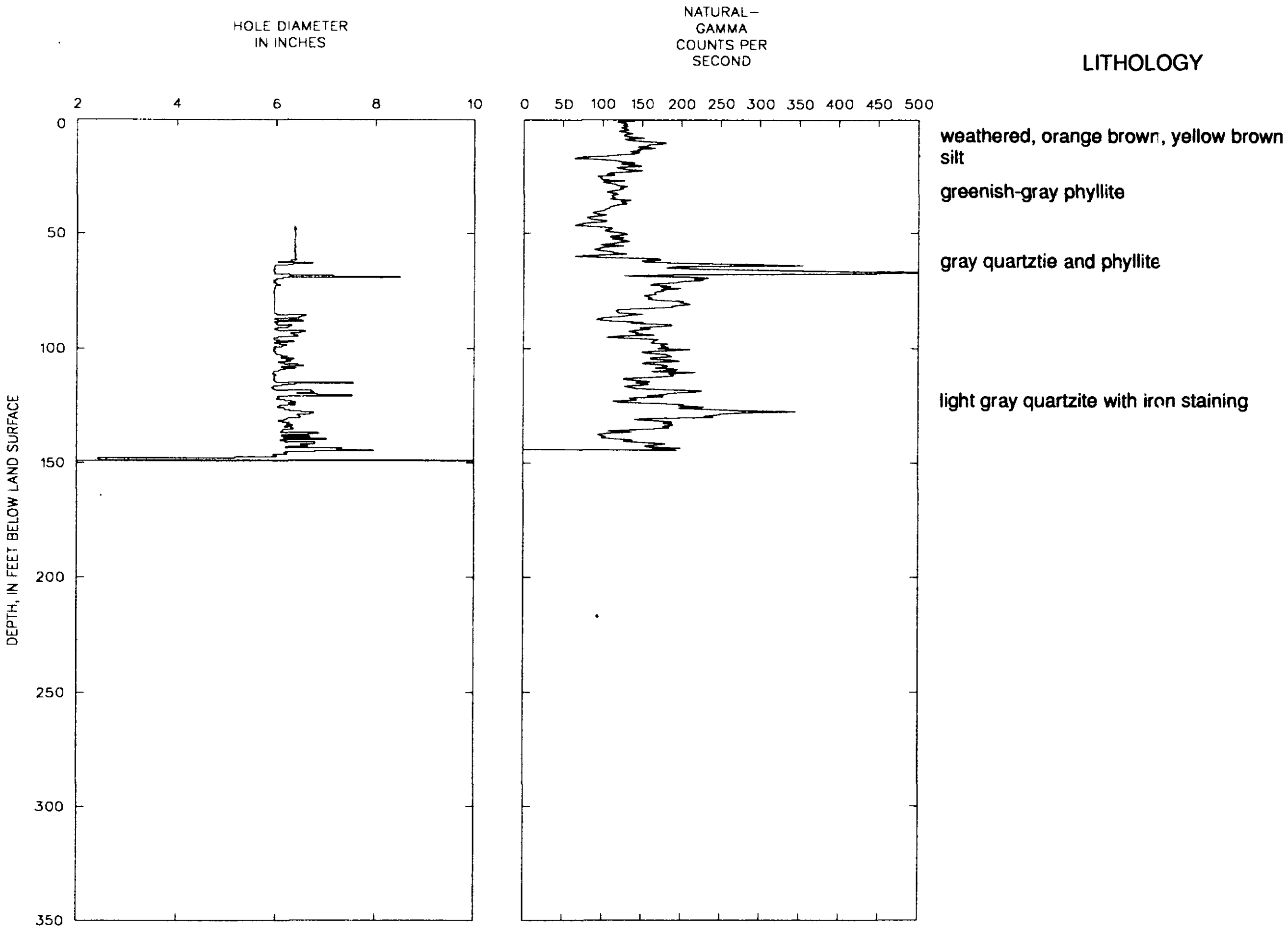
Caliper and natural gamma logs for well LN-1713 in the Chickies Quartzite, southeastern Pennsylvania.



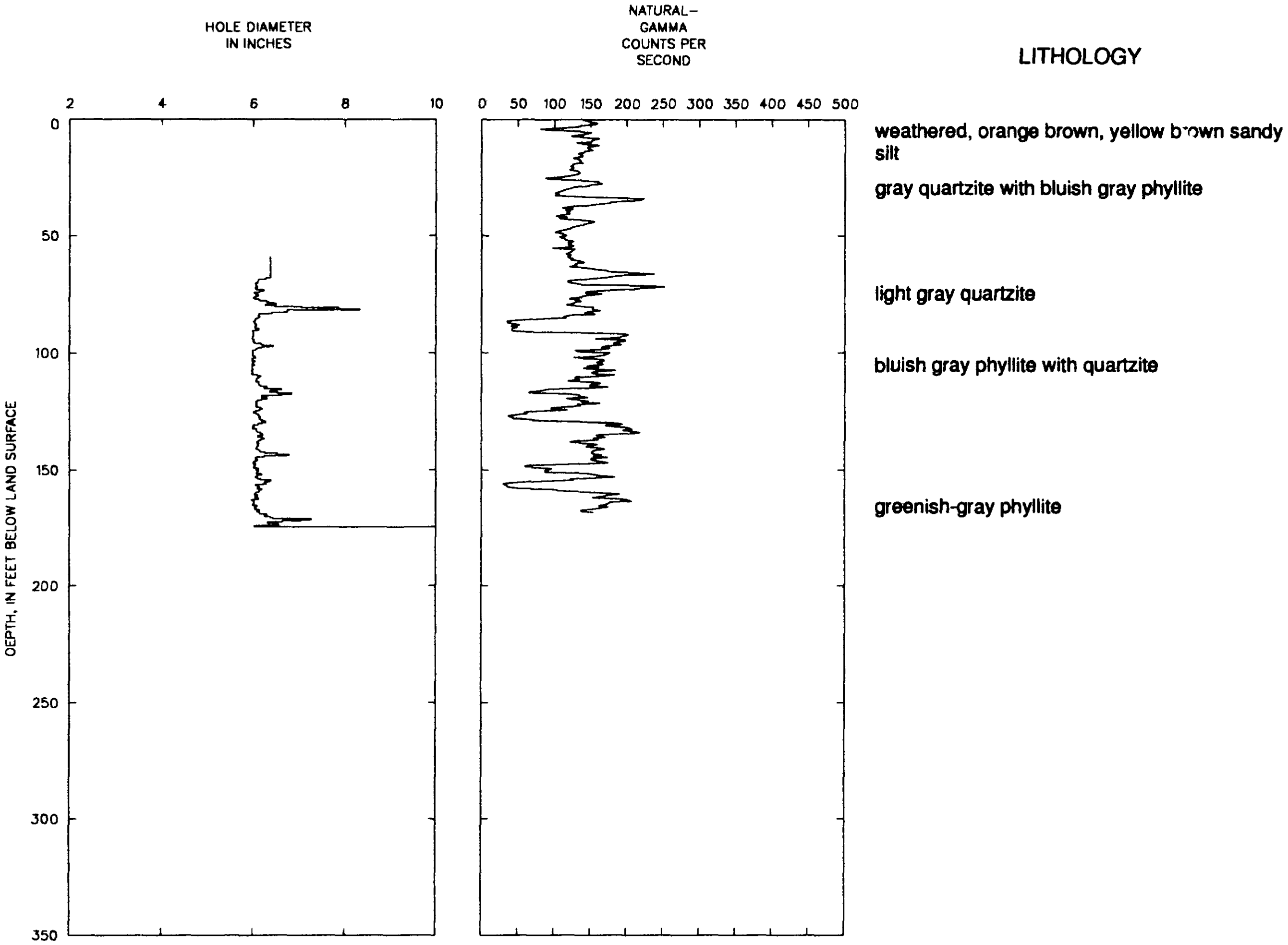
Caliper and natural gamma logs for well LN-1715 in the Chickies Quartzite, southeastern Pennsylvania.



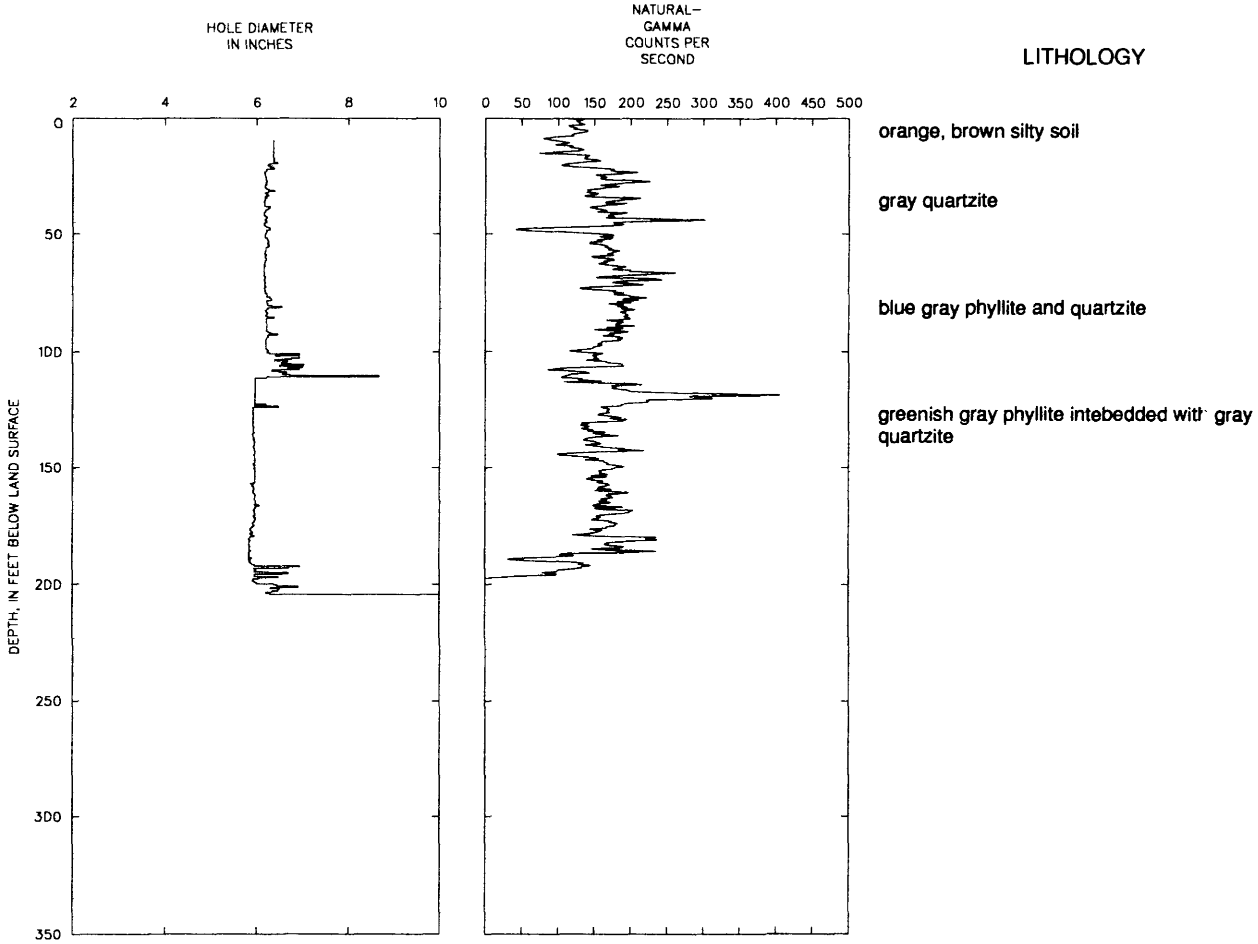
Caliper and natural gamma logs for well LN-1716 in the Chickies Quartzite, southeastern Pennsylvania.



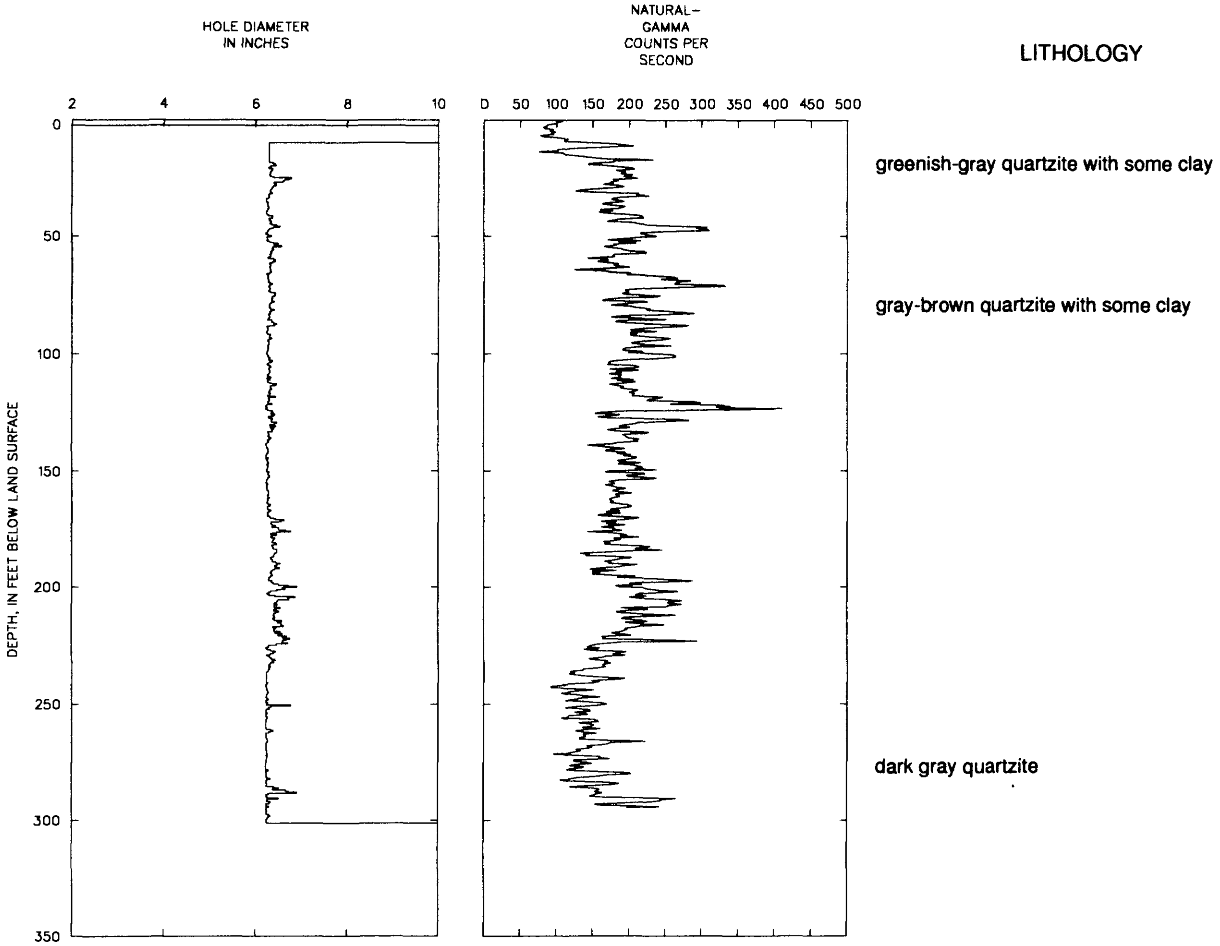
Caliper and natural gamma logs for well YO-1169 in the Chickies Quartzite, southeastern Pennsylvania.



Caliper and natural gamma logs for well YO-1170 in the Chickies Quartzite, southeastern Pennsylvania.



Caliper and natural gamma logs for well YO-1171 in the Chickies Quartzite, southeastern Pennsylvania.



Caliper and natural gamma logs for well YO-1172 in the Chickies Quartzite, southeastern Pennsylvania.