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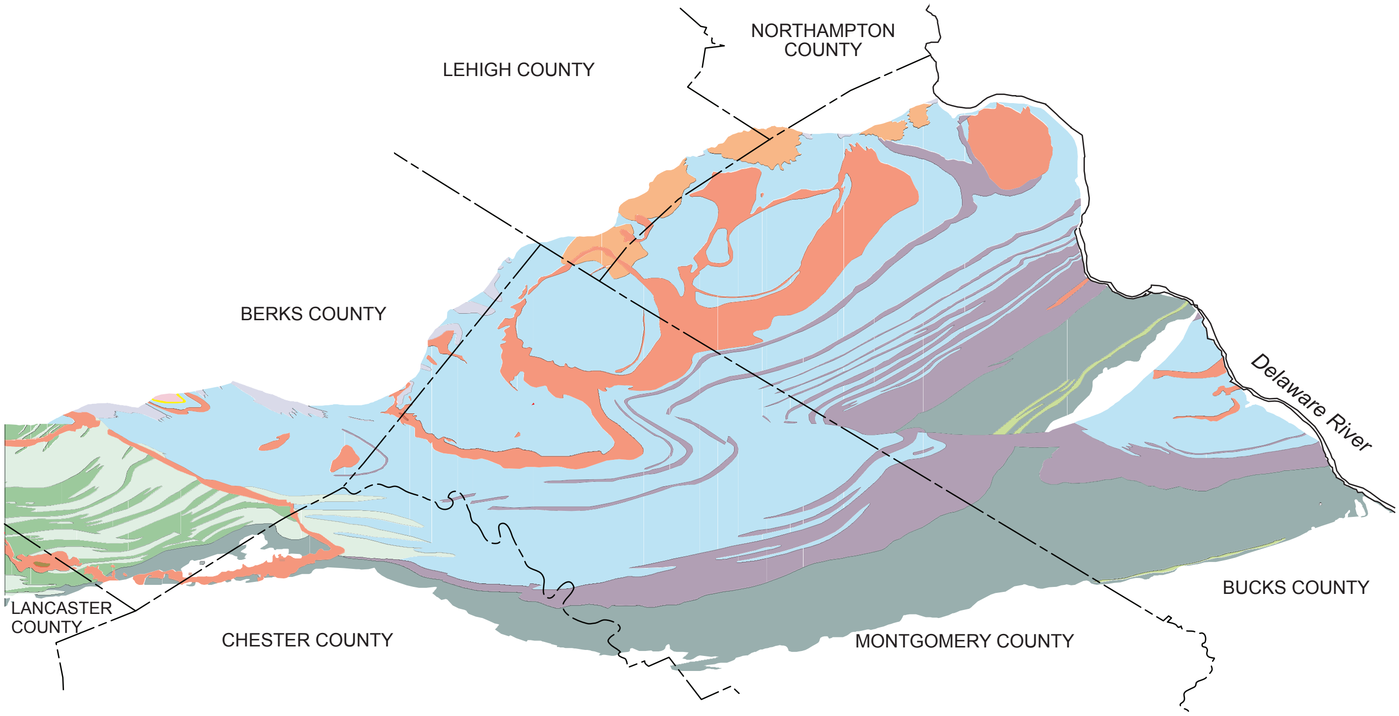
Arsenic, Boron, and Fluoride Concentrations in Ground Water in and Near Diabase Intrusions, Newark Basin, Southeastern Pennsylvania



Scientific Investigations Report 2006–5261

U.S. Department of the Interior
U.S. Geological Survey

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By Lisa A. Senior and Ronald A. Sloto

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U.S. Geological Survey
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U.S. Geological Survey, Reston, Virginia: 2006

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Suggested citation:
Senior, L.A., and Sloto, R.A., 2006, Arsenic, boron, and fluoride in ground water in and near diabase intrusions, Newark Basin, southeastern Pennsylvania: U.S. Geological Survey Scientific Investigations Report 2006-5261, 105 p.

Contents

Plates

Figures

Appendix 1

Tables

Appendix 1

Conversion Factors and Datum Conversion Factors and Datum

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
yard (yd)	0.9144	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
gallon (gal)	3.785	cubic decimeter (dm^3)
cubic mile (mi^3)	4.168	cubic kilometer (km^3)
	Flow rate	
gallon per minute (gal/min)	0.06309	liter per second (L/s)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
	Specific capacity	
gallon per minute per foot [(gal/min)/ft)]	0.2070	liter per second per meter [(L/s/m]
	Mass	
ounce, avoirdupois (oz)	28.35	gram
pound avoirdupois (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	0.9072	megagram (Mg)
ton, long (2,240 lb)	1.016	megagram (Mg)

Temperature is given in degrees Celsius (°C) which may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

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

$$°C = (°F - 32) / 1.8$$

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 88).

Altitude, as used in this report, refers to distance above the vertical datum.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L), which are approximately equivalent to parts per million (ppm) or parts per billion (ppb), respectively.

Arsenic, Boron, and Fluoride Concentrations in Ground Water in and Near Diabase Intrusions, Newark Basin, Southeastern Pennsylvania

By Lisa A. Senior and Ronald A. Sloto

Abstract

During an investigation in 2000 by the U.S. Environmental Protection Agency (USEPA) of possible contaminant releases from an industrial facility on Congo Road near Gilbertsville in Berks and Montgomery Counties, southeastern Pennsylvania, concentrations of arsenic and fluoride above USEPA drinking-water standards of 10 µg/L and 4 mg/L, respectively, and of boron above the USEPA health advisory level of 600 µg/L were measured in ground water in an area along the northwestern edge of the Newark Basin. In 2003, the USEPA requested technical assistance from the U.S. Geological Survey (USGS) to help identify sources of arsenic, boron, and fluoride in the ground water in the Congo Road area, which included possible anthropogenic releases and naturally occurring mineralization in the local bedrock aquifer, and to identify other areas in the Newark Basin of southeastern Pennsylvania with similarly elevated concentrations of these constituents. The USGS reviewed available data and collected additional ground-water samples in the Congo Road area and four similar hydrogeologic settings.

The Newark Basin is the largest of the 13 major exposed Mesozoic rift basins that stretch from Nova Scotia to South Carolina. Rocks in the Newark Basin include Triassic through Jurassic-age sedimentary sequences of sandstones and shales that were intruded by diabase. Mineral deposits of hydrothermal origin are associated with alteration zones bordering intrusions of diabase and also occur as strata-bound replacement deposits of copper and zinc in sedimentary rocks.

The USGS review of data available in 2003 showed that water from about 10 percent of wells throughout the Newark Basin of southeastern Pennsylvania had concentrations of arsenic greater than the USEPA maximum contaminant level (MCL) of 10 µg/L; the highest reported arsenic concentration was at about 70 µg/L. Few data on boron were available, and the highest reported boron concentration in well-water samples was 60 µg/L in contrast to concentrations over 5,000 µg/L in the Congo Road area. Although concentrations of fluoride up to 4 mg/L were reported for a few well-water samples collected throughout the Newark Basin, about 90 percent of the samples had concentrations of 0.5 mg/L or less.

The USGS sampled 58 wells primarily in 5 areas in the Newark Basin, southeastern Pennsylvania, from February 2004 through April 2005 to identify other possible areas of elevated arsenic, boron, and fluoride and to characterize the geochemical environment associated with elevated concentrations of these constituents. Sampled wells included 12 monitor wells at an industrial facility near Congo Road, 45 private-supply wells in Berks, Montgomery, and Bucks Counties, and 1 private-supply well near Dillsburg, York County, an area where elevated fluoride in ground water had been reported in the adjacent Gettysburg Basin. Wells were sampled in transects from the diabase through the adjacent hornfels and into the unaltered shales of the Brunswick Group. Field measurements were made of pH, temperature, dissolved oxygen concentration, and specific conductance. Samples were analyzed in the laboratory for major ions, nutrients, total organic carbon, dissolved and total concentrations of selected trace elements, and boron isotopic composition.

Generally, the ground water from the 46 private-supply wells had relatively neutral to alkaline pH (ranging from 6.1 to 9.1) and moderate concentrations of dissolved oxygen. Most water samples were of the calcium-bicarbonate type. Concentrations of arsenic up to 60 µg/L, boron up to 3,950 µg/L, and fluoride up to 0.70 mg/L were measured. Drinking-water standards or health advisories (for constituents that do not have standards established) were exceeded most frequently (about 20 percent of samples) for arsenic and boron and less frequently (6 percent or less of samples) for total iron, manganese, sulfate, nitrate, lead, molybdenum, and strontium. In water from 12 monitor wells at the industrial facility on Congo Road, concentrations of arsenic up to 61 µg/L, boron up to 5,240 µg/L, and fluoride up to 6.51 mg/L were measured, and drinking-water standards or health advisories were exceeded most frequently (more than 30 percent of samples) for manganese, boron, strontium, and arsenic and less frequently (8 to 25 percent of samples) for chloride, sulfate, fluoride, ammonia, iron, and selenium.

Statistical comparisons of constituent concentrations in five sampling areas (including the Congo Road area) and three main lithologies using the nonparametric Kruskal-Wallis test found few statistically significant differences for water from private-supply wells in the five sampling areas, but those differ-

ences included arsenic and boron concentrations. Arsenic concentrations were lowest in the Jacksonwald area of Berks County, and boron concentrations were lowest in the Quakertown area of Bucks County. Many differences in water quality were found in the comparison of private-supply and monitor-well samples; water from the monitor wells had higher concentrations of numerous constituents, including major cations, chloride, fluoride, ammonia, total organic carbon, barium, cobalt, iron, lithium, manganese, nickel, selenium, strontium, and uranium. Statistically significant differences were not found in arsenic and boron concentrations when water from the private-supply wells and monitor wells were compared, suggesting that elevated arsenic and boron concentrations are not restricted to the industrial site and can occur naturally in ground water elsewhere in the Newark Basin.

Statistically significant differences in concentrations of some major ions and trace elements and for boron isotopic compositions were found when water from wells in the three main lithologies--diabase, hornfels, and unaltered shales--was compared, although significant differences were not found in concentrations of arsenic, boron, or fluoride. Concentrations of most constituents tended to be lowest in water from wells in diabase and highest in water from wells in the shales and generally intermediate in water from wells in the hornfels, but water from wells in the diabase and hornfels tended to have higher concentrations of silica and vanadium than water from wells in the unaltered shales. Water from wells in the diabase tended to have water most enriched in the heavier isotope of boron, ^{11}B. The boron isotope compositions of most water samples from private-supply wells in all the sampled areas indicate natural mineral sources, such as datolite, for boron.

Relations between chemical constituents were explored using the nonparametric Spearman rho correlation test. In water samples from 46 private-supply wells, arsenic correlated most strongly and positively with pH, boron, and molybdenum. Arsenic also correlated positively with selenium, uranium, nickel, lithium, fluoride, and strontium, and negatively with total organic carbon, copper, and dissolved oxygen. Arsenic concentrations may be controlled partly by pH affecting adsorption of the anion arsenate. All samples with pH of 8 or higher had arsenic concentrations greater than the MCL of 10 μg/L, whereas no sample with pH of 7 or lower had arsenic concentrations that exceeded the MCL. The correlation of arsenic with many of the other trace elements suggests similar geochemical controls and (or) distribution in the aquifer materials.

For wells completed in and near diabase, the percentage of wells with ground-water concentrations of arsenic above the MCL of 10 μg/L appears to be greater than for the Newark Basin as a whole (about 20 percent compared to 10 percent), suggesting some arsenic enrichment in the rocks and (or) a favorable geochemical environment to mobilize arsenic. Also, the amount of boron in and near diabase intrusions probably is higher than in the Newark Basin as a whole. Boron may have been introduced or remobilized during the intrusion of diabase in the basin, especially where connate brines or residual brines associated with evaporites may have been present. Only a few elevated fluoride concentrations, other than those related to anthropogenic sources at the industrial facility near Congo Road, were measured in samples from wells in and near diabase, indicating limited local natural fluoride enrichment. Possible natural sources of arsenic, boron, and fluoride in the rocks include minerals deposits associated with the diabase intrusions and minerals in unaltered shales.

Introduction

Elevated concentrations of arsenic, boron, and fluoride were measured in ground water by the U.S. Environmental Protection Agency (USEPA) in 2000 in an area along Congo Road near Gilbertsville in northwestern Montgomery County, Pa. (Towle and Kelly, 2000), near the western edge of the Newark Basin (fig. 1). Sources of the elevated arsenic, boron, and fluoride in ground water were not conclusively identified but included possible releases from an industrial facility on Congo Road and naturally occurring mineralization in the local bedrock aquifer. Geologic units in the Congo Road area include sedimentary rocks that were intruded by diabase. Few data on boron concentrations in ground water were available in geologic settings similar to the Congo Road area to evaluate the probability that the boron was naturally occurring. However, elsewhere in the Newark Basin in southeastern Pennsylvania, arsenic concentrations above the USEPA drinking water maximum contaminant level (MCL) of 10 μg/L have been reported in ground water. In northern Bucks County, arsenic concentrations up to 28 μg/L and fluoride concentrations up to 1 mg/L (1,000 μg/L) were measured in ground-water samples from Newark Basin rocks (Sloto and Schreffler, 1994). The USEPA MCL for fluoride is 4 mg/L in drinking water. The USEPA has not established a drinking-water standard for boron but lists a lifetime Health Advisory (HA) level of 600 μg/L for boron in drinking water as a guideline to protect human health (U.S. Environmental Protection Agency, 2004). The lifetime HA (not a legally enforceable standard) for boron in drinking water currently (2006) is under review by USEPA (Jack Kelly, U.S. Environmental Protection Agency, written commun., 2006).

The USEPA requested technical assistance from the U.S. Geological Survey (USGS) in 2003 to help determine the source of elevated concentrations of arsenic, boron, and fluoride in ground water in the Congo Road area and identify other areas that also may have elevated concentrations of these constituents in ground water. The USGS began a study in 2003 to evaluate the relation between elevated concentrations of arsenic, boron, and fluoride in ground water and the geologic setting. The study approach was to sample in the Congo Road area and other similar hydrogeologic localities. In addition, available data on the distribution of arsenic, boron, and fluoride in ground water were reviewed and geologic occurrences of arsenic, boron, and fluoride mineralization summarized.

Arsenic and boron occur in ground water in the Newark Basin rocks in concentrations that may be harmful to human

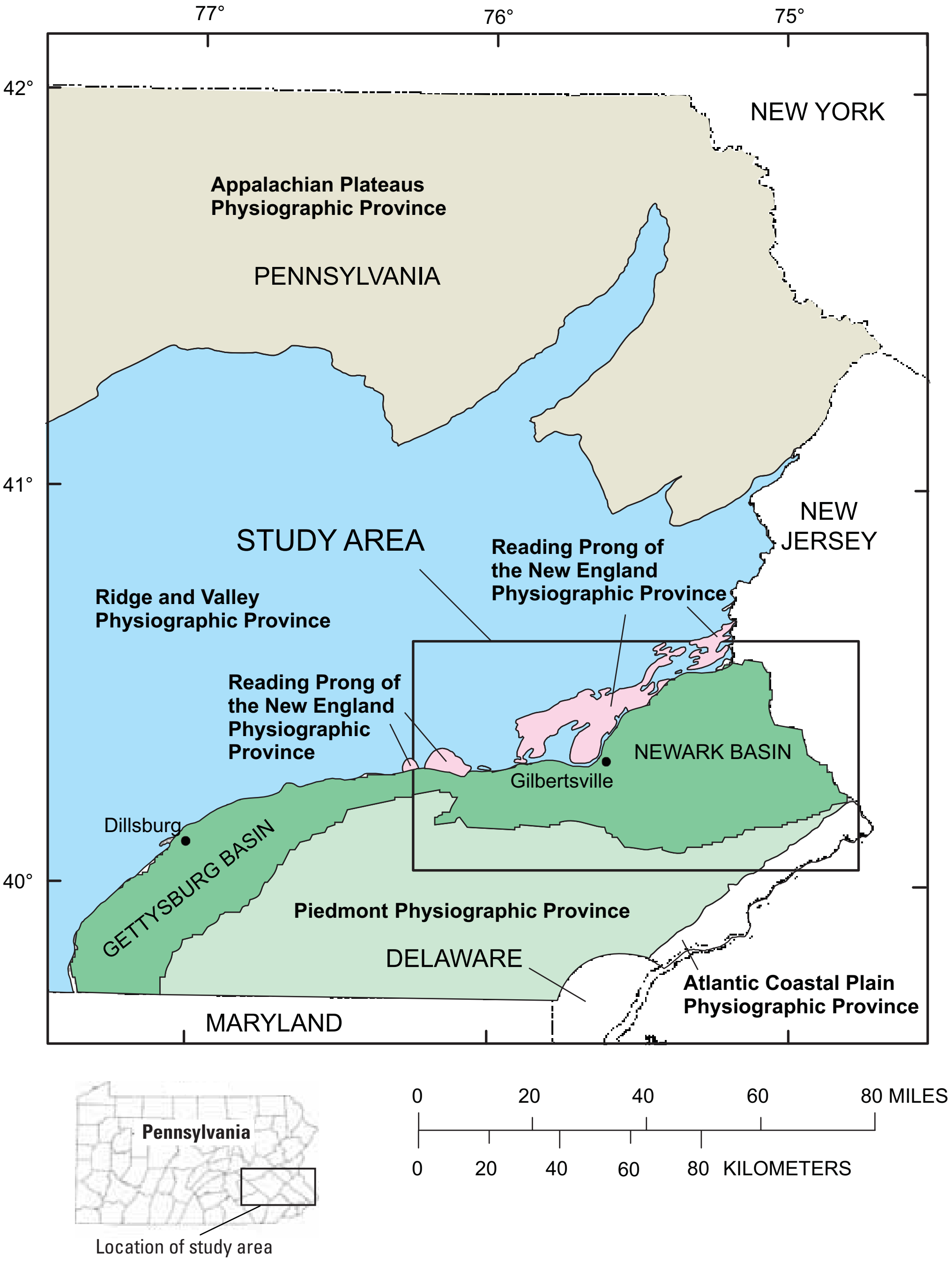


Figure 1. Location of Newark Basin and physiographic provinces, southeastern Pennsylvania.

health and, therefore, were the primary targets of the USGS ground-water investigation. Fluoride concentrations were of secondary interest because, although fluoride concentrations appear to be slightly higher in Newark Basin rocks than in other rocks in southeastern Pennsylvania and are of potential concern in the Congo Road area, concentrations rarely exceeded the secondary MCL of 2 mg/L.

Background

Following complaints from farmers and dairy operators that their crops and herd health and production were possibly affected by releases from an industrial facility on Congo Road in the Gilbertsville area, Montgomery and Berks Counties, Pa., investigations led by USEPA in the vicinity included sampling of air, soil, and water in addition to veterinary studies (Towle and Kelly, 2000). The area was designated by the USEPA as the Congo Road Boron Site, a CERCLA (Superfund) removal site and investigations were initiated in 1999. Results of ground-water sampling indicated that elevated concentrations of trichloroethylene, boron, fluoride, and selenium were present in ground water at the industrial facility in the area. The facility processes ore for metals extraction using hydrogen fluoride, ammonia, sodium, and other compounds and currently (2006) manages contamination on its site under a Resource Conservation and Recovery Act (RCRA) Corrective Action issued by USEPA in 1999 (U.S. Environmental Protection Agency, 2006). Elevated concentrations of arsenic, boron, and fluoride also were present in samples from some residential wells in the vicinity of the Congo Road Boron Site, including wells that are upgradient from the industrial facility. Towle and Kelly (2000) tentatively concluded that some arsenic, boron, and fluoride in the vicinity of the Congo Road Boron Site could be derived from natural sources. Maximum concentrations measured in residential well samples in the area were 66.8 μg/L for arsenic, 2,660 μg/L for boron, and 1,150 μg/L for fluoride. The USEPA, Region 3, in the investigation of the Congo Road Boron Site, established site-specific action levels in 2000 for boron in residential wells used for drinking-water supply of 800 μg/L for children and 2,100 μg/L for adults. USEPA provided bottled water to homes where well water concentrations were found to be above these values (the action level used at each home was dependent upon resident age). Based on a 2004 reassessment of the toxicity of boron by the USEPA National Center for Environmental Assessment, the site-specific action level for boron formally may be raised approximately two-fold in the near future, potentially negating the need for USEPA to provide bottled water to all or most residences in the Congo Road area (Jack Kelly, U.S. Environmental Protection Agency, written and oral commun., 2006).

Purpose and Scope

This report presents results of an investigation of elevated arsenic, boron, and fluoride concentrations in ground water in the Congo Road area and four similar hydrogeologic settings in and near diabase intrusions in the Newark Basin in Pennsylvania. The report describes the geologic setting of the Congo Road area and other similar areas; summarizes what is known about the extent of mineralization that could be associated with elevated arsenic, boron, and fluoride; reviews and summarizes available data prior to 2004 on the concentrations of arsenic, boron, and fluoride in ground water in the Newark Basin; describes the general ground-water hydrology and distribution of arsenic, boron, and fluoride in ground water in the Congo Road area and four other study localities based on samples collected by USGS from 46 private-supply wells and 12 monitor wells from February 2004 through April 2005; and describes geochemical controls on the solubility of these constituents in ground water. Because of the relatively small number of samples collected, the field investigation begun in 2004 should be considered a reconnaissance. Data on boron isotopes are presented to help identify sources of elevated boron in ground water.

Study Area

The study area includes the vicinity of Congo Road near Gilbertsville, Pa., and other selected localities in Berks, Montgomery, and Bucks Counties in the Newark Basin in southeastern Pennsylvania (fig. 1). The Newark Basin is in the Gettysburg-Newark Lowlands section of the Piedmont Physiographic Province and is bordered to the north by the Reading Prong section of the New England Physiographic Province and the Great Valley section of the Ridge and Valley Physiographic Province and to the south by the Piedmont Upland and Lowland sections of the Piedmont Physiographic Province (Sevon, 2000). Land use in the study area is diverse and includes agricultural, residential, industrial, and urban uses (mixture of commercial, high-density residential, institutional, and other uses). Ground water is a major source of drinking-water and industrial supply in most of the Newark Basin.

Previous Investigations

In addition to ground-water-quality data collected by USEPA in the Congo Road area (Towle and Kelly, 2000), data on arsenic, boron, and (or) fluoride concentrations in ground water in the Newark Basin in Pennsylvania have been collected by USGS under numerous programs, including the Delaware River Basin National Water-Quality Assessment (NAWQA) Program and a northern Bucks County study (Sloto and Schreffler, 1994). The Pennsylvania Department of Environmental Protection (PADEP) also collected data on arsenic and fluoride concentrations in ground water in southeastern Pennsylvania through several programs, including an ambient ground-water-quality monitoring program (1987-1997) and drinking-water-quality monitoring programs (1993-2003). Arsenic in ground water in rocks of the Newark Basin in New Jersey was reported on by Szabo and others (1997) and has been studied by the New Jersey Geological Survey (Serfes, 2004; 2005).

Hydrogeologic Setting

The occurrence of arsenic, boron, and fluoride in ground water in elevated concentrations is due to the presence of natural or anthropogenic sources in the aquifer and geochemistry of the ground-water system that promotes solubilization of these elements. Natural sources in the Newark Basin include the possible concentration of these elements in the sedimentary environment, during diagenesis, or through mineralization associated with diabase intrusions or with other geothermal fluids.

Arsenic, boron, and fluoride may accumulate in arid, closed-basin sedimentary environments (Smedley and Kinniburg, 2002; Robertson, 1991). Certain facies of some geologic units in the Newark Basin are thought to have been deposited under those sedimentary conditions. Arsenic also is known to be associated with iron sulfides that can form under reducing conditions in lake deposits or during diagenesis of sediments, with hydrothermal activity, and with sulfide mineralization (Welch and others, 2000). Arsenic, boron, and fluoride also may be enriched in areas with volcanic or geothermal activity (Smedley and Kinniburg, 2000; Wood and Low, 1987). Remobilization of arsenic, boron, and fluoride in host rocks affected by diabase intrusions may result in concentration of these elements in areas near the intrusions.

Geology

The Triassic-Jurassic age Newark Supergroup rocks in Pennsylvania (fig. 2) that underlie most of the study area are part of the Newark Basin, which is approximately 140 mi long and 32 mi wide and is the largest of the 13 major exposed Mesozoic rift basins that stretch from Nova Scotia to South Carolina. Sedimentation in the Newark Basin was the result of infilling of a rift basin formed during the initial stages of continental breakup (Turner-Peterson and Smoot, 1985, p. 10). The sediments were deposited over a period of 45 million years on folded and deeply eroded rocks of Precambrian and Paleozoic age, which are exposed northwest and southeast of the Newark Basin. Following deposition, the sediments were intruded by diabase, faulted, uplifted, and eroded. The intruding diabase locally metamorphosed the adjacent rocks to a hornfels. In places, basalt flows also occurred. Subsequently, hydrothermal fluids are thought to have migrated through the basin (Sutter, 1988; Pratt and Burruss, 1988).

Geologic Structure

The Newark Basin is a half graben bounded on its northwestern margin by a low-angle extensional fault system. The northern border fault system strikes northeast. Newark Basin rocks dip 5° to 20° northwest toward the northern border fault system. Younger strata generally dip at a more shallow angle than older strata. On the basis of seismic data and drill cores in northern Bucks County, Ratcliffe and others (1986) determined that the border fault dips 25° to 30° SE. and that the faulting was the reactivation of Paleozoic imbricate thrust faults in the basement rocks. Faulting continued contemporaneously with basin filling; the down-faulted basin floor provided a continually deepening sink for sediment. Strata of all ages thicken toward the northern border fault system. Alluvial fan conglomerates are present on the downthrown side of the border faults. Post-depositional faulting also occurred within the basin, resulting, for example, in the Furlong and Chalfont faults mapped in Pennsylvania (Ratcliffe and Burton, 1988). Structural development of the Newark Basin is described by Schlische (1992).

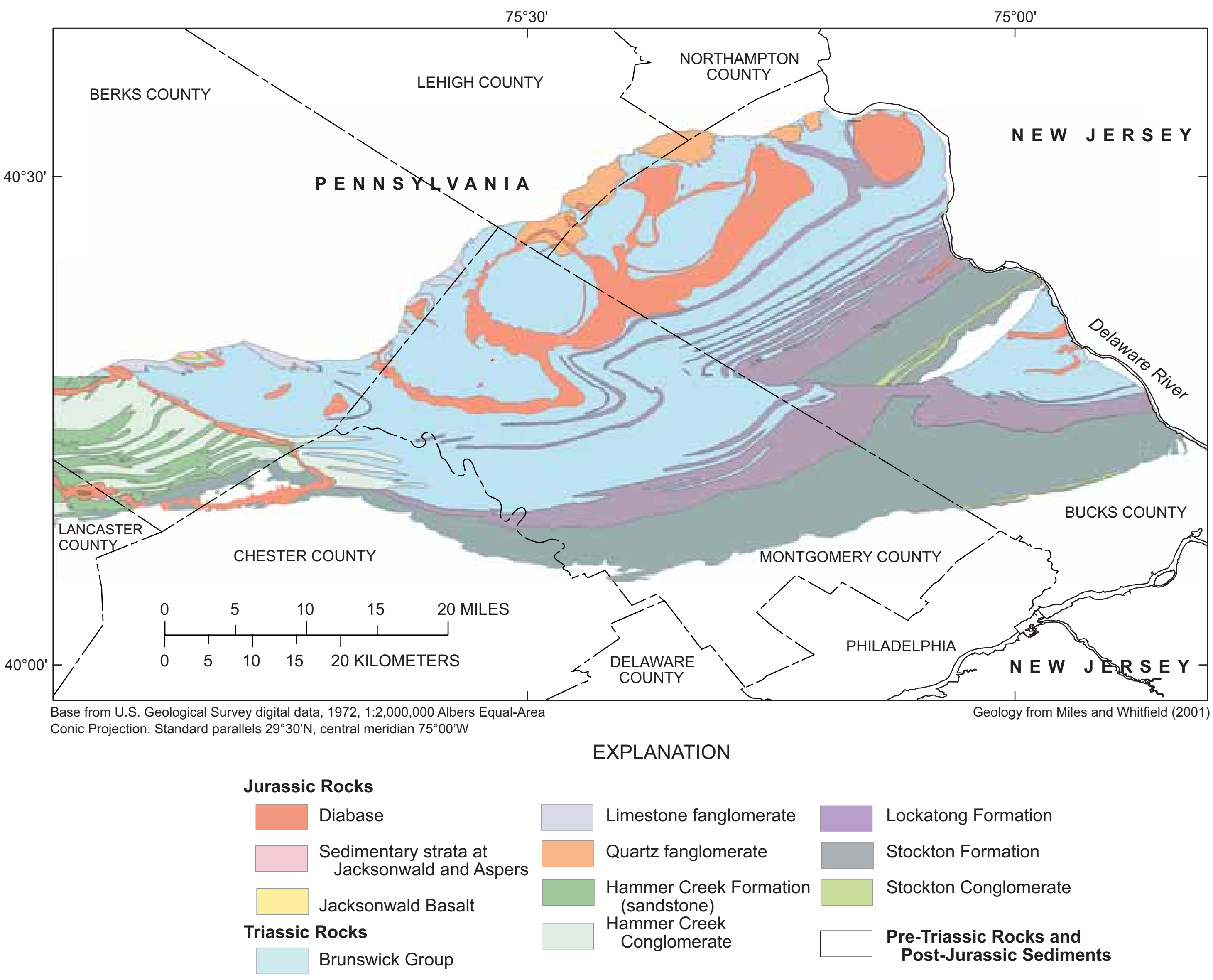
Geologic Units

Bedrock geologic units underlying the study area are described from oldest to youngest. The oldest units, Precambrian to Paleozoic in age, are complex assemblages of rocks that have undergone several episodes of deformation and metamorphism. The youngest units, Triassic and Jurassic in age, in contrast, have undergone relatively mild deformation and localized thermal metamorphism.

Precambrian and Paleozoic Rocks

Precambrian and Paleozoic rocks of the Reading Prong (fig. 1) are present north of the Triassic border fault that forms the northern edge of the Newark Basin. Precambrian and Paleozoic rocks of the Piedmont are present along the southern margin of the Newark Basin in Pennsylvania. These crystalline rocks were the source of some of the sediments deposited in the Newark Basin. The rocks of the Reading Prong are allochthonous and represent an overlapping stack of thrust sheets that have been thrust over the Paleozoic Rocks of the Great Valley to the north. These rocks have undergone at least one high-grade and two low-grade metamorphic events and are metamorphosed to amphibolite to granulite facies. Some of the rock sequences are overturned, resulting in older rocks on top of younger rocks. The rocks of the Piedmont also have undergone several deformation and metamorphic events and are metamorphosed from greenschist to granulite facies.

The Precambrian rocks of the Reading Prong are Middle Proterozoic in age and include potassic feldspar gneiss, hornblende granite and associated biotite granite, and amphibolite. The Paleozoic rocks associated with the Reading Prong in contact with Triassic rocks include Cambrian-age quartzites and carbonates (Hardyston Quartzite and Leithesville Formation). The Precambrian rocks of the Piedmont include felsic, mafic, and graphitic gneisses. Paleozoic rocks of the Piedmont in contact with Triassic rocks along the southern margin of the basin include quartzites and carbonates (Chickies Quartzite, Ledger Formation, and others). Tourmaline, a boron-bearing mineral, is present in some of the metamorphosed Precambrian rocks of the



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic Projection. Standard parallels 29°30'N, central meridian 75°00'W

Geology from Miles and Whitfield (2001)

Figure 2. Bedrock geology of the Newark Basin, southeastern Pennsylvania.

Reading Prong and also in the Hardyston Quartzite and Chickies Quartzite. Lithologies of the Precambrian and Paleozoic rocks are described in greater detail by Lyttle and Epstein (1987). Two slivers of Precambrian and Paleozoic rocks similar to or same as rocks of the Reading Prong and Piedmont occur in the Newark Basin in Pennsylvania. In the eastern Basin, one sliver underlies Buckingham Mountain in Bucks County, and in the western Basin, another sliver occurs along the border between Berks and Chester Counties (fig. 2).

Mesozoic Rocks

Sediments of the Newark Basin range in age from Late Triassic to Jurassic and include sandstones, siltstones, and shales. The sediments mainly were derived from crystalline rocks flanking the basin to the northwest and southeast of the basin. The sedimentary formations in the basin are a large-scale time-transgressive facies whose distribution is in response to the tectonic asymmetry of the basin (Turner-Peterson, 1980; Turner-Peterson and Smoot, 1985). Tectonic activity and climatic changes during basin infilling accompanied by fluctuations in sediment input caused migration of facies belts and boundaries. These external controls probably were the most significant factors in determining the relative proportions of fluvial and lacustrine depositional environments. The diabase and basalt in the Newark Basin are Jurassic in age.

Stockton Formation

The Stockton Formation of Late Triassic age is the oldest of the Newark Basin sediments and forms the basal unit. The Stockton rests unconformably on rocks of Paleozoic and Precambrian age. Sedimentation in the Newark Basin began with an influx of arkosic detritus from uplifted crystalline rocks to the south not far from the present day southern basin margin (Glaeser, 1966). The Stockton Formation includes alluvial fans, fluvial and lacustrine sandstones, and fluvial and near-shore lacustrine mudstones and siltstones (Turner-Peterson and Smoot, 1985). Thick, poorly defined, upward fining cycles possibly were deposited by large, perennial, meandering rivers resulting in interbedded sandstone, arkose, arkosic sandstone, arkosic conglomerate, siltstone, and shale. Conglomerates are more abundant in the lower half of the formation than in the upper half, and fine-grained sandstones are more abundant in the upper half of the formation than in the lower half. Arkose is abundant everywhere in the formation, except for the uppermost few hundred feet. The rocks contain channels, ripple marks, mudcracks, crossbeds, lenses, pinch-and-swell structures, and minor burrows. Rapid lithologic changes are characteristic of the Stockton Formation. Single beds may grade along strike from fine grained to coarse grained within a few yards (Willard and others, 1959, p. 65). Conglomerate units average about 320 ft thick (Lyttle and Epstein, 1987).

Some gray marginal lacustrine and black siltstone beds in the Stockton Formation may contain anomalously high concentrations of uranium that correlate with high total organic carbon and sulfur content. In occurrences along the Delaware River, the uranium minerals metatorbernite and metazeunerite are associated with pyrite and minor zircon, tourmaline, illmenite, and topaz. The deposits are characterized by minor amounts of uranium, arsenic, zinc, and, in one case, lead and copper (McCauley, 1961, p. 6-9). Uranium was precipitated at or near the sediment-water interface during deposition of lake-bottom sediments in a reducing environment. Turner-Peterson and others (1985, p. 120) reported a shaley, black mudstone containing lacustrine fossils in the Stockton Formation near the Delaware River that contained 0.29 percent uranium oxide, which is considered to be ore grade.

The Stockton Formation grades into the Lockatong Formation. Olsen (1980, p. 8) places the Stockton-Lockatong boundary at the base of the lowest continuous black siltstone bed. The Stockton also laterally interfingers with the Lockatong.

Lockatong Formation

Sediments of the Lockatong Formation of Late Triassic age were deposited in a large, shallow, thermally stratified, alkaline lake. The Lockatong predominantly consists of laminated to thick-bedded, gray and black siltstone and shale. Climate variations were a major control on lacustrine deposits, producing small-scale detrital and chemical-lacustrine cycles (Van Houten cycles), which were first recognized by Van Houten (1962). The detrital cycles average 17.1 ft thick and consist of laminated, medium dark-gray to black, calcareous, pyritic siltstone and shale in the lower part of the cycle overlain by platy to massive, disrupted (mudcracked and burrowed), dark-gray, calcareous siltstone, ripple-bedded siltstone, and fine-grained sandstone. The chemical-lacustrine cycles average 10.5 ft thick and consist of platy, medium dark-gray to black, dolomitic siltstone and marlstone with shrinkage cracks and lenses of pyritic limestone in the lower part overlain by massive, gray or red, analcime- and carbonate-rich, disrupted siltstone.

Van Houten cycles apparently were produced by the rise and fall of a very large lake that corresponded to periodic climate changes controlled by variations in the earth's orbit (Van Houten, 1962; Olsen, 1984, 1985). The lake covered over 2,700 mi^2 and was as much as 300 ft deep. Chemical cycles accumulated when the lake was low and had no outlet; chemical constituents from a deeply weathered source area were concentrated and precipitated in the lake. Detrital cycles accumulated when the lake level was high during wetter periods that maintained a through-flowing drainage, which carried most of the soluble material to the ocean (Van Houten, 1964). Each Van Houten cycle consists of three divisions interpreted by Olsen (1980, p. 352) as lake transgression (division 1), high stand (division 2), and regression plus low stand (division 3) facies. Features, such as mudcracks, burrows, and root disruptions indicate that lake levels were substantially lowered during drier periods, and, in some instances, the lake may have been completely dry. Smoot and Olsen (1985) interpret such features as representing a playa floor.

Some black siltstone beds in the Lockatong Formation may contain anomalously high concentrations of uranium.

Turner-Peterson and others (1985) correlate uraniferous zones with division 2 Van Houten cycles, which are characterized by a high organic carbon content (Olsen, 1984). Division 2 sediments may contain as much as 20 percent total organic carbon (Olsen, 1985, p. 61).

Shales and siltstones of the Lockatong Formation surrounding diabase have been thermally metamorphosed to a purplish-red, light gray, and dark gray, indurated, brittle, and fine-grained hornfels in a zone averaging about 2,000 ft wide (Lyttle and Epstein, 1987). Hematite in the shale has been reduced to magnetite, giving it a dark color.

The Lockatong interfingers laterally with and grades upward into the lower part of the Brunswick Group. The thickness of the Lockatong at the Delaware River is about 3,900 ft (Willard and others, 1959, p. 85).

Brunswick Group

The Brunswick Group is Late Triassic in age. Sediments of the Brunswick Group were deposited in a lacustrine-nearshore environment. The Brunswick Group consists of shale, siltstone, and fine-grained sandstone containing a few shale interbeds. Mudcracks, ripple marks, crossbeds, and burrows are common. The Brunswick contains detrital cycles of thin-bedded shale and siltstone. Near the base are tongues of thick-bedded red argillite interbedded with dark-gray argillite characteristic of the underlying Lockatong Formation. Higher in the formation, the gray beds are softer and are largely mud- and silt-shale and siltstone.

Thin beds previously mapped as the Lockatong Formation interbedded with the Brunswick Group are now considered the lower beds of the Brunswick Group. The lower contact of the Brunswick Group is conformable and gradational with the Lockatong Formation over about 1,640 ft (Lyttle and Epstein, 1987) or is unconformable on basement rocks. The Brunswick also interfingers laterally with the Lockatong Formation. The boundary between the Brunswick and the Lockatong generally is placed where the thickness of red beds is dominant over the thickness of gray and black beds, both horizontally and vertically.

The evaporite minerals gypsum and anhydrite occur in the Brunswick Group within massive red mudstone and siltstone lithologies in the form of diffuse cements, void fillings, euhedral crystals, crystal clusters, and nodules (El-Tabak and others, 1997). A well-developed upward increase in the amount of evaporite minerals present in the Brunswick Group resulted from (1) a long-term, progressive increase in aridity; and (2) a significant increase in evaporation surface area of the Newark Basin during its tectonic evolution.

Shales and siltstones of the Brunswick Group surrounding diabase intrusions have been thermally metamorphosed to a purplish-red, light gray, and dark gray, indurated, brittle, fine-grained hornfels in a zone averaging about 2,000 ft wide. The transition across this zone from a soft, red shale to a dark, tough hornfels is gradual. The hornfels closely resembles the Lockatong Formation.

Arsenic and boron content of unaltered red shales of the Passaic Formation in New Jersey, which are equivalent to the Brunswick Group in Pennsylvania, were analyzed in 16 samples and found to be approximately correlated, with arsenic content ranging from 3 to 15 mg/Kg (milligrams per kilogram) and boron content ranging from about 80 to 600 mg/Kg (M. Serfes, New Jersey Geological Survey, written commun., 2006); in contrast, the arsenic content of samples of black and gray shales of the Passaic Formation was higher, ranging up to 140 mg/Kg and the boron content was lower, ranging up to 60 mg/Kg. In black and gray shale samples from the Passaic and Lockatong Formations, the mineral pyrite was found to have elevated arsenic concentrations (up to 40,000 mg/Kg) (Serfes, 2005).

Hammer Creek Formation

The Hammer Creek Formation (Brunswick Formation quartz pebble conglomerate of Bascom and Stose, 1938, p. 74) sediments were deposited in an alluvial fan. Wood (1980, plate 1, part 3) mapped both a quartz conglomerate unit (Hammer Creek Conglomerate of Berg and others, 1980) and a sandstone unit (Hammer Creek sandstone) of the Hammer Creek Formation. The Hammer Creek quartz conglomerate is a fanglomerate made up of poorly sorted pebbles to boulders of vein quartz and red siltstone in a red silty sandstone matrix. The Hammer Creek sandstone is a fine- to coarse-grained sandstone containing pebbles and some cobbles of well-rounded vein quartz and quartzite and some clasts of siltstone and sandstone. The Hammer Creek Formation may be as much as 9,200 ft thick (Lyttle and Epstein, 1987).

Limestone Fanglomerate

Limestone conglomerate is mapped as limestone fanglomerate (Berg and others, 1980) at the northern border of the Newark Basin. The unit consists of limestone and dolomite clasts as much as 3.3 ft in diameter derived from limestone and dolomite of Cambrian and Ordovician age in the immediate area and rare gneiss pebbles and cobbles in a matrix of red, partly arkosic sandstone and siltstone. The conglomerate generally becomes finer grained toward the south (Lyttle and Epstein, 1987).

Quartzite Fanglomerate

Quartzite conglomerate is mapped as quartzite fanglomerate (Berg and others, 1980) along the northern border of the Newark Basin. The unit consists of rounded pebbles, cobbles, and boulders, as much as 1 ft long, of quartzite and lesser calcareous sandstone in a matrix of red, partly arkosic siltstone. The source of the clasts is rocks of Silurian age to the north. The conglomerate generally becomes finer grained toward the south and grades into the Brunswick Group. The quartzite conglomerate is about 1,000 ft thick (Willard and others, 1959, p. 95).

Diabase

Diabase of early Jurassic age, which occurs as extensive sheets, is considered a York Haven-type diabase based on composition (Smith, 1973). The diabase is a dark-gray to black, fine- to coarse-grained, crystalline rock composed largely of calcic plagioclase and augite. Near the chilled margins, the diabase is very fine- to fine-grained. Diabase intruded under high temperature and low pressure into rocks of pre-Jurassic age. The diabase has been exposed by weathering of the softer intruded rocks. The Boyertown diabase sheet is estimated to be 1,200 ft thick, 15 mi^2 in area, and have a volume of 3.5 mi^3 (Froelich and Gottfried, 1999, p. 206).

Diabase sheets generally form prominent hills and are discordant sheets with oval or ring-like outcrop patterns (Hotz, 1952). Drill hole and geophysical data confirm that the diabase of these rings has the form of generally discordant curved sheets. Pre-existing fractures or potential lines of weakness may have controlled the sheet-like form or pressure may have forced magma to spread laterally rather than to rise vertically.

Hotz (1952), in describing the ring-like diabase structure in the Quakertown and Boyertown areas, stated that "*although at the surface Triassic sedimentary rocks occupy the center of the ellipse of diabase, a gravitational high over the area indicates the presence of diabase beneath a thin layer of sedimentary rock. Many, if not all of these diabase bodies are continuous beneath a cover of Triassic sedimentary rock and are basin shaped. Erosion has removed some of the sedimentary cover so that the high parts of the sheet are exposed, giving the effect at the surface of connected links in a chain.*" These areas can be visualized as diabase bowls filled with sediment. Thermally altered sediments not mapped at the surface may be encountered by wells.

Diabase dikes in Pennsylvania rarely show any sign of a differentiate other than a chilled margin and an occasional textural coarsening. The large sheets, however, always contain additional differentiates, diabase pegmatite being the most common (Lapham and Gray, 1973, p. 207).

Jacksonwald Basalt

The Jacksonwald Basalt is the only surface flow of intrusive rocks east of the Susquehanna River in Pennsylvania. Its nature as a surface flow was first recognized by Wherry (1910, p. 9), who noted the vesicular character of the rock and the absence of thermal alteration in the enclosing shales. It is a dark gray, fine-grained basalt with a highly vesicular top. The cavities are in part filled by secondary minerals, chiefly calcite, prehnite, and datolite (Wherry, 1910, p. 12).

The Jacksonwald Basalt is a York Haven-type extrusive (Smith, 1973, p. 48-49). A sample of the basalt analyzed by Smith (1973, p. 48) contained an atypically high amount of copper. MacLachlan (1983) estimated the thickness as 500 ft and stated that it was possibly too thick to be a single flow; however, no internal divisions have been identified. MacLachlan (1983) considered the Jacksonwald Basalt to be a member of the Brunswick Group. Epstein and Lyttle (1987) considered the Jacksonwald Basalt a separate unit within the Brunswick Group and correlated it with the Orange Mountain Basalt in New Jersey.

Sedimentary Strata at Jacksonwald and Aspers

A small area of Jurassic-age sedimentary rock referred to as "sedimentary strata at Jacksonwald" were deposited on top of the Jacksonwald basalt. It was formerly mapped as part of the Brunswick Formation. The rocks primarily are arkosic sandstone, fossiliferous shale and limestone, ripple-cross-laminated siltstone, and boulder conglomerate (Miles and Whitfield, 2001).

Effects of Thermal Metamorphism

Thermally metamorphosed sedimentary rocks enclosed the intrusive diabase bodies. The thickness of the thermally metamorphosed sediments is highly variable and ranges from 10 to 30 percent of the thickness of the intrusive sheet. Aureoles are commonly zoned. Normally red Triassic-age sandstone and shale in contact with diabase is metamorphosed to a hornfels. Hornfels is the most common contact metamorphic rock (Froelich and Gottfried, 1999, p. 208). The hornfels is typically a dark-gray to black, fine-grained rock, often difficult to distinguish from the diabase chilled margin. Secondary zeolite mineralization (veinlets and vugs) in addition to secondary quartz and calcite is common, yielding many notable mineral localities (Lapham and Gray, 1973, p. 39).

Van Houten (1971, p. 12) noted that "*datolite, tourmaline, scapolite, and fluorite in highest-grade Newark hornfels and datolite in calc-silicate hornfels suggest minor additions of volatile boron, chlorine, and fluorine from adjacent diabase*." Froelich and Gottfried (1999, p. 208) postulate that some of these minerals may have developed from residual brines.

Mineral Deposits in the Newark Basin

Four principal types of mineral deposits are defined for Mesozoic basins in the eastern United States. They follow the modes of ore occurrence described by Wherry (1908a, p. 731), although there is overlap in these categories. Robinson (1988, p. 303) and Robinson and Sears (1988, p. 265) divide the deposits into (1) magnetite skarn and skarn/replacement deposits, (2) hornfels copper deposits, (3) diabase hosted vein and late-stage igneous segregation deposits, and (4) sediment hosted and stratabound replacement deposits. The first three types are of hydrothermal origin and are associated with hydrothermal alteration zones bordering intrusions of diabase and its differentiates (Robinson, 1988, p. 316), and show many similar features of geology and mineralization. Arsenic, boron, and fluoride may be elevated in some of these mineralized areas.

Many, if not most, known mineral deposits in the Newark Basin in Pennsylvania are associated with or near the diabase intrusions (fig. 3). A few mineralized areas that are not near diabase intrusions include vein-type deposits (lead) in the Stockton Formation and some sedimentary-host type deposits in the Lockatong Formation and Brunswick Group.

Magnetite skarn and skarn/replacement deposits generally are found in carbonate rocks bordering diabase sheets. Skarns are formed by replacement of carbonate-bearing rocks during contact metamorphism and metasomatism. Such deposits contain abundant magnetite and accessory sulfide minerals enriched in Cu, Co, Au, and Ag.

Hornfels copper deposits generally are found in metamorphosed calcareous siltstone bordering diabase and late-stage differentiates, mainly bodies of ferrogabbro and granophyre. In such deposits, hornfels is enriched in Cu or Cu and Fe locally with Au, Mo, Ag, Bi, and other trace metals.

Diabase hosted vein and late-stage igneous segregation deposits generally are found within or bordering diabase sheets. The segregations and veins formed by combined magmatic and postmagmatic processes resulted in disseminated replacements of host rock by metallic minerals and epigenetic mineral fillings of tabular or sheet-like fractures in the host rock. The segregations and veins are enriched in Cu and locally in precious and other trace metals (minor Co and As and trace Ag, Au, and Pd).

Sediment hosted and stratabound replacement deposits of Cu, Zn, and Pb mineralization are found in fluvial sandstones and lacustrine mudstones. Mineral deposition appears to be associated with depositional conditions that favor preservation of organic material within permeable strata. Elevated arsenic concentrations are associated with these deposits in some instances, although correlations between arsenic and other metals apparently is variable (Serfes, 2005).

Analyses for trace metals were presented by Smith and others (1988) for composite samples from mine dumps, quarries, and outcrops in the Newark and Gettysburg Basins in Pennsylvania. Ranges for Au, Ag, Cu, Co, Ni, As, Bi, and Mo are summarized in table 1.

Some of the arsenic-, boron-, and fluorine-bearing minerals identified in Newark Basin rocks in Pennsylvania, including mineralized areas, are listed in table 2. In addition, Serfes (2005) proposed that arsenic may be associated with clay and hematite in red mudstone and siltstones and with pyrite in anoxic lake sediments (gray and black shales) in the basin.

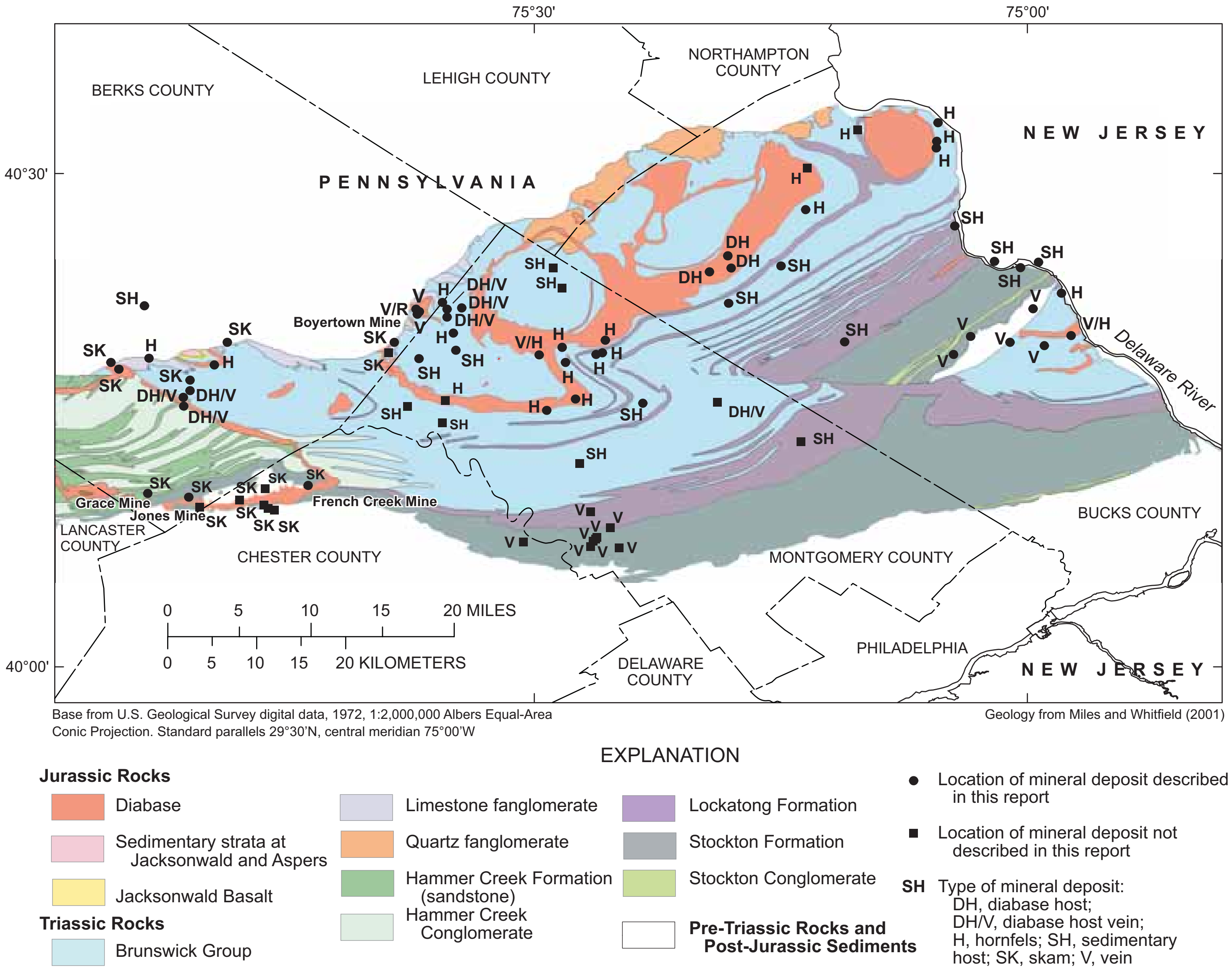
Magnetite Skarn and Skarn/Replacement Deposits

Magnetite skarn and skarn/replacement deposits are the most common, largest, and most economically significant of the deposits. They are referred to as Cornwall-type ore bodies (Spencer, 1908) after the large ore body mined at Cornwall, Pa. Some notable examples of Cornwall-type ore bodies include the Cornwall, Grace, French Creek, Jones, and Boyertown Mines (fig. 3). The Boyertown Mine is about 3 mi west of the Congo Road area. These deposits are metasomatic replacements of carbonate rocks adjacent to diabase sheets.

Table 1. Summary of analyses of selected early Mesozoic copper occurrences in Pennsylvania. Data from Smith and others (1988, p. 330).

[Au, gold; Ag, silver; Cu, copper; Co, cobalt; Ni, nickel; As, arsenic; Bi, bismuth; Mo, molybdenum; oz/ton, ounces per ton; ppm, parts per million; <, less than]

Deposit type	Sample numbers	Au (oz/ton)	Ag (oz/ton)	Cu (percent)	Co (ppm)	Ni (ppm)	As (ppm)	Bi (ppm)	Mo (ppm)
Cornwall-type iron-copper skarns	6, 7, 8, 9, 10, 16, 18, 20, 25, 30, 31	<0.001 - 0.11	<0.1 - 9.2	0.02 - 9.2	90 - 11,000	27 - 1,100	5 - 220	<0.1 - 1	<5 - 20
Low-iron skarns	1, 2, 3, 4, 5, 19, 22, 23	<.001 - .262	<.1 - 7.15	.04 - 8.22	<5 - 490	2 - 155	<5 - 740	<10 - 300	2 - 180
Diabase	11, 12, 13, 28	<.001 - .012	<.1	.02 - .31	30 - 100	35 - 60	3 - 60	<10	<5
Diabase veinlets	11, 12, 13, 28	<.001 - .12	<.1	.2 - .31	30 - 100	35 - 60	3 - 60	<0.1 - .2	0.1 - <5
Diabase differentiates	14, 15, 27	<.001 - .008	<.1	<.1 - .2	9 - 15	<5 - 17	<5	<10	<5
Red-bed copper	26, 29	<.001 - .006	<.1 - .13	1.02 - 1.65	6 - 15	9 - 45	<2 - 10	<10	<5



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic Projection. Standard parallels 29°30'N, central meridian 75°00'W

Geology from Miles and Whitfield (2001)

Figure 3. Types of mineral deposits in the Newark Basin, southeastern Pennsylvania.

Table 2. Arsenic-, boron-, and fluorine-bearing minerals identified in Newark Basin rocks, Pennsylvania.

Mineral	Chemical formula[1]	Occurrence
Arsenic minerals		
alloclasite	(Co,Fe)AsS	hornfels
arsenopyrite	FeAsS	diabase-hosted vein/late-stage igneous segreation deposits, hornfels
cobaltite	(Ni,Co,Fe)AsS	hornfels
erytherite	$CO_3(AsO_4)\bullet 8H_2O$	hornfels
gersdorffite	NiAsS	hornfels
safflorite	$(Co,Fe,Ni)As_2$	hornfels
Boron minerals		
datolite	$Ca_2B_2Si_2O_8(OH)_2$	Jacksonwald basalt, diabase-hosted vein/late-stage igneous segreation deposits, hornfels
ferro-axinite	$Ca_2Fe^{2+}Al_2BSi_4O_{15}(OH)$	hornfels
tourmaline group	[2]$AX_3Y_6(BO_3)_3Si_6O_{18}(O,OH,F)_4$	hornfels
Fluorine minerals		
fluorapophyllite	$KCa_4Si_8O_{20}(F,OH)\bullet 8H_2O$	hornfels
fluorite	CaF_2	hornfels

[1] From Fleischer and Mandarino (1995).

[2] Where A is Ca or Na, X is Al, Fe, Li, or Mg, and Y is Al, Cr, or Fe.

Spencer (1908, p. 13) first recognized the method of deposition of Cornwall-type ore bodies. He stated that the ores were "*formed by more or less metasomatic replacement of sedimentary rocks by iron minerals precipitated from heated solutions set into circulation by the invading diabase*." The model for ore deposition was developed by Eugster and Chou (1979). During the early Jurassic, diabase intruded the Paleozoic and Triassic rocks. Convective hydrothermal cells driven by temperature gradients were established by the intruding diabase. Fluids, consisting mostly of ground water, but including some connate brine and late-stage diabase differentiates, were set into motion. The circulating fluid coupled three spatially separated reactions: (1) formation of HCl by conversion of muscovite, quartz, and KCl to K-feldspar in the hottest, deepest part of the cell; (2) dissolution of Fe-bearing minerals; and (3) precipitation of magnetite, pyrite, and chalcopyrite in the host rock.

The heated HCl solution leached Fe, Cu, Co, and other elements to form an $FeCl_2$ solution containing some H_2S. Fe is relatively soluble in a Cl-rich solution at 500-650°C (Chou and Eugster, 1977, p. 1312-1313). The $FeCl_2$ solution flowed by convection to the host rock where magnetite, pyrite, and chalcopyrite were precipitated by neutralization. Rose and others (1985, p. 437) estimated that ore deposition occurred over the 4,000 years necessary for the diabase to cool from 600° to 350°C.

Sulfide deposition appears to be related to the cooling of the hydrothermal fluid. The late position of sulfides in the paragenetic sequence suggests that most were deposited at lower temperatures than the magnetite. The $\delta^{34}S$ of the fluid was higher than that of the sulfide minerals (Rose and others, 1985). Sulfur isotope composition of sulfide minerals from the ore body show enrichment of ^{34}S (5.4 per mil), considerably above the 0.1 per mil average $\delta^{34}S$ for diabase in the Newark basin (Smitheringale and Jensen, 1963). The sulfur isotope concentrations of the sulfide minerals in the ore body are similar to values for sulfides from nearby non-igneous rocks, indicating a non-igneous source for sulfur in the ore.

Hornfels Copper Deposits

Hornfels copper deposits commonly are associated with diabase sheets but are insignificant in terms of historical metal production; most are only mineralogical curiosities (Robinson, 1988, p. 314). These occurrences, however, are characteristically enriched in precious and other rare metals, which make them interesting from a geochemical perspective. The deposits appear to be metasomatic replacements of original calcareous siltstones and shales thermally metamorphosed to hornfels near diabase intrusive bodies. Copper is the principal metal at most of the deposits, and small amounts of Au and Ag are present in a few areas. This deposit type differs from the other deposit types by being enriched in Bi, Mo, and sometimes Sn. Chalcopyrite and bornite with, at some places, magnetite, hematite, and chalcocite in the ore zone are typically disseminated in dark-gray, fine-grained hornfels. Chrysocolla and malachite, formed by supergene alteration of the copper minerals, commonly occurs on fracture and weathered-rock surfaces.

The hornfels copper deposits either underlie or overlie the diabase sheets. Those with polymetallic metallization (Cu, Au, Ag, Mo, Bi, Sn) appear to be associated with late-stage diabase differentiates (ferrogabbro and granophyre) enriched in volatiles and copper. Ore is found in dark-colored, fine-grained, massive hornfels. The primary ore occurs in small veins and replacements and consists chiefly of chalcopyrite and bornite; chalcocite has been reported at a few places. The secondary copper minerals chrysocolla and malachite are found in most deposits. The copper minerals generally occur in the lower temperature facies of contact metamorphism, often just within the recognizable hornfels. Copper mineralization of this type associated with large diabase sheets may be separated from diabase by tens to hundreds of feet of unmineralized hornfels. The mineralized zones may be fractured, vuggy, or faulted.

Large bodies of late-stage differentiates enriched in volatile and incompatible elements were involved in the formation of auriferous hornfels copper deposits; these bodies occur in local areas of much larger diabase sheets, apparently as a result of processes promoting lateral and vertical migration of residual fluids. Near their solidus temperature, these late-stage differentiates may have released a chlorine-rich fluid from the magma enriched in Cu, Fe, Au, and other trace metals. Ground-water hydrothermal cells set up by cooling diabase also may have provided additional Cu and other metals. Fracturing of the host rock promoted and focused fluid flow. The hornfels copper deposits appear to differ from the magnetite skarn deposits in being formed from solutions of lower oxygen fugacity and temperature than those from which the magnetite skarns formed (Robinson, 1988, p. 315).

Diabase-Hosted Vein and Late-Stage Igneous Segregation Deposits

The few diabase hosted vein deposits are largely mineralogical curiosities as the amount of mineralized rock is small and not of economic importance. Vein occurrences of this type are not unusual in diabase sheets. They are near diabase pegmatite or segregation veins commonly found in the upper part of diabase sheets (Robinson, 1988, p. 315-316). Most veins occur in diabase and may be either parallel or crosscut igneous layering (Shannon, 1926); some veins are in shear zones or rock adjacent to diabase. The veins appear to have been formed by hydrothermal fluids derived from late-stage differentiates. The significance of this type of deposit is that it may be genetically linked to hornfels copper deposits. Most deposits have been prospected for Au, Ag, or Cu. In most cases, Au and Ag concentrations are low; however, anomalous concentrations of Au, Ag, As, and Co have been reported. Chalcopyrite and pyrite typically are the most abundant sulfide minerals, but trace amounts of bornite, galena, native silver, arsenopyrite, and sphalerite have been reported.

The vein deposits appear to be associated with pegmatitic phases of diabase that grade into ferrogabbro or granophyre. They commonly are near the periphery of the upper part of diabase sheets but may occur in shear zones or fracture zones anywhere in the sheet. Mineralization also may be associated with miariolitic cavities developed from fluids evolved from the enclosing ferrogabbro or granophyre. Diabase near the veins is bleached and shows alteration of hypersthene to chlorite and intermediate plagioclase to pink orthoclase. Common vein minerals, such as chlorite, epidote, datolite, prehnite, calcite, and zeolite minerals, are characteristic of low temperature hydrothermal alteration of diabase.

The diabase-hosted vein deposits are associated with segregations of late-stage diabase differentiates enriched in incompatible elements. The vein mineralization apparently is related to the evolution of hydrothermal fluids from these late-stage differentiates near their solidus temperature as evidenced by mineralization both in miariolitic cavities and crosscutting veins. The deposition of sulfides probably is related to cooling of the hydrothermal fluid. The source of the metals and sulfur presumably is the residual diabase differentiates. Fracturing of the host rock promoted and focused fluid flow (Robinson, 1988, p. 316).

Sediment-Hosted and Stratabound Replacement Deposits

Sediment hosted and stratabound replacement deposits of Cu and Zn are found in fluvial sandstones and lacustrine mudstones. They are introduced into the host rocks after sedimentation by flowing subsurface Cl-rich water approximately in equilibrium with hematite, quartz, feldspar, and mica at temperatures of less than about 75°C. Precipitation of Cu as a sulfide is caused by the metal-rich fluid encountering a reducing environment; the Cu-sulfides are precipitated as sulfate is reducted or by replacement of pyrite (Rose, 1976). The origin of mineralizing fluids and the timing of their introduction is unknown. Sandstone deposits are Cu rich and typically also are enriched in Ag and in, places, U; they are associated with areas rich in organic debris contained in the rocks. Black mudstone hosted deposits are Cu and (or) Zn rich and occur, in general, as stratabound disseminations or stratabound discordant veinlets and replacements (Smoot and Robinson, 1988, p. 356-357).

The Cu-rich zones are stratabound but lenticular and may cut across sedimentary layering. The mineralized zones are characteristically associated with redox interfaces in the sedimentary sections, with typical reductants being plant fossil debris and sometimes pyrite or thermally metamorphosed rocks. The primary sulfide minerals are chalocite and pyrite. In some places bornite, chalcopyrite, native copper, or covellite may be primary or secondary minerals. Native silver, galena, sphalerite, and various arsenic, cobalt, nickel, and molybdenum minerals also may occur in small amounts. Secondary supergene minerals malachite, azurite, and chrysocolla are common and sometimes coat weathered surfaces or impregnate fractures with conspicuous color. Base-metal minerals in the fluvial sandstones from surface outcrops consist mainly of malachite and chrysocolla filling intergranular spaces or coating carbonized wood. These minerals are interpreted as weathering products of copper sulfides that replaced woody debris and partially filled intergranular spaces. The ores have extreme copper enrichment and also are enriched in Ag and Ba and slightly enriched in Sr but not enriched in Zn and Pb relative to the representative unmineralized sandstones (Smoot and Robinson, 1988, p. 357-358).

Evaporites

Accumulations of non-marine evaporites may form where the evaporation rate exceeds inflow, where inflow is sufficient to supply solutes, and where the inflow accumulates in a closed basin (Langbien, 1961). These conditions were met numerous times during the deposition of Newark Basin sediments. Evaporite minerals typically found in non-marine evaporites include a large number of borate and sulfate minerals (Smoot and Lowenstein, 1991, p. 198). Barite (barium sulfate) is an evaporite mineral.

El Tabakh and others (1998) in a study of cores from the Passaic Formation in New Jersey (Brunswick Group in Pennsylvania) found that evaporite minerals generally are absent at depths to about 330 ft below land surface because of dissolution by ground-water flushing. From about 330 to 1,000 ft below land surface, gypsum is present as post-depositional fracture fillings. Below the zone of fracturing (greater than about 1,000 ft below land surface) considerable quantities of anhydrite (up to 15 percent of rock volume) are present in nodular forms, finely disseminated cement, pore filling, and psuedmorphs after the precursor evaporite minerals gypsum, glauberite, and thenardite. The gypsum-filled fractures were derived by dissolution of anhydrite by meteoric water and connate brine, subsequent transport of gypsum-saturated brines, and recrystallization in fractures; the gypsum, therefore, is not an evaporite mineral but a chemically re-mobilized sulfate.

Cummings (1988) proposed that the deposition of copper minerals in and adjacent to basalts in New Jersey was the result of fluids migrating out of highly oxidized red beds into fractures in the basalt. These fluids were connate brines trapped in Newark Basin sediments that originated in sulfate-rich playas. Glauberite was the dominant evaporite mineral, and anhydrite was the dominant saline mineral. Cummings (1988, p. 145) proposed datolite as a possible indicator that the Newark Basin sediments were the source of the mineralizing fluids. Datolite contains 4,000 times the amount of boron found in basalt and originated in the clay-rich sediments of the Newark Basin. Cummings (1988, p. 145) also states that it is possible that the evaporites in the Newark Basin sediments contained soluble borates and that their dissolution added boron to the connate water.

Sloto and Davis (1983, p. 45) correlated elevated sulfate concentrations in ground water with elevated calcium concentrations suggesting they were the result of circulating ground water leaching gypsum and (or) anhydrite from the formation. A water sample collected by Sloto and others (1996, p. 44-46) with an elevated sulfate concentration (500 mg/L) also contained elevated calcium (180 mg/L) and strontium (5,000 μg/L).

Ground-Water System

Ground water in the Newark Basin originates from infiltration of local precipitation through soil and saprolite to fractured bedrock. After recharge, ground water moves through vertical and horizontal fractures in the rocks and ultimately discharges to streams, springs, and to pumping wells. The sedimentary rocks in the basin (mainly shales and sandstones) form layered fractured-rock aquifers. Ground-water flow in this leaky, semi-confined, multi-aquifer system may follow complex pathways through fracture networks and bedding planes and commonly has been described as anisotropic, with predominant flow in the direction of strike (Vecchioli and others, 1969, p. 154).

The diabase that intrudes the sedimentary rocks generally is less permeable and more resistant to erosion than the host sedimentary rocks. Consequently, the diabase forms a low-yielding aquifer that underlies hilltops. Ground-water flow in the diabase aquifers is thought to be relatively shallow because the depth of fracturing rarely exceeds 150 ft (Sloto and Schreffler, 1994, p. 17) and some ground water may discharge locally in springs along hillsides underlain by the diabase or near the contact between diabase and adjacent rocks. Away from the edge of the diabase sheets, little or no hydraulic connection generally exists between the diabase and underlying sedimentary rocks (Sloto and Schreffler, 1994).

Primary porosity is very low or nonexistent in the fractured-rock aquifers. Permeability and storage are very low. Ground water in rocks may be under confined, unconfined, and (or) perched conditions. Ground water in the uppermost part of the aquifers may be under unconfined (water-table) conditions; ground water in the deeper part of the aquifers may be confined or partially confined, resulting in local artesian conditions. Recharge rates average about 8 in/yr (Sloto and Schreffler, 1994). The hydrology of the diabase and sedimentary rocks in the Newark Basin in Pennsylvania is described further by Sloto and Schreffler (1994).

Ground water acquires its chemical composition through dissolution of aquifer minerals or other weathering reactions. In addition, anthropogenically introduced constituents associated with various land uses may infiltrate to the ground-water system. In fractured-rock aquifers, ground-water quality can vary spatially in the vertical and horizontal directions over short distances because of differences in the aquifer materials and chemical processes along complex flow paths.

Arsenic, Boron, and Fluoride in Ground Water

Naturally occurring mineral sources for arsenic, boron, and fluoride are known to be present in areas of the Newark Basin. Elevated concentrations of arsenic, boron, and fluoride in ground water may be related to the distribution of such minerals in the aquifer materials and a geochemical environment that promotes release of these constituents into ground water by mineral dissolution or desorption from mineral surfaces. Anthropogenic sources of arsenic include pesticides and treated wood products (fences, posts) (Welch and others, 2000). Common anthropogenic sources of boron are laundry detergents or additives. Anthropogenic sources of fluoride in ground water include phosphate fertilizers and industrial releases of hydrofluoric acid. Fluoride is sometimes added to public supplies of drinking water to reduce dental decay.

Geochemical Controls on Arsenic, Boron, and Fluoride in Ground Water

The solubility of arsenic-, boron-, and fluorine-bearing minerals and subsequent aqueous mobility of dissolved arsenic, boron, and fluoride species vary and depend in part upon the pH, oxidation-reduction potential, presence of complexing agents and competing ions in the ground water, and the type and availability of sorption sites in the aquifer materials. Arsenic commonly occurs in two valence states (As^{+3} and As^{+5}) and, therefore, the form of arsenic and its solubility is sensitive to the oxidation-reduction potential of the ground water. Arsenate (AsO_4^{-3}) and arsenite ($H_nAsO_3^{n-3}$) are the predominant inorganic dissolved species of arsenic (Hem, 1985). Arsenate is formed from the more oxidized state of arsenic, As^{+5}, and arsenite is formed from the less oxidized state of arsenic, As^{+3}. Sorption of arsenic species on iron hydroxides, which is pH dependent, is a major control on arsenic in ground water (Pierce and Moore, 1980). Phosphate can compete with arsenate for sorption sites and, thus, result in increased arsenic mobility.

Boron and fluoride have one valence state, and their solubility is not directly related to the oxidation-reduction potential of the ground water. Boric acid (H_3BO_3) is the main form of dissolved boron and largely is present as an uncharged ion in waters with pH below 9.2 (Hem, 1985). Dissolved boron generally is mobile in most naturally occurring ground waters. Fluoride (F^-), a monovalent anion, is the predominant form of dissolved fluorine. Like boron, fluoride generally is mobile in ground water. Fluoride may replace the hydroxy ion (OH^-) in some cases and, therefore, might be expected to be partly removed from solution by some clay minerals.

Elevated concentrations of arsenic in ground water have been found where reductive dissolution of iron hydroxides occurs or where pyrite is dissolving in oxidizing conditions (Smedley and Kinniburgh, 2002). Elevated concentrations of arsenic, boron, and fluoride have been found in geothermal waters and in closed arid basins (Smedley and Kinniburgh, 2002). Recent work by Serfes (2005) indicates that elevated concentrations of arsenic in ground water in red shales of the Newark Basin may be associated with pH-related desorption from iron oxides and clays. Elevated concentrations of boron have been found in ground water in altered basalts where the borosilicate mineral datolite was present (Allen and others, 1996). These occurrences of elevated arsenic, boron, and fluoride in ground water have similarities to the past or present hydrogeologic setting of the Newark Basin.

Review of Available Data

A review of data collected prior to 2004 by USGS, PADEP, and USEPA on the concentration of arsenic, boron, and fluoride in ground water in the Newark Basin indicates that more is known about the distribution of arsenic than the distribution of boron and fluoride. Data on ground-water composition collected by these agencies varied by agency and by project. Most samples collected by PADEP and USEPA were analyzed for total concentrations of constituents. Most samples collected by USGS were analyzed for dissolved concentrations of constituents. Data from PADEP mainly were obtained from two sources: an ambient ground-water-quality sampling program, which includes samples that probably have undergone no treatment; and a public-supply drinking-water sampling program, which may or may not include samples that have undergone treatment. Data from USGS generally are for untreated ground-water samples. Data from USEPA are from areal assessments near suspected sources of anthropogenic contamination and consist of background and site-affected ground-water samples that may or may not have undergone treatment.

Arsenic

Data on arsenic concentrations in ground water in the Newark Basin in southeastern Pennsylvania indicate that the highest reported concentrations range from 40 to almost 70 µg/L, as shown in tables 3-6 that list the maximum arsenic concentrations in datasets from USEPA, USGS, and PADEP. On the basis of these data, about 10 percent of all wells in the Newark Basin in Pennsylvania are estimated to have ground-water concentrations of arsenic greater than or equal to 10 µg/L. Some local areas in the Newark Basin appear to have a larger percentage (more than 10 percent) of wells with arsenic concentrations greater than or equal to the MCL of 10 µg/L. For example, intensive sampling by the USEPA in the area near the Watson-Johnson Superfund site near Richlandtown and Quakertown, Bucks County (J. Kelly, U.S. Environmental Protection Agency, written commun., 2004) indicates that almost 30 percent of the well-water samples contained total arsenic in concentrations greater than or equal to 10 µg/L (table 3) and that the arsenic is probably not directly related to contaminants at the site.

Table 3. Summary of U.S. Environmental Protection Agency data on arsenic concentrations in water samples from residential wells in Newark Basin rocks at or near contamination sites, southeastern Pennsylvania.

[μg/L, micrograms per liter; ≥, greater than or equal to; nd, not detected and detection limit unknown; <, less than]

Location of data	Number of wells sampled	Range of sample dates	Arsenic concentration, in μg/L[1]				Number (percent) of samples with arsenic ≥ 10 μg/L
			Minimum	Median	90th percentile	Maximum	
Watson-Johnson area	122	2002 - 2003	nd	5.2	30	41	34 (27.9)
Congo Road area	141	1999 - 2000	<.5	<10	11.9	55.9	17 (12.1)

[1] For wells with more than one sample, the most recent sample was used to calculate summary statistics.

Table 4. Summary of U.S. Geological Survey data on dissolved arsenic concentrations in ground water by geologic unit for Newark Basin and other rocks, southeastern Pennsylvania, 1973-2001.

[μg/L, micrograms per liter; ≥, greater than or equal to; <, less than]

Geologic unit	Number of wells sampled	Arsenic concentration, in μg/L				Number (percent) of samples with arsenic ≥ 10 μg/L
		Minimum	Median	90th percentile	Maximum	
Diabase	13	<1	<1	3	13	1 (7.6)
Brunswick Group	47	<1	3	6	28	3 (6.4)
Lockatong Formation	22	<1	1	7	11	1 (4.5)
Stockton Formation	84	<1	1	6	69	3 (3.6)
Hammer Creek Formation	6	<1	<1	2.5	3	0 (0.0)
All Newark Basin units	172	<1	1	6	69	8 (4.7)
Other units[1]	395	< .2	<1	1	10	1 (0.3)

[1] Precambrian and Paleozoic units in Berks and Chester Counties, Pa.

Table 5. Summary of Pennsylvania Department of Environmental Protection data on arsenic concentrations in ambient network well-water samples by geologic unit for Newark Basin rocks, Bucks and Montgomery Counties, Pennsylvania, 1985-2001.

[μg/L, micrograms per liter; ≥, greater than or equal to; <, less than; --, insufficient data to calculate statistic]

Geologic unit	Number of wells sampled	Arsenic concentration, in μg/L				Number (percent) of samples with arsenic ≥ 10 μg/L
		Minimum[1]	Median	90th percentile	Maximum	
Diabase	23	<4	<4	5.7	22	1 (4.3)
Brunswick Group	83	<4	<4	8.8	46	7 (8.2)
Lockatong Formation	24	<4	<4	6.1	6.8	0 (0.0)
Stockton Formation	31	<4	<4	4.2	4.5	0 (0.0)
Quartz Conglomerate	3	<4	<4	--	<4	0 (0.0)

[1] Statistics for average concentration of samples from each well.

Table 6. Summary of Pennsylvania Department of Environmental Protection data on arsenic concentrations in water samples from public drinking-water supplies with ground-water sources by geologic unit for Newark Basin rocks, southeastern Pennsylvania, 1993-2003.

[µg/L, micrograms per liter; ≥, greater than or equal to; <, less than]

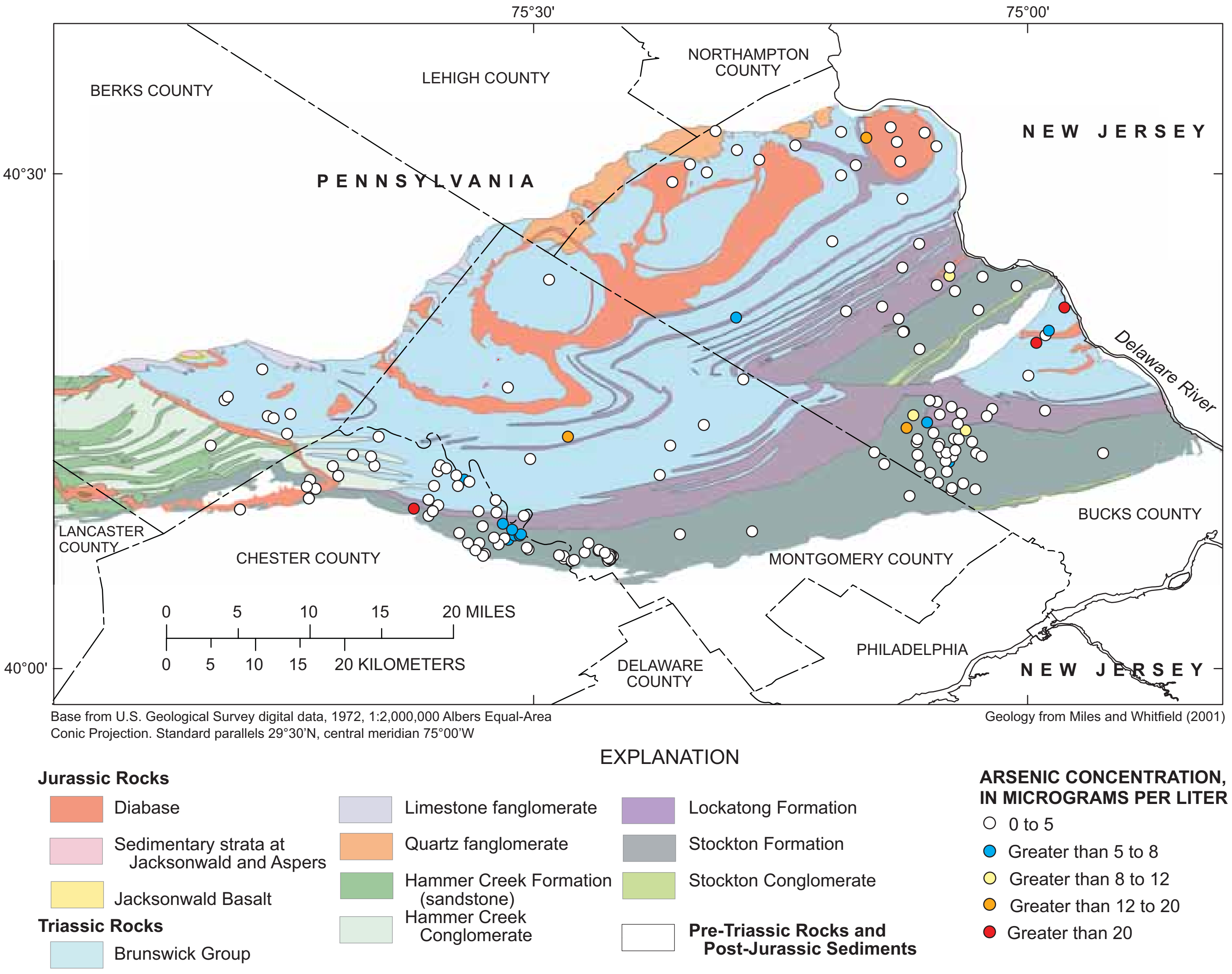
Geologic Unit	Number of systems sampled	Number of entry points[1] sampled	Total number of samples	Arsenic concentration, in µg/L				Number (percent) of entry points with average arsenic concentration≥ 10 µg/L
				Minimum[2]	Median	90th percentile	Maximum	
Diabase	10	11	19	0	5	5	8	0 (0.0)
Brunswick Group	100	164	439	0	5	15	33	42 (25.6)
Lockatong Formation	17	20	55	2	5	20	23	6 (30.0)
Stockton Formation	25	35	54	0	4	14	40	4 (11.4)
Hammer Creek Formation	11	15	55	<.2	0	2	2	0 (0.0)
Limestone Fanglomerate	4	5	10	0	0	0	6	0 (0.0)

[1] Point of entry from source to system; for ground water, source usually is a well.

[2] Statistics for average arsenic concentration at entry points.

Data on arsenic concentrations in ground water near other contamination sites in the Newark Basin indicate that concentrations in the range of 4-10 µg/L were common and were as high as 22 µg/L in ground-water samples in the vicinity of North Penn Area 6 Superfund site, Lansdale, Montgomery County, Pa. (Black&Veatch, 1998), 16.7 µg/L in ground-water samples in the vicinity of the North Penn Area 12 Superfund site, Worcester Township, Montgomery County, Pa. (CH2M Hill, 1996), and 15.6 µg/L in ground-water samples in the vicinity of the Salford Quarry Superfund site (A. Alexander, U.S. Environmental Protection Agency, written commun., 2003). The North Penn Area 6 and the Salford Quarry sites are underlain by rocks of the Brunswick Group and the North Penn Area 12 site is underlain by the Lockatong Formation. Arsenic is not thought to be a site-related contaminant at any of the three Superfund sites.

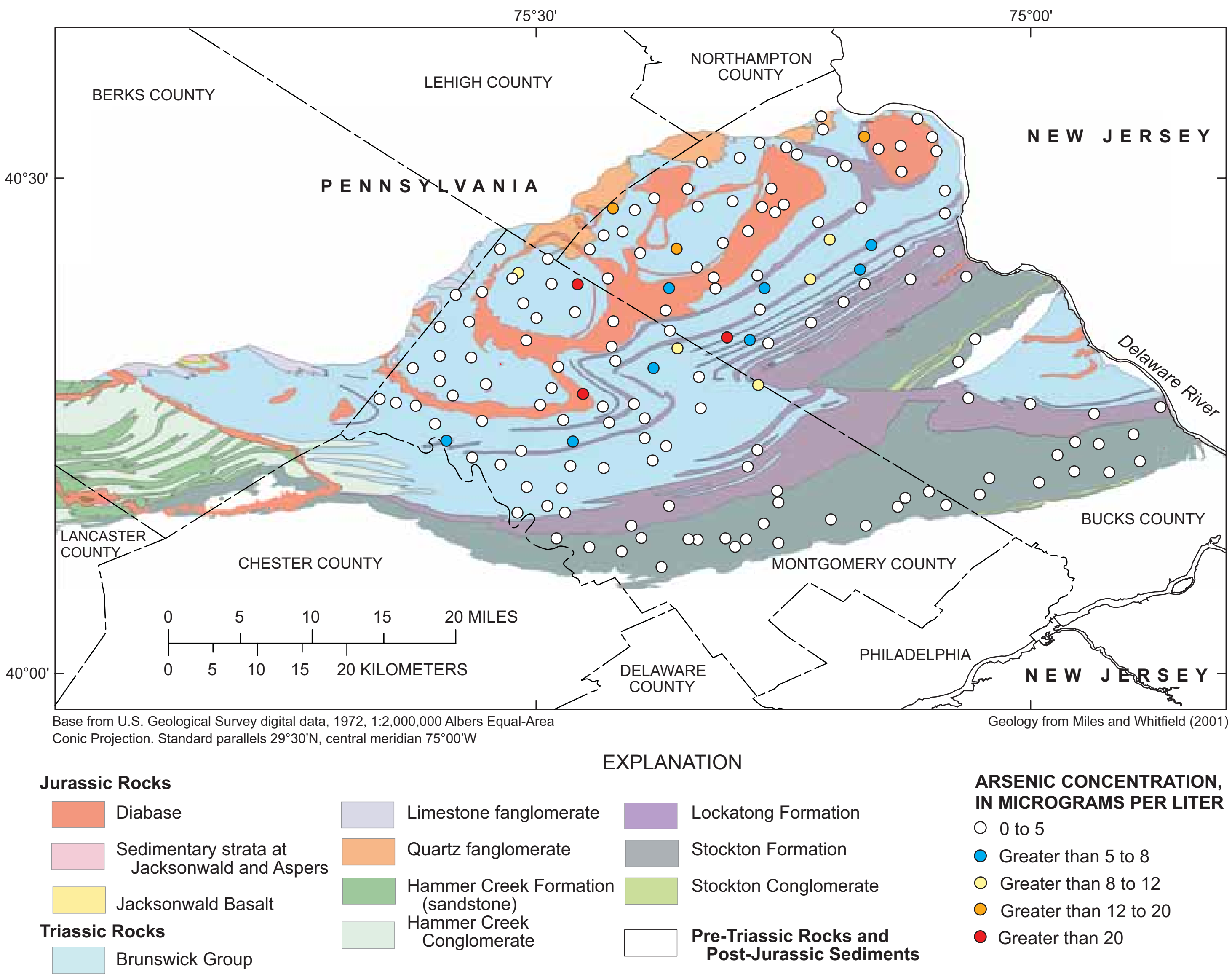
Overall, arsenic concentrations in ground water in the Newark Basin rocks of southeastern Pennsylvania were higher than in adjacent geologic terranes (Precambrian and Paleozoic rocks) in the region based on data collected by USGS (table 4). Arsenic concentrations in Newark Basin well-water samples collected by USGS (fig. 4) and PADEP (fig. 5) are summarized by geologic formation in tables 4 and 5. For wells with more than one sample, the most recent result was included in the analysis. Arsenic concentrations in water samples from entry points to public drinking-water systems supplied by ground water (fig. 6) are summarized in table 6. Data on arsenic concentrations indicate that highest reported concentrations were in ground-water samples from wells in the Brunswick Group and Stockton Formation. Although the highest arsenic concentration in the Newark Basin (69 µg/L) was reported for a sample from a well in the Stockton Formation, a smaller percentage of water samples exceeded 10 µg/L of arsenic from wells in the Stockton Formation than from wells in the Brunswick Group and Lockatong Formation (tables 4-6).



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic Projection. Standard parallels 29°30'N, central meridian 75°00'W

Geology from Miles and Whitfield (2001)

Figure 4. Location of wells sampled by the U.S. Geological Survey for arsenic and magnitude of dissolved arsenic concentrations in ground water in Triassic-Jurassic rocks, Newark Basin, southeastern Pennsylvania, 1973-2001.



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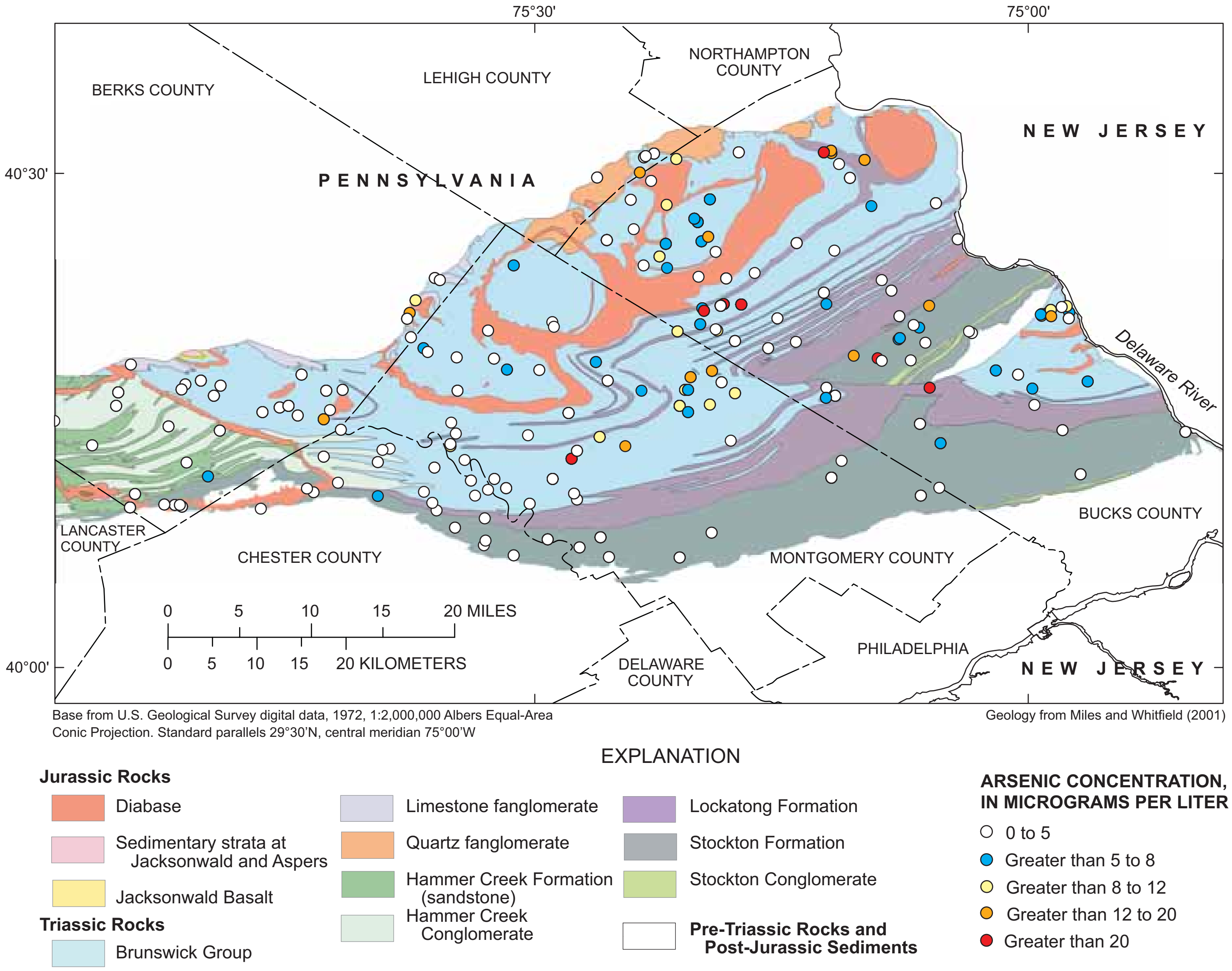
Geology from Miles and Whitfield (2001)

Figure 5. Location of wells sampled by the Pennsylvania Department of Environmental Protection for arsenic and magnitude of total arsenic concentrations in ground water in ambient ground-water quality network in Triassic-Jurassic rocks, Bucks and Montgomery Counties, Newark Basin, southeastern Pennsylvania, 1985-2001.



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic Projection. Standard parallels 29°30'N, central meridian 75°00'W

Geology from Miles and Whitfield (2001)

Figure 6. Location of wells sampled by the Pennsylvania Department of Environmental Protection for arsenic and magnitude of total arsenic concentrations in public drinking-water supplies relying on ground water in Triassic-Jurassic rocks, Newark Basin, southeastern Pennsylvania, 1993-2003.

Boron

Water samples from relatively few wells in the Newark Basin in southeastern Pennsylvania have been analyzed for boron, and, therefore, knowledge of the distribution of boron in ground water is limited. Most samples in the region were collected by USGS (fig. 7). Boron concentrations in well-water samples collected by USGS are summarized by geologic unit in table 7. For wells sampled more than once, the most recent result was used in the analysis. The highest boron concentration was 60 µg/L (table 7), although a concentration of 250 µg/L was reported by USGS for sample from a well completed in Newark Basin rocks in New Jersey (Durlin and Schaffstall, 2001). On the basis of the few data collected by USGS, natural background concentrations of boron in ground water in these rocks generally are less than about 50 µg/L, and concentrations greater than 50 µg/L may indicate contamination from anthropogenic sources or unusual natural occurrences. These data suggest that less than 10 percent of well-water samples in the Newark Basin would be expected to have boron concentrations greater than 50 µg/L (table 7). In some areas, however, boron concentrations appeared to be locally elevated. Boron concentrations in residential-well samples collected by USEPA were as high as 5,200 µg/L in the Congo Road area, where median boron concentrations were at least 10 times greater than median boron concentrations in samples collected in the Brunswick Group and other units elsewhere in the Newark Basin (table 8). In the Congo Road area, water from 87 of 95 residential wells sampled (about 90 percent) had boron concentrations greater than or equal to 50 µg/L. Concentrations of boron greater than 250 µg/L have been reported only in the Congo Road area and in a water sample from a 3,500-ft deep well in the Triassic sedimentary rocks of the Gettysburg Basin in York County, Pa., which had 2,700 µg/L of dissolved boron and was a brine in composition (Wood, 1980).

Table 7. Summary of U.S. Geological Survey data on dissolved boron concentrations in ground water by geologic unit for Newark Basin and other rocks, southeastern Pennsylvania, 1973-2000.

[µg/L, micrograms per liter; ≥, greater than or equal to; <, less than; --, insufficient data to calculate statistic]

Geologic unit	Number of wells sampled	Boron concentration, in µg/L				Number (percent) of samples with boron ≥ 50 µg/L
		Minimum[1]	Median	90th percentile	Maximum	
Diabase	2	<20	--	--	40	0 (0.0)
Brunswick Group	20	<20	21	60	60	2 (10.5)
Lockatong Formation	3	20	20	--	50	1 (33.3)
Stockton Formation	15	<10	<20	40	50	1 (6.6)
Hammer Creek Formation	4	<20	<20	<20	<20	0 (0.0)
All Newark Basin units	44	<10	20	45	60	4 (9.8)
Other units[2]	215	<10	<20	40	[3]200	18 (8.4)

[1] Statistics for most recent sample from wells with more than one sample.

[2] Precambrian and Paleozoic units in Berks, Bucks, and Chester Counties, Pa.

[3] Excludes sample containing 20,000 µg/L of boron that was collected downgradient from known contaminant source.

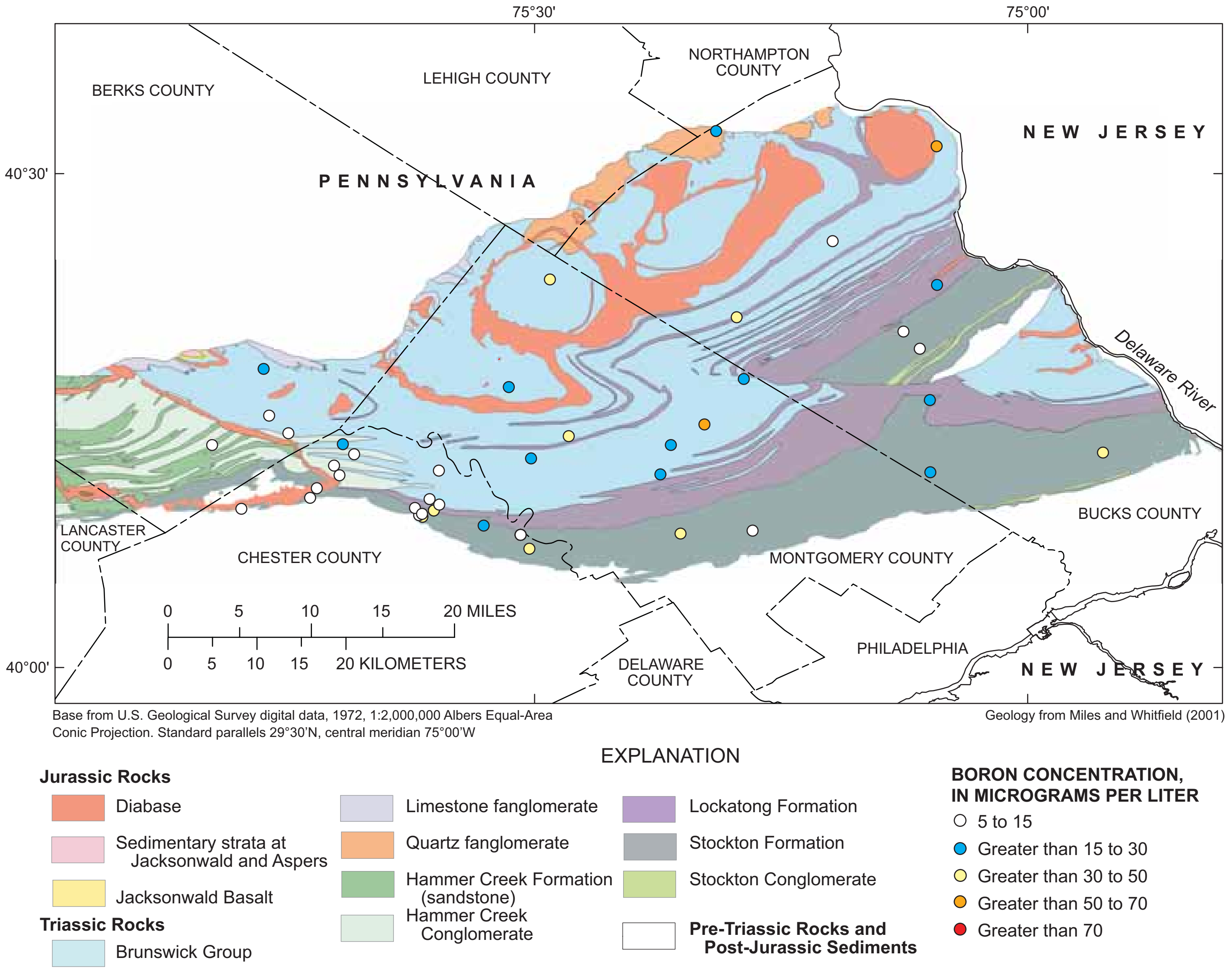
Table 8. Summary of U.S. Environmental Protection Agency data on boron concentrations in residential and industrial facility well-water samples near Congo Road, Gilbertsville Area, Montgomery County, Pennsylvania, 2000.

[µg/L, micrograms per liter; ≥, greater than or equal to; <, less than]

Sample type	Number of wells sampled	Boron concentration, in µg/L				Number (percent) of samples with boron ≥ 50 µg/L
		Minimum[1]	Median	90th percentile	Maximum	
Residential wells with quantified boron in sample[2]	95	30.9	215	1,120	5,210	88 (91.7)
Industrial Facility wells	10	<31.1	587	2,290	5,830	8 (80.0)

[1] Statistics for most recent sample from wells with more than one sample.

[2] Sample data set does not include 29 results reported with less than values: 18 samples with <500 µg/L; 1 sample with <200 µg/L; 4 samples with 31.1 µg/L; 5 samples with <25 µg/L; and 1 samples with <20 µg/L.



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Geology from Miles and Whitfield (2001)

Figure 7. Location of wells sampled by the U.S. Geological Survey for boron and magnitude of dissolved boron concentrations in ground water in Triassic-Jurassic rocks, Newark Basin, southeastern Pennsylvania, 1973-2000.

Fluoride

Data on fluoride concentrations in ground water in the Newark Basin in southeastern Pennsylvania indicate that highest reported concentrations ranged from 2 to 4 mg/L, as shown in tables 9-11 that list the maximum fluoride concentrations in datasets from USGS, PADEP, and USEPA. On the basis of regional data from USGS and PADEP for public-supply systems (tables 9 and 10), about 10 to 25 percent of all wells in Newark Basin rocks in Pennsylvania were estimated to have ground-water concentrations of fluoride greater than or equal to 0.3 mg/L (300 µg/L). Natural background concentrations of fluoride in ground water in rocks adjacent to the Newark Basin typically are less than 0.3 mg/L (table 9). Some local areas in the Newark Basin appear to have a larger percentage (more than 25 percent) of wells with fluoride concentrations greater than or equal to 0.3 mg/L, such as the industrial facility near Congo Road (table 11).

Table 9. Summary of U.S. Geological Survey data on dissolved fluoride concentrations in ground water by geologic unit for Newark Basin and other rocks, southeastern Pennsylvania, 1949-2002.

[mg/L, milligrams per liter; ≥, greater than or equal to; <, less than]

Geologic Unit	Number of wells sampled	Fluoride concentration, in mg/L				Number (percent) of samples with fluoride ≥ 0.30 mg/L
		Minimum[1]	Median	90th percentile	Maximum	
Diabase	17	<0.1	0.1	0.3	0.4	2 (11.8)
Brunswick Group	131	<.1	.1	.29	.9	12 (9.2)
Lockatong Formation	37	<.1	.1	.5	1.7	7 (18.9)
Stockton Formation	218	<.1	.1	.11	4.0	7 (3.2)
Hammer Creek Formation	10	<.1	.1	.1	.1	0 (0.0)
All Newark Basin units	413	<.1	.1	.2	4.0	28 (6.8)
Other units[2]	758	<.1	<.1	.2	1.7	40 (5.3)

[1] Statistics for most recent sample from wells with more than one sample.

[2] Precambrian and Paleozoic units in Berks, Bucks, Chester and Montgomery Counties, Pa.

Table 10. Summary of Pennsylvania Department of Environmental Protection data on fluoride concentrations in water samples from public drinking-water supplies with ground-water sources by geologic unit for Newark Basin rocks, southeastern Pennsylvania, 1993-2003.

[mg/L, milligrams per liter; ≥, greater than or equal to; <, less than]

Geologic Unit	Number of systems sampled	Number of entry points[1] sampled	Total number of samples	Fluoride concentration, in mg/L				Number (percent) of entry points with average fluoride concentration≥ 0.30 mg/L
				Minimum[2]	Median	90th percentile	Maximum	
Diabase	12	13	28	0	0.10	0.5	2.47	4 (30.8)
Brunswick Group	112	204	425	0	.16	.5	2.0	45 (22.1)
Lockatong Formation	32	37	88	.04	.20	.45	.91	8 (21.6)
Stockton Formation	73	113	227	.01	.12	.40	.75	28 (24.7)
Hammer Creek Formation	5	8	25	0	.01	.06	.07	0 (0.0)
Hammer Creek Conglomerate	7	9	35	0	0	.02	.05	0 (0.0)
Limestone Conglomerate	4	4	9	0	0	0	.68	1 (25.0)

[1] Point of entry from source to system; for ground water, source usually is a well.

[2] Statistics for average arsenic concentration at entry points.

Table 11. Summary of U.S. Environmental Protection Agency data on fluoride concentrations in residential and industrial facility well-water samples near Congo Road, Gilbertsville Area, Montgomery County, Pennsylvania.

[mg/L, milligrams per liter; ≥, greater than or equal to; <, less than]

Geologic Unit	Number of wells sampled	Fluoride concentration, in mg/L				Number (percent) of samples with fluoride ≥ 0.30 mg/L
		Minimum[1]	Median	90th percentile	Maximum	
Residential wells	96	<0.100	0.160	0.340	0.931	12 (12.5)
Industrial facility wells	10	<.100	.602	3.02	3.70	5 (50.0)

[1] Statistics for most recent sample from wells with more than one sample.

Fluoride concentrations in well-water samples collected by USGS and PADEP are summarized by geologic unit in tables 9 and 10, respectively. In table 9, for wells with more than one sample, the most recent result was used in the analysis, and in table 10, average fluoride concentrations in water samples from entry points to public drinking-water systems supplied by ground water are summarized. Data from USGS on fluoride concentrations in ground water in the Newark Basin in southeastern Pennsylvania indicate that relatively higher reported concentrations were in ground-water samples from areas mapped as the Lockatong Formation and as hornfels around diabase intrusions (fig. 8). Data from PADEP for drinking-water systems supplied by ground water indicate that fluoride concentrations above 0.3 mg/L occur throughout the Newark Basin (fig. 9) and in all major rock types (table 9).

Methods of Data Collection and Analysis

For this study, ground-water samples were collected and analyzed for arsenic, boron, fluoride, and other selected constituents. Sample collection and analysis was designed to investigate the spatial distribution of elevated arsenic, boron, and fluoride concentrations in ground water in selected areas and the relation of elevated concentrations of these constituents to hydrogeologic and geochemical controls. Because of the relatively small number of samples collected from wells constructed as open holes, with one or more water-bearing zones, the investigation should be considered reconnaissanced in nature.

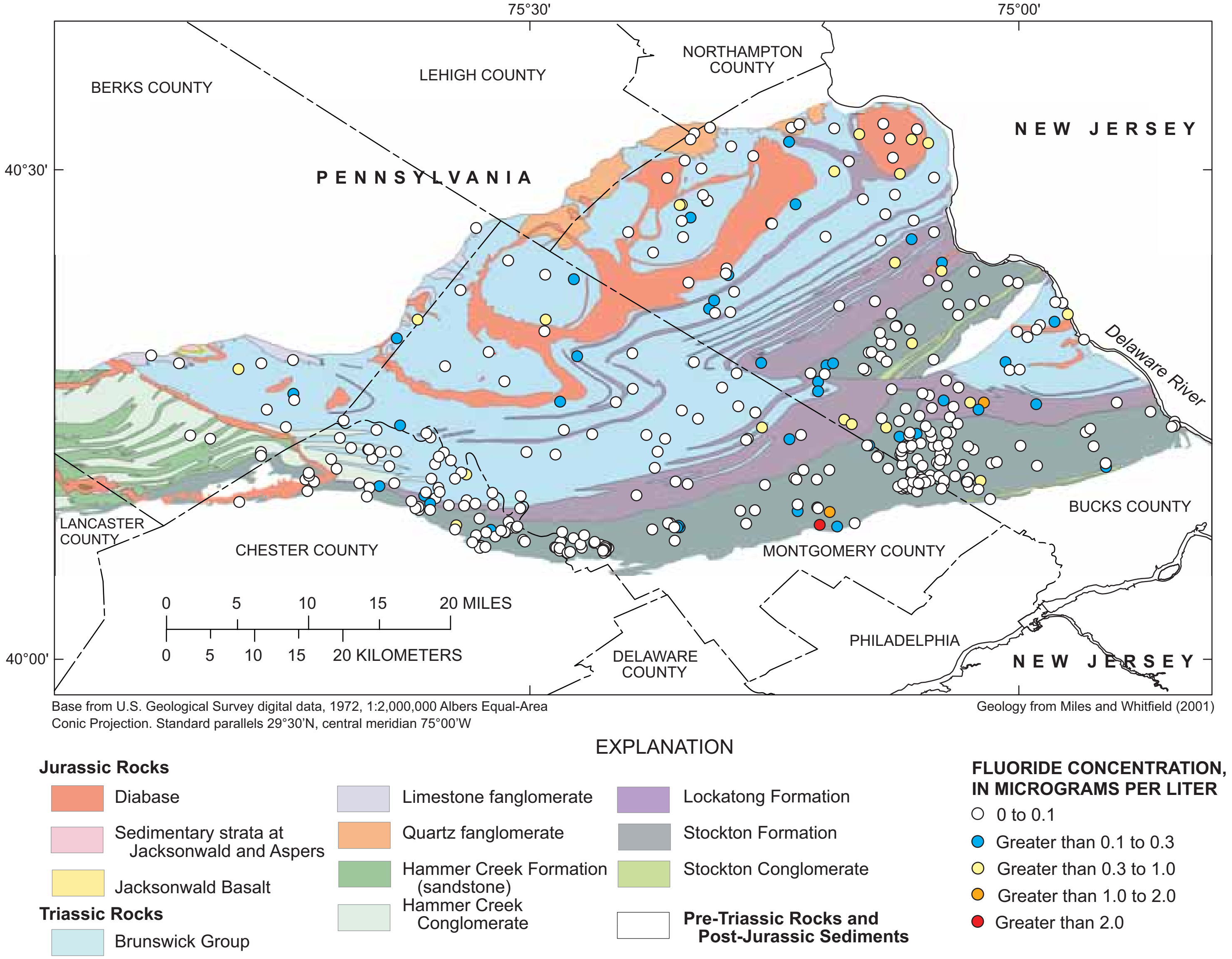
To determine whether the elevated boron concentrations in ground water previously identified in the Congo Road area in Berks and Montgomery Counties (Towle and Kelly, 2000) occurred elsewhere in similar hydrogeologic settings, ground-water quality was assessed in the Congo Road area and four other areas in the Newark Basin in Pennsylvania. The areas selected for sampling were in the vicinities of Congo Road, Jacksonwald, Kibblehouse Quarry, New Hope, and Quakertown (fig. 10). Samples primarily were collected in Berks, Bucks, and Montgomery Counties, Pa. (fig. 10), although one sample was collected in York County, Pa. The main geologic units sampled in these areas included diabase, adjacent hornfels, and shales of the Brunswick Group unaffected by thermal metamorphism. A single well in diabase near Dillsburg, York County, Pa. (fig. 1), was sampled to determine if elevated boron also might be present near where datolite, a boron-mineral, had been identified in the Mesozoic Gettysburg Basin. In most of the tables and figures in the remaining sections of the report, the single well sampled in the Gettysburg Basin is grouped with the 45 private-supply wells in the Newark Basin. Mineralization associated with diabase intrusions was documented in most areas sampled but was not a criterion used to select sampling areas, except in the Kibblehouse Quarry locality.

To assess the relation between ground-water concentrations of arsenic, boron, and fluoride and geologic unit, ground-water geochemistry, and ground-water-flow paths, wells in transects through the different geologic units were sampled in these areas. Also, samples for dissolved and total metals analysis were collected to determine if and how frequently elevated concentrations of arsenic, boron, or fluoride in ground water may be attributed to the particulate phase rather than the dissolved phase.

Ground-Water Sample Collection

Most wells sampled were private-supply wells serving individual residences; a few had other uses. A total of 58 wells were sampled from February 2004 through April 2005; of these, 46 were private-supply wells (44 residential wells, 1 irrigation well, 1 institutional well), and 12 were monitor wells at an industrial facility known to have used fluoride and boron in the Congo Road area. Data on location and characteristics of sampled wells, listed by local well number, are given in table 21 at the back of the report.

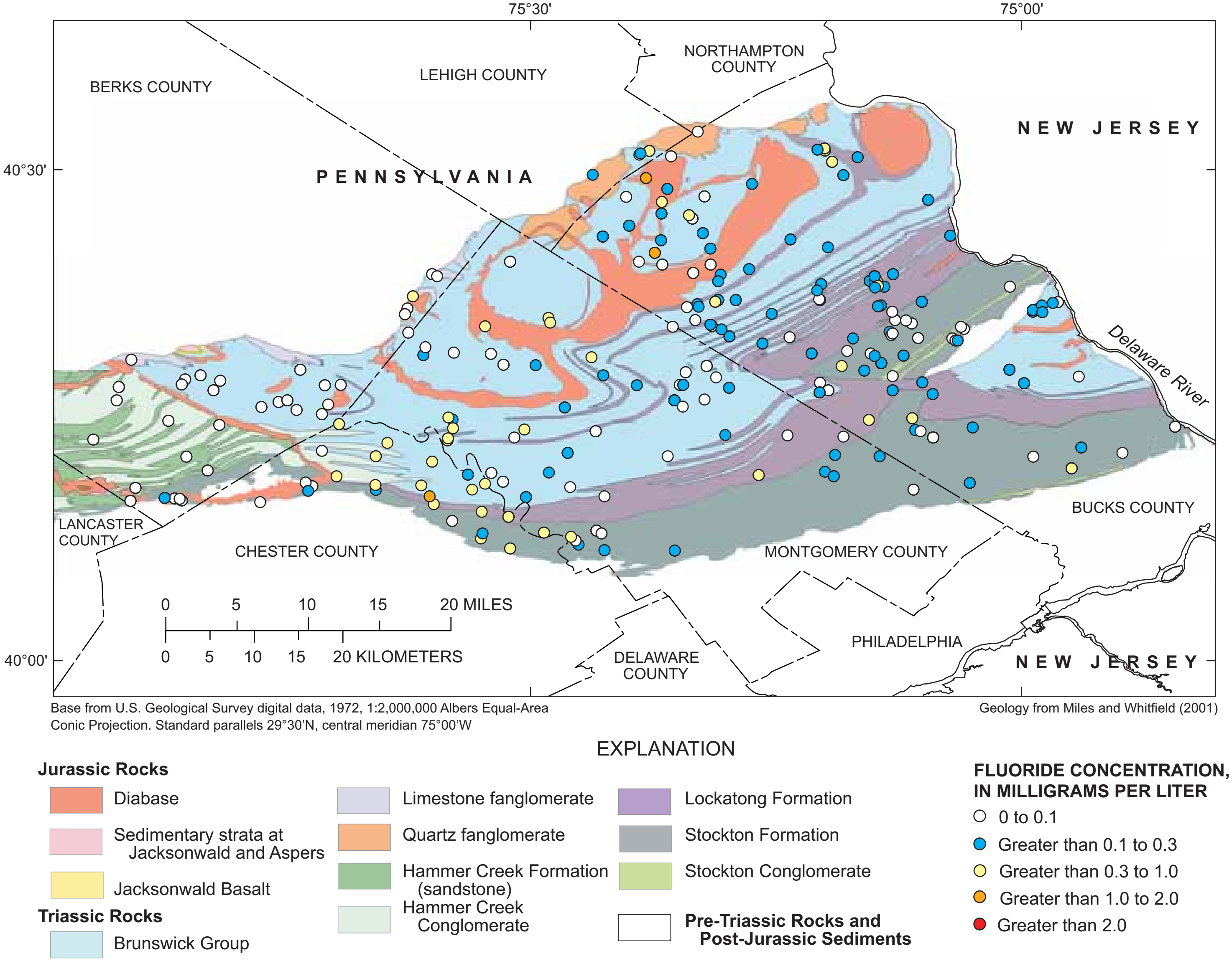
Wells were sampled using standard methods (Wilde and others, 1999). The depth to water was recorded before pumping the well, and all water-treatment systems on residential supplies were bypassed. Wells were pumped to remove standing water from the well bore and plumbing. Field measurements of pH, dissolved oxygen concentration, specific conductance, and temperature were made during pumping using a calibrated multiparameter sonde. When these constituents stabilized, samples were collected for chemical analysis. Samples from all 46 private-supply wells and from 4 of the 12 monitor wells were analyzed for selected dissolved (filtered samples) and total (unfiltered samples) trace elements to determine if concentrations in the two phases differed. Samples for dissolved constituent analysis were filtered in the field though a 0.45 μm (micron) filter, and samples for total constituent analysis were unfiltered.



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic Projection. Standard parallels 29°30'N, central meridian 75°00'W

Geology from Miles and Whitfield (2001)

Figure 8. Location of wells sampled by the U.S. Geological Survey for fluoride and magnitude of dissolved fluoride concentrations in ground water in Triassic-Jurassic rocks, Newark Basin, southeastern Pennsylvania, 1949-2002.



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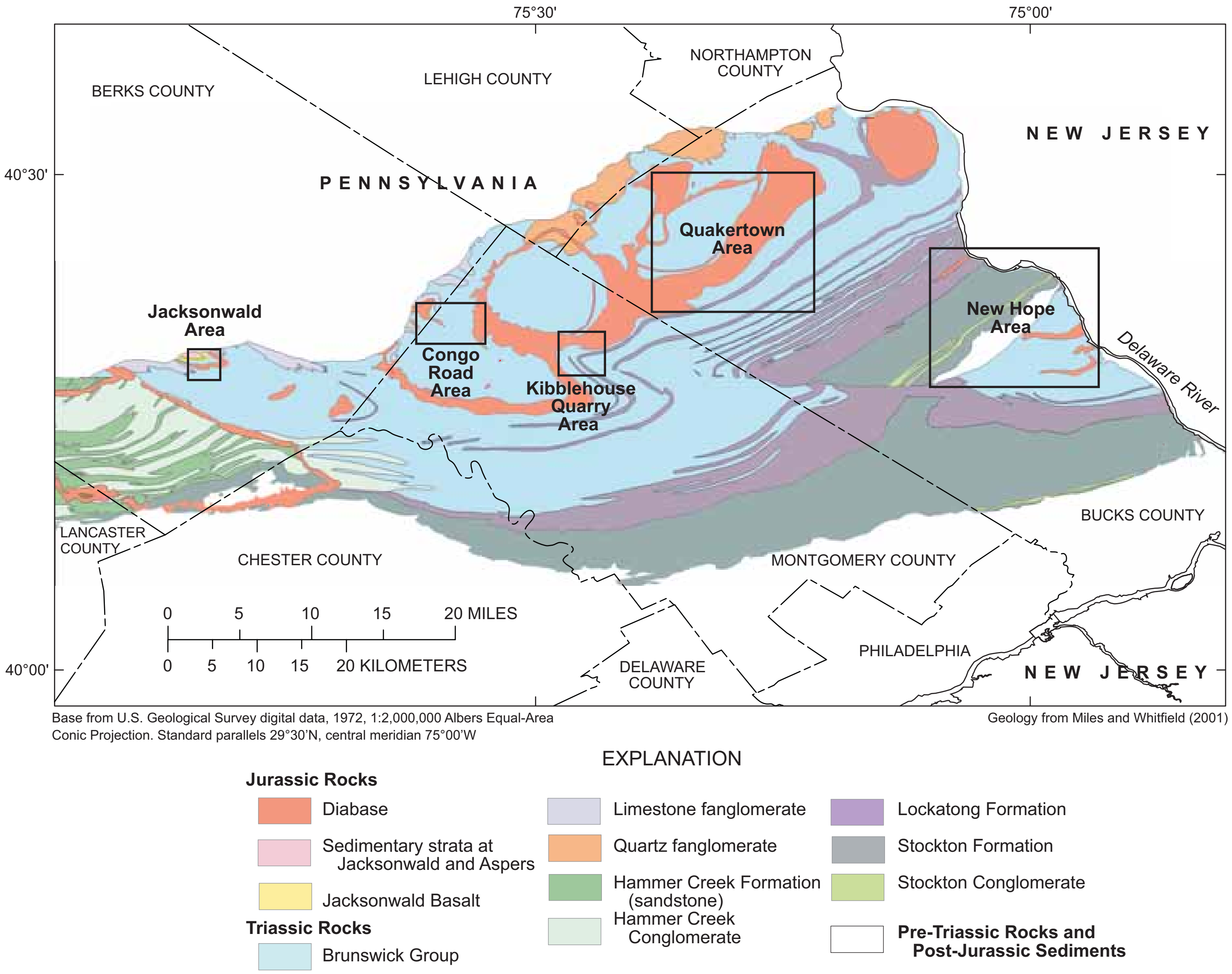
Geology from Miles and Whitfield (2001)

Figure 9. Location of wells sampled by the Pennsylvania Department of Environmental Protection for fluoride and magnitude of total fluoride concentrations in non-fluoridated public drinking-water supplies relying on ground water in Triassic-Jurassic rocks, Newark Basin, southeastern Pennsylvania, 1993-2003.



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Geology from Miles and Whitfield (2001)

Figure 10. Location of study areas sampled for arsenic, boron, fluoride, and other constituents in and near diabase rocks in the Newark Basin in Berks, Montgomery, and Bucks Counties, southeastern Pennsylvania.

Sample Analysis

Alkalinity was determined in the field by titration and the inflection-point method (Rounds and Wilde, 2001). Field measurements of pH, dissolved oxygen concentration, specific conductance, and temperature made using a calibrated multiparameter sonde were recorded at the end of the well-purge period. Water samples were analyzed by the USGS National Water Quality Laboratory (NWQL) for dissolved major ions, dissolved nutrients, selected dissolved and total trace elements, and total organic carbon (American Public Health Association, 1998; Faires, 1993; Fishman, 1993; Fishman and Friedman, 1989; Struzeski and others, 1996; Wershaw and others, 1987). The boron isotopic ratios in water samples were determined by a private laboratory, Geochemical Technology Corporation.

For quality-assurance purposes, the following water samples were collected and analyzed during the period of investigation: one pair of sequential (replicate) samples analyzed by the same laboratory; one pair of sequential (replicate) samples analyzed by the different laboratories; one equipment blank. For the set of replicates (from well BK-2199, table 22) analyzed by NWQL, the difference in reported concentrations was less than 5 percent for major ions, nutrients, and most dissolved trace elements; larger differences in concentrations were reported for some total metals analyses, including copper, iron, lead, nickel, and zinc, with higher levels overall in one of the replicates, which suggests that the samples themselves may have differed. For the set of replicates (from well MG-2103) analyzed by NWQL and a different laboratory, the difference in reported concentrations was less than 20 percent for major ions and less than 5 percent for some trace elements, including arsenic, boron, molybdenum, lithium, strontium, and uranium; larger differences in concentrations were reported for other trace elements. Results of the replicate sampling indicate that laboratory analyses are repeatable and reliable for major ions, nutrients and selected trace elements, including arsenic, boron, and fluoride but potentially are less accurate for some dissolved and total trace elements. Analytical results for the equipment blank indicate no sample contamination. In addition, a comparison of the NWQL laboratory analyses for dissolved and total metals shows that some total concentrations are reported as less than dissolved concentrations but these differences are within the methods' precision for most samples. The cation-anion balance was calculated as a check on analytical results and a measure of completeness of major-ion characterization. The error in cation-anion balance was generally smaller for the private-supply well samples than for the monitor-well samples and was positive (excess cations or insufficient anions) for 52 of the 56 well samples. The error in cation-anion balance was considered good (less than 5 percent) for 33 of 46 private-supply-well and 3 of 12 monitor-well samples and fair (5 to 10 percent) for 10 of 46 residential-well samples and 6 of 12 monitor-well samples. Three of 46 private-supply-well and 3 of 12 monitor-well samples had errors in the range of 10 to 16 percent.

One ground-water sample inadvertently was collected (from well BK-3020 in November 2004) after a water-treatment system (water softener) designed to reduce hardness (calcium and magnesium) from the water. The well BK-3020 was subsequently resampled in January 2005 after bypassing the water-treatment system. Results for both samples are listed in table 22 at the back of the report to show the effects of the water-treatment on the ground-water quality. The water-treatment system apparently removes or reduces concentrations of calcium, magnesium, potassium, lithium, selenium, strontium, zinc, and possibly uranium and dissolved iron; increases concentrations of sodium; but has little effect on the concentrations of other ions analyzed, including arsenic and boron. Results for the untreated water sample only were included in the data analysis.

Summary of Ground-Water Composition

The composition of ground-water samples in 46 private-supply wells and 12 monitor wells sampled by USGS for this study from February 2004 through April 2005 is summarized below for major ions, trace elements, and boron isotopes. These two types of samples (private-supply well and monitor well) are summarized separately because of differences in well type, land use, and possible anthropogenic influences on water quality. Results of chemical analyses for individual well-water samples are listed in table 22 at the back of the report.

Major Ions and Characteristics

Generally, the ground water had near-neutral to alkaline pH and few water-quality problems associated with major ions. Ground water in samples from the 46 private-supply wells met most USEPA drinking-water standards for pH and major ions with some exceptions for elevated pH (1 sample), elevated sulfate (2 samples), and elevated nitrate (1 sample) (table 12). Ground water in samples from the 12 monitor wells at the industrial site near Congo Road met most USEPA drinking-water standards for major ions but with a larger percentage of exceptions than in residential well samples for elevated chloride (3 samples), elevated fluoride (2 samples), elevated sulfate (3 samples), and elevated ammonia (1 sample) (table 13).

Most samples from private-supply wells were predominantly calcium-bicarbonate or calcium-plus-magnesium-bicarbonate type water as shown in the Piper diagram that depicts the relative proportion of major cations and anions (fig. 11A). Exceptions to this characterization included samples from two residential wells (BE-1765 and MG-2113) that had relatively large amounts of sulfate, samples from two residential wells (BK-3017 and BK-3023) that had relatively large amounts of sodium, and a sample from one residential well (BK-3029) that had relatively large amounts of chloride. Samples from monitor wells had a broader range of anionic water types (fig. 11B) than the private-supply-well samples. Water samples from several monitor wells had relatively large amounts of chloride (BE-1759, BE-1760, BE-1761, MG-2106, and MG-2107) and (or) sulfate (BE-1759, BE-1760, and BE-1761) (fig. 11B). Although calcium and magnesium were predominant cations for most monitor-well samples, samples from two wells (BE-1760 and MG-2106) had relatively large amounts of sodium.

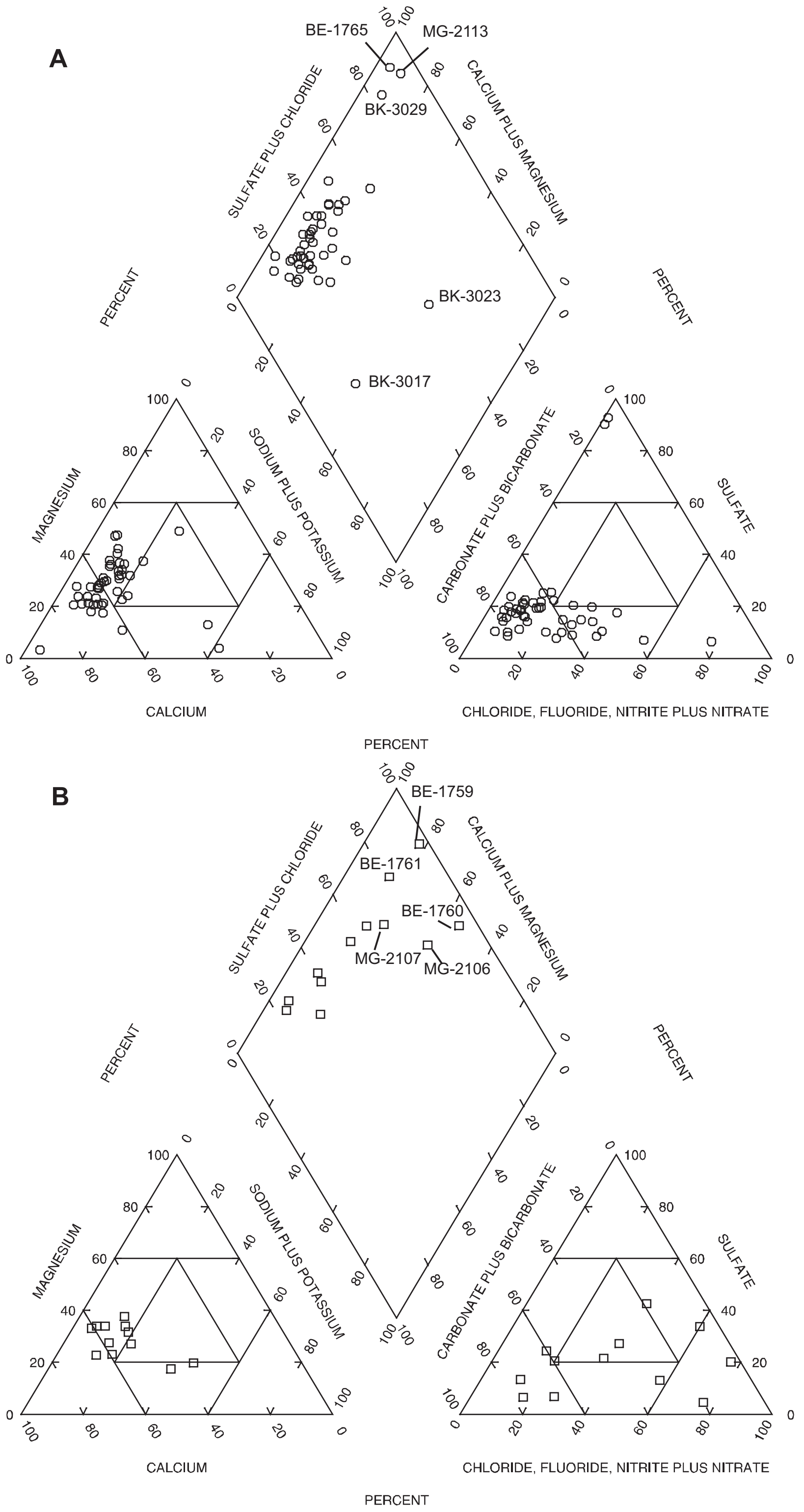

Figure 11. Piper diagram showing relative contributions of major cations and anions in water samples from (A) 46 private-supply wells and (B) 12 monitor wells in the Newark Basin, southeastern Pennsylvania, 2004-2005. Unusual compositions of selected individual well samples identified by well number.

Table 12. Minimum, maximum, and median values for selected chemical properties and concentrations of dissolved major ions and total organic carbon in ground-water samples collected from 46 private-supply wells in the Newark Basin, southeastern Pennsylvania, February 2004 - April 2005.

[MCL, maximum contaminant level; °C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; N, nitrogen, P, Phosphorus; --, no data or not applicable; < less than; E, estimated value]

Chemical property or constituent	Units	MCL or other standard[1]	Number of samples that exceed MCL or other standard	Percent of samples that exceed MCL or other standard	Minimum reporting level	Number of values less than the reporting level	Minimum	Median	Maximum
Water temperature	°C	--	--	--	--	--	11.23	12.53	16.45
pH	pH units	[2]6.5 - 8.5	1	2	--	--	6.11	7.30	9.09
Dissolved oxygen	mg/L	--	--	--	0.1	0	.14	4.5	9.7
Specific conductance	µS/cm	--	--	--	3	0	155	332	1,996
Alkalinity as $CaCO_3$	mg/L	--	--	--	2	0	41	106	247
Calcium, dissolved	mg/L	--	--	--	.02	0	12.6	39.5	382
Magnesium, dissolved	mg/L	--	--	--	.008	0	1.08	12.5	69.3
Potassium, dissolved	mg/L	--	--	--	.16	0	.20	.84	3.20
Sodium, dissolved	mg/L	--	--	--	.20	0	3.5	10.3	57.0
Chloride, dissolved	mg/L	[2]250	0	0	.20	0	1.64	7.78	180
Fluoride, dissolved	mg/L	4	0	0	[3]<.10	22	<.1	.05E	.7
Silica, dissolved	mg/L	--	--	--	.20	0	13.6	32.3	48.8
Sulfate, dissolved	mg/L	[2]250	2	4	.18	0	11.7	24.9	1,164
Ammonia, dissolved	mg/L	[4]30	0	0	<.04	45	<.04	<.04	.02E
Nitrate, dissolved as N	mg/L	10	1	2	<.06	0	.06	1.48	13.5
Nitrite, dissolved as N	mg/L	1	0	0	<.008	44	.007E	<.008	.009
Orthophosphate, dissolved as P	mg/L	--	--	--	<.018	18	<.018	.011E	.102
Organic carbon, total	mg/L	--	--	--	<.4	1	.23E	1.61	16.3

[1] U.S. Environmental Protection Agency, 2004.

[2] Secondary maximum contaminant level.

[3] Alternate minimum reporting level was less than 0.17 mg/L for 19 of the 22 samples with less than values.

[4] Life-time consumption Health Advisory drinking-water concentration.

Table 13. Minimum, maximum, and median values for selected chemical properties and concentrations of dissolved major ions and total organic carbon in ground-water samples collected from 12 monitor wells at an industrial facility near Congo Road in Berks and Montgomery Counties, Pennsylvania, March 2004.

[MCL, maximum contaminant level; °C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; N, nitrogen, P, Phosphorus; --, no data or not applicable; < less than; E, estimated value]

Chemical property or constituent	Units	MCL or other standard[1]	Number of samples that exceed MCL or other standard	Percent of samples that exceed MCL or other standard	Minimum reporting level	Number of values less than the reporting level	Minimum	Median	Maximum
Water temperature	°C	--		--	--	--	8.69	11.51	12.79
pH	pH units	[2]6.5 - 8.5	0	0	--	--	6.64	6.93	7.36
Dissolved oxygen[3]	mg/L	--	--	--	0.1	0	.2	1.43	8.5
Specific conductance	µS/cm	--	--	--	3	0	189	1,075	8,077
Alkalinity	mg/L as $CaCO_3$	--	--	--	2	0	76	157	299
Calcium, dissolved	mg/L	--	--	--	.02	0	29.6	123	662
Magnesium, dissolved	mg/L	--	--	--	.008	0	10.9	40	156
Potassium, dissolved	mg/L	--	--	--	.16	0	.57	1.50	103
Sodium, dissolved	mg/L	--	--	--	.20	0	5.8	32.7	303
Chloride, dissolved	mg/L	[2]250	3	25	.20	0	8.5	91.4	1,541
Fluoride, dissolved	mg/L	4	2	17	<.17	3	<.17	.64	6.5
Silica, dissolved	mg/L	--	--	--	.20	0	14.1	18.6	24.8
Sulfate, dissolved	mg/L	[2]250	3	25	.18	0	17.1	64.7	651
Ammonia, dissolved	mg/L	[4]30	1	8	<.04	6	<.04	.05	101
Nitrate, dissolved	mg/L as N	10	0	0	<.06	0	.04E	.54	3.79
Nitrite, dissolved	mg/L as N	1	0	0	<.008	9	.004E	<.008	.089
Orthophosphate, dissolved	mg/L as P	--	--	--	<.018	9	<.018	<.018	.011E
Organic carbon, total	mg/L	-	--	--	<.4	0	.062	2.59	11.8

[1] U.S. Environmental Protection Agency, 2004.

[2] Secondary maximum contaminant level.

[3] Dissolved oxygen measured in 11 of 12 samples.

[4] Life-time consumption Health Advisory drinking-water concentration.

Trace Elements

Of the trace elements analyzed, concentrations exceeded drinking-water standards or health advisories (HA) in private-supply-well samples most frequently for arsenic and boron; standards or advisories for iron, lead, manganese, molybdenum, and strontium were exceeded occasionally (table 14). About 20 percent of the 46 private-supply-well samples had concentrations of arsenic and (or) boron that exceeded the MCL of 10 µg/L for arsenic and the lifetime HA of 600 µg/L for boron. In samples from 12 monitor wells at the industrial site near Congo Road, concentrations exceeded drinking-water standards or HA most frequently for arsenic, boron, manganese, and strontium and less frequently (1 sample each) for iron and selenium (table 15). Compared to the private-supply-well samples, the frequency of drinking-water standard or HA exceedences in monitor-well samples was similar for arsenic concentrations but greater for boron, manganese, and strontium concentrations. Concentrations in 25 percent of the 12 monitor-well samples exceeded the MCL for arsenic, 42 percent exceeded the lifetime HA for boron, 75 percent exceeded the secondary maximum contaminant level (SMCL) for manganese, and 42 percent exceeded the lifetime HA for strontium.

Comparison of dissolved and total concentrations of trace elements indicates that for most analytes, the dissolved concentrations were about equal to the total concentrations, indicating that these constituents were present primarily in dissolved phase. Comparisons of dissolved and total concentrations of arsenic and boron are shown as an example in figure 12. For some analytes, including cobalt and, to a lesser extent, manganese, dissolved concentrations commonly were reported as somewhat less than total concentrations, especially at the lower concentrations in the range measured (fig. 13). These differences between dissolved and total concentrations could indicate that both dissolved and particulate phases were present, although uncertainty in laboratory analysis may explain some of the apparent differences. For iron, dissolved concentrations were almost always less than total concentrations by up to several orders of magnitude (fig. 13), indicating that the undissolved or particulate phase of iron tended to predominate in these waters. Concentrations of total iron and manganese were not frequently (about 6 percent of samples) elevated above the SMCLs of 300 µg/L and 50 µg/L, respectively (tables 14 and 15).

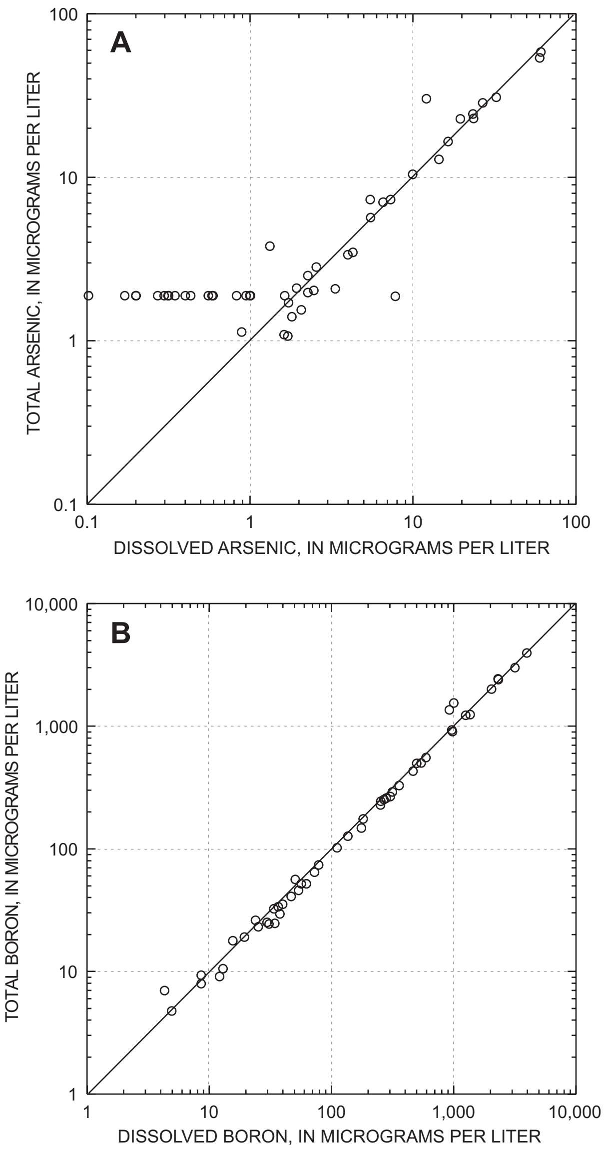

Figure 12. Comparison of dissolved and total concentrations of (A) arsenic and (B) boron in 46 private-supply-well and 4 monitor-well samples in the Newark Basin, southeastern Pennsylvania, February 2004 - 2005.

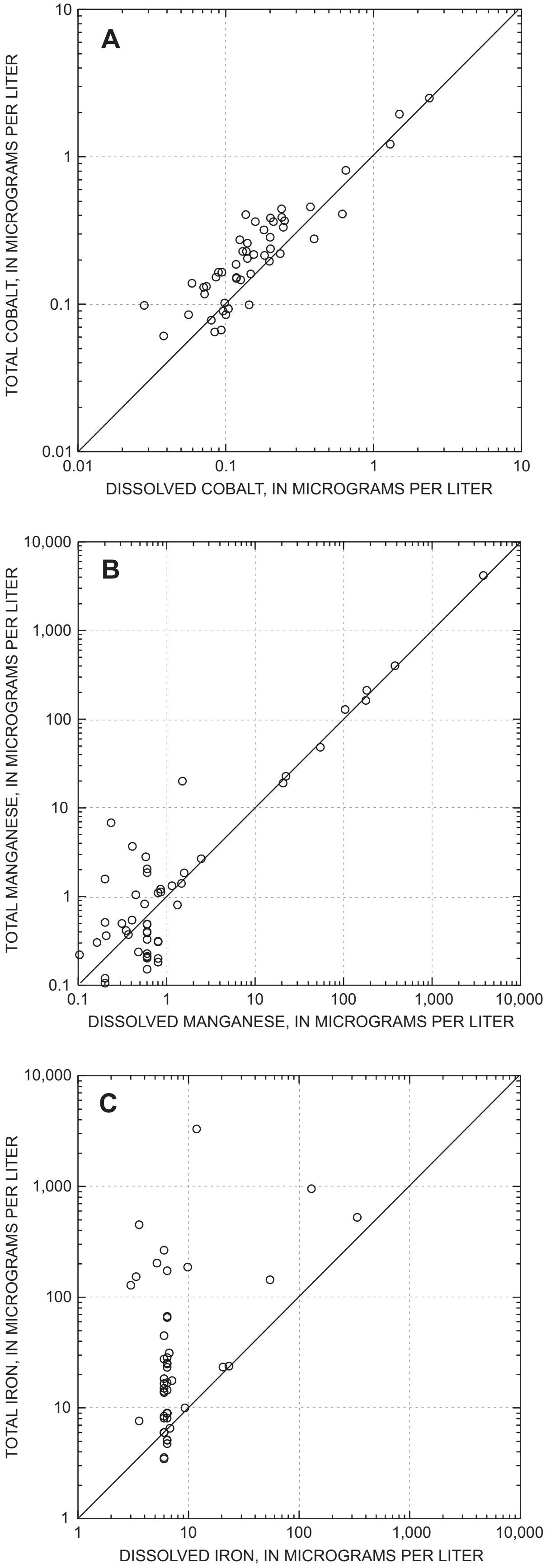

Figure 13. Comparison of dissolved and total concentrations of (A) cobalt, (B) manganese, and (C) iron in 46 private-supply well and 4 monitor-well samples in the Newark Basin, southeastern Pennsylvania, February 2004-April 2005.

Table 14. Minimum, median, and maximum values for dissolved and total concentrations of selected trace elements in ground-water samples collected from 46 private-supply wells in the Newark Basin, southeastern Pennsylvania, February 2004 - April 2005.

[MCL, maximum contaminant level; µg/L, microgram per liter; --, none or no data; E, estimated value; <, less than]

Chemical constituent	MCL or other standard[1] (µg/L)	Number of samples that exceed MCL	Percent of samples that exceed MCL	Minimum reporting level (µg/L)	Number of values less than the reporting level	Minimum concentration (µg/L)	Median concentration (µg/L)	Maximum concentration (µg/L)
Arsenic, dissolved	10	9	19	<0.2	2	0.10E	1.67	60.0
Arsenic, total	10	10	21	[2]<1.9	20	1.07E	<1.9	54.0
Barium, dissolved	2,000	0	0	<.2	6	.11E	.60	298
Barium, total	2,000	0	0	<.2	4	.14E	.56	278
Boron, dissolved	[3]600	9	19	<7		4.3E	75.6	3,950
Boron, total	[3]600	9	19	<7	1	4.8E	69.3	3,950
Cobalt, dissolved	--	--	--	<.04		.028	.128	1.295
Cobalt, total	--	--	--	<.04	0	.061	.176	1.221
Copper, dissolved	[4]1,300	0	0	<.4	0	.86	7.74	70.62
Copper, total	[4]1,300	0	0	<.6	0	1.091	9.163	60.692
Iron, dissolved	[5]300	0	0	[6]<6	34	3.0E	<6.4	129.6
Iron, total	[5]300	3	6	[7]<6	9	3.457E	14.79	3,315
Lead, dissolved	[4]15	0		<.08	3	.04E	.245	2.63
Lead, total	[4]15	1	2	<.06	1	.044E	.314	18.02
Lithium, dissolved	--	--	--	<.6	1	.361E	8.128	59.3
Lithium, total	--	--	--	<.6	2	.442E	7.887	58.3
Manganese, dissolved	[5]50	3	6	[8]<.2	21	.103E	<.6	182
Manganese, total	[5]50	2	4	<.2	1	.106E	.507	212
Molybdenum, dissolved[9]	[3]40	1	2	<.4	16	.212E	<.4	83.4
Molybdenum, total	[3]40	1	2	<.2	9	.106E	.388	79.1
Nickel, dissolved	[3]100	0	0	<.06	1	<.06	.673	4.68
Nickel, total	[3]100	0	0	<.16	0	.22	.611	6.79
Selenium, dissolved	[3]50	0	0	<.4	8	.214E	.406	2.52
Selenium, total	[3]50	0	0	<.4	7	.206E	.424	2.65
Strontium, dissolved	[3]4,000	1	2	<.4	0	16.1	143	6,872
Strontium, total	[3]4,000	1	2	<.2	0	15.5	132	7,018
Vanadium, dissolved	--	--	--	<.014	1	<.014	3.97	17.2
Vanadium, total	--	--	--	[10]<1	7	.74E	4.15	18.1
Zinc, dissolved	[3]2,000	0	0	.6	0	1.35	8.05	584
Zinc, total	[3]2,000	0	0	2		1.07E	6.34	510
Uranium, dissolved	30	0	0	.04	0	.025E	.975	11.7
Uranium, total	30	0	0	.012	0	.021E	1.03	10.2

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[1] U.S. Environmental Protection Agency, 2004.

[2] Reported as less than 3.8 µg/L for 1 of 20 samples with less than values.

[3] Life-time consumption Health Advisory drinking-water concentration.

[4] Action level.

[5] Secondary maximum contaminant level.

[6] Reported as less than 6.4 µg/L for 20 of 34 samples with less than values.

[7] Reported as less than 9 µg/L for 7 of 9 samples with less than values.

[8] Reported as less than 6 µg/L for 12 of 21 samples and less than 8 µg/L for 5 of 21 samples with less than values.

[9] Molybdenum concentrations reported for 44 of 46 samples.

[10] Reported as less than 2 µg/L for 3 of 7 samples and less than 6 µg/L for 1 of 7 samples with less than values.

Table 15. Minimum, median, and maximum values for dissolved concentrations of selected trace elements in ground-water samples collected from 12 monitor wells at an industrial facility near Congo Road in Berks and Montgomery Counties, Pennsylvania, March 2004.

[MCL, maximum contaminant level; µg/L, microgram per liter; --, no data or not applicable; E, estimated value; <, less than]

Chemical constituent	Number of well samples	MCL or other standard[1] (µg/L)	Number of well samples that exceed MCL	Percent of well samples that exceed MCL	Minimum reporting level (µg/L)	Number of values less than the reporting level	Minimum concentration (µg/L)	Median concentration (µg/L)	Maximum concentration (µg/L)
Arsenic, dissolved	12	10	4	33	<0.2	0	0.9	3.98	60.9
Barium, dissolved[2]	12	2,000	0	0	<.2	0	71	118	706
Boron, dissolved	12	[3]600	5	42	<7	0	29.9	236	5,240
Cobalt, dissolved	4	--	--	--	.04	0	.24	1.07	2.38
Copper, dissolved	12	[4]1,300	0	0	.4	0	.74	.93	1.07
Iron, dissolved	12	[5]300	1	8	<6.4	4	<6.4	12.4	1,820
Lead, dissolved	4	[4]15	0	0	<.08	1	[6].05E	.11	.18
Lithium, dissolved	12	--	--	--	<.6	0	9.6	35.9	56.4
Manganese, dissolved	12	[5]50	9	75	<.2	2	[6].16E	200	3,789
Molybdenum, dissolved	12	[3]40	0	0	<.4	0	.62	2.88	25.2
Nickel, dissolved	4	[3]100	0	0	<.06	0	1.8	4.6	10.4
Selenium, dissolved	4	[3]50	1	25	<.4	0	.41	1.03	135
Strontium, dissolved	12	[3]4,000	5	42	<.4	0	186	2,454	17,230
Vanadium, dissolved	4	--	--	--	<.01	0	2.2	4.0	4.8
Zinc, dissolved	12	[3]2,000	0	0	<.6	0	.66	1.63	2.29
Uranium, dissolved[1]	12	30	0	0	<.04	0	.65	4.3	23.1

[1] U.S. Environmental Protection Agency, 2004.

[2] Includes data from Environmental Standards, Inc. for 8 of 12 samples.

[3] Life-time consumption Health Advisory drinking-water concentration.

[4] Action level.

[5] Secondary maximum contaminant level.

[6] Estimated value below reporting level.

Boron Isotopes

Boron has two naturally occurring isotopes, ^{10}B and ^{11}B. The ratio of these isotopes in boron-bearing minerals varies and may be used to help identify the origin of boron in ground water and other geologic processes involving boron. Boron isotopic compositions commonly are expressed as the difference in ratios of the isotopes in a sample relative to a standard ratio or as follows, in units of parts per thousand or per mil (also expressed as 0/00):

$$\delta^{11}B\ (0/00) = \{[(^{11}B\ /^{10}B)_{sample}/(^{11}B\ /^{10}B)_{standard}]\ -1\}\ x\ 10^3 (1)$$

Recent reviews of the boron isotopic composition of seawater, rock types, and minerals were given by Bassett (1990) and Swihart (1987). Generally, boron minerals formed in non-marine evaporites are the primary source of boron used in industrial and domestic applications (including the laundry additive borax) and commonly are relatively enriched in the lighter isotope, ^{10}B, compared to boron minerals in marine evaporites and many other geologic sources. Boron isotopic ratios for diabase and the boron mineral datolite appear to be slightly more enriched in the heavier isotope, ^{11}B, than the boron minerals in non-marine evaporites. Residual brines associated with non-marine evaporites, however, should be more enriched in ^{11}B than the evaporite deposits, such has been found by Vengosh and others (1992), who give a predicted range for $\delta^{11}B$ of 0 to +30 per mil in non-marine brines.

Naturally occurring boron varies by rock type, although analyses of rocks from the eastern United States are not extensive. In a review of boron isotopic compositions, reported values of $\delta^{11}B$ are about -7 to -12 per mil for pegmatites in Maine and North Carolina, +0.8 permil for a diabase in Virginia, +5.3 per mil for a granite in Rhode Island, +1 to +12 per mil in tourmalines in metamorphic rocks in New York, +18 to +32 per mil for Jurassic or older marine evaporites in Louisiana and Eastern Canada (Bassett, 1990). From samples collected in the eastern United States, Swihart (1989) determined ranges of $\delta^{11}B$ for datolite in Triassic rift basalt of +15 to +28 per mil and in diabase of +25 to +31 per mil. For rocks elsewhere (New Caledonia and Turkey), reported values of $\delta^{11}B$ in datolite are about +3 to +4 per mil (Bassett, 1990).

Studies of precipitation indicate that boron concentrations can range up to 20 µg/L near coastal regions in Great Britain, be somewhat lower inland, and have variable isotopic compositions of $\delta^{11}B$ ranging from -13 to +48 per mil, with heavier values associated with storms from the Atlantic Ocean and lighter values associated with storms from the European continent (Mather and Porteous, 2001). Thus, precipitation that recharges an aquifer may be a source for background concentrations of boron in ground water where few boron minerals are present. Under present conditions, eastern Pennsylvania receives precipitation from both coastal and continental storms.

For the Congo Road study done by USEPA (Towle and Kelly, 2000), three well-water samples were analyzed for boron isotopes (George Swihart, The Univ. of Memphis, written commun., June 2002). Because of the few data, sources of boron in ground water could not be clearly identified, although differences in the boron isotopic composition among the samples were apparent (table 16).

The boron isotopic composition of samples collected by USGS for this study ranged from $\delta^{11}B$ of +1.2 to +23.8 per mil in samples from 40 private-supply wells and from $\delta^{11}B$ of -0.1 to +24.1 in samples from 12 monitor wells near Congo Road. Samples from six private-supply wells were not analyzed for boron isotopes because boron concentrations were too low in the volume collected to permit the analysis. The distribution of boron isotopic compositions for these two groups of samples is shown in fig. 14. Most samples had compositions with $\delta^{11}B$ greater than 5 per mil, indicating that for most samples the likely source of boron is aquifer materials rather than sewage effluent containing boron-bearing laundry additives that can infiltrate to ground water from septic systems. Boron used in laundry additives is largely from non-marine evaporite deposits with a reported $\delta^{11}B$ in the range of -16 to +10 per mil, and commercial borax has a boron isotopic composition in the range of about -5 to +5 per mil for $\delta^{11}B$ (Barth, 1998). Given these values, the $\delta^{11}B$ measured in many of the ground-water samples collected for this study are within the range of +15 to + 31 per mil reported by Swihart (1989) for datolite in altered basalt and diabase in the eastern United States. The boron isotopic compositions for all well samples are listed by sampling area in table 21 at the back of the report.

Relation to Hydrogeologic Setting

Ground-water composition and flow directions are controlled by lithology in the study area. The diabase, hornfels, and sedimentary rocks of the Newark Basin all receive direct recharge from precipitation. Ground water generally flows from the diabase, which typically underlies hills, into the adjacent hornfels or sedimentary rocks. Thus, ground-water composition downgradient from the diabase may reflect mixtures of water that has interacted with more than one rock type.

Water-level data indicating the potentiometric surface from which ground-water gradients and flow directions may be inferred were collected as part of sampling in each study area. In addition, water-level data were collected more extensively in the Congo Road area (fig. 6).

Table 16. Boron concentration and isotopic composition of three ground-water samples in the Congo Road area. Data from George Swihart (The Univ. of Memphis, written commun., June 2002).

[ppm, parts per million]

Sample identification number	Type of well sampled	Boron concentration (ppm)	$\delta^{11}B$ (per mil)
MW-1	monitor	8.2	15.0
RW-1	residential	2.1	22.7
RW-2	residential	2.6	13.6

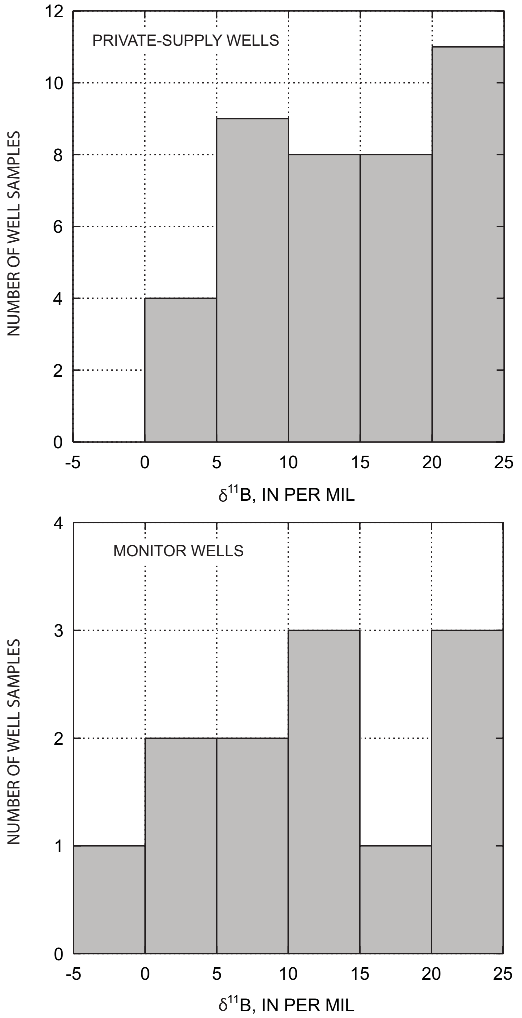


Figure 14. Distribution of boron isotopic compositions in 40 private-supply and 12 monitor wells in the Newark Basin, southeastern Pennsylvania, February 2004 - April 2005.

Congo Road Area

Prior to collecting ground-water samples in the Congo Road area (fig. 6), a map of ground-water levels was made to show the directions of ground-water flow and to form a basis for sampling wells in transects through the different rock types. The Congo Road area is underlain by sedimentary rocks of the Brunswick Group and limestone conglomerate and intrusive rocks of diabase and adjacent hornfels (fig. 15). The Newark Basin rocks in the Congo Road area are near the fault contact with older crystalline rocks of the Reading Prong to the north. Water levels were measured in 153 wells in the area during the fall of 2004. The water-level map prepared using these measurements shows that the altitudes of ground-water levels are highest in the diabase that forms the hills and generally decline with topography (plate 1). Depth to water generally is greatest in wells on hilltops and least along the toe of slopes underlain by the hornfels and diabase and in the flat area drained by Swamp Creek. The water-level map indicates that ground water flows from the diabase through the hornfels and into the shales of the Brunswick Formation. Some ground water in the diabase may discharge through small seeps along the margin of the diabase.

Three transects of wells were sampled (fig. 15) as listed in approximate downgradient order in table 17. The western transect included 4 private-supply wells completed in diabase and hornfels and 12 monitor wells at an industrial facility on Congo Road completed in the unmetamorphosed Brunswick Group shales. In this transect, ground-water-level altitudes are lowest in wells at the industrial facility, indicating these wells are downgradient from other wells in the transect (table 17). In two well nests consisting of two wells each at the industrial facility, altitudes of water levels in the deeper well [MG-2105 (1d) and MG-2108 (3d)] were higher than in the shallower well [MG-2104 (1s) and MG-2107 (3s)] at the time of sampling, indicating the presence of an upward vertical gradient. The upward vertical gradient in these well nests is consistent with the location near Swamp Creek (fig. 15) being a discharge zone. Past pumping of production wells at the facility may have altered nearby ground-water flow such that past vertical gradients could have been downward in the area of the well nests. The central transect included eight private-supply wells in the metamorphosed limestone fanglomerate, hornfels, and unmetamorphosed shales. The eastern transect consisted of only two private-supply wells, one in diabase and one in hornfels.

The arsenic, boron, and fluoride concentrations and boron isotope composition of ground water from the 26 wells sampled in the Congo Road area are listed in table 17, and complete results of laboratory analyses for the samples are listed in table 22 at the back of the report.

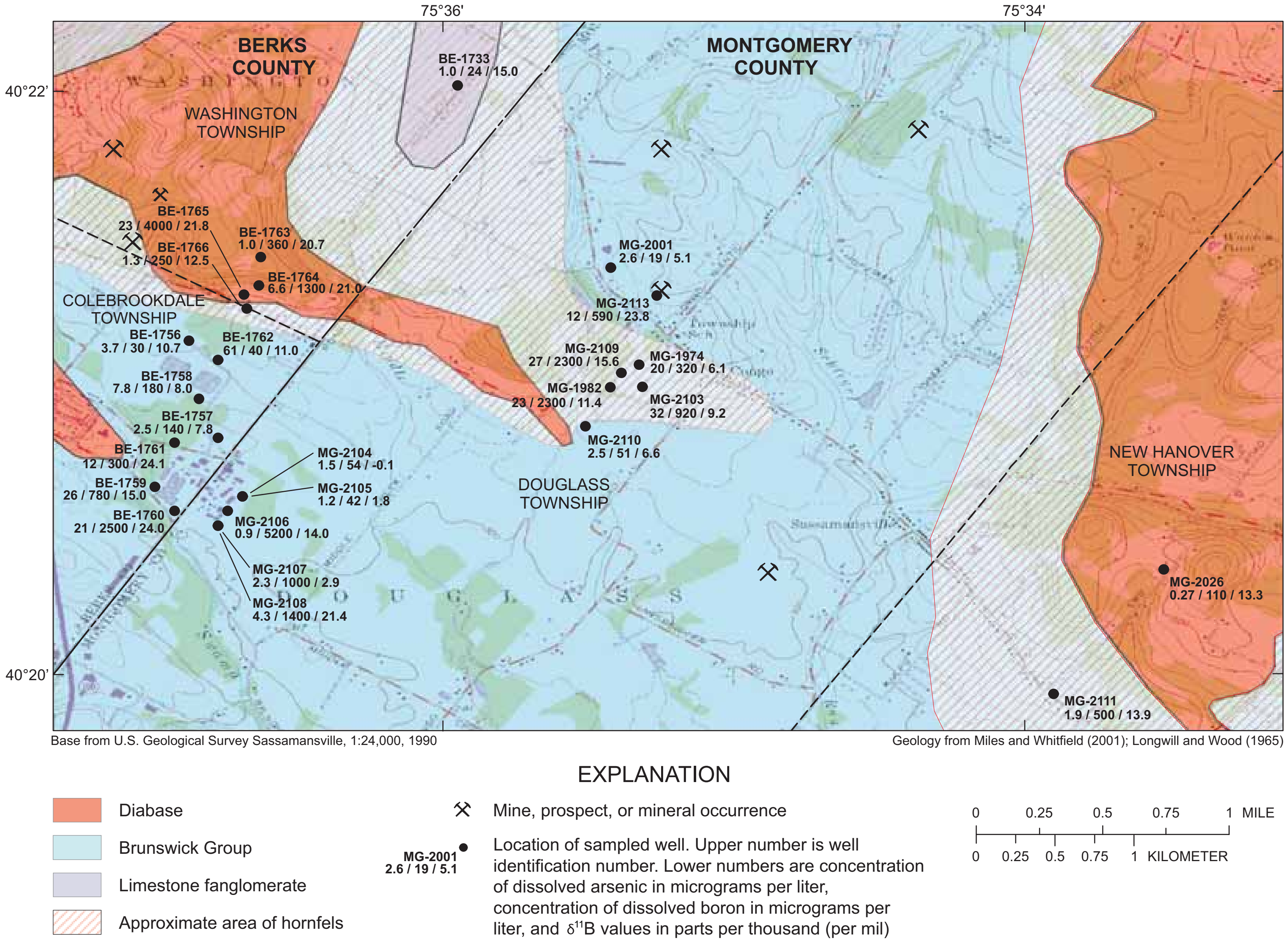


Figure 15. Concentrations of dissolved arsenic and boron and boron isotopic ratios in ground water from wells sampled in the Congo Road area, Berks and Montgomery Counties, southeastern Pennsylvania, February - July 2004.

Table 17. Dissolved arsenic, boron, and fluoride concentrations and boron isotopic composition of 58 well-water samples collected by USGS in the Newark Basin in transects in five study areas, southeastern Pennsylvania, February 2004-April 2005. Location of sample areas shown in figure 6. Wells listed in order of increasing distance from diabase and approximate downgradient order of transects.

[USGS, U.S. Geological Survey; ft., feet; NVGD 29, National Geodetic Vertical Datum of 1929; --, no data; µg/L, micrograms per liter; mg/L, milligrams per liter, 0/00, per mil; <, less than; E, estimated value; Aquifer code: 231BRCK, Brunswick Group; 231DIBS, diabase; 231LCKG, Lockatong Formation; 231BRCKF, Limestone Conglomerate; 231BSLT, basalt; Lithology: SHLE, unaltered shales; MMPC, metamorphosed shales or hornfels; DIAB, diabase]

USGS local well number	Owner well name	Sample area	Aquifer code	Lithology	Land-surface altitude (ft above NGVD 29)	Water-level altitude (ft above NGVD 29)	Arsenic, dissolved (µg/L)	Boron, dissolved (µg/L)	δ^{11}B (o/oo)	Fluoride, dissolved (mg/L)
Congo road - western transect										
BE 1763		Congo Rd	231DIBS	DIAB	525	495	1.00	358	20.7	<0.17
BE 1764		Congo Rd	231DIBS	DIAB	400	--	6.57	1,250	21.0	<.17
BE 1765		Congo Rd	231BRCK	MMPC	395	395	23.48	3,950	21.8	.71
BE 1766		Congo Rd	231BRCK	MMPC	393	--	1.32	253	12.5	<.17
BE 1756	95-01	Congo Rd - Industry	231BRCK	SHLE	357	350	3.67	30	10.7	<.17
BE 1762	mmw-5	Congo Rd - Industry	231BRCK	SHLE	340	--	60.87	40	11.0	2.29
BE 1758	95-04	Congo Rd - Industry	231BRCK	SHLE	328	322	7.79	176	8.0	<.17
BE 1757	97-06	Congo Rd - Industry	231BRCK	SHLE	325	323	2.51	143	7.8	.18
BE 1761	00-08	Congo Rd - Industry	231BRCK	SHLE	318	316	12.42	296	24.1	<.17
BE 1759	90-7s	Congo Rd - Industry	231BRCK	SHLE	312	310	25.90	776	15.0	.97
BE 1760	90-6s	Congo Rd - Industry	231BRCK	SHLE	310	307	20.93	2,502	24.0	1.39
MG 2104	90-1s	Congo Rd - Industry	231BRCK	SHLE3	315	312	1.50	54	-.1	.31
MG 2105	90-1d	Congo Rd - Industry	231BRCK	SHLE	316	314	1.18	42	1.8	.26
MG 2106	90-4s	Congo Rd - Industry	231BRCK	SHLE	312	310	.89	5,240	14.0	4.42
MG 2107	90-3s	Congo Rd - Industry	231BRCK	SHLE	313	309	2.26	1,000	2.9	6.51
MG 2108	90-3d	Congo Rd - Industry	231BRCK	SHLE	313	311	4.28	1,361	21.4	1.31
Congo Road - central transect										
BE 1733		Congo Rd	231BRCKF	MMPC	586	505	1.00	24	15.0	<.17
MG 2001		Congo Rd	231BRCK	SHLE	457	411	2.55	19	5.1	<.17
MG 2113		Congo Rd	231BRCK	SHLE	410	374	12.05	594	23.8	.19
MG 1974		Congo Rd	231BRCK	MMPC	423	391	19.54	315	6.1	<.17
MG 2109		Congo Rd	231BRCK	MMPC	410	392	26.80	2,320	15.6	<.17
MG 2103		Congo Rd	231BRCK	MMPC	390	--	32.44	920	9.2	<.17
MG 1982		Congo Rd	231BRCK	MMPC	392	389	23.29	2,300	11.4	<.17
MG 2110		Congo Rd	231BRCK	SHLE	348	--	2.46	51	6.6	<.17
Congo Road - eastern transect										
MG 2026		Congo Rd	231DIBS	DIAB	484	446	.27	111	13.3	<.17
MG 2111		Congo Rd	231BRCK	MMPC	370	--	1.93	500	13.9	.24
Jacksonwald - diabase transect										
BE 1772		Jacksonwald	231DIBS	DIAB	500	--	1.70	252	15.7	.18
BE 1770		Jacksonwald	231BRCK	MMPC	380	--	<.20	34	21.5	.17
BE 1768		Jacksonwald	231DIBS	DIAB	383	--	.32	78	23.3	<.17
BE 1767		Jacksonwald	231BRCK	SHLE	278	278	.10E	37	15.0	.20

Table 17. Dissolved arsenic, boron, and fluoride concentrations and boron isotopic composition of 58 well-water samples collected by USGS in the Newark Basin in transects in five study areas, southeastern Pennsylvania, February 2004-April 2005. Location of sample areas shown in figure 6. Wells listed in order of increasing distance from diabase and approximate downgradient order of transects.

[USGS, U.S. Geological Survey; ft., feet; NVGD 29, National Geodetic Vertical Datum of 1929; --, no data; µg/L, micrograms per liter; mg/L, milligrams per liter, 0/00, per mil; <, less than; E, estimated value; Aquifer code: 231BRCK, Brunswick Group; 231DIBS, diabase; 231LCKG, Lockatong Formation; 231BRCKF, Limestone Conglomerate; 231BSLT, basalt; Lithology: SHLE, unaltered shales; MMPC, metamorphosed shales or hornfels; DIAB, diabase]

USGS local well number	Owner well name	Sample area	Aquifer code	Lithology	Land-surface altitude (ft above NGVD 29)	Water-level altitude (ft above NGVD 29)	Arsenic, dissolved (µg/L)	Boron, dissolved (µg/L)	$\delta^{11}B$ (o/oo)	Fluoride, dissolved (mg/L)
Jacksonwald - basalt samples										
BE 1769		Jacksonwald	231BSLT		430	--	0.35	541	8.3	<0.17
BE 1771		Jacksonwald	231BSLT		425	405	.95	302	7.6	<.17
New Hope - Jericho Mountain transect										
BK 3017		New Hope - Jericho	231DIBS	DIAB	382	264	3.98	2,030	20.1	.10E
BK 3020		New Hope - Jericho	231DIBS	DIAB	362	--	14.4	3,170	18.4	.09E
BK 3021		New Hope - Jericho	231BRCK	MMPC	248	235	2.06	975	14.9	.09E
BK 3018		New Hope - Jericho	231BRCK	MMPC	210	169	1.63	465	18.7	.10E
BK 3019		New Hope - Jericho	231BRCK	SHLE	185	168	7.30	280	17.9	.23
New Hope - Solebury Mountain transect										
BK 3023		New Hope -Solebury	231DIBS	DIAB	320	--	60.0	964	20.3	.28
BK 3022		New Hope -Solebury	231BRCK	MMPC	280	--	.43	9	--	.07E
BK 2199		New Hope -Solebury	231BRCK	MMPC	250	198	3.34	62	7.4	.11
BK 2153		New Hope -Solebury	231BRCK	SHLE	130	118	5.51	54	3.0	.20
New Hope - Plumstead Township diabase										
BK 3029		New Hope - Ferry Rd	231DIBS	DIAB	438	436	<.20	4E	--	<.10
Kibblehouse Quarry area transect										
MG 2117		Kibblehouse	231DIBS	DIAB	270	262	.31	31	20.6	<.10
MG 2118		Kibblehouse	231BRCK	MMPC	362	206	16.4	136	10.1	.40
MG 2116		Kibblehouse	231BRCK	MMPC	202	--	1.73	25	--	<.17
MG 2115		Kibblehouse	231BRCK	MMPC	307	241	9.95	73	4.6	<.17
MG 2114		Kibblehouse	231BRCK	MMPC	403	387	2.26	268	4.6	<.17
MG 2112		Kibblehouse	231BRCK	MMPC	445	--	.89	182	7.6	<.17
Quakertown - northern transect										
BK 3032		Quakertown	231DIBS	DIAB	580	--	.17E	47	22.0	.05E
BK 3033		Quakertown	231BRCK	MMPC	645	611	.83	12	--	.22
Quakertown - southern transect (from valley over hill to valley)										
BK 3024		Quakertown	231BRCK	SHLE	515	501	5.46	30	1.2	.09E
BK 3028		Quakertown	231DIBS	DIAB	559	--	.59	5E	nd	.10E
BK 3025		Quakertown	231DIBS	DIAB	535	522	.59	57	16.3	.05E
BK 3027		Quakertown	231BRCK	MMPC	500	--	.40	13	6.4	.05E
BK 3026		Quakertown	231BRCK	SHLE	507	471	.56	9	--	.16
BK 3030		Quakertown	231LCKG	LCKG	565	500	1.80	34	11.7	.19
BK 3031		Quakertown	231BRCK	SHLE	439	--	1.61	38	22.3	.12
Dillsburg, York County diabse										
YO 1224		Dillsburg	231DIBS	DIAB	690	--	.30	16	12.0	<.10

Arsenic concentrations ranged from 0.27 to 60.9 µg/L in the Congo Road area and were at or above the MCL of 10 µg/L for arsenic in samples from 10 of the 26 wells sampled. Elevated arsenic was measured in 6 of 14 (43 percent) private-supply-well samples and 4 of 12 (33 percent) monitor-wells samples. Arsenic concentrations greater than 10 µg/L were measured in samples from wells completed in either hornfels (5 of 7 wells) or unaltered shales (5 of 15 wells) as mapped. The highest measured concentration of arsenic (60.9 µg/L) was in a sample from a monitor well completed in unaltered shales.

Boron concentrations ranged from 19 to 5,240 µg/L in samples from the 26 wells and were near or greater than the drinking-water lifetime HA of 600 µg/L in 6 of the 14 (43 percent) private well samples and in 5 of the 12 (42 percent) monitor-well samples. The highest boron concentrations (greater than 600 µg/L) in samples from private-supply wells generally were from wells completed in the diabase and hornfels. At the industrial facility, the highest boron concentrations (greater than 600 µg/L) were measured in samples from monitor wells completed in unaltered shales in the southern part of the property; these wells are downgradient from other wells in the western transect.

The $\delta^{11}B$ in the Congo Road area ranged from +5.1 to +23.8 per mil in samples from the private-supply wells and from -0.1 to +24.1 per mil in samples from the monitor wells at the industrial facility. Ground-water samples from the diabase generally had the highest values of $\delta^{11}B$ (three of four samples greater than 20 per mil) of sampled private-supply wells. The highest $\delta^{11}B$ of 23.8 per mil measured in private-supply-well samples was from a well (MG-2113) completed in what is mapped as unaltered shales of the Brunswick Group (fig. 15) but is near a diabase host/vein-type mineral occurrence (appendix table 1-1). Ground-water samples from other wells in unaltered shales of the Brunswick Group had the among the lowest values of $\delta^{11}B$ (5.1 and 6.6 per mil) of sampled private-supply wells. Ground-water samples from private-supply wells in the hornfels generally had intermediate values of $\delta^{11}B$ (ranging from 6.1 to 15.6 per mil).

At the industrial facility, all wells are completed in unaltered shales. A general clustering or spatial pattern of boron isotope distributions in ground water at the industrial facility is apparent, which partly may be related to lithology and partly to anthropogenic release of boron. The highest values of $\delta^{11}B$ (greater than +21 per mil) were in samples from monitor wells (BE-1760 and BE-1761) near or downgradient from a diabase intrusion on the western side of the industrial facility (fig. 15). The lowest values of $\delta^{11}B$ (less than +3 per mil) are from monitor wells in the southern part of the facility. Intermediate values of $\delta^{11}B$ (+7 to +15 per mil) measured in samples are mostly from wells in the northern part of the property, although one well (BE-1759) is near the diabase intrusion to the west and another (MG-2106) is near the southern wells with low $\delta^{11}B$ (less than 3 per mil) in samples. Most monitor-well samples with relatively low boron concentrations (less than 180 µg/L) also were typically relatively less enriched in the heavier isotope of boron ($\delta^{11}B$ of 11 per mil or less) than samples with higher concentrations of boron. A notable exception to this relation between boron concentration and isotopic composition is the sample from monitor well MG-2107 that has 1,000 µg/L of boron and $\delta^{11}B$ of 2.9 per mil (table 17), suggesting that the boron at this location was probably introduced as part of activities at the site.

Fluoride concentrations ranged from less than reporting level of 0.17 mg/L to 6.51 mg/L in samples from wells in the Congo Road area. Samples from only 3 of 14 (21 percent) private-supply wells had fluoride concentrations greater than the reporting level; the concentrations of fluoride in samples from these three wells ranged from 0.19 to 0.71 mg/L. In contrast to samples from the private-supply wells, 9 of 12 (75 percent) monitor-well samples had fluoride concentrations greater than the reporting level and 5 of 12 well samples had fluoride concentrations greater than 1 mg/L. Samples from two monitor wells (MG-2106 and MG-2107) had fluoride concentrations greater than the MCL of 4 mg/L.

Jacksonwald Area

The Newark Basin rocks in the Jacksonwald area (fig. 6) are in fault contact with the older crystalline rocks of the Reading Prong to the north, a geologic setting similar to the Congo Road area. Geologic units in the Jacksonwald area include Brunswick Group shales and hornfels, diabase, and basalt. The basalt exposure near Jacksonwald is the only one in eastern Pennsylvania.

The diabase and basalt underlie hills, and the shales underlie valleys in this area. Six wells in a transect from the Jacksonwald Basalt through the Brunswick Group, hornfels, and diabase were sampled in the Jacksonwald area (fig. 16). The arsenic, boron, and fluoride concentrations and boron isotope composition of ground-water samples from the six wells are listed in table 17, and complete results of laboratory analyses for the samples are listed in table 22 at the back of the report.

In the Jacksonwald area, arsenic and fluoride concentrations were relatively low in the six ground-water samples; arsenic concentrations were less than 2 µg/L, and fluoride concentrations were 0.2 mg/L or less. Dissolved boron concentrations ranged from 34 to 540 µg/L; the highest concentrations were in samples from the basalt and the next highest in samples were from the diabase (fig. 16; table 17) The boron mineral datolite [$CaBSiO_4(OH)$] is common in the Jacksonwald basalt. The boron isotopic composition of the basalt ground-water samples was distinctly different (about $\delta^{11}B$ of +8 per mil) from the diabase and hornfels ground-water samples (ranging from about $\delta^{11}B$ of +15 to +23 per mil).

Kibblehouse Quarry Area

The Newark Basin rocks in the Kibblehouse Quarry area include the Lockatong Formation, Brunswick Group shales and hornfels, and diabase. The Kibblehouse Quarry area is along the southern margin of a diabase intrusion and is closer to the center of the Newark Basin than the Jacksonwald and Congo Road areas (fig. 6).

Six wells were sampled in a transect from the diabase through the adjacent hornfels (fig. 17) near areas of known mineralization (appendix 1, fig. 1-3). The transect of wells represents approximate distance from the diabase but not downgradient order because of topography in the Kibblehouse Quarry area. The arsenic, boron, and fluoride concentrations and boron isotope composition of ground-water samples from the six wells are listed in table 17, and complete results of laboratory analyses for the samples are listed in table 22 at the back of the report.

Arsenic concentrations ranged from 0.31 to 16.4 µg/L and were at or above the MCL of 10 µg/L for arsenic in samples from two wells (MG-2115 and MG-2118) completed in the hornfels. Fluoride concentrations were less than the reporting level of 0.17 mg/L (or 0.10 mg/L in one case) in samples from five wells. The highest fluoride concentration of 0.40 mg/L was in the well sample that also had the highest arsenic concentration; this well (MG-2118) is along strike from the Kibblehouse Quarry, where mineralization involving F and As has been documented (see table 3 in appendix). Boron concentrations ranged from 25 to 270 µg/L in samples from the six wells. The highest boron concentrations (180 and 270 µg/L) were measured in samples from wells (MG-2112 and MG-2114) completed in the Brunswick Group hornfels near the Lockatong Formation outcrop and areas of mineralization (fig. 17). The diabase groundwater sample was more enriched in the heavier boron isotope, with a $\delta^{11}B$ of 20.6 per mil, than samples from the hornfels, in which $\delta^{11}B$ ranged from +4.6 to +10.1 per mil (table 17).

New Hope Area

In the New Hope area in eastern Bucks County (fig. 6), three outcrops of diabase are present south of New Hope borough underlying Solebury Mountain, Bowman's Hill, and Jericho Mountain (fig. 18). Blocks of rocks including the diabase intrusions and adjacent Brunswick Group shales have been faulted and, in the case of Solebury Mountain, are in fault contact with a slice of PreCambrian and Paleozoic crystalline rocks that form Buckingham Mountain (fig. 18) (Willard and others, 1959). Another thin outcrop of diabase occurs northeast of New Hope in Plumstead Township (fig. 18).

In the New Hope area, the diabase generally underlies hills, and the Brunswick Group shales underlie valleys. Five wells were sampled in a transect through Jericho Mountain, and four wells were sampled in a transect through Solebury Mountain (fig. 18). One well (BK-3029) completed in diabase along Ferry Road in Plumstead Township also was sampled. The arsenic, boron, and fluoride concentrations and boron isotope compositions of ground-water samples from the 10 wells are listed in table 17, and complete results of laboratory analyses for the samples are listed in table 22 at the back of the report.

Arsenic concentrations ranged from 0.43 to 60 µg/L in water samples from the 10 wells and were at or above the MCL of 10 µg/L in samples from 2 wells (BK-3020 and BK-3023) completed in diabase. The highest arsenic concentrations were in samples from wells in diabase underlying Solebury Mountain (60 µg/L) and Jericho Mountain (14.4 µg/L). Fluoride concentrations were low, less than the reporting level of 0.17 mg/L, in all but three samples. The highest fluoride concentration of 0.28 mg/L was in the well sample that also had the highest arsenic concentration.

Boron concentrations ranged from 9 to 3,170 µg/L in samples from the 10 wells. Boron concentrations greater than 600 µg/L were measured in samples from three wells completed in the diabase and one well completed in the hornfels. The highest boron concentrations (3,170 and 2,030 µg/L) were measured in water samples from wells in diabase in the Jericho Mountain transect (fig. 18). In the Solebury and Jericho Mountain transects, the range of $\delta^{11}B$ in water samples from wells in diabase (+18.4 to +20.3 per mil) and in water samples with relatively high boron concentrations (greater than 200 µg/L) from wells in hornfels (+14.9 and +18.7 per mil) indicated more enrichment in heavier boron isotope than the samples from other wells in hornfels or unaltered shale ($\delta^{11}B$ ranged from +3.0 to +7.4 per mil) (table 17).

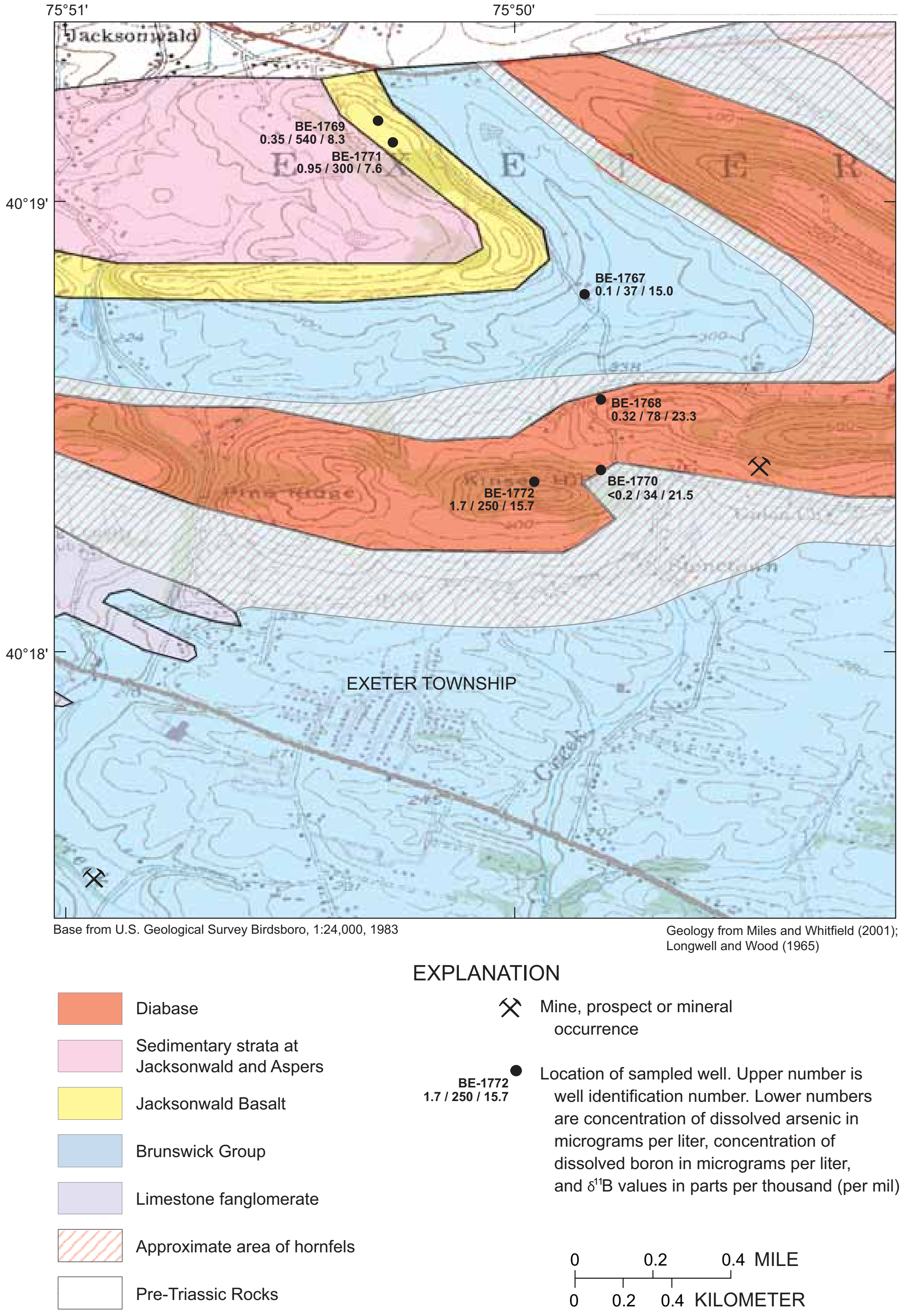
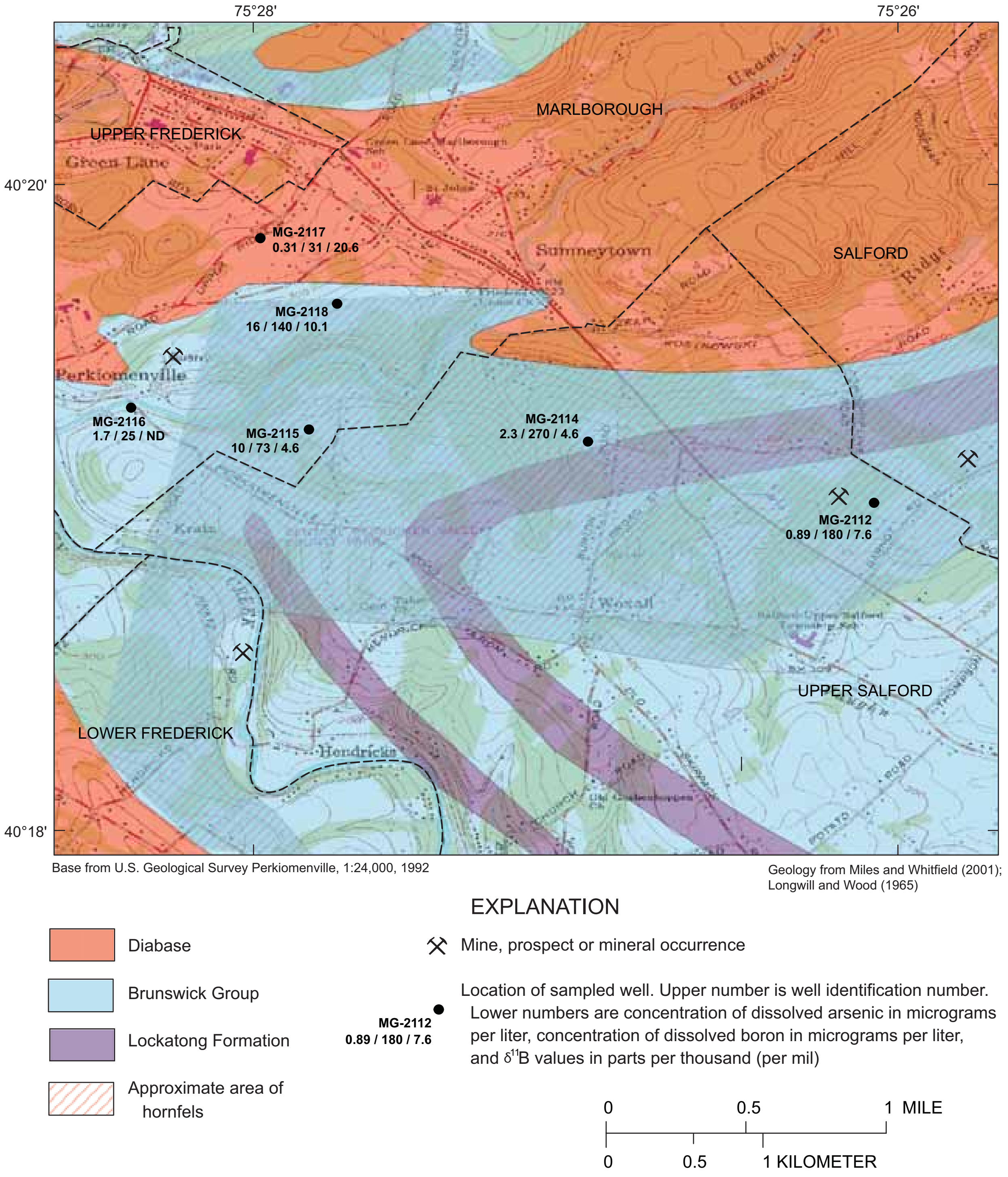


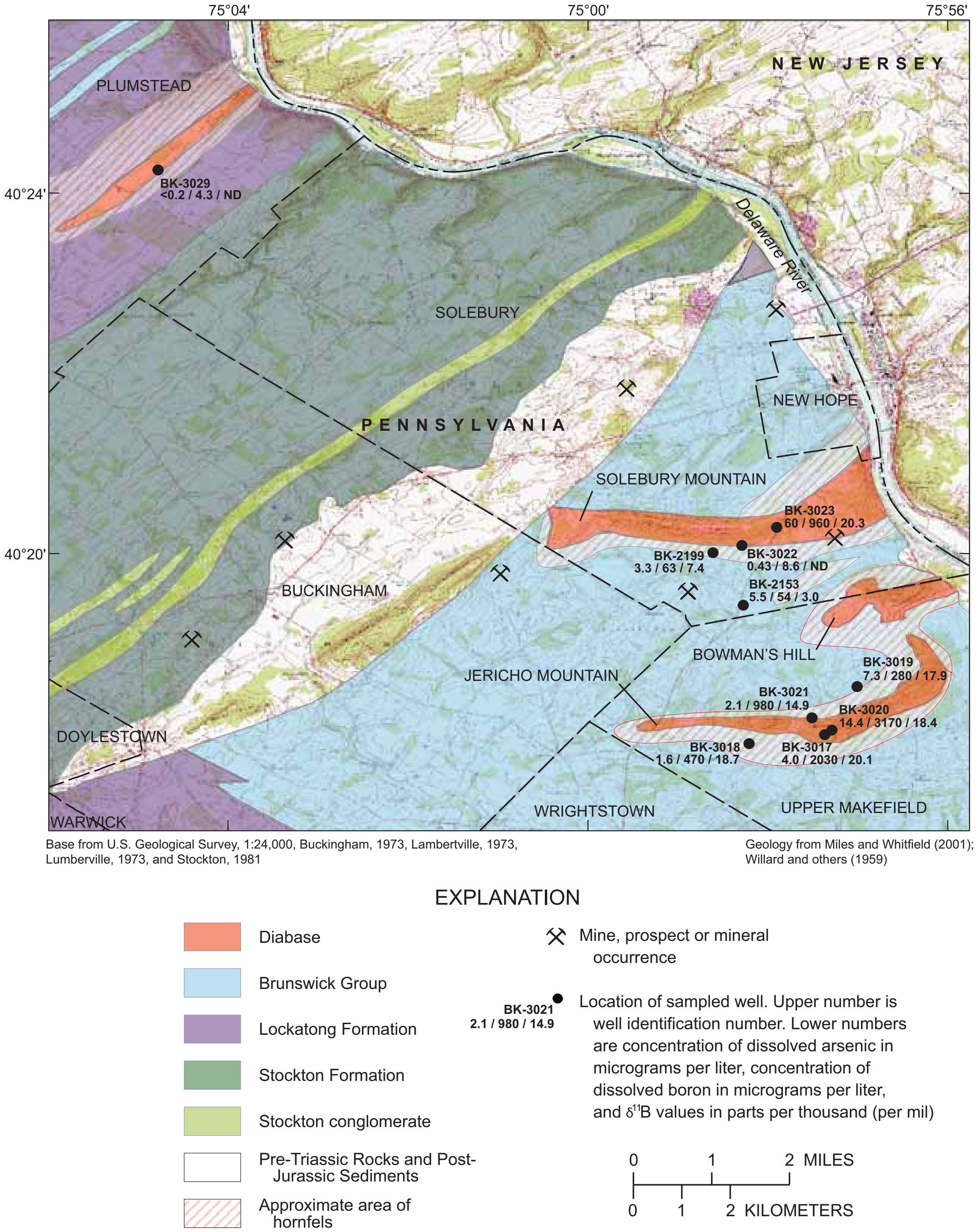
Figure 16. Concentrations of dissolved arsenic and boron and boron isotopic ratios in ground water from wells sampled in the Jacksonwald area, Berks County, southeastern Pennsylvania, June - August 2004.



Base from U.S. Geological Survey Perkiomenville, 1:24,000, 1992

Geology from Miles and Whitfield (2001); Longwill and Wood (1965)

Figure 17. Concentrations of dissolved arsenic and boron and boron isotopic ratios in ground water from wells sampled in the Kibblehouse Quarry area, Montgomery County, southeastern Pennsylvania, September - November 2004.



Base from U.S. Geological Survey, 1:24,000, Buckingham, 1973, Lambertville, 1973, Lumberville, 1973, and Stockton, 1981

Geology from Miles and Whitfield (2001); Willard and others (1959)

Figure 18. Concentrations of dissolved arsenic and boron and boron isotopic ratios in ground water from wells sampled in the New Hope area, Bucks County, southeastern Pennsylvania, October 2004 - April 2005.

Quakertown Area

The borough of Quakertown is surrounded by diabase dikes and sheets. The largest intrusion (Haycock sheet) trends northeast and lies primarily to the south and east of the borough. To the northwest of Quakertown, another large diabase body (Shelly intrusion) is connected by dikes to the Haycock sheet (Willard and others, 1959). Hornfels is present adjacent to the diabase sheets and dikes. Quakertown is underlain by unbaked shales of the Brunswick Group. Southeast of Quakertown and the Haycock sheet are the boroughs of Sellersville and Perkasie, which are underlain by Brunswick Group rocks and the Lockatong Formation.

Nine wells were sampled in a transect from the diabase northwest of Quakertown, through the diabase southeast of Quakertown, to the Lockatong Formation and Brunswick Group near Perkasie (fig. 19). As in most other areas, the hills are underlain by diabase and the valleys are underlain by rocks of the Brunswick Group. The arsenic, boron, and fluoride concentrations and boron isotope composition of ground-water samples from the nine wells are listed in table 17, and complete results of laboratory analyses for the samples are listed in table 22 at the back of the report.

Arsenic concentrations ranged from 0.17 to 5.5 µg/L in water samples from the nine wells. The highest arsenic concentration of 5.5 µg/L was from a well (BK-3024) completed in Brunswick shale near Quakertown. Arsenic concentrations measured in the nine wells were lower than has been reported for some well samples near Richlandtown, in which arsenic concentrations up to 41 µg/L were measured (table 1) and near Sellersville and Perkasie, in which arsenic concentrations over 30 µg/L were measured (Pa. Department of Environmental Protection, written commun., 2004). Fluoride concentrations were low, less than the laboratory reporting level of 0.17 mg/L, in all but two samples. The highest fluoride concentration was 0.22 mg/L.

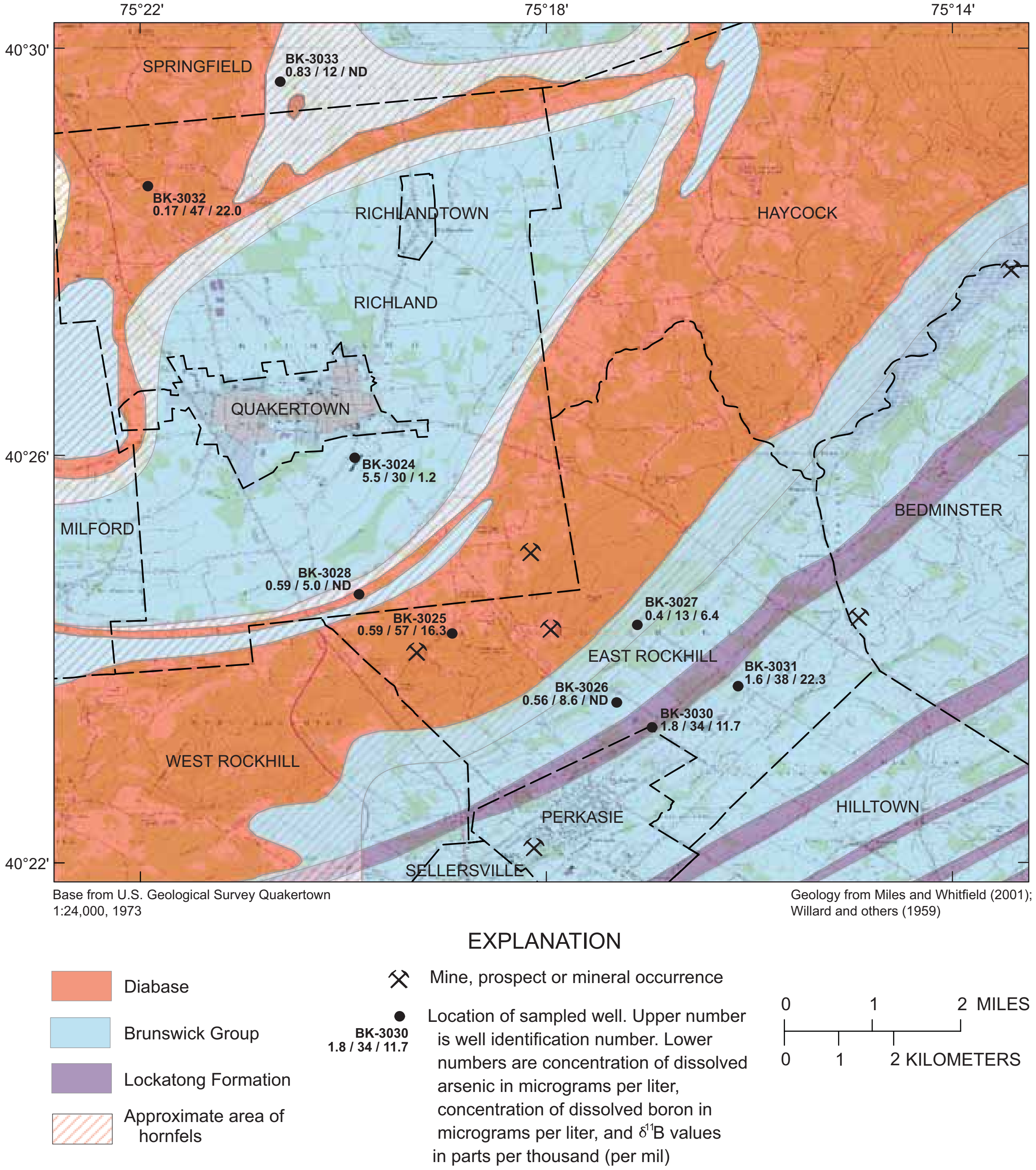
Boron concentrations ranged from 5 to 57 µg/L in samples from the nine wells and generally were lower in ground water in the Quakertown area than in any of the other areas sampled. The highest boron concentrations (47 and 57 µg/L) in the Quakertown area were measured in water samples from wells in diabase (fig. 19). The boron isotopic composition of water samples from diabase (δ^{11}B ranged from +16.3 to +22.0 per mil) indicated more enrichment in heavier isotope than the other samples (δ^{11}B ranged from +1.2 to +11.7 per mil) except for one sample from a well (BK-3031) in Brunswick Group rocks northeast of Perkasie (δ^{11}B of +22.3 per mil) (table 17) (fig. 19). The well BK-3031 is approximately along strike from and between two mapped sedimentary-hosted copper occurrences (appendix 1, fig. 1-4) and may be affected by local mineralization.

Comparison of Water Quality in Sampling Areas and Lithologies

Water quality in the sampling areas and in lithologies was compared to determine similarities and differences. The nonparametric Kruskal-Wallis test was used to test whether differences in concentrations or chemical properties in these groups were statistically significant. If differences in arsenic, boron, and fluoride concentrations among the groups were statistically significant using the Kruskal-Wallis tests, the Tukey test on ranked data was used to determine which groups were different. Nonparametric statistical tests, based on ranks rather than actual continuous values, can be applied to non-normally distributed data, such as environmental data (Helsel and Hirsch, 1992). In the comparison of water quality in sampling areas and lithologies, samples from the monitor wells at the industrial site near Congo Road were grouped separately from private-supply wells in the area.

In the comparison of sampling areas, differences in arsenic, boron, and fluoride concentrations were statistically significant for some groups. The distributions of arsenic and boron concentrations and boron isotopic compositions in water from the monitor wells at the industrial facility on Congo Road, however, were not statistically different from that in water from some of the other groups. No statistically significant differences were found among the monitor wells, private-supply wells near Congo Road, New Hope, and Kibblehouse Quarry areas for arsenic and among wells near Congo Road, New Hope, Kibblehouse Quarry, and Jacksonwald areas for boron. The lack of statistically significant differences in arsenic and boron concentrations in the comparison of water from the monitor wells and private wells indicates that industrial activities have not resulted in concentrations of these constituents that are above concentrations found elsewhere in areas unaffected by the industry. Arsenic concentrations tended to be lowest in the Jacksonwald area, and boron concentrations tended to be lowest in the Quakertown area. Fluoride concentrations were statistically significantly different and highest in samples from monitor wells at the industrial facility near Congo Road compared to private-supply wells in all areas. Most fluoride concentrations were close to or below the reporting level of 0.17 mg/L in water from areas other than from the monitor-well group near Congo Road. In the comparison of the monitor wells and private wells in five sampling areas, the difference in fluoride concentrations indicates that the elevated fluoride concentrations are restricted to the industrial site and probably are related to industrial activities there. No differences in the distribution of boron isotopic compositions of water from the sampling areas were statistically significant. The distribution of arsenic, boron, and fluoride concentrations and boron isotopic compositions in sampling area groups are shown in boxplots (figs. 20 and 21).

Few other differences in water quality among the groups were apparent, except for the monitor-well group, which differed from other sampling areas in many constituent concentrations. Water from the monitor wells at the industrial facility tended to have statistically significantly higher dissolved concentrations of calcium, magnesium, potassium, sodium, chloride, ammonia, total organic carbon, barium, cobalt, iron, lithium, manganese, nickel, selenium, strontium, and uranium and lower concentrations of silica, copper, lead, and zinc than water from the private-supply wells (table 22 at the back of the report). The higher concentrations of numerous constituents



Base from U.S. Geological Survey Quakertown 1:24,000, 1973

Geology from Miles and Whitfield (2001); Willard and others (1959)

Figure 19. Concentrations of dissolved arsenic and boron and boron isotopic ratios in ground water from wells sampled in the Quakertown area, Bucks County, southeastern Pennsylvania, January - April 2005.

including fluoride, chloride, sodium, and ammonia in the monitor-well samples likely are related to releases at the industrial facility near Congo Road (U.S. Environmental Protection Agency, 2006). The lower concentrations of copper, lead, and zinc in monitor-well samples compared to private-supply samples may be related to the lack of plumbing in sample collection. Although private-supply-well samples were collected before or by-passing any treatment, existing pumps and plumbing were used and are possible sources of these metals.

Excluding the monitor-well group and two samples from isolated areas in Dillsburg and Plumstead Township diabase, differences in other water-quality constituents among the other sampling areas were statistically significant for potassium, nitrate, total organic carbon, iron, and manganese.

In the comparison of three main lithologies, diabase, hornfels, and unaltered shales, several differences in water quality among the groups were apparent, although concentrations of arsenic, boron, and fluoride in water from wells in the three main lithologies were not statistically different from each other. Statistical tests were run on private-supply-well data and excluded the monitor-well data and data from the sparsely sampled lithologies, basalt (two samples), limestone fanglomerate (one sample), and Lockatong Formation (one sample). For some constituents, concentrations tended to increase in ground water from the diabase to the hornfels to the unaltered shale; these constituents included calcium, magnesium, barium, cobalt, nickel, strontium, and uranium. Water from the wells completed in unaltered shales and hornfels tended to have higher concentrations of potassium, sodium, sulfate, cobalt, lithium, and molybdenum than water from wells completed in diabase. Water from wells completed in diabase and hornfels had higher concentrations of silica and vanadium than water from wells completed in unaltered shales. Possible sources of silica include zeolite minerals known to occur in the diabase and hornfels. Water from wells completed in the diabase tended to have boron isotopic compositions more enriched with the heavier isotope ^{11}B than water from either the unaltered shale and hornfels (fig. 22).

Although the concentrations of arsenic and boron in ground water from unaltered shale, hornfels, and diabase were not determined to be statistically different from each other, the percentage of samples with arsenic or boron concentrations above certain values appear to differ. The percentage of water samples with arsenic concentrations above the MCL of 10 μg/L was greater for wells in hornfels than for wells in diabase or unaltered shale. The distribution of samples shown on a probability plot (fig. 23A) indicates that about 30 percent of samples from the hornfels might have arsenic concentrations that exceeded 10 μg/L, whereas about 10 to 15 percent of samples from the unaltered shales and diabase might have arsenic concentrations that exceeded 10 μg/L. The percentage of water samples with boron concentrations above the HA level of 600 μg/L was greater for wells in hornfels and diabase than for wells in unaltered shale. From the probability plot (fig. 23B), about 30 percent of wells sampled in the hornfels and diabase had boron concentrations greater than 600 μg/L; whereas, only 5 percent of wells in unaltered shales had boron concentrations greater than 600 μg/L.

The relation between boron concentration and boron isotopic composition shown in figure 20 indicates that the range of boron isotopic compositions generally decreased as boron concentrations increased. For samples with less than 100 μg/L of dissolved boron, δ^{11}B ranged from about 0 to +24 per mil. For samples with more than 100 μg/L but less than 1,000 μg/L of dissolved boron, δ^{11}B ranged from about +5 to +24 per mil. For samples with more than 1,000 μg/L of dissolved boron, δ^{11}B ranged from about +11 to +24 per mil. Of ground-water samples collected from different lithologies, only samples from the hornfels seem to show a pattern of increasing enrichment with ^{11}B as concentrations of boron increase. Samples from wells in the diabase overall tend to have a smaller range of isotopic compositions and be enriched with the heavier boron isotope (δ^{11}B of about +12 to +24 per mil) compared to samples from wells in other lithologies. Samples from monitor wells at the industrial facility near Congo Road had the widest range of boron isotope compositions that generally correspond to the range of compositions measured in samples from private-supply wells. One monitor-well sample from the industrial facility near Congo Road that has about 1,000 μg/L of dissolved boron also has an apparently low boron isotopic composition, δ^{11}B of +2.9 per mil (fig. 24, table 17), suggesting an anthropogenic source of boron.

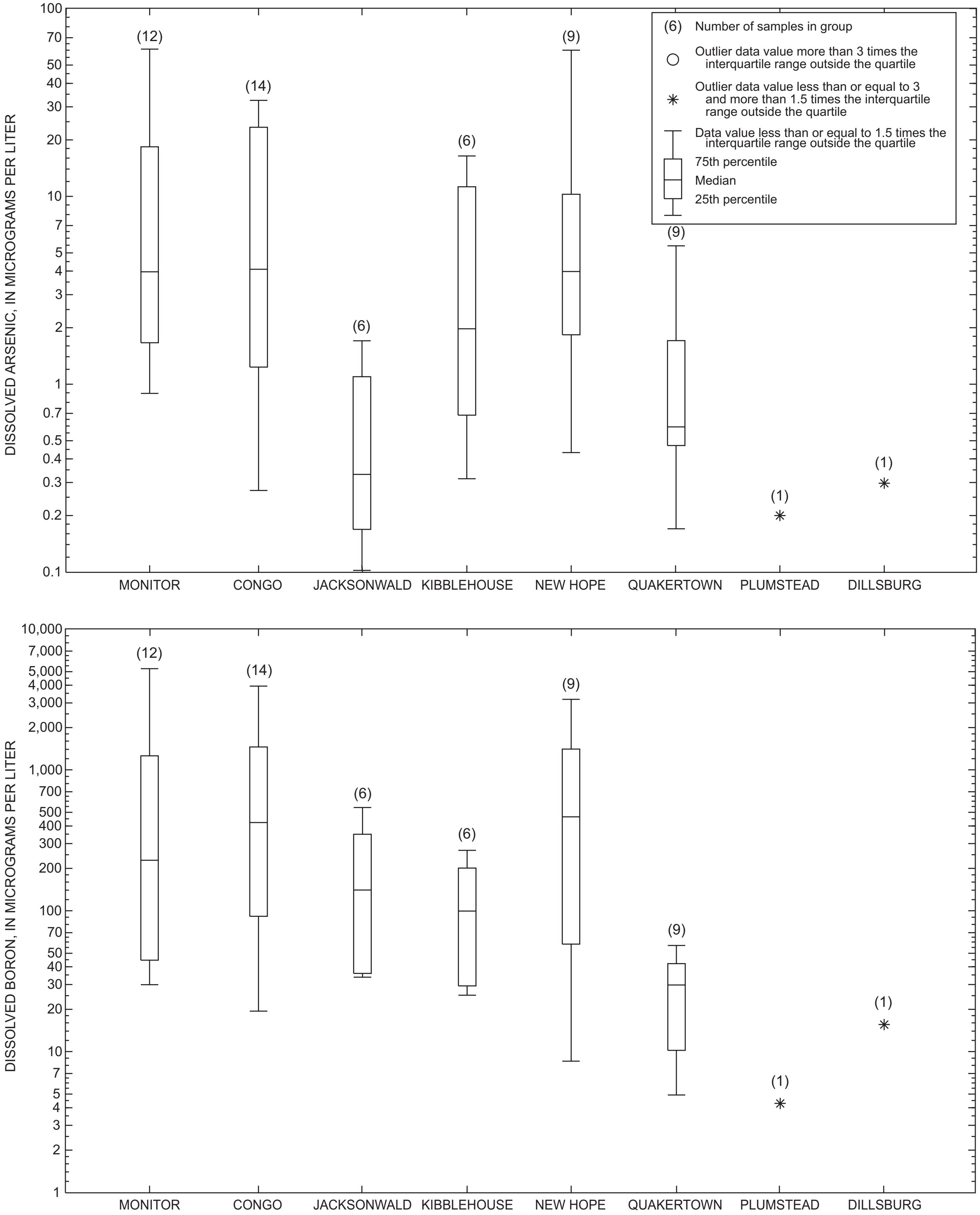


Figure 20. Boxplots showing distribution of dissolved arsenic and boron concentrations in ground water in sampling areas in and near diabase intrusions, Newark Basin, southeastern Pennsylvania, 2004-2005. Location of sampling areas shown in fig. 10.

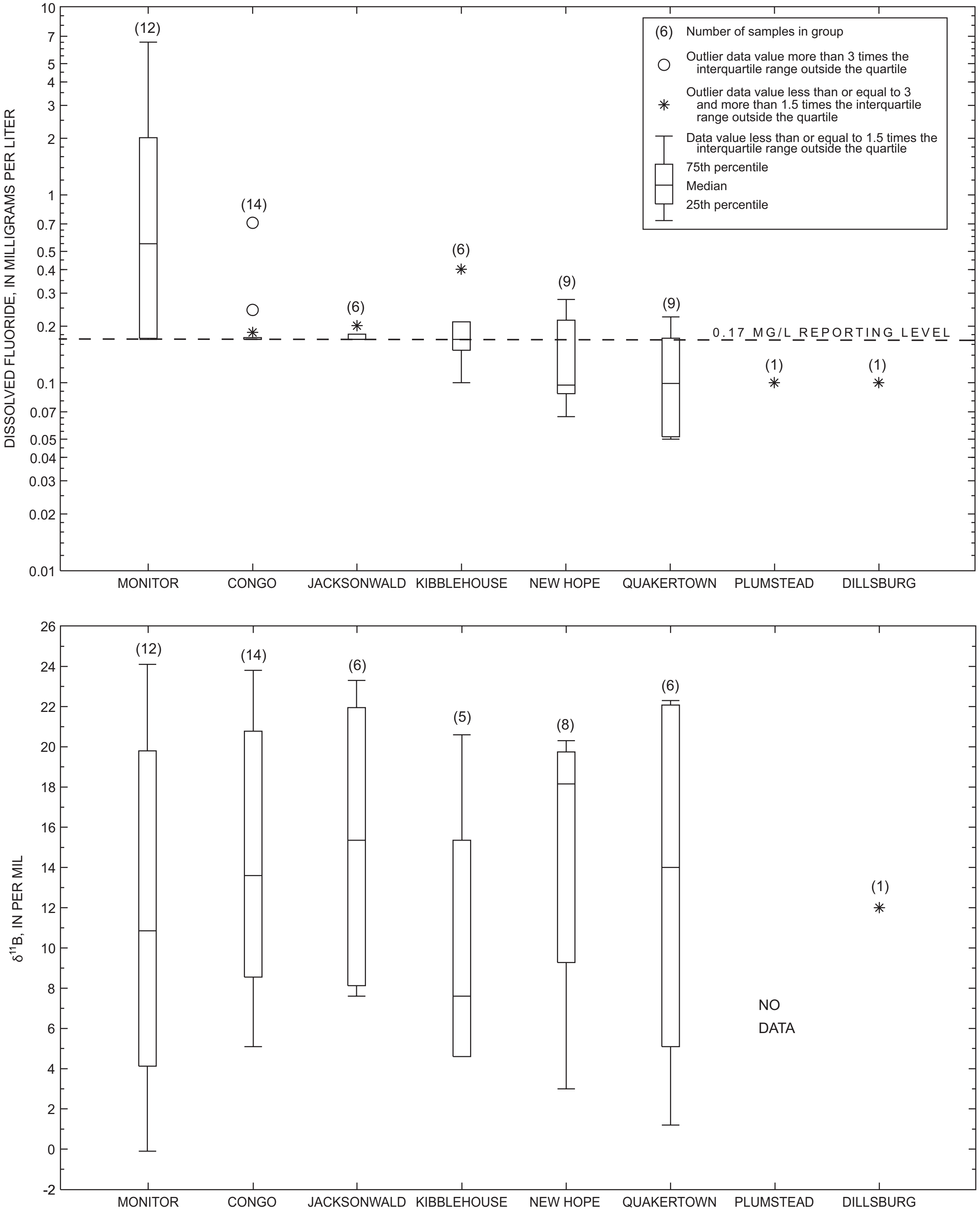


Figure 21. Boxplots showing distribution of dissolved fluoride concentrations and boron isotopic compositions in ground water in sampling areas in and near diabase intrusions, Newark Basin, southeastern Pennsylvania, 2004-2005. Location of sampling areas shown in fig. 10.

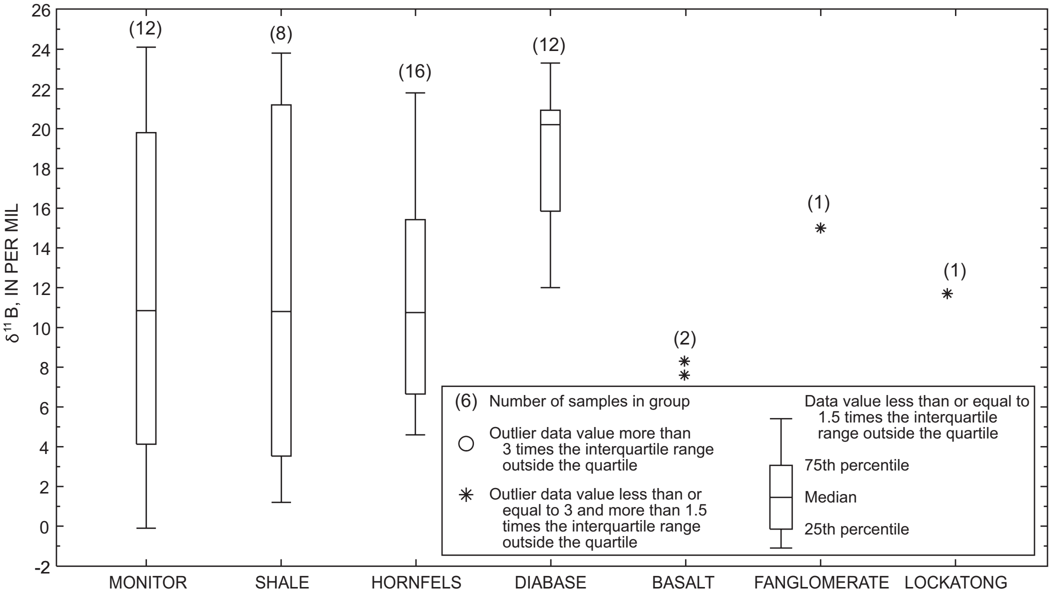


Figure 22. Boxplots showing distribution of boron isotopic compositions in ground water from lithologies sampled in and near diabase intrusions, Newark Basin, southeastern Pennsylvania, 2004-2005.

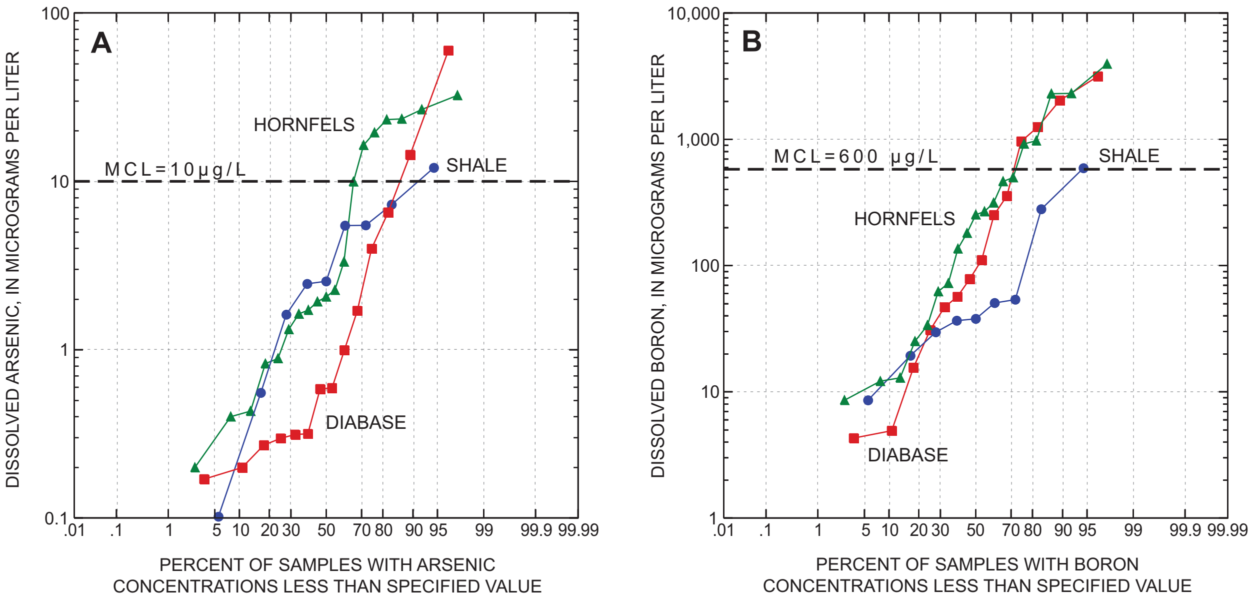


Figure 23. Probability plots showing distribution of (A) arsenic and (B) boron concentrations in ground-water samples from 43 private-supply wells completed in diabase, hornfels, and unaltered shales in and near diabase intrusions, Newark Basin, southeastern Pennsylvania.

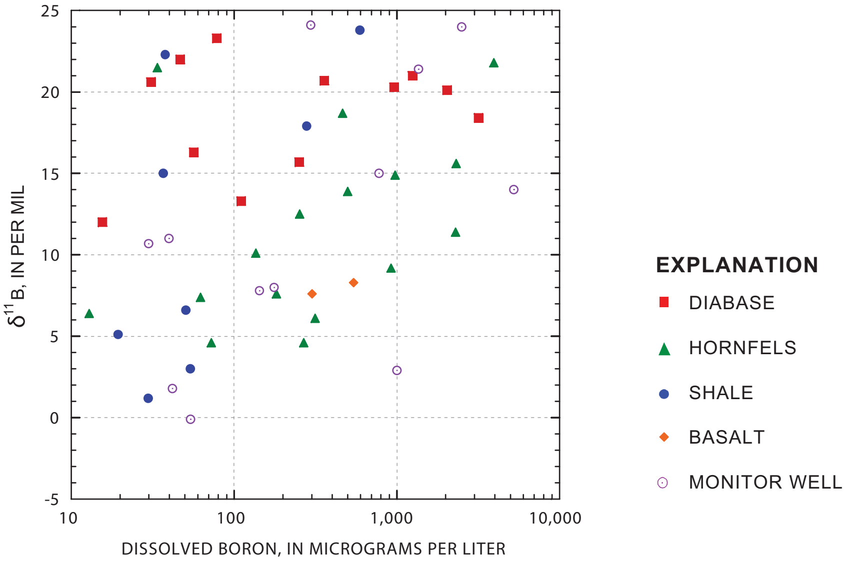


Figure 24. Relation between dissolved boron concentrations and boron isotopic compositions in samples from 50 wells in four lithologies sampled in and near diabase intrusions, Newark Basin, southeastern Pennsylvania, 2004-2005. Samples were from 12 wells in diabase, 16 wells in hornfels, 8 wells in unaltered shales, 2 wells in basalt, and 12 monitor wells in unaltered shales.

Relation to Trace Elements and Other Chemical Constituents

To investigate geochemical controls on arsenic, boron, and fluoride in the Newark Basin and relations of these three constituents to other constituents in ground water, nonparametric correlations between chemical constituents and properties were done using ground-water-quality data collected by USGS. Statistically significant (probability, $p < 0.05$, or 95 percent confidence interval) nonparametric Spearman's rho correlations are presented. Positive correlations indicate that increasing concentrations of one constituent are associated with increasing concentrations of another constituent. Negative correlations indicate that increasing concentrations of one constituent are associated with decreasing concentrations of another constituent.

The geochemical relations between arsenic, boron, and fluoride and other chemical constituents in ground water near diabase intrusions were determined by nonparametric correlations for 46 private-supply-well samples collected for this study (table 18). Arsenic concentrations were positively correlated most strongly with pH, boron, and molybdenum. Relations between arsenic concentrations and pH are shown for each lithology in fig. 25. No samples with pH less than 7 had arsenic concentrations that exceeded the MCL of 10 µg/L, but almost all samples with pH greater than 8 had arsenic concentrations that exceeded the MCL. Smedley and Kinniburgh (2002) state that, under high pH conditions (pH > 8.5), arsenic can be released or desorbed from mineral oxides (especially iron oxides) in aquifer materials, as can other anion-forming elements such as vanadium, boron, fluoride, molybdenum, selenium, and uranium. Relations between arsenic and boron concentrations are shown for each lithology in fig. 26.

Arsenic also was positively correlated, but less strongly, with selenium, uranium, nickel, lithium, fluoride, sodium, and strontium. The correlation of arsenic with boron and these other constituents indicates that they may co-occur with arsenic in the geologic environment and, in some cases, be mobile under similar chemical conditions. At at least one mineralized area, the Kibblehouse Quarry, several minerals occur that contain both arsenic and nickel (cobaltite, gersdorffite, safflorite; appendix 1, table 1-3). Arsenic correlated negatively, but weakly, with total organic carbon, copper, and dissolved oxygen. Geochemical controls on arsenic mobilization and solubility suggested by these correlations are pH and, to a lesser extent, oxidation-reduction potential (indicated by dissolved oxygen). Adsorption by iron oxide can limit concentrations of arsenic in water (Hem, 1985, p. 144), but under reducing conditions, iron oxides may release arsenic (Smedley and Kinneburgh, 2002). Molybenum (as molybdate), selenium (as selenate), and uranium (as anionic species or uranyl complex) are mobile in oxidizing, alkaline conditions (pH greater than 7). In contrast, copper is more likely to be present in acidic (pH less than 7) waters (Hem, 1985). Although some arsenic may have been introduced with the copper-mineralization in the Newark Basin, arsenic and copper appear to be mobilized in ground water in the study area under different geochemical conditions. The negative correlation with dissolved arsenic and total organic carbon may be related to competitive adsorption on aquifer materials, a possibility suggested by a laboratory study (Yean and others, 2005), or other processes involving organic-carbon oxidation. Some other constituents correlated with arsenic have mobilties less affected by pH than arsenic or copper; these constituents include boron, lithium, fluoride, sodium, and strontium.

Boron concentrations were positively correlated most strongly with arsenic and pH (table 18). Boron also correlated positively with vanadium and fluoride and negatively with total organic carbon, copper, barium, and magnesium. Fluoride correlated positively with pH, arsenic, lithium, molybdenum, calcium, and boron.

In contrast to correlations for all 46 private-supply wells, correlations for arsenic, boron, and fluoride in wells at the industrial facility were different. To compare effects of local conditions, correlations were run separately for water-quality data from 12 monitor wells and 14 residential wells in the Congo Road area (table 19). Unlike water samples from residential wells study-wide and in the Congo Road area, arsenic concentrations in water samples from the monitor wells did not correlate with pH (fig. 25B) or boron concentrations (fig. 26B). Some of the monitor-well samples with elevated arsenic also have low dissolved oxygen and (or) elevated dissolved iron and manganese concentrations, indicating reductive dissolution of iron and manganese oxides may be a mechanism that releases some arsenic in ground water at the industrial site. Boron in water samples from the monitor wells correlated positively with chloride, another soluble constituent present in high concentrations and of anthropogenic origin. However, in water from residential wells in the Congo Road area, boron correlated negatively with chloride (table 19; fig. 27).

Table 18. Spearman's rho correlations statistically significant at probability values less than 0.05 between dissolved arsenic, boron, and fluoride and other dissolved constituents and chemical properties, listed in order of decreasing significance, for ground-water samples collected by U.S. Geological Survey in 2004-2005 from 46 private-supply wells in and near diabase intrusions, Newark Basin, southeastern Pennsylvania.

[r_S, Spearman's rho correlation coefficient; p-value, probability value; TOC, total organic carbon; DO, dissolved oxygen]

Constituent	Correlated constituent	r_S	p-value	Constituent	Correlated constituent	r_S	p-value	Constituent	Correlated constituent	r_S	p-value
Arsenic	pH	0.75	<0.0001	Boron	Arsenic	0.63	<0.0001	Fluoride	pH	0.43	0.0029
	Boron	.63	<.0001		pH	.60	<.0001		Arsenic	.38	.0093
	Molybdenum	.57	<.0001		TOC	-.50	.0004		Lithium	.36	.0142
	Selenium	.49	.0006		Copper	-.42	.0029		Molybdenum	.36	.0175
	Uranium	.48	.0008		Barium	-.36	.0128		Calcium	.30	.0453
	Nickel	.43	.0027		Magnesium	-.36	.0154		Boron	.29	.0510
	Lithium	.40	.0060		Vanadium	.35	.0166				
	TOC	-.39	.0082		Fluoride	.29	.0510				
	Fluoride	.38	.0093								
	Sodium	.35	.0180								
	Copper	-.32	.0285								
	Strontium	.31	.0347								
	DO	-.31	.0358								

Table 19. Spearman's rho correlations statistically significant at probability values less than 0.05 between dissolved arsenic, boron, and fluoride and other dissolved constituents and chemical properties, listed in order of decreasing significance, for ground-water samples collected by U.S. Geological Survey in 2004-2005 from 12 monitor wells and 14 private-supply wells in the Congo Road area, Berks and Montgomery Counties, southeastern Pennsylvania.

[r_S, Spearman's rho correlation coefficient; p-value, probability value; TOC, total organic carbon; DO, dissolved oxygen; Spec.Cond., specific conductance]

Constituent	Correlated constituent	r_S	p-value	Constituent	Correlated constituent	r_S	p-value	Constituent	Correlated constituent	r_S	p-value
Monitor wells											
Arsenic	Sulfate	0.69	0.0139	Boron	Sodium	0.88	0.0002	Fluoride	DO	-0.95	<0.0001
	Calcium	.62	.0332		Chloride	.84	.0006		Manganese	.82	.0012
	$\delta^{11}B$	.61	.0358		Potassium	.78	.0025		Iron	.64	.0256
					Manganese	.66	.0202		Spec. Cond.	.61	.0342
					Ammonia	.63	.0267				
					TOC	.62	.0307				
Residential wells											
Arsenic	Boron	0.71	0.0042	Boron	Zinc	-0.74	0.0027	Fluoride	Silica	.66	.01063
	Molybdenum	.76	.0045		Arsenic	.71	0.0042		Manganese	.62	.0186
	pH	.63	.0154		Chloride	-.71	.0045		Sulfate	.61	.0193
	Sulfate	.62	.0184		Selenium	.61	.0211		DO	-.55	.0427
	Potassium	.58	.0302		Lead	-.58	.0282				
					$\delta^{11}B$	.53	.0492				

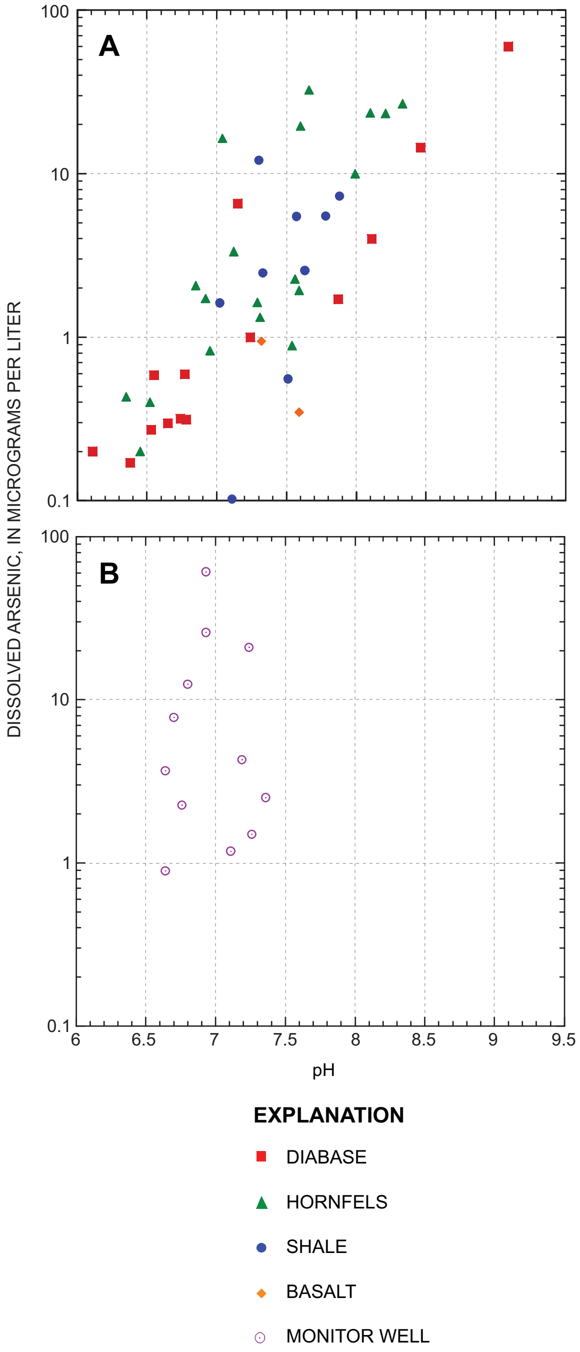


Figure 25. Relation between dissolved arsenic concentrations and pH in water samples from (A) 46 private-supply wells and (B) 12 monitor wells in and near diabase intrusions, Newark Basin, southeastern Pennsylvania.

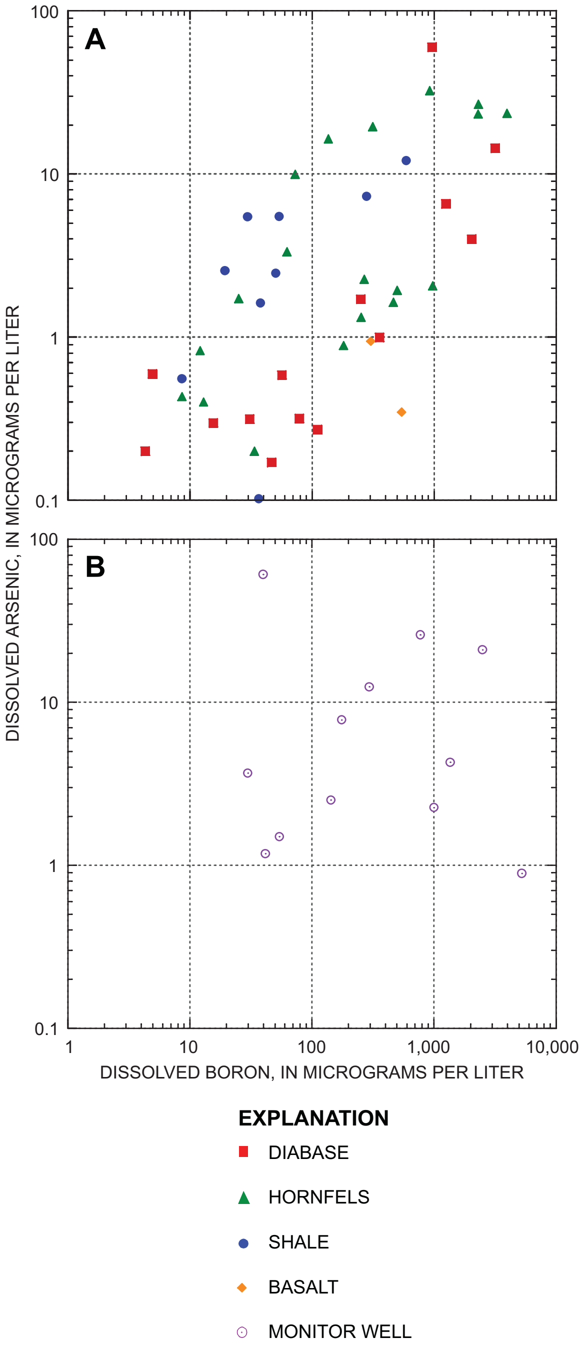


Figure 26. Relation between dissolved arsenic and boron concentrations in water samples from (A) 46 private-supply wells and (B) 12 monitor wells in and near diabase intrusions, Newark Basin, southeastern Pennsylvania.

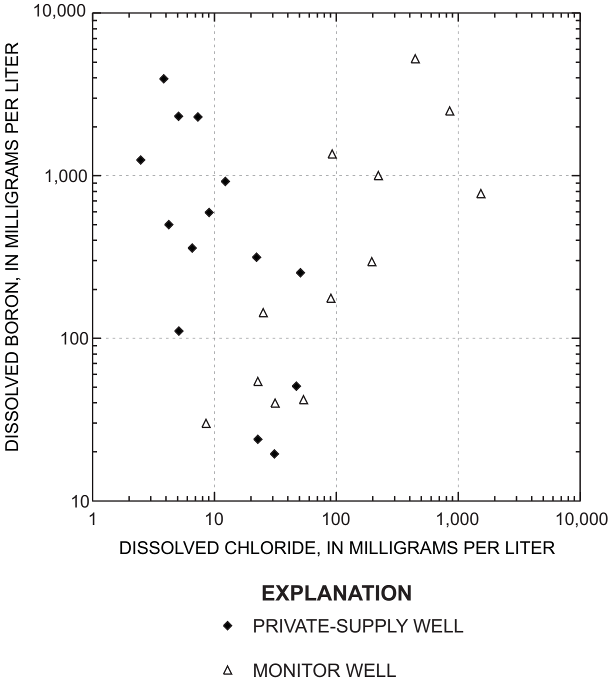


Figure 27. Relation between dissolved boron and chloride concentrations in water samples from 12 monitor wells and 14 private-supply wells in the Congo Road area, Berks and Montgomery Counties, Pennsylvania.

Water-quality data collected previous to this study from 30 wells during 1999 throughout the Newark Basin in southeastern Pennsylvania and west-central New Jersey (Durlin and Schaffstall, 2001) included samples from 6 wells completed in the Stockton Formation, 2 wells in the Lockatong Formation, 18 wells in the Brunswick group (unmetamorphosed), 1 well in the hornfels of the Brunswick Group, and 2 wells in the quartz conglomerate of the Brunswick Group. All analyses were for dissolved constituents. Similar to the samples collected for this study, arsenic correlated positively with pH, molybdenum, alkalinity, uranium, and boron and negatively with copper; arsenic also correlated positively with magnesium, hardness, and organic carbon and negatively with phosphorus and nitrate (table 20). These correlations suggest that ground water with higher pH and alkalinity and lower oxidation-reduction potential may promote increased arsenic mobility in parts of the Newark Basin other than areas in and near diabase intrusions. Phosphorus may compete with arsenic for sorption sites on aquifer materials. Boron correlated positively but weakly with pH, molybdenum, and arsenic. The correlation between boron and arsenic may indicate that these constituents were sometimes both present in aquifer materials and (or) both mobilized into solution under similar geochemical conditions. Fluoride correlated negatively with nitrate. The few statistical correlations between dissolved boron and fluoride and other chemical constituents suggest that boron and fluoride concentrations were relatively less affected than arsenic by geochemical controls and (or) that boron and fluoride distributions in aquifer materials were more variable than arsenic distributions.

Table 20. Spearman's rho correlations statistically significant at probability values less than 0.05 between dissolved arsenic, boron, and fluoride and other dissolved constituents and chemical properties, listed in order of decreasing significance, for ground-water samples collected by U.S. Geological Survey in 2000 from 30 wells in Newark Basin rocks, Pennsylvania and New Jersey.

[r_S, Spearman's rho correlation coefficient; p-value, probability value; DOC, dissolved organic carbon]

Constituent	Correlated constituent	r_S	p-value	Constituent	Correlated constituent	r_S	p-value	Constituent	Correlated constituent	r_S	p-value
Arsenic	pH	0.63	0.0002	Boron	pH	0.48	.0074	Fluoride	Nitrate	-0.50	.0049
	Molybdenum	.60	.0004		Molybdenum	.42	.0201				
	Alkalinity	.59	.0005		Arsenic	.37	.0434				
	Phosphorus	-.57	.0009								
	Uranium	.50	.0046								
	Nitrate	-.49	.0060								
	Magnesium	.47	.0079								
	Copper	-.46	.0089								
	Hardness	.38	.0389								
	DOC	.37	.0432								
	Boron	.37	.0434								

Hydrogeochemical Controls on the Distribution of Arsenic, Boron, and Fluoride in Ground Water

Arsenic concentrations in water samples collected for this study from wells in and near diabase intrusions were measured up to 60 µg/L and are within the range reported for the Newark Basin as a whole. Sources for arsenic in the sedimentary rocks include pyrite and adsorbed arsenic on iron oxides (Serfes, 2004, 2005) and numerous other minerals in areas of localized mineralization (appendix 1). Differences in arsenic concentrations in the three main lithologies sampled for this study are not statistically significant, although the percentage of samples with arsenic concentrations greater than the USEPA MCL of 10 µg/L appears to be greatest in samples from wells completed in the hornfels. About 30 percent of samples from wells in the hornfels and about 10 percent of samples from wells in diabase and shales had arsenic concentrations greater than 10 µg/L. Overall, about 20 percent of the wells sampled had arsenic concentrations greater than 10 µg/L. Arsenic concentrations differed spatially in that some of the sampling areas tended to have higher concentrations than others. Arsenic concentrations were highest in the New Hope and Congo Road areas and lowest in the Jacksonwald area. The pH of water is a probable geochemical control on the mobility of arsenic. Above pH 8, all water samples from private-supply wells had arsenic greater than 10 µg/L and below pH 7, no sample had arsenic greater than 10 µg/L. The lack of correlation between pH and arsenic in samples from monitor wells at the industrial facility near Congo Road (table 18; fig. 25B) suggest other geochemical controls may be present there.

Boron concentrations in water samples collected for this study in and near diabase intrusions are greater than those reported previously for samples in the Newark Basin in Pennsylvania (Durlin and Schaffstall, 2001), which ranged from less than 20 µg/L up to 60 µg/L). In samples collected for this study, boron concentrations ranged from about 5 µg/L up to 3,950 µg/L, with a median of about 75 µg/L. The highest boron concentrations were measured in samples from wells in the diabase and hornfels. As for arsenic, boron concentrations differed in the study areas. Boron concentrations were highest in the New Hope and Congo Road areas and lowest in the Quakertown area. The elevated concentrations initially reported in the Congo Road area (Towle and Kelly, 2000) also were found in the New Hope area. Ground water in mineralized areas can have unusually elevated concentrations of constituents locally (such as sample from well MG-2113) but in broader areas near some diabase intrusions also can have generally elevated concentrations of constituents relative to the basin as a whole, as shown by comparison of study localities (some have elevated arsenic, elevated boron, both, or neither).

Overall, the amount of boron in and near diabase intrusions probably is higher than in the Newark Basin as a whole. Boron may have been introduced or remobilized during the emplacement of diabase intrusions in the basin. A possible mineral source for some boron in ground water is datolite, a calcium borosilicate. Simple dissolution of datolite would release boron, silica, and calcium into solution and raise pH, as outlined by Yang (1990). Although boron concentrations do not correlate with silica or calcium concentrations, other mineral weathering reactions also release silica and calcium into solution and these processes may mask results of datolite dissolution. Silica concentrations were highest in the water from diabase. Swihart (1989) states that datolites from eastern United States rift basalt and diabases are more enriched in ^{11}B than has been reported for whole-rock data and suggests that the boron in the datolites was introduced. Boron may have been present prior to diabase intrusions in residual brines associated with Triassic evaporites or in basin brines, both of which may have had boron isotopic compositions that were relatively enriched in ^{11}B. Possible inclusion of or interaction with residual or basin brines during hydrothermal mineralization during diabase intrusions has been postulated (VanHouten, 1971; Cummings, 1988; Froelich and Gottfried, 1999). Evidence for possible evaporites preserved locally are elevated sulfate and strontium concentrations in a few wells (BE-1765 and MG-2113, table 1). At least some of the boron in ground water at the industrial facility near Congo Road is anthropogenic, as indicated by a samples from the southern part of the site with low $\delta^{11}B$ (2.9 per mil or less) and boron concentrations up to 1,000 µg/L.

Arsenic and boron concentrations are correlated positively. Geochemical controls such as pH may affect the release of arsenic and boron from aquifer materials and (or) arsenic and boron co-occur in the geologic materials. Arsenic also correlates with a number of other trace elements, such as molybdenum, selenium, nickel, and strontium, some of which have been noted to be present in areas of mineralization in the Newark Basin.

Fluoride concentrations in most samples from private-supply wells were less than the reporting level of 0.17 mg/L although a few samples had fluoride concentrations up to about 0.70 mg/L. These concentrations are well within the range of fluoride concentrations reported for ground-water samples from elsewhere in the Newark Basin. However, fluoride concentrations in water samples from monitor wells at the industrial facility were much higher than those in samples from private-supply-wells samples collected for this study, indicating that the source of elevated fluoride in ground water at that facility probably is anthropogenic. Fluoride correlated weakly with arsenic and boron in samples from the private supply wells, suggesting that fluoride may have been introduced to a limited extent with arsenic and boron mineralization in and near diabase intrusions in the Newark Basin.

Summary and Conclusions

Concentrations of arsenic and fluoride in ground water above drinking-water standards of 10 µg/L and 4 mg/L, respectively, and of boron above the life-time health advisory (HA) of 600 µg/L were measured by the U.S. Environmental Protection Agency (USEPA) in 2000 in an area near Congo Road in Berks and Montgomery Counties, southeastern Pennsylvania, along the northwestern edge of the Newark Basin. Sources of the elevated arsenic, boron, and fluoride in ground water were not conclusively identified but include naturally occurring mineralization in the local bedrock aquifer. Nearby, ground water at an industrial facility on Congo Road contained some locally elevated concentrations of fluoride that may be associated with releases from the facility. The USEPA requested technical assistance from the U.S. Geological Survey (USGS) in 2003 to help identify sources of arsenic, boron, and fluoride in the ground water in the Congo Road area and to identify other areas in the Newark Basin of southeastern Pennsylvania with similarly elevated concentrations of these constituents. The USGS reviewed available data and collected additional ground-water samples in geologic settings similar to the Congo Road area.

The Newark Basin is the largest of the 13 major exposed Mesozoic rift basins that stretch from Nova Scotia to South Carolina. Rocks in the Newark Basin include Triassic to Jurassic-age sedimentary sequences of sandstones and shales that were intruded by diabase. Four types of mineral deposits occur in the Newark Basin, including three types of hydrothermal origin associated with zones bordering diabase intrusions and one sediment-hosted and strata-bound replacement copper- and zinc-deposit type in fluvial sandstones and lacustrine mudstones. Mineral sources of arsenic, boron, and fluoride and other trace elements have been identified at some mineralized localities.

In southeastern Pennsylvania, bedrock aquifers consist of fractured rocks, with little primary porosity, that are recharged by precipitation. Ground-water chemical composition is affected by dissolution of minerals and chemical reactions within the aquifer and by introduction of anthropogenic constituents at the land surface through recharge. The diabase that intrudes the sedimentary rocks generally is less permeable and more resistant to erosion than the host sedimentary rocks. Consequently, the diabase forms a low-yielding aquifer that underlies hilltops. Locally, the direction of ground-water flow commonly is from the topographically high diabase toward the adjacent sedimentary rocks.

The USGS review of available data prior to 2004 showed that about 10 percent of wells throughout the Newark Basin of southeastern Pennsylvania had concentrations of arsenic greater than the USEPA maximum contaminant level (MCL) of 10 µg/L. The highest arsenic concentrations ranged from about 40 to 70 µg/L. Relatively few data on boron were available, and the highest reported boron concentration in well water samples was 60 µg/L, in contrast to concentrations over 5,000 µg/L reported by USEPA (2000) in the Congo Road area. Although concentrations of fluoride up to 4 mg/L were reported for a few well-water samples collected throughout the Newark Basin, about 90 percent of the samples had 0.5 mg/L or less of fluoride.

The USGS sampled 58 wells primarily in 5 areas in the Newark Basin of southeastern Pennsylvania from February 2004 through April 2005 to identify other possible areas of elevated arsenic, boron, and fluoride and to characterize the geochemical environment associated with elevated concentrations of these constituents. One of the 58 wells sampled was a private-supply well in the Gettysburg Basin near Dillsburg, York County, an area where elevated fluoride in ground water had been reported. Of the other 57 wells sampled, 12 were monitor wells at an industrial facility near Congo Road, 45 were private-supply wells near Congo Road, Jacksonwald, Kibble House Quarry, New Hope, and Quakertown areas in Berks, Montgomery, and Bucks Counties in the Newark Basin. Mineralization associated with diabase intrusions was documented in most areas sampled but was not a criterion used to select sampling areas, except in the Kibblehouse Quarry locality. Wells were sampled in transects from the diabase through the adjacent hornfels and into the unaltered shales of the Brunswick Group. The direction of ground-water flow commonly was estimated from ground-water levels and is from areas underlain by diabase, which forms hills, through areas underlain by hornfels to areas underlain by unaltered shales. Generally, about 6 to 14 wells were sampled in each of the 5 areas. Field measurements were made of pH, temperature, dissolved oxygen concentration, and specific conductance. Samples were analyzed in the laboratory for major ions, nutrients, total organic carbon, dissolved and total concentrations of selected trace elements, and boron isotopic composition. Differences between dissolved and total metal concentrations were small to negligible, except for iron, indicating that the dissolved phase of most constituents is predominant. For iron, however, the particulate phase can be a large component of the concentration in ground water.

Generally, the ground water from the 46 private-supply wells had relatively neutral to alkaline pH (ranging from 6.1 to 9.1) and moderate concentrations of dissolved oxygen. Most well samples were calcium-bicarbonate-type water. Concentrations of arsenic up to 60 µg/L, boron up to 3,950 µg/L, and fluoride up to 0.40 mg/L were measured. Drinking-water standards or health advisories were exceeded most frequently (about 20 percent of wells sampled) for arsenic and boron and less frequently (6 percent or less of wells sampled) for total iron, manganese, sulfate, nitrate, lead, molybdenum, and strontium. Drinking-water standards or health advisories were exceeded in 10 samples for arsenic, 9 samples for boron, 3 samples for total iron, 3 samples for manganese, 2 samples for sulfate, 1 sample for nitrate, 1 sample for lead, 1 sample for molybdenum, and 1 sample for strontium. In water from 12 monitor wells at the industrial facility near Congo Road, concentrations of arsenic up to 61 µg/L, boron up to 5,240 µg/L, and fluoride up to 6.51 mg/L were measured, and drinking-water standards were exceeded in 9 samples for manganese, 5 samples for boron, 5 samples for strontium, 4 samples for arsenic, 3 samples for chloride, 3 samples for sulfate, 2 samples for fluoride, 1 sample for ammonia,1 sample for iron, and 1 sample for selenium. The drinking-water standard or health advisory exceedences for arsenic, boron, and fluoride represented about 33, 42, and 17 percent, respectively, of the monitor-well samples.

Statistical comparisons of constituent concentrations in different sampling areas and different lithologies were performed using the nonparametric Krusal-Wallis and Tukey tests. Few differences were determined to be statistically significant for water from private-supply wells in the different sampling areas, but those differences included concentrations of arsenic and boron. Arsenic concentrations were lowest in the Jacksonwald area of Berks County, and boron concentrations were lowest in the Quakertown area of Bucks County. The highest concentrations of arsenic and boron were measured in the Congo Road and the New Hope areas. Concentrations of arsenic up to 60 μg/L and boron up to 3,170 μg/L measured in the New Hope-Jericho Mountain area in Bucks County were of the same magnitude measured in the Congo Road area. Many differences in water quality were found in the comparison of private-supply and monitor-well samples; water from the monitor wells at the industrial facility near Congo Road was found to have higher concentrations of numerous constituents, including major cations, chloride, fluoride, ammonia, total organic carbon, barium, cobalt, iron, lithium, manganese, nickel, selenium, strontium, and uranium. Statistically significant differences were not found for arsenic and boron concentrations when water from the private-supply well and monitor wells were compared. However, correlation between boron and chloride concentrations in samples from the monitor wells and a few boron isotope compositions with low $\delta^{11}B$ values (less than 5 per mil) suggest some anthropogenic introduction of boron at the industrial facility. Based on ground-water levels, statistical comparisons of boron concentrations in all sampled areas, varying correlations between boron and chloride, and boron isotopic compositions, elevated boron concentrations in water from private-supply wells near but upgradient of the industrial facility in the Congo Road area appear to be related to natural sources in aquifer materials.

When water from the three main lithologies—diabase, hornfels, and unaltered shales—was compared, statistically significant differences were found for concentrations of some major ions and trace elements and for boron isotopic compositions, although significant differences were not found for concentrations of arsenic, boron, or fluoride. Concentrations of most constituents tended to be lowest in the water from diabase and highest in water from the shales and often intermediate in water from the hornfels, but water from wells in the diabase and hornfels tended to have higher concentrations of silica and vanadium than water from the unaltered shales. Water from wells in the diabase tended to be most enriched in the heavier isotope of boron, ^{11}B. The boron isotope compositions of most water samples from private-supply wells in all of the study areas (including the Congo Road area) indicate natural mineral sources for boron. Differences in isotopic composition suggests that mineral sources of boron may differ by lithology, although ground water in wells downgradient from diabase is probably a mixture of water that has interacted with the diabase and adjacent geologic units.

Relations between chemical constituents were explored using the nonparametric Spearman rho correlation test. Resulting statistically significant correlations suggest geochemical controls and possible distributions of elements in the aquifer. In water samples from 46 private-supply wells, arsenic correlated most strongly and positively with pH, boron, and molybdenum. Arsenic also correlated positively with selenium, uranium, nickel, lithium, fluoride, and strontium, and negatively with total organic carbon, copper, and dissolved oxygen. Arsenic concentrations may be controlled partly by pH affecting adsorption of the anion, arsenate. All private-supply-well samples with pH of 8 or higher had arsenic concentrations greater than the MCL of 10 μg/L, whereas no private-supply-well sample with pH of 7 or lower had arsenic concentrations that exceeded the MCL of 10 μg/L. The correlation of arsenic with many of the other trace elements suggests similar geochemical controls and (or) distribution in the aquifer materials. In water samples from monitor wells at the industrial site, arsenic did not correlate with pH, and some of the monitor-well samples with elevated arsenic also had low dissolved oxygen and (or) elevated dissolved iron and manganese concentrations, indicating reductive dissolution of iron and manganese oxides may be a mechanism that released some arsenic in ground water at that locality.

For wells completed in and near diabase, the percentage with ground-water concentrations of arsenic above the MCL of 10 μg/L appears to be greater than for the Newark Basin as a whole (about 20 percent compared to 10 percent), suggesting some arsenic enrichment in the rocks and (or) a favorable geochemical environment to mobilize arsenic. In addition, the amount of boron in and near diabase intrusions probably is higher than in the Newark Basin as a whole. Boron may have been introduced or remobilized during the emplacement of diabase intrusions in the basin, especially where basin brines or residual brines associated with evaporites may have been present. Reported boron isotopic compositions for datolite in Mesozoic rift basalt and diabases in the eastern United States have a similar range as those measured in ground water in the diabase in this study, indicating datolite may be a source of boron in ground water. Only a few elevated fluoride concentrations, other than those related to anthropogenic sources at the industrial facility near Congo Road, were measured in samples from wells in and near diabase, indicating limited local natural fluoride enrichment. Possible sources of arsenic, boron, and fluoride in the rocks include mineral deposits associated with the diabase intrusions.

Acknowledgments

Individuals at USEPA who contributed data and their knowledge and time included Jack Kelly, Michael Towle, Nicholas Tymchenko, and Richard Rogers. The industrial facility near Congo Road and numerous private-supply well owners permitted sampling of their wells. Gerald Kirkpatrick of Environmental Standards, Inc., and Nancy Shannon of TetraTech, Inc., shared data. The field work was done by Abdul Mohammad and Elaine Gee of USGS, and Lindsay Hale of USGS assisted in preparing the map of ground-water levels. Technical reviews of the manuscript were provided by Julia Barringer of USGS and Michael Serfes of the New Jersey Geological Survey.

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Table 21. Description of wells sampled by the U.S. Geological Survey, Newark Basin, southeastern Pennsylvania, February 2004 - April 2005.

[NAD83, North American Datum 1983; NVGD29, National Vertical Geodetic Datum of 1929; Aquifer code: 231BRCK, Brunswick Group; 231 DIBS, diabase; 231LCKG, Lockatong Formation; Lithologic code: MMPC, metamorphic indicating baked zone adjacent to diabase; blank, none specified; --, no data; ft, feet; bls, below land surface; in., inches; gal/min, gallons per minute; (gal/min)/ft; Type of casing: S, steel; P, plastic; Type of opening: S, screen; F, fracture; Use of well: O, obervation; W, withdrawl; Use of Water: C, commercial; H, domestic; I, irrigation; U, unused]

U.S. Geological Survey local well number	U.S. Geological Survey station identification number	Municipality	Owner identifier	Location (NAD83)		Altitude, in ft above NVGD29	Aquifer code	Litho-logic code	Year well drilled
				Latitude (degrees)	Longitude (degrees)				
Monitor wells at industrial property									
BE 1756	402109075365101	COLEBROOKDALE TWP	95-01	402109	753651	358	231BRCK		--
BE 1756									--
BE 1757	402049075364501	COLEBROOKDALE TWP	97-06	402049	753645	326	231BRCK		--
BE 1757									--
BE 1758	402057075364901	COLEBROOKDALE TWP	95-04	402057	753649	328	231BRCK		--
BE 1758									--
BE 1759	402039075365801	COLEBROOKDALE TWP	90-7S	402039	753658	312	231BRCK		--
BE 1759									--
BE 1760	402034075365401	COLEBROOKDALE TWP	90-6S	402034	753654	311	231BRCK		--
BE 1760									--
BE 1761	402048075365401	COLEBROOKDALE TWP	00-08	402048	753654	318	231BRCK		--
BE 1761									--
BE 1762	402105075364501	COLEBROOKDALE TWP	MMW-5	402105	753645	341	231BRCK		--
BE 1762									--
MG 2104	402037075364001	DOUGLASS TWP	90-1SR	402037	753640	316	231BRCK		--
MG 2104									--
MG 2105	402037075364002	DOUGLASS TWP	90-1D	402037	753640	317	231BRCK		--
MG 2105									--
MG 2106	402034075364301	DOUGLASS TWP	90-4S	402034	753643	313	231BRCK		--
MG 2106									--
MG 2107	402031075364501	DOUGLASS TWP	90-3S	402031	753645	313	231BRCK		--
MG 2107									--
MG 2108	402031075364502	DOUGLASS TWP	90-3D	402031	753645	313	231BRCK		--
MG 2108									--
Other wells									
BE 1733	402201075355601	WASHINGTON TWP		402201	753556	586	231BRCKF	MMPC	1966
BE 1733									
BE 1763	402126075363801	WASHINGTON TWP		402126	753636	525	231DIBS		1999
BE 1764	402117075363301	WASHINGTON TWP		402120	753637	400	231DIBS		--
BE 1765	402116075363501	WASHINGTON TWP		402119	753640	395	231BRCK	MMPC	2002
BE 1766	402113075363701	WASHINGTON TWP		402116	753639	393	231BRCK	MMPC	1971
BE 1767	401848075494901	EXETER TWP		401848	754949	278	231BRCK		--
BE 1768	401834075494701	EXETER TWP		401834	754947	383	231BSLT		1957
BE 1769	401911075501701	EXETER TWP		401911	755017	430	231BSLT		1987
BE 1770	401825075494701	EXETER TWP		401825	754947	380	231BRCK	MMPC	1970
BE 1771	401908075501501	EXETER TWP		401908	755015	425	231DIBS		1976
BE 1772	401823075495601			401823	754956	500	231DIBS		2002

Table 21. Description of wells sampled by the U.S. Geological Survey, Newark Bason, southeastern Pennsylvania, February 2004 - April 2005.—Continued

[NAD83, North American Datum 1983; NVGD29, National Vertical Geodetic Datum of 1929; Aquifer code: 231BRCK, Brunswick Group; 231 DIBS, diabase; 231LCKG, Lockatong Formation; Lithologic code: MMPC, metamorphic indicating baked zone adjacent to diabase; blank, none specified; --, no data; ft, feet; bls, below land surface; in., inches; gal/min, gallons per minute; (gal/min)/ft; Type of casing: S, steel; P, plastic; Type of opening: S, screen; F, fracture; Use of well: O, obervation; W, withdrawl; Use of Water: C, commercial; H, domestic; I, irrigation; U, unused]

Well depth (ft bls)	Casing		Casing material	Depth to top of opening (ft bls)	Depth to bottom of opening (ft bls)	Type of opening	Depth to water (ft bls)	Date of water-level measure-ment (YYYYMMDD)	Reported yield (gal/min)	Specific capacity [(gal/min)/ft]	Use of well	Use of water	U.S. Geological Survey local well number
	Length (ft)	Dia-meter (in.)											
													Monitor wells at industrial property
60	7	6	S	30	60	S	7.92	20040301	--	--	O	U	BE 1756
	30	2	P										BE 1756
94	11	6	S	74	94	S	1.5	20040302	--	--	O	U	BE 1757
	74	2	P										BE 1757
60	9	6	S	40	60	S	5.48	20040302	--	--	O	U	BE 1758
	40	2	P										BE 1758
54	19	8	S	32		F	1.16	20040304	--	--	O	U	BE 1759
	29	6	S										BE 1759
47	17	2	P	17	47	S	3.24	20040304	--	--	O	U	BE 1760
													BE 1760
56.8	18	6	S	40	55	S	2.13	20040308	--	--	O	U	BE 1761
	40	2	P										BE 1761
101	20	6	S	40	70	S		--	--	--	O	U	BE 1762
	40	2	P										BE 1762
31	10	2	P	10	30	S	3.64	20040303	--	--	O	U	MG 2104
													MG 2104
89.5	20	6	S	69.5	89.5	S	1.94	20040303	--	--	O	U	MG 2105
	69.5	2	P										MG 2105
31.6	11.6	2	P	11.6	31.6	S	1.84	20040303	--	--	O	U	MG 2106
													MG 2106
36.8	13.5	6	S	16.8	36.8	S	3.63	20040305	--	--	O	U	MG 2107
	16.8	2	P										MG 2107
89.2	20	6	S	69.2	89.2	S	1.4	20040305	--	--	O	U	MG 2108
	69.2	2	P										MG 2108
													Other wells
280	--	---	--	--		--	77.2	20030815	--	--	W	H	BE 1733
				--		--	81.49	20040505	--	--	W	H	BE 1733
280	40	6	S	--		--	29.64	20040504	--	--	W	H	BE 1763
--	---	--	--	--		--	--	--	--	--	W	H	BE 1764
200	60	6	S	--		--	0	20040504	--	--	W	H	BE 1765
--	---	--	--	--		--	--		--	--	W	H	BE 1766
20	20	36	R	--		--	0	20040621	--	--	W	H	BE 1767
160	--	---	--	--		--	--	--	--	--	W	H	BE 1768
160	21	6	S	--		--	--	--	--	--	W	H	BE 1769
130	--	---	--	--		--	--	--	--	--	W	H	BE 1770
165	--	---	--	--		--	19.97	20040802	--	--	W	H	BE 1771
660	--	---	--	--		--	--	--	--	--	W	H	BE 1772

Table 21. Description of wells sampled by the U.S. Geological Survey, Newark Basin, southeastern Pennsylvania, February 2004 - April 2005.—Continued

[NAD83, North American Datum 1983; NVGD29, National Vertical Geodetic Datum of 1929; Aquifer code: 231BRCK, Brunswick Group; 231 DIBS, diabase; 231LCKG, Lockatong Formation; Lithologic code: MMPC, metamorphic indicating baked zone adjacent to diabase; blank, none specified; --, no data; ft, feet; bls, below land surface; in., inches; gal/min, gallons per minute; (gal/min)/ft; Type of casing: S, steel; P, plastic; Type of opening: S, screen; F, fracture; Use of well: O, obervation; W, withdrawl; Use of Water: C, commercial; H, domestic; I, irrigation; U, unused]

U.S. Geological Survey local well number	U.S. Geological Survey station identification number	Municipality	Owner identifier	Location (NAD83)		Altitude, in ft above NVGD29	Aquifer code	Litho-logic code	Year well drilled
				Latitude (degrees)	Longitude (degrees)				
BK 2153	401926074581601	SOLEBURY TWP		401926	745815	130	231BRCK		1983
BK 2199	402001074583601	SOLEBURY TWP		402001	745835	250	231BRCK	MMPC	1990
BK 3017	401800074572101	U MAKEFIELD TWP		401760	745721	382	231DIBS		1984
BK 3018	401754074581101	U MAKEFIELD TWP		401754	745811	210	231BRCK	MMPC	1990
BK 3019	401832074565901	UPPER MAKEFIELD TWP		401832	745659	185	231BRCK		2002
BK 3020	401803074571601	UPPER MAKEFIELD TWP		401803	745716	362	231DIBS		1993
BK 3021	401811074572901	UPPER MAKEFIELD TWP		401811	745729	248	231BRCK	MMPC	1979
BK 3022	402006074581601	SOLEBURY TWP		402006	745816	280	231BRCK	MMPC	1962
BK 3023	402018074575301	SOLEBURY TWP		402018	745753	320	231DIBS		
BK 3024	402559075195201	RICHLAND TWP		402559	751952	515	231BRCK		1993
BK 3025	402415075185401	E ROCKHILL TWP		402415	751854	535	231DIBS		1969
BK 3026	402335075171701	E ROCKHILL TWP		402335	751717	507	231BRCK		1988
BK 3027	402420075170501	E ROCKHILL TWP		402420	751705	500	231BRCK	MMPC	1966
BK 3028	402438075194901	RICHLAND TWP		402438	751949	559	231DIBS		1991
BK 3029	402416075044501	PLUMSTEAD TWP		402416	750445	438	231DIBS		1970
BK 3030	402320075165601	EAST ROCKHILL T		402320	751656	565	231LCKG		1997
BK 3031	402344075160501	EAST ROCKHILL T		402344	751605	439	231BRCK		1975
BK 3032	402839075215401	RICHLAND TWP		402839	752154	580	231DIBS		
BK 3033	402940075203601	SPRINGFIELD TWP		402940	752036	645	231BRCK	MMPC	1982
MG 1974	402104075351801	DOUGLASS TWP		402104	753518	423	231BRCK	MMPC	1993
MG 1982	402059075352401	DOUGLASS TWP		402059	753524	392	231BRCK	MMPC	1990
MG 1982									
MG 2001	402124075352401	DOUGLASS TWP		402124	753524	457	231BRCK		1993
MG 2001									
MG 2026	402022075333001	NEW HANOVER TWP		402022	753330	484	231DIBS		1970
MG 2026									
MG 2103	402056075351301	DOUGLASS TWP		402060	753518	390	231BRCK	MMPC	
MG 2109	402103075351801	DOUGLASS TWP		402102	753522	410	231BRCK	MMPC	1991
MG 2110	402051075352901	DOUGLASS TWP		402051	753529	348	231BRCK		1961
MG 2111	401956075335301	NEW HANOVER TWP		401956	753353	370	231BRCK	MMPC	1946
MG 2112	401901075260301	UPPER SALFORD TWP		401901	752603	445	231BRCK	MMPC	1988
MG 2113	402118075351501	DOUGLASS TWP		402118	753515	410	231BRCK		1991
MG 2114	401913075265601	UPPER SALFORD TWP		401913	752656	403	231BRCK	MMPC	1991
MG 2115	401915075274801	MARLBOROUGH TWP		401915	752748	307	231BRCK	MMPC	2002
MG 2116	401919075282101	MARLBOROUGH TWP		401919	752821	202	231BRCK	MMPC	
MG 2117	401950075275701	MARLBOROUGH TWP		401950	752757	270	231DIBS		1997
MG 2118	401938075274301	MARLBOROUGH TWP		401938	752743	362	231DIBS		1987
YO 1224	400549076590201	CARROLL TWP		400549	765902	690	231DIBS		1965

Table 21. Description of wells sampled by the U.S. Geological Survey, Newark Bason, southeastern Pennsylvania, February 2004 - April 2005.—Continued

[NAD83, North American Datum 1983; NVGD29, National Vertical Geodetic Datum of 1929; Aquifer code: 231BRCK, Brunswick Group; 231 DIBS, diabase; 231LCKG, Lockatong Formation; Lithologic code: MMPC, metamorphic indicating baked zone adjacent to diabase; blank, none specified; --, no data; ft, feet; bls, below land surface; in., inches; gal/min, gallons per minute; (gal/min)/ft; Type of casing: S, steel; P, plastic; Type of opening: S, screen; F, fracture; Use of well: O, obervation; W, withdrawl; Use of Water: C, commercial; H, domestic; I, irrigation; U, unused]

Well depth (ft bls)	Casing		Casing material	Depth to top of opening (ft bls)	Depth to bottom of opening (ft bls)	Type of opening	Depth to water (ft bls)	Date of water-level measurement (YYYYMMDD)	Reported yield (gal/min)	Specific capacity [(gal/min)/ft]	Use of well	Use of water	U.S. Geological Survey local well number
	Length (ft)	Diameter (in.)											
115	40	6	S	80, 105		F	12.2	19911211	20	0.24	W	H	BK 2153
525		6	S	--		--	52.5	19920305	55	--	W	I	BK 2199
500	66	6	S	--		--	117.75	20041007	12	0.12	W	H	BK 3017
198	60	6	S	150, 180		F	41.1	20041007	8	--	W	H	BK 3018
--				--		--	16.82	20041117	--	--	W	H	BK 3019
375	55	6	S	220, 373		F	--	--	60	1.5	W	H	BK 3020
140	--	---	--	--		--	12.73	20041201	--	--	W	H	BK 3021
140	--	---	--	--		--	--	--	--	--	W	H	BK 3022
250	30	6	S	--		--	--	--	--	--	W	H	BK 3023
200	90	6	S	160, 190		F	13.73	20050110	20	--	W	H	BK 3024
77	15	6	S	--		--	13.08	20050111	--	--	W	H	BK 3025
200	25	6	S	--		--	36.34	20050111	--	--	W	H	BK 3026
90	--	---	--	--		--	--	--	--	--	W	H	BK 3027
180	40	6	S	67, 110, 162, 176		F	--	--	12	--	W	H	BK 3028
80	--	6	S	--		--	1.75	20050216	--	--	W	H	BK 3029
--	--	--	--	--		--	64.65	20050411	--	--	W	H	BK 3030
--	--	--	--	--		--	--	--	--	--	W	H	BK 3031
--	--	--	--	--		--	--	--	--	--	W	H	BK 3032
225	32.5	6	S	--		--	34.22	20050414	12	--	W	H	BK 3033
347	42	6	S	66, 200, 288, 345		F	38.08	20030813	5	0.05	W	H	MG 1974
250	--	--	--	--		--	5.47	20030814	--	--	W	H	MG 1982
							2.96	20040505			W	H	MG 1982
247	84.33	6.25	S	115, 155, 190		F	49.16	20030812	30	0.16	W	C	MG 2001
						F	45.74	20040506			W	C	MG 2001
325	--	--	--	--		--	24.01	20030911	--	--	W	H	MG 2026
--	--	--	--	--		--	37.6	20040504	--	--	W	H	MG 2026
--	--	--	--	--		--	---	--	--	--	W	H	MG 2103
300	--	--	--	--		--	18.23	20040504	--	--	W	H	MG 2109
100	--	--	--	--		--	--	--	--	--	W	H	MG 2110
120	20	6	S	--		--	--	--	--	--	W	H	MG 2111
200	40	6	S	95, 125		F	--	--	12	--	W	H	MG 2112
360	40	6	S	--		--	36.25	20040727	--	--	W	H	MG 2113
610	40	6	S	80, 480, 610		F	15.87	20040922	4	--	W	H	MG 2114
360	40.5	6	S	75, 215		F	66.5	20040923	6	--	W	H	MG 2115
141	--	--	--	--		--	--	--	--	--	W	H	MG 2116
400	--	--	--	--		--	7.9	20041026	--	--	W	H	MG 2117
400	31	6	S	200, 380		F	156.5	20041115	10	0.03	W	H	MG 2118
111	--	--	--	--		-	--	--	--	--	W	H	YO 1224

Table 22. Field chemical measurements and results of laboratory analysis of water samples collected from 12 monitor wells and 46 private-supply wells in and near diabase intrusions, Newark Basin, southeastern Pennsylvania, February 2004-April 2005. Wells listed by geologic unit in each study area.

[Geologic unit code: 231BRCK, Brunswick Group; 231BRCKF, Limestone fanglomerate; 231DIBS, diabase; 231LCKG, Lockatong Formation; Lithology: MMPC, metamorphosed (hornfels); blank, none specified; Agency collecting sample code: 1028, U.S. Geological Survey; USEPA, U.S. Environmental Protection Agency contactor TetraTech. Inc.; Agency analyzing sample code: 80020, U.S. Geological Survey; USEPA, U.S. Environmental Protection Agency contact laboratory.; LSD, land surface datum; gal/min, gallons per minute; NTU, nephelometric turbidity units; mm HG, millimeters of mercury; mg/L, milligrams per liter; uS/cm, microsiemens per centimeter at 25 degrees Celsius; deg C, degrees Celsius; ANC, acid neutralizing capacity; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; mg/L as N, milligrams per liter as nitrogen; mg/L as P, milligrams per liter as phosphorus; µg/L, micrograms per liter; --, no data; <, less than; E, estimated value below reporting level; M, measured but not quantified value below reporting level]

Table 22. Field chemical measurements and results of laboratory analysis of water samples collected from 12 monitor wells and 46 private-supply wells in and near diabase intrusions, Newark Basin, southeastern Pennsylvania, February 2004-April 2005. Wells listed by geologic unit in each study area.

U.S. Geological Survey local well number	Geologic unit code	Lithology	Date of sample	Time of sample	Agency collecting sample	Agency analyzing sample	Well depth (feet)	Depth to water (feet below LSD)	Flow rate, instantaneous (gal/min)	Pump or flow period prior to sampling (minutes)
					(00027)	(00028)	(72008)	(72019)	(00059)	(72004)
Monitor wells - Congo Road area										
BE 1756	231BRCK		03-01-04	1030	1028	80020	60	--	--	--
BE 1757	231BRCK		03-02-04	1130	1028	80020	94	--	--	--
BE 1758	231BRCK		03-02-04	1330	1028	80020	60	--	--	--
BE 1759	231BRCK		03-04-04	1010	1028	80020	54	--	--	--
BE 1759	231BRCK		03-08-04	1120	1028	80020	54	--	--	--
BE 1760	231BRCK		03-04-04	1140	1028	80020	47	--	--	--
BE 1761	231BRCK		03-08-04	1510	1028	80020	56.8	--	--	--
BE 1762	231BRCK		03-09-04	1020	1028	80020	101	--	--	--
MG 2104	231BRCK		03-03-04	1100	1028	80020	31	--	--	--
MG 2105	231BRCK		03-03-04	1200	1028	80020	89.5	--	--	--
MG 2106	231BRCK		03-03-04	1520	1028	80020	31.6	--	--	--
MG 2107	231BRCK		03-05-04	1040	1028	80020	36.8	--	--	--
MG 2108	231BRCK		03-05-04	1100	1028	80020	89.2	--	--	--
Private-supply wells - Congo Road area										
BE 1763	231DIBS		05-04-04	1110	1028	80020	280	29.64	2.5	31
BE 1764	231DIBS		05-06-04	1000	1028	80020	--	--	3.0	39
MG 2026	231DIBS		05-04-04	0740	1028	80020	325	37.60	1.2	30
BE 1765	231BRCK	MMPC	05-04-04	1010	1028	80020	200	.00	.80	22
BE 1766	231BRCK	MMPC	05-06-04	1330	1028	80020	--	--	1.5	40
MG 1974	231BRCK	MMPC	07-26-04	1010	1028	80020	347	--	--	--
MG 1982	231BRCK	MMPC	05-05-04	0940	1028	80020	250	2.96	2.1	30
MG 2103	231BRCK	MMPC	02-18-04	1320	1028	80020	--	--	2.5	80
MG 2103	231BRCK	MMPC	02-18-04[2]		USEPA	USEPA	--	--	2.5	80
MG 2109	231BRCK	MMPC	05-04-04	1340	1028	80020	300	18.23	2.0	23
MG 2111	231BRCK	MMPC	06-07-04	1000	1028	80020	120	--	2.5	30
BE 1733	231BRCKF	MMPC	05-05-04	1100	1028	80020	280	81.49	3.0	25
MG 2001	231BRCK		05-06-04	1200	1028	80020	247	45.74	3.4	67
MG 2110	231BRCK		06-03-04	1010	1028	80020	100	--	2.7	54
MG 2113	231BRCK		07-27-04	0930	1028	80020	360	--	--	--
Private-supply wells - Jacksonwald area										
BE 1769	231BSLT		06-29-04	1020	1028	80020	160	--	2.5	67
BE 1771	231BSLT		08-02-04	0930	1028	80020	165	--	--	--
BE 1768	231DIBS		06-21-04	1100	1028	80020	160	--	2.2	33
BE 1772	231DIBS		08-02-04	1120	1028	80020	660	--	--	--
BE 1770	231BRCK	MMPC	08-04-04	1020	1028	80020	130	--	--	--
BE 1767	231BRCK		06-21-04	0930	1028	80020	20	.00	1.5	38

Table 22. Field chemical measurements and results of laboratory analysis of water samples collected from 12 monitor wells and 46 private-supply wells in and near diabase intrusions, Newark Basin, southeastern Pennsylvania, February 2004-April 2005. Wells listed by geologic unit in each study area.—Continued

U.S. Geological Survey local well number	Geologic unit code	Lithology	Date of sample	Time of sample	Agency collecting sample	Agency analyzing sample	Well depth (feet)	Depth to water (feet below LSD)	Flow rate, instan-taneous (gal/min)	Pump or flow period prior to sampling (minutes)
					(00027)	(00028)	(72008)	(72019)	(00059)	(72004)
Private-supply wells - Kibblehouse area										
MG 2117	231DIBS		10-26-04	1050	1028	80020	400	7.90	5.0	62
MG 2112	231BRCK	MMPC	09-22-04	0900	1028	80020	200	--	9.0	55
MG 2114	231BRCK	MMPC	09-22-04	1100	1028	80020	610	15.87	2.5	55
MG 2115	231BRCK	MMPC	09-23-04	0900	1028	80020	360	66.50	3.0	60
MG 2116	231BRCK	MMPC	09-23-04	1040	1028	80020	141	--	8.0	62
MG 2118	231BRCK	MMPC	11-15-04	1020	1028	80020	400	156.50	4.0	60
Private-supply wells - New Hope area										
BK 3029	231DIBS		02-16-05	1100	1028	80020	80	1.75	7.0	57
BK 3017	231DIBS		10-07-04	1100	1028	80020	500	117.75	8.0	75
BK 3020	231DIBS		11-22-04[4]	1220	1028	80020	375	--	4.0	60
BK 3020	231DIBS		01-27-05	0900	1028	80020	375	--	3.2	60
BK 3023	231DIBS		12-07-04	1010	1028	80020	250	--	4.0	69
BK 3018	231BRCK	MMPC	10-07-04	1310	1028	80020	198	41.10	6.0	62
BK 3021	231BRCK	MMPC	12-01-04	1010	1028	80020	140	12.73	4.0	64
BK 3022	231BRCK	MMPC	12-06-04	1210	1028	80020	140	--	5.0	55
BK 2199	231BRCK	MMPC	02-07-05	1201	1028	80020	525	--	12.6	71
BK 2199	231BRCK	MMPC	02-07-05[2]	1200	1028	80020	525	--	12.6	71
BK 3019	231BRCK		11-17-04	1140	1028	80020	--	16.82	4.0	61
BK 2153	231BRCK		04-06-05	1240	1028	80020	115	5.35	5.0	66
Private-supply wells - Quakertown area										
BK 3025	231DIBS		01-11-05	1000	1028	80020	77	13.08	4.0	58
BK 3028	231DIBS		01-13-05	1200	1028	80020	180	--	4.1	58
BK 3032	231DIBS		04-13-05	1130	1028	80020	--	--	2.3	60
BK 3027	231BRCK	MMPC	01-13-05	1010	1028	80020	90	--	3.9	65
BK 3033	231BRCK	MMPC	04-14-05	1140	1028	80020	225	34.22	5.1	59
BK 3024	231BRCK		01-10-05	1050	1028	80020	200	13.73	3.7	62
BK 3026	231BRCK		01-11-05	1140	1028	80020	200	36.34	3.8	64
BK 3031	231BRCK		04-11-05	1200	1028	80020	--	--	5.3	62
BK 3030	231LCKG		04-11-05	1020	1028	80020	--	64.65	--	69
Private-supply wells - Dillsburg area, Gettysburg Basin										
YO 1224	231DIBS		12-02-04	0940	1028	80020	111	--	4.0	65

Table 22. Field chemical measurements and results of laboratory analysis of water samples collected from 12 monitor wells and 46 private-supply wells in and near diabase intrusions, Newark Basin, southeastern Pennsylvania, February 2004-April 2005. Wells listed by geologic unit in each study area.—Continued

U.S. Geological Survey local well number	Geologic unit code	Lithology	Date of sample	Turbidity (NTU)	Baro-metric pressure (mm HG)	Dissolved oxygen (mg/L)	Dissolved oxygen (percent satur-ation)	pH, water, unfiltered field (standard units)	pH, water, unfiltered lab (standard units)	Specific conduct-ance, water unf lab (µS/cm)	Specific conduct-ance, water unf (µS/cm)
				(00076)	(00025)	(00300)	(00301)	(00400)	(00403)	(90095)	(00095)
Monitor wells - Congo Road area											
BE 1756	231BRCK		03-01-04	0.90	757	7.1	65	6.6	7.3	252	189
BE 1757	231BRCK		03-02-04	1.1	753	4.5	40	7.4	7.2	562	411
BE 1758	231BRCK		03-02-04	.20	753	8.5	79	6.7	7.5	883	678
BE 1759	231BRCK		03-04-04	260	758	6.0	56	6.7	7.1	5,660	4,180
BE 1759	231BRCK		03-08-04	5.5	745	--	--	6.9	6.8	5,230	4,090
BE 1760	231BRCK		03-04-04	1.7	758	.5	4	7.2	7.4	4,270	8,080
BE 1761	231BRCK		03-08-04	9.8	745	4.3	41	6.8	7.0	1,500	1,460
BE 1762	231BRCK		03-09-04	.10	753	.4	4	6.9	7.0	920	948
MG 2104	231BRCK		03-03-04	4.8	761	.5	5	7.3	7.4	600	465
MG 2105	231BRCK		03-03-04	30	759	2.9	27	7.1	7.3	636	520
MG 2106	231BRCK		03-03-04	33	758	.2	2	6.6	7.2	2,020	1,490
MG 2107	231BRCK		03-05-04	14	754	.2	2	6.8	7.2	1,370	1,920
MG 2108	231BRCK		03-05-04	13	754	1.4	13	7.2	7.2	854	1,200
Private-supply wells - Congo Road area											
BE 1763	231DIBS		05-04-04	--	749	6.1	57	7.2	7.6	291	302
BE 1764	231DIBS		05-06-04	--	755	6.3	60	7.2	7.2	204	207
MG 2026	231DIBS		05-04-04	--	750	7.7	72	6.5	7.5	189	195
BE 1765	231BRCK	MMPC	05-04-04	--	749	.3	3	8.1	7.9	961	995
BE 1766	231BRCK	MMPC	05-06-04	--	753	1.8	17	7.3	7.4	520	540
MG 1974	231BRCK	MMPC	07-26-04	--	755	6.4	62	7.6	7.5	486	512
MG 1982	231BRCK	MMPC	05-05-04	--	751	2.8	26	8.2	8.0	277	293
MG 2103	231BRCK	MMPC	02-18-04	--	752	5.0	46	7.7	E7.2	362	377
MG 2103	231BRCK	MMPC	02-18-04[2]	--	752	--	--	--	--	--	--
MG 2109	231BRCK	MMPC	05-04-04	--	749	1.3	12	8.3	8.1	233	245
MG 2111	231BRCK	MMPC	06-07-04	--	755	2.1	20	7.6	7.6	323	338
BE 1733	231BRCKF	MMPC	05-05-04	--	746	9.3	88	8.1	8.0	269	290
MG 2001	231BRCK		05-06-04	--	754	6.3	61	7.6	7.5	459	496
MG 2110	231BRCK		06-03-04	--	753	.4	4	7.3	7.5	642	669
MG 2113	231BRCK		07-27-04	--	754	.4	4	7.3	7.0	2,030	2,000
Private-supply wells - Jacksonwald area											
BE 1769	231BSLT		06-29-04	--	753	8.5	80	7.6	7.4	272	288
BE 1771	231BSLT		08-02-04	--	750	5.7	54	7.3	7.3	400	403
BE 1768	231DIBS		06-21-04	--	756	8.1	75	6.7	7.1	277	280
BE 1772	231DIBS		08-02-04	--	749	3.8	36	7.9	E7.6	306	308
BE 1770	231BRCK	MMPC	08-04-04	--	747	9.7	91	6.5	7.0	155	155
BE 1767	231BRCK		06-21-04	--	756	.2	2	7.1	7.2	793	769

Table 22. Field chemical measurements and results of laboratory analysis of water samples collected from 12 monitor wells and 46 private-supply wells in and near diabase intrusions, Newark Basin, southeastern Pennsylvania, February 2004-April 2005. Wells listed by geologic unit in each study area.—Continued

U.S. Geological Survey local well number	Geologic unit code	Lithology	Date of sample	Turbidity (NTU)	Baro-metric pressure (mm HG)	Dissolved oxygen (mg/L)	Dissolved oxygen (percent satur-ation)	pH, water, unfiltered field (standard units)	pH, water, unfiltered lab (standard units)	Specific conduct-ance, water unf lab (µS/cm)	Specific conduct-ance, water unf (µS/cm)
				(00076)	(00025)	(00300)	(00301)	(00400)	(00403)	(90095)	(00095)
Private-supply wells - Kibblehouse area											
MG 2117	231DIBS		10-26-04	--	759	5.8	57	6.8	7.2	530	549
MG 2112	231BRCK	MMPC	09-22-04	--	756	.6	6	7.5	E7.0	593	595
MG 2114	231BRCK	MMPC	09-22-04	--	757	1.4	14	7.6	7.2	542	548
MG 2115	231BRCK	MMPC	09-23-04	--	759	2.3	21	8.0	7.9	254	263
MG 2116	231BRCK	MMPC	09-23-04	--	759	6.3	63	6.9	7.5	252	261
MG 2118	231BRCK	MMPC	11-15-04	--	766	6.4	60	7.0	6.6	245	260
Private-supply wells - New Hope area											
BK 3029	231DIBS		02-16-05	--	742	4.8	44	6.1	6.8	643	682
BK 3017	231DIBS		10-07-04		762	.9	9	8.1	8.1	336	340
BK 3020	231DIBS		11-22-04[4]		755	.5	5	8.7	8.7	198	211
BK 3020	231DIBS		01-27-05		756	.7	6	8.5	8.3	187	195
BK 3023	231DIBS		12-07-04		754	1.0	10	9.1	8.7	228	245
BK 3018	231BRCK	MMPC	10-07-04		767	2.9	30	7.3	7.4	349	371
BK 3021	231BRCK	MMPC	12-01-04		742	6.8	63	6.8	7.5	208	235
BK 3022	231BRCK	MMPC	12-06-04		760	5.5	52	6.3	7.0	276	293
BK 2199	231BRCK	MMPC	02-07-05		764	5.9	56	7.1	E6.8	330	332
BK 2199	231BRCK	MMPC	02-07-05[2]		764	5.9	56	7.1	7.0	330	332
BK 3019	231BRCK		11-17-04		765	2.3	22	7.9	7.7	247	264
BK 2153	231BRCK		04-06-05		761	.1	1	7.8	7.3	418	464
Private-supply wells - Quakertown area											
BK 3025	231DIBS		01-11-05		752	4.6	43	6.5	6.8	225	229
BK 3028	231DIBS		01-13-05		749	2.0	19	6.8	7.1	228	236
BK 3032	231DIBS		04-13-05		744	1.9	18	6.4	6.6	289	311
BK 3027	231BRCK	MMPC	01-13-05		751	4.3	40	6.5	7.1	238	235
BK 3033	231BRCK	MMPC	04-14-05		745	.7	7	7.0	7.1	343	339
BK 3024	231BRCK		01-10-05		749	.9	8	7.6	7.6	465	509
BK 3026	231BRCK		01-11-05		753	5.2	48	7.5	7.4	385	393
BK 3031	231BRCK		04-11-05		752	7.2	70	7.0	7.0	564	577
BK 3030	231LCKG		04-11-05		749	7.9	74	7.3	7.2	927	937
Private-supply wells - Dillsburg area, Gettysburg Basin											
YO 1224	231DIBS		12-02-04		746	7.0	64	6.7	6.5	239	273

Table 22. Field chemical measurements and results of laboratory analysis of water samples collected from 12 monitor wells and 46 private-supply wells in and near diabase intrusions, Newark Basin, southeastern Pennsylvania, February 2004-April 2005. Wells listed by geologic unit in each study area.—Continued

U.S. Geological Survey local well number	Geologic unit code	Lithology	Date of sample	Temperature, air (deg C)	Temperature, water, (deg C)	Calcium, water, filtered (mg/L)	Magnesium, water, filtered (mg/L)	Potassium, water, filtered (mg/L)	Sodium, water, filtered (mg/L)	ANC, water, unfiltered, fixed endpoint (mg/L as $CaCO_3$)	Alkalinity, water, filtered, inc. titration, field (mg/L as $CaCO_3$)
				(00020)	(00010)	(00915)	(00925)	(00935)	(00930)	(90410)	(39086)
Moniotor wells - Congo Road area											
BE 1756	231BRCK		03-01-04	17.0	11.4	29.6	10.9	0.57	5.76	76	--
BE 1757	231BRCK		03-02-04	6.5	9.4	84.2	18.0	1.04	18.5	147	--
BE 1758	231BRCK		03-02-04	18.5	11.7	110	31.7	1.29	30.7	170	--
BE 1759	231BRCK		03-04-04	9.0	11.1	673	159	8.50	230	69	--
BE 1759	231BRCK		03-08-04	6.0	11.1	662	156	9.21	221	89	--
BE 1760	231BRCK		03-04-04	9.5	11.6	241	83.7	103	303	126	--
BE 1761	231BRCK		03-08-04	6.0	11.4	158	75.1	1.66	53.3	137	--
BE 1762	231BRCK		03-09-04	2.0	8.7	135	44.8	.97	15.1	299	--
MG 2104	231BRCK		03-03-04	12.5	12.6	78.4	27.4	1.45	10.3	209	--
MG 2105	231BRCK		03-03-04	14.5	12.0	65.6	25.3	1.55	27.3	224	--
MG 2106	231BRCK		03-03-04	14.5	12.5	168	41.2	8.03	171	167	--
MG 2107	231BRCK		03-05-04	8.5	12.8	138	44.4	3.57	65.3	170	--
MG 2108	231BRCK		03-05-04	8.5	11.1	93.6	38.7	1.45	34.7	129	--
Private-supply wells - Congo Rooad area											
BE 1763	231DIBS		05-04-04	12.0	12.1	41.5	10.9	.38	6.30	103	--
BE 1764	231DIBS		05-06-04	14.5	13.3	28.9	5.41	.66	6.16	79	--
MG 2026	231DIBS		05-04-04	9.5	12.3	28.0	5.33	.36	5.11	73	--
BE 1765	231BRCK	MMPC	05-04-04	11.5	12.5	218	4.62	.55	12.4	47	--
BE 1766	231BRCK	MMPC	05-06-04	17.5	14.7	81.4	13.9	.52	8.54	170	--
MG 1974	231BRCK	MMPC	07-26-04	24.0	13.5	63.5	18.8	2.16	12.6	--	136
MG 1982	231BRCK	MMPC	05-05-04	15.0	12.3	32.8	11.5	1.14	11.0	107	--
MG 2103	231BRCK	MMPC	02-18-04	6.5	12.4	51.6	13.8	2.00	10.2	131	--
MG 2103	231BRCK	MMPC	02-18-04^2	--	--	45.5	12.4	8.92	1.71	135	--
MG 2109	231BRCK	MMPC	05-04-04	13.5	12.3	30.4	8.45	1.50	10.5	90	--
MG 2111	231BRCK	MMPC	06-07-04	22.5	13.7	37.2	14.6	1.88	11.0	132	130
BE 1733	231BRCKF	MMPC	05-05-04	14.5	12.5	36.6	7.12	.84	8.88	69	--
MG 2001	231BRCK		05-06-04	15.5	14.0	66.7	14.5	1.58	10.2	147	--
MG 2110	231BRCK		06-03-04	20.5	13.8	75.2	30.1	1.04	17.0	140	227
MG 2113	231BRCK		07-27-04	20.0	14.7	382	69.3	1.81	57.0	--	80
Private-supply wells - Jacksonwald area											
BE 1769	231BSLT		06-29-04	21.0	12.5	43.7	9.05	.20	4.65	--	130
BE 1771	231BSLT		08-02-04	24.5	13.0	63.7	15.7	.26	4.33	--	170
BE 1768	231DIBS		06-21-04	26.0	12.1	37.4	10.5	.27	7.66	108	105
BE 1772	231DIBS		08-02-04	29.5	12.9	46.4	7.43	.22	10.5	--	112
BE 1770	231BRCK	MMPC	08-04-04	26.5	12.2	17.1	5.54	.49	3.50	--	41
BE 1767	231BRCK		06-21-04	26.0	12.0	118	19.3	.84	36.5	253	247

Table 22. Field chemical measurements and results of laboratory analysis of water samples collected from 12 monitor wells and 46 private-supply wells in and near diabase intrusions, Newark Basin, southeastern Pennsylvania, February 2004-April 2005. Wells listed by geologic unit in each study area.—Continued

U.S. Geological Survey local well number	Geologic unit code	Lithology	Date of sample	Temperature, air (deg C)	Temperature, water, (deg C)	Calcium, water, filtered (mg/L)	Magnesium, water, filtered (mg/L)	Potassium, water, filtered (mg/L)	Sodium, water, filtered (mg/L)	ANC, water, unfiltered, fixed endpoint (mg/L as $CaCO_3$)	Alkalinity, water, filtered, inc. titration, field (mg/L as $CaCO_3$)
				(00020)	(00010)	(00915)	(00925)	(00935)	(00930)	(90410)	(39086)
Private-supply wells - Kibblehouse area											
MG 2117	231DIBS		10-26-04	15.5	13.6	52.4	32.5	0.87	8.32	--	129
MG 2112	231BRCK	MMPC	09-22-04	14.0	12.7	84.7	22.5	2.96	15.8	--	167
MG 2114	231BRCK	MMPC	09-22-04	25.0	13.1	71.7	22.7	1.45	17.3	--	167
MG 2115	231BRCK	MMPC	09-23-04	19.5	13.3	29.4	8.00	.61	13.7	--	91
MG 2116	231BRCK	MMPC	09-23-04	24.5	15.1	35.8	7.84	1.15	7.47	--	100
MG 2118	231BRCK	MMPC	11-15-04	15.0	12.3	26.8	10.6	3.03	10.3	--	79
Private-supply wells - New Hope area											
BK 3029	231DIBS		02-16-05	12.5	11.2	56.6	36.1	.80	10.1	--	46
BK 3017	231DIBS		10-07-04	14.0	12.8	24.2	5.65	.25	44.3	--	152
BK 3020	231DIBS		11-22-04[4]	13.5	12.5	<.02	<.008	<.16	49.4	--	69
BK 3020	231DIBS		01-27-05	23.0	11.6	24.2	2.58	.26	12.1	--	49
BK 3023	231DIBS		12-07-04	6.0	12.3	15.9	1.08	.46	32.5	--	46
BK 3018	231BRCK	MMPC	10-07-04	21.0	16.4	42.2	18.3	1.14	8.36	--	149
BK 3021	231BRCK	MMPC	12-01-04	12.0	11.7	24.3	10.1	.64	5.38	--	64
BK 3022	231BRCK	MMPC	12-06-04	3.5	12.7	30.3	13.5	1.51	8.53	--	97
BK 2199	231BRCK	MMPC	02-07-05	11.0	12.5	46.6	11.9	2.60	8.27	--	109
BK 2199	231BRCK	MMPC	02-07-05[2]	11.0	12.5	46.2	12.3	2.49	8.07	--	112
BK 3019	231BRCK		11-17-04	12.0	12.5	34.5	6.74	.81	9.34	--	100
BK 2153	231BRCK		04-06-05	18.5	12.7	53.0	19.5	.93	17.7	--	97
Private-supply wells - Quakertown area											
BK 3025	231DIBS		01-11-05	3.0	12.1	23.3	12.6	.48	5.42	--	83
BK 3028	231DIBS		01-13-05	11.0	11.6	12.6	15.2	3.20	13.6	--	76
BK 3032	231DIBS		04-13-05	13.0	12.6	33.2	15.1	.53	11.6	--	91
BK 3027	231BRCK	MMPC	01-13-05	7.0	12.1	29.6	9.06	1.15	6.39	--	80
BK 3033	231BRCK	MMPC	04-14-05	14.5	13.4	32.4	17.6	2.54	16.8	--	94
BK 3024	231BRCK		01-10-05	6.5	12.8	54.4	27.4	1.12	13.3	182	164
BK 3026	231BRCK		01-11-05	3.0	11.6	53.8	11.0	1.01	15.1	--	147
BK 3031	231BRCK		04-11-05	14.5	13.4	60.9	25.1	.78	21.0	152	--
BK 3030	231LCKG		04-11-05	12.0	12.4	109	26.7	.77	46.9	173	--
Private-supply wells - Dillsburg area, Gettysburg Basin											
YO 1224	231DIBS		12-02-04	5.5	11.4	27.2	10.3	.65	9.56	--	91

Table 22. Field chemical measurements and results of laboratory analysis of water samples collected from 12 monitor wells and 46 private-supply wells in and near diabase intrusions, Newark Basin, southeastern Pennsylvania, February 2004-April 2005. Wells listed by geologic unit in each study area.—Continued

U.S. Geological Survey local well number	Geologic unit code	Lithology	Date of sample	Chloride, water, filtered (mg/L)	Fluoride, water, filtered (mg/L)	Silica, water, filtered (mg/L)	Sulfate, water, filtered (mg/L)	Ammonia, water, filtered (mg/L as N)	Nitrite + nitrate, water, filtered (mg/L as N)	Nitrite, water, filtered (mg/L as N)	Ortho-phos-phate, water, filtered (mg/L as P)
				(00940)	(00950)	(00955)	(00945)	(00608)	(00631)	(00613)	(00671)
Monitor wells - Congo Road area											
BE 1756	231BRCK		03-01-04	8.50	<0.2	14.1	25.1	<0.04	3.69	<0.008	E0.01
BE 1757	231BRCK		03-02-04	25.2	.2	18.8	57.2	<.04	.44	E.004	<.02
BE 1758	231BRCK		03-02-04	90.3	<.2	17.8	81.1	<.04	2.72	<.008	<.02
BE 1759	231BRCK		03-04-04	1,630	.7	19.5	571	6.87	<.06	<.008	<.02
BE 1759	231BRCK		03-08-04	1,540	1.0	18.6	549	7.93	<.06	<.008	<.02
BE 1760	231BRCK		03-04-04	852	1.4	14.9	651	101	<.06	<.008	E.01
BE 1761	231BRCK		03-08-04	196	<.2	21.0	296	.05	<.06	<.008	<.02
BE 1762	231BRCK		03-09-04	31.5	2.3	20.7	52.0	<.04	.06	<.008	<.02
MG 2104	231BRCK		03-03-04	22.7	.3	18.6	17.1	<.04	3.79	<.008	<.02
MG 2105	231BRCK		03-03-04	53.8	.3	17.1	21.8	.06	3.71	.089	<.02
MG 2106	231BRCK		03-03-04	446	4.4	19.8	37.4	2.63	.64	E.004	<.02
MG 2107	231BRCK		03-05-04	221	6.5	24.8	72.0	.60	E.04	<.008	E.01
MG 2108	231BRCK		03-05-04	92.5	1.3	15.8	95.3	<.04	.65	<.008	<.02
Private-supply wells - Congo Road area											
BE 1763	231DIBS		05-04-04	6.55	<.2	30.2	14.9	<.04	6.94	<.008	<.02
BE 1764	231DIBS		05-06-04	2.48	<.2	30.4	20.2	<.04	.63	<.008	<.02
MG 2026	231DIBS		05-04-04	5.11	<.2	30.3	16.4	<.04	.45	<.008	.02
BE 1765	231BRCK	MMPC	05-04-04	3.83	.7	48.8	485	<.04	.10	<.008	<.02
BE 1766	231BRCK	MMPC	05-06-04	50.8	<.2	36.1	25.9	<.04	.96	<.008	.07
MG 1974	231BRCK	MMPC	07-26-04	22.1	<.2	33.0	36.1	<.04	13.5	<.008	.02
MG 1982	231BRCK	MMPC	05-05-04	7.31	<.2	30.5	23.0	<.04	2.51	<.008	E.01
MG 2103	231BRCK	MMPC	02-18-04	12.3	<.2	33.2	36.8	<.04	3.27	<.008	.02
MG 2103	231BRCK	MMPC	02-18-04[2]	11.3	.11	--	36.5	--	--	--	--
MG 2109	231BRCK	MMPC	05-04-04	5.09	<.2	29.8	22.8	<.04	1.54	<.008	<.02
MG 2111	231BRCK	MMPC	06-07-04	4.23	.2	35.6	29.7	<.04	1.81	<.008	.10
BE 1733	231BRCKF	MMPC	05-05-04	22.7	<.2	27.2	18.5	<.04	4.55	<.008	.04
MG 2001	231BRCK		05-06-04	31.1	<.2	20.0	21.0	<.04	9.40	<.008	.02
MG 2110	231BRCK		06-03-04	47.0	<.2	19.0	25.7	<.04	7.60	<.008	<.02
MG 2113	231BRCK		07-27-04	9.05	.2	22.5	1160	E.02	.51	<.008	<.02
Private-supply wells - Jacksonwald area											
BE 1769	231BSLT		06-29-04	5.36	<.2	29.5	15.5	<.04	.47	<.008	E.01
BE 1771	231BSLT		08-02-04	6.14	<.2	29.5	17.3	<.04	4.11	<.008	E.01
BE 1768	231DIBS		06-21-04	6.57	<.2	42.0	26.1	<.04	1.43	<.008	.02
BE 1772	231DIBS		08-02-04	4.09	.2	39.5	35.7	<.04	.28	<.008	E.01
BE 1770	231BRCK	MMPC	08-04-04	1.64	<.2	34.7	17.2	<.04	2.51	<.008	<.02
BE 1767	231BRCK		06-21-04	85.1	.2	13.8	52.9	<.04	1.65	<.008	E.01

Table 22. Field chemical measurements and results of laboratory analysis of water samples collected from 12 monitor wells and 46 private-supply wells in and near diabase intrusions, Newark Basin, southeastern Pennsylvania, February 2004-April 2005. Wells listed by geologic unit in each study area.—Continued

U.S. Geological Survey local well number	Geologic unit code	Lithology	Date of sample	Chloride, water, filtered (mg/L)	Fluoride, water, filtered (mg/L)	Silica, water, filtered (mg/L)	Sulfate, water, filtered (mg/L)	Ammonia, water, filtered (mg/L as N)	Nitrite + nitrate, water, filtered (mg/L as N)	Nitrite, water, filtered (mg/L as N)	Ortho-phos-phate, water, filtered (mg/L as P)
				(00940)	(00950)	(00955)	(00945)	(00608)	(00631)	(00613)	(00671)
Private-supply wells - Kibblehouse area											
MG 2117	231DIBS		10-26-04	65.3	<0.1	47.7	26.2	<0.04	3.83	<0.008	<0.02
MG 2112	231BRCK	MMPC	09-22-04	44.8	<.2	35.6	61.0	<.04	5.10	<.008	.02
MG 2114	231BRCK	MMPC	09-22-04	43.7	<.2	33.6	39.7	<.04	2.71	<.008	E.02
MG 2115	231BRCK	MMPC	09-23-04	8.59	<.2	22.0	17.2	<.04	1.72	<.008	<.02
MG 2116	231BRCK	MMPC	09-23-04	2.23	<.2	19.7	12.1	<.04	2.60	<.008	.03
MG 2118	231BRCK	MMPC	11-15-04	7.85	.4	37.5	22.7	<.04	2.00	<.008	.04
Private-supply wells - New Hope area											
BK 3029	231DIBS		02-16-05	151	<.1	30.0	17.6	<.04	2.15	<.008	<.02
BK 3017	231DIBS		10-07-04	6.87	E.1	37.9	26.3	<.04	.88	<.008	<.02
BK 3020	231DIBS		11-22-04[4]	7.61	.1	37.7	20.7	<.04	.15	<.008	<.02
BK 3020	231DIBS		01-27-05	10.4	E.1	31.6	17.9	<.04	.24	<.008	<.02
BK 3023	231DIBS		12-07-04	32.5	.3	42.0	19.0	<.04	.07	<.008	<.02
BK 3018	231BRCK	MMPC	10-07-04	5.34	E.1	35.7	34.7	<.04	.53	<.008	.02
BK 3021	231BRCK	MMPC	12-01-04	9.00	E.1	40.6	21.1	<.04	.65	<.008	.04
BK 3022	231BRCK	MMPC	12-06-04	11.6	E.1	46.9	30.2	<.04	.72	<.008	.02
BK 2199	231BRCK	MMPC	02-07-05	4.91	.1	35.8	33.2	<.04	2.37	E.007	.03
BK 2199	231BRCK	MMPC	02-07-05[2]	4.88	.1	35.8	33.4	<.04	2.35	E.007	.03
BK 3019	231BRCK		11-17-04	3.50	.2	21.1	19.4	<.04	.48	<.008	E.01
BK 2153	231BRCK		04-06-05	46.3	.2	13.6	38.7	<.04	E.06	.009	<.02
Private-supply wells - Quakertown area											
BK 3025	231DIBS		01-11-05	6.28	E.1	39.0	11.7	<.04	1.67	<.008	<.02
BK 3028	231DIBS		01-13-05	4.77	E.1	39.3	24.2	<.08	1.11	<.008	.10
BK 3032	231DIBS		04-13-05	7.72	E.1	48.6	26.2	<.04	.69	<.008	<.02
BK 3027	231BRCK	MMPC	01-13-05	5.92	E.1	28.4	20.2	<.08	.33	<.008	.03
BK 3033	231BRCK	MMPC	04-14-05	14.8	.2	35.8	37.2	<.04	.09	<.008	.02
BK 3024	231BRCK		01-10-05	19.0	E.1	19.7	48.0	<.04	3.98	<.008	E.01
BK 3026	231BRCK		01-11-05	6.59	.2	13.6	28.5	<.04	1.14	<.008	<.02
BK 3031	231BRCK		04-11-05	75.4	.1	17.2	23.8	<.04	2.59	<.008	E.01
BK 3030	231LCKG		04-11-05	180	.2	17.0	31.0	<.04	.49	<.008	<.02
Private-supply wells - Dillsburg area, Gettysburg Basin											
YO 1224	231DIBS		12-02-04	7.25	<.1	44.4	20.0	<.04	1.42	<.008	E.01

Table 22. Field chemical measurements and results of laboratory analysis of water samples collected from 12 moniotor wells and 46 private-supply wells in and near diabase intrusions, Newark Basin, southeastern Pennsylvania, February 2004-April 2005. Wells listed by geologic unit in each study area.—Continued

U.S. Geological Survey local well number	Geologic unit code	Lithology	Date of sample	Organic carbon, water, unfiltered (mg/L)	Arsenic, water, filtered (ug/L)	Arsenic, water, unfiltered (ug/L)	Barium, water, filtered (ug/L)	Barium, water, unfiltered (ug/L)	Boron, water, filtered (ug/L)	Boron, water, unfiltered (ug/L)
				(00680)	(01000)	(01002)	(01005)	(01007)	(01020)	(01022)
Moniotor wells - Congo Road area										
BE 1756	231BRCK		03-01-04	0.6	3.7	--	--	--	30	--
BE 1757	231BRCK		03-02-04	1.8	2.5	--	--	--	143	--
BE 1758	231BRCK		03-02-04	10.2	7.8	E2	138	126	176	148
BE 1759	231BRCK		03-04-04	1.8	24.9	--	--	--	755	--
BE 1759	231BRCK		03-08-04	1.9	25.9	--	--	--	776	--
BE 1760	231BRCK		03-04-04	2.4	20.9	--	--	--	2,500	--
BE 1761	231BRCK		03-08-04	3.0	12.4	--	--	--	296	--
BE 1762	231BRCK		03-09-04	.8	60.9	58	344	370	40	35
MG 2104	231BRCK		03-03-04	2.4	1.5	--	--	--	54	--
MG 2105	231BRCK		03-03-04	2.8	1.2	--	--	--	42	--
MG 2106	231BRCK		03-03-04	7.1	.9	--	--	--	5,240	--
MG 2107	231BRCK		03-05-04	11.8	2.3	2	252	256	1,000	1,550
MG 2108	231BRCK		03-05-04	2.8	4.3	3	112	116	1,360	1,250
Private-supply wells - Congo Road area										
BE 1763	231DIBS		05-04-04	E.3	1.0	<2	<.2	M	358	328
BE 1764	231DIBS		05-06-04	.4	6.6	7	M	M	1,250	1,220
MG 2026	231DIBS		05-04-04	1.6	.3	<2	<.2	<.2	111	102
BE 1765	231BRCK	MMPC	05-04-04	.7	23.5	23	3	3	3,950	3950
BE 1766	231BRCK	MMPC	05-06-04	16.3	1.3	<4	214	202	253	244
MG 1974	231BRCK	MMPC	07-26-04	.5	19.5	23	M	M	315	291
MG 1982	231BRCK	MMPC	05-05-04	.4	23.3	24	M	M	2,300	2,430
MG 2103	231BRCK	MMPC	02-18-04	1.6	32.4	31	M	M	920	1360
MG 2103	231BRCK	MMPC	02-18-04[2]	--	27.0	27.9	.04	.31	928	934
MG 2109	231BRCK	MMPC	05-04-04	1.7	26.8	29	M	M	2,320	2,410
MG 2111	231BRCK	MMPC	06-07-04	2.2	1.9	2	M	M	500	498
BE 1733	231BRCKF	MMPC	05-05-04	1.1	1.0	<2	116	106	24	26
MG 2001	231BRCK		05-06-04	1.6	2.5	3	298	278	19	19
MG 2110	231BRCK		06-03-04	.9	2.5	2	262	239	51	56
MG 2113	231BRCK		07-27-04	<.4	12.0	30	27	28	594	556
Private-supply wells - Jacksonwald area										
BE 1769	231BSLT		06-29-04	E.2	.3	<2	M	M	541	500
BE 1771	231BSLT		08-02-04	.9	.9	<2	M	M	302	268
BE 1768	231DIBS		06-21-04	2.0	.3	<2	M	M	78	74
BE 1772	231DIBS		08-02-04	1.5	1.7	E1	<.2	M	252	228
BE 1770	231BRCK	MMPC	08-04-04	3.1	<.2	<2	M	M	34	33
BE 1767	231BRCK		06-21-04	1.6	E.1	<2	180	173	37	34

Table 22. Field chemical measurements and results of laboratory analysis of water samples collected from 12 moniotor wells and 46 private-supply wells in and near diabase intrusions, Newark Basin, southeastern Pennsylvania, February 2004-April 2005. Wells listed by geologic unit in each study area.—Continued

U.S. Geological Survey local well number	Geologic unit code	Lithology	Date of sample	Organic carbon, water, unfiltered (mg/L)	Arsenic, water, filtered (ug/L)	Arsenic, water, unfiltered (ug/L)	Barium, water, filtered (ug/L)	Barium, water, unfiltered (ug/L)	Boron, water, filtered (ug/L)	Boron, water, unfiltered (ug/L)
				(00680)	(01000)	(01002)	(01005)	(01007)	(01020)	(01022)
Private-supply wells - Kibblehouse area										
MG 2117	231DIBS		10-26-04	3.7	0.3	<2	M	M	31	24
MG 2112	231BRCK	MMPC	09-22-04	2.1	.9	E1	<.2	<.2	182	176
MG 2114	231BRCK	MMPC	09-22-04	2.3	2.3	3	M	M	268	254
MG 2115	231BRCK	MMPC	09-23-04	1.9	9.9	10	M	M	73	64
MG 2116	231BRCK	MMPC	09-23-04	4.4	1.7	E2	M	M	25	23
MG 2118	231BRCK	MMPC	11-15-04	.4	16.4	17	M	M	136	127
Private-supply wells - New Hope area										
BK 3029	231DIBS		02-16-05	3.7	<.2	<2	2	3	E4.3	<7.0
BK 3017	231DIBS		10-07-04	1.3	4.0	3	<.2	<.2	2,030	2,010
BK 3020	231DIBS		11-22-04[4]	.5	12.3	12	<.2	<.2	2,920	2,590
BK 3020	231DIBS		01-27-05	E.2	14.4	13	<.2	<.2	3,170	3,020
BK 3023	231DIBS		12-07-04	.8	60.0	54	M	M	964	937
BK 3018	231BRCK	MMPC	10-07-04	.6	1.6	<2	13	12	465	430
BK 3021	231BRCK	MMPC	12-01-04	2.9	2.1	E2	2	2	975	904
BK 3022	231BRCK	MMPC	12-06-04	.5	.4	<2	3	3	8.6	9.3
BK 2199	231BRCK	MMPC	02-07-05	.7	3.4	3	2	2	63	67
BK 2199	231BRCK	MMPC	02-07-05[2]	.7	3.3	2	2	2	62	52
BK 3019	231BRCK		11-17-04	E.3	7.3	7	100	97	280	260
BK 2153	231BRCK		04-06-05	1.7	5.5	6	127	124	54	46
Private-supply wells - Quakertown area										
BK 3025	231DIBS		01-11-05	4.0	.6	<2	M	M	57	52
BK 3028	231DIBS		01-13-05	.5	.6	<2	M	M	E4.9	E4.8
BK 3032	231DIBS		04-13-05	1.4	E.2	<2	M	M	47	41
BK 3027	231BRCK	MMPC	01-13-05	4.3	.4	<2	1	1	13	11
BK 3033	231BRCK	MMPC	04-14-05	2.5	.8	<2	M	M	12	9.1
BK 3024	231BRCK		01-10-05	3.0	5.5	7	77	77	30	25
BK 3026	231BRCK		01-11-05	4.6	.6	<2	18	17	8.6	7.9
BK 3031	231BRCK		04-11-05	5.0	1.6	E1	87	81	38	30
BK 3030	231LCKG		04-11-05	3.4	1.8	E1	68	68	34	25
Private-supply wells - Dillsburg area, Gettysburg Basin										
YO 1224	231DIBS		12-02-04	2.9	.3	<2	M	M	16	18

Table 22. Field chemical measurements and results of laboratory analysis of water samples collected from 12 moniotor wells and 46 private-supply wells in and near diabase intrusions, Newark Basin, southeastern Pennsylvania, February 2004-April 2005. Wells listed by geologic unit in each study area.—Continued

U.S. Geological Survey local well number	Geologic unit code	Lithology	Date of sample	Cobalt, water, filtered (ug/L)	Cobalt, water, unfiltered (µg/L)	Copper, water, filtered (µg/L)	Copper, water, unfiltered (µg/L)	Iron, water, filtered (µg/L)	Iron, water, unfiltered (µg/L)	Lead, water, filtered (µg/L)	Lead, water, unfiltered (µg/L)
				(01035)	(01037)	(01040)	(01042)	(01046)	(01045)	(01049)	(01051)
Moniotor wells - Congo Road area											
BE 1756	231BRCK		03-01-04	--	--	--	--	<6	--	--	--
BE 1757	231BRCK		03-02-04	--	--	--	--	<6	--	--	--
BE 1758	231BRCK		03-02-04	.238	0.445	1.1	1.4	7	M	E0.05	<0.06
BE 1759	231BRCK		03-04-04	--	--	--	--	2,190	--	--	--
BE 1759	231BRCK		03-08-04	--	--	--	--	1,820	--	--	--
BE 1760	231BRCK		03-04-04	--	--	--	--	15	--	--	--
BE 1761	231BRCK		03-08-04	--	--	--	--	<6	--	--	--
BE 1762	231BRCK		03-09-04	.650	.810	.9	1.1	20	20	<.08	<.06
MG 2104	231BRCK		03-03-04	--	--	--	--	<6	--	--	--
MG 2105	231BRCK		03-03-04	--	--	--	--	15	--	--	--
MG 2106	231BRCK		03-03-04	--	--	--	--	49	--	--	--
MG 2107	231BRCK		03-05-04	1.49	1.95	.9	1.5	10	190	.18	.46
MG 2108	231BRCK		03-05-04	2.38	2.50	.7	2.9	335	530	.17	1.45
Private-supply wells - Congo Road area											
BE 1763	231DIBS		05-04-04	.137	.406	9.7	14.4	E4	450	.34	1.08
BE 1764	231DIBS		05-06-04	.096	.090	10.2	9.6	<6	M	.16	.13
MG 2026	231DIBS		05-04-04	.100	.085	38.2	23.7	<6	<9.0	.74	.62
BE 1765	231BRCK	MMPC	05-04-04	.617	.410	3.4	5.4	23	20	.18	.22
BE 1766	231BRCK	MMPC	05-06-04	.234	.221	7.5	6.2	<6	<9.0	1.32	1.08
MG 1974	231BRCK	MMPC	07-26-04	.181	.320	8.4	13.8	<6	70	.35	.80
MG 1982	231BRCK	MMPC	05-05-04	.098	.102	2.6	5.0	<6	170	<.08	.22
MG 2103	231BRCK	MMPC	02-18-04	.094	.165	11.4	10.7	<6	M	.41	.27
MG 2103	231BRCK	MMPC	02-18-04[2]	.16	.15	27.0	46.5	4.9	12.3	1.9	2.39
MG 2109	231BRCK	MMPC	05-04-04	.080	.078	.9	1.5	<6	20	E.08	.10
MG 2111	231BRCK	MMPC	06-07-04	.130	.228	3.4	4.3	E3	150	.08	.48
BE 1733	231BRCKF	MMPC	05-05-04	.104	.093	2.2	2.2	<6	30	.13	1.57
MG 2001	231BRCK		05-06-04	.198	.196	12.3	14.2	<6	70	.65	1.32
MG 2110	231BRCK		06-03-04	.245	.334	6.7	8.8	<6	<9.0	.52	.55
MG 2113	231BRCK		07-27-04	1.29	1.22	7.3	10.1	130	960	<.08	.16
Private-supply wells - Jacksonwald area											
BE 1769	231BSLT		06-29-04	.148	.161	7.5	7.6	<6	M	.20	.12
BE 1771	231BSLT		08-02-04	.200	.285	6.7	4.4	<6	<9.0	.14	.16
BE 1768	231DIBS		06-21-04	.144	.099	13.0	12.6	<6	<9.0	.25	.20
BE 1772	231DIBS		08-02-04	.155	.218	5.3	5.9	<6	20	.13	.29
BE 1770	231BRCK	MMPC	08-04-04	.056	.085	43.1	35.9	<6	10	.35	.34
BE 1767	231BRCK		06-21-04	.397	.278	1.1	1.1	<6	<9.0	<.08	<.06

Table 22. Field chemical measurements and results of laboratory analysis of water samples collected from 12 moniotor wells and 46 private-supply wells in and near diabase intrusions, Newark Basin, southeastern Pennsylvania, February 2004-April 2005. Wells listed by geologic unit in each study area.—Continued

U.S. Geological Survey local well number	Geologic unit code	Lithology	Date of sample	Cobalt, water, filtered (ug/L)	Cobalt, water, unfiltered (µg/L)	Copper, water, filtered (µg/L)	Copper, water, unfiltered (µg/L)	Iron, water, filtered (µg/L)	Iron, water, unfiltered (µg/L)	Lead, water, filtered (µg/L)	Lead, water, unfiltered (µg/L)
				(01035)	(01037)	(01040)	(01042)	(01046)	(01045)	(01049)	(01051)
Private-supply wells - Kibblehouse area											
MG 2117	231DIBS		10-26-04	0.201	0.385	20.1	19.2	<6	20	0.38	0.29
MG 2112	231BRCK	MMPC	09-22-04	.201	.238	7.7	7.0	<6	<9.0	.24	.25
MG 2114	231BRCK	MMPC	09-22-04	.183	.214	17.0	16.4	<6	30	2.63	3.47
MG 2115	231BRCK	MMPC	09-23-04	.072	.117	10.9	12.3	<6	M	.24	.17
MG 2116	231BRCK	MMPC	09-23-04	.126	.146	6.6	6.6	<6	20	.10	.26
MG 2118	231BRCK	MMPC	11-15-04	.071	.130	31.4	24.2	<6	M	.45	.42
Private-supply wells - New Hope area											
BK 3029	231DIBS		02-16-05	.210	.363	32.5	35.5	55	140	.64	.96
BK 3017	231DIBS		10-07-04	.084	.065	6.0	5.1	<6	M	.58	.47
BK 3020	231DIBS		11-22-04[4]	<.014	<.016	.9	2.2	<6	M	.14	.20
BK 3020	231DIBS		01-27-05	.038	.061	1.7	2.6	<6	20	E.06	.20
BK 3023	231DIBS		12-07-04	.093	.067	1.1	1.2	<6	E10	.16	.12
BK 3018	231BRCK	MMPC	10-07-04	.140	.205	3.3	3.8	<6	40	1.80	2.13
BK 3021	231BRCK	MMPC	12-01-04	.059	.139	13.0	11.5	<6	270	.36	.37
BK 3022	231BRCK	MMPC	12-06-04	.118	.152	22.7	27.9	E4	M	.32	.35
BK 2199	231BRCK	MMPC	02-07-05	.131	.213	1.6	5.9	<6	60	2.15	2.87
BK 2199	231BRCK	MMPC	02-07-05[2]	.124	.274	1.4	13.3	E3	130	1.93	18.0
BK 3019	231BRCK		11-17-04	.074	.132	17.6	21.4	<6	30	E.04	E.04
BK 2153	231BRCK		04-06-05	.374	.459	8.1	10.6	E5	200	.20	.33
Private-supply wells - Quakertown area											
BK 3025	231DIBS		01-11-05	.086	.153	7.7	7.0	<6	M	.71	.65
BK 3028	231DIBS		01-13-05	.028	.098	70.6	60.7	7	30	.17	.14
BK 3032	231DIBS		04-13-05	.138	.229	5.2	5.3	9	M	.25	.18
BK 3027	231BRCK	MMPC	01-13-05	.089	.165	62.6	52.6	<6	10	.46	.39
BK 3033	231BRCK	MMPC	04-14-05	.117	.187	20.8	21.2	<6	<6	.54	.45
BK 3024	231BRCK		01-10-05	.159	.363	8.7	13.1	12	3320	E.06	.96
BK 3026	231BRCK		01-11-05	.250	.369	5.0	5.3	7	20	E.04	E.05
BK 3031	231BRCK		04-11-05	.140	.260	9.3	6.9	<6	M	.84	.57
BK 3030	231LCKG		04-11-05	.240	.389	4.4	5.2	<6	<6	.09	.06
Private-supply wells - Dillsburg area, Gettysburg Basin											
YO 1224	231DIBS		12-02-04	.118	.150	9.9	10.0	<6	20	.39	.38

Table 22. Field chemical measurements and results of laboratory analysis of water samples collected from 12 moniotor wells and 46 private-supply wells in and near diabase intrusions, Newark Basin, southeastern Pennsylvania, February 2004-April 2005. Wells listed by geologic unit in each study area.—Continued

U.S. Geological Survey local well number	Geologic unit code	Lithology	Date of sample	Lithium, water, filtered (µg/L)	Lithium, water, unfiltered (µg/L)	Manga-nese, water, filtered (µg/L)	Manga-nese, water, unfiltered (µg/L)	Molyb-denum, water, filtered (µg/L)	Molyb-denum, water, unfiltered (µg/L)	Nickel, water, filtered (µg/L)	Nickel, water, unfiltered (µg/L)
				(01130)	(01132)	(01056)	(01055)	(01060)	(01062)	(01065)	(01067)
Monitor wells - Congo Road area											
BE 1756	231BRCK		03-01-04	9.6	--	E.4	--	8.8	--	--	--
BE 1757	231BRCK		03-02-04	21.2	--	65.9	--	3.2	--	--	--
BE 1758	231BRCK		03-02-04	48.6	48.7	E.2	M	22.9	22.5	2.42	3.01
BE 1759	231BRCK		03-04-04	64.8	--	1,630	--	3.4	--	--	--
BE 1759	231BRCK		03-08-04	52.0	--	1,570	--	5.3	--	--	--
BE 1760	231BRCK		03-04-04	47.2	--	2,680	--	3.1	--	--	--
BE 1761	231BRCK		03-08-04	39.1	--	222	--	1.2	--	--	--
BE 1762	231BRCK		03-09-04	17.2	17.9	381	403	1.9	2.2	1.77	2.42
MG 2104	231BRCK		03-03-04	27.5	--	1.4	--	.6	--	--	--
MG 2105	231BRCK		03-03-04	23.4	--	127	--	1.6	--	--	--
MG 2106	231BRCK		03-03-04	56.4	--	1,840	--	2.7	--	--	--
MG 2107	231BRCK		03-05-04	51.0	53.0	3,790	4190	2.4	2.0	6.86	7.25
MG 2108	231BRCK		03-05-04	32.7	33.8	178	163	25.2	25.0	10.4	10.4
Private-supply wells - Congo Road area											
BE 1763	231DIBS		05-04-04	4.4	3.8	.2	7	<.4	E.2	.74	.62
BE 1764	231DIBS		05-06-04	3.8	3.2	.4	M	E.2	.3	.56	.29
MG 2026	231DIBS		05-04-04	2.7	2.3	.3	M	<.4	<.2	.75	.40
BE 1765	231BRCK	MMPC	05-04-04	10.3	8.9	54.7	48	4.5	4.5	3.09	.57
BE 1766	231BRCK	MMPC	05-06-04	23.2	19.6	E.1	M	<.4	<.2	1.57	.24
MG 1974	231BRCK	MMPC	07-26-04	24.6	24.3	<.8	1	5.6	5.4	1.07	2.19
MG 1982	231BRCK	MMPC	05-05-04	4.3	3.7	<.2	2	4.6	4.6	.53	.36
MG 2103	231BRCK	MMPC	02-18-04	18.0	18.7	<.2	M	22.7	22.3	.69	.99
MG 2103	231BRCK	MMPC	02-18-04[2]	17.2	18.5	.57	.31	22.5	22.7	6.39	6.09
MG 2109	231BRCK	MMPC	05-04-04	8.2	6.9	.3	M	5.8	5.9	.47	.29
MG 2111	231BRCK	MMPC	06-07-04	36.0	36.2	.4	4	--	3.2	.66	.86
BE 1733	231BRCKF	MMPC	05-05-04	15.9	13.4	<.2	M	<.4	E.1	.53	.30
MG 2001	231BRCK		05-06-04	10.0	8.3	.6	M	<.4	E.2	1.29	.39
MG 2110	231BRCK		06-03-04	22.3	22.8	.2	M	--	1.8	.66	1.38
MG 2113	231BRCK		07-27-04	59.3	58.3	182	212	9.8	9.9	4.68	6.79
Private-supply wells - Jacksonwald area											
BE 1769	231BSLT		06-29-04	9.5	9.6	<.8	<.2	E.2	E.2	.88	.67
BE 1771	231BSLT		08-02-04	7.5	8.4	E.5	M	<.4	E.1	.94	1.31
BE 1768	231DIBS		06-21-04	1.0	1.2	<.2	M	<.4	<.2	.95	.45
BE 1772	231DIBS		08-02-04	3.6	4.4	1.5	1	E.3	.2	.54	.94
BE 1770	231BRCK	MMPC	08-04-04	E.4	E.4	<.8	M	<.4	<.2	.35	.60
BE 1767	231BRCK		06-21-04	9.1	11.2	1.3	M	.7	.6	2.76	1.42

Table 22. Field chemical measurements and results of laboratory analysis of water samples collected from 12 moniotor wells and 46 private-supply wells in and near diabase intrusions, Newark Basin, southeastern Pennsylvania, February 2004-April 2005. Wells listed by geologic unit in each study area.—Continued

U.S. Geological Survey local well number	Geologic unit code	Lithology	Date of sample	Lithium, water, filtered (µg/L)	Lithium, water, unfiltered (µg/L)	Manga-nese, water, filtered (µg/L)	Manga-nese, water, unfiltered (µg/L)	Molyb-denum, water, filtered (µg/L)	Molyb-denum, water, unfiltered (µg/L)	Nickel, water, filtered (µg/L)	Nickel, water, unfiltered (µg/L)
				(01130)	(01132)	(01056)	(01055)	(01060)	(01062)	(01065)	(01067)
Private-supply wells - Kibblehouse area											
MG 2117	231DIBS		10-26-04	1.1	0.8	0.9	1	<0.4	E0.2	1.35	1.44
MG 2112	231BRCK	MMPC	09-22-04	31.7	28.8	<.8	M	.5	.6	.51	1.05
MG 2114	231BRCK	MMPC	09-22-04	36.0	32.6	1.2	1	1.1	1.2	<.06	.73
MG 2115	231BRCK	MMPC	09-23-04	8.5	8.2	<.8	M	2.8	2.8	.30	.60
MG 2116	231BRCK	MMPC	09-23-04	11.8	11.3	E.4	1	E.3	.3	.47	.57
MG 2118	231BRCK	MMPC	11-15-04	24.2	23.7	<.6	M	4.8	4.5	.24	.71
Private-supply wells - New Hope area											
BK 3029	231DIBS		02-16-05	E.4	<.6	20.7	19	<.4	<.2	2.40	1.97
BK 3017	231DIBS		10-07-04	6.1	5.4	<.6	M	2.9	3.3	.24	.40
BK 3020	231DIBS		11-22-04[4]	<.6	<.6	<.6	M	3.5	3.3	.20	.49
BK 3020	231DIBS		01-27-05	3.7	3.7	<.6	M	3.6	3.5	.18	.22
BK 3023	231DIBS		12-07-04	4.8	5.0	E.4	M	1.5	1.2	.28	.34
BK 3018	231BRCK	MMPC	10-07-04	23.6	22.5	.9	1	.4	.4	.22	.69
BK 3021	231BRCK	MMPC	12-01-04	8.1	7.6	<.6	2	E.4	.4	1.03	.55
BK 3022	231BRCK	MMPC	12-06-04	4.5	3.8	<.6	M	<.4	<.2	.56	.81
BK 2199	231BRCK	MMPC	02-07-05	16.1	14.2	.8	1	E.4	.3	1.09	.73
BK 2199	231BRCK	MMPC	02-07-05[2]	17.5	15.5	E.6	3	E.3	.3	1.01	1.01
BK 3019	231BRCK		11-17-04	12.3	11.5	<.6	M	6.7	6.5	.52	.61
BK 2153	231BRCK		04-06-05	9.4	8.4	22.3	23	83.4	79.1	3.60	.30
Private-supply wells - Quakertown area											
BK 3025	231DIBS		01-11-05	1.1	.9	<.6	M	<.4	<.2	.54	.37
BK 3028	231DIBS		01-13-05	40.1	38.9	2.5	3	.7	.7	.28	.35
BK 3032	231DIBS		04-13-05	<.6	<.6	1.6	2	<.4	<.2	.83	.34
BK 3027	231BRCK	MMPC	01-13-05	7.9	7.6	<.6	M	<.4	<.2	.94	.61
BK 3033	231BRCK	MMPC	04-14-05	32.7	35.3	104	130	1.7	1.6	2.36	.46
BK 3024	231BRCK		01-10-05	22.0	22.6	1.5	20	7.3	6.6	1.45	.76
BK 3026	231BRCK		01-11-05	5.7	5.3	<.6	M	.8	.7	1.08	.68
BK 3031	231BRCK		04-11-05	7.5	6.5	<.6	M	<.4	E.1	2.30	.95
BK 3030	231LCKG		04-11-05	6.8	5.8	<.6	2	6.2	5.8	3.52	1.00
Private-supply wells - Dillsburg area, Gettysburg Basin											
YO 1224	231DIBS		12-02-04	.8	.8	<.6	M	<.4	E.1	.52	.70

Table 22. Field chemical measurements and results of laboratory analysis of water samples collected from 12 moniotor wells and 46 private-supply wells in and near diabase intrusions, Newark Basin, southeastern Pennsylvania, February 2004-April 2005. Wells listed by geologic unit in each study area.—Continued

U.S. Geological Survey local well number	Geologic unit code	Lithology	Date of sample	Vanadium, water, filtered (µg/L)	Vanadium, water, unfiltered (µg/L)	Selenium, water, filtered (µg/L)	Selenium, water, unfiltered (µg/L)	Strontium, water, filtered (µg/L)	Strontium, water, unfiltered (µg/L)
				(01085)	(01087)	(01145)	(01147)	(01080)	(01082)
Monitor wells - Congo Road area									
BE 1756	231BRCK		03-01-04	--	--	--	--	186	--
BE 1757	231BRCK		03-02-04	--	--	--	--	1420	--
BE 1758	231BRCK		03-02-04	2.1	M	135	132	8,310	8,300
BE 1759	231BRCK		03-04-04	--	--	--	--	18,100	--
BE 1759	231BRCK		03-08-04	--	--	--	--	17,200	--
BE 1760	231BRCK		03-04-04	--	--	--	--	3,490	--
BE 1761	231BRCK		03-08-04	--	--	--	--	4,640	--
BE 1762	231BRCK		03-09-04	4.8	M	.4	E.2	838	811
MG 2104	231BRCK		03-03-04	--	--	--	--	395	--
MG 2105	231BRCK		03-03-04	--	--	--	--	463	--
MG 2106	231BRCK		03-03-04	--	--	--	--	698	--
MG 2107	231BRCK		03-05-04	4.2	<1.0	1.2	.8	5,320	5,310
MG 2108	231BRCK		03-05-04	3.7	M	.9	.5	7,330	7,390
Private-supply wells - Congo Road area									
BE 1763	231DIBS		05-04-04	6.1	M	E.3	<.4	18.3	17.3
BE 1764	231DIBS		05-06-04	4.1	M	.6	E.2	111	108
MG 2026	231DIBS		05-04-04	2.1	M	.6	.4	43.8	45.3
BE 1765	231BRCK	MMPC	05-04-04	.8	M	.6	.4	1,420	1,340
BE 1766	231BRCK	MMPC	05-06-04	3.3	M	E.2	E.3	217	208
MG 1974	231BRCK	MMPC	07-26-04	2.4	M	E.3	.5	159	142
MG 1982	231BRCK	MMPC	05-05-04	13.9	10	1.8	1.5	271	264
MG 2103	231BRCK	MMPC	02-18-04	5.3	M	.9	.8	117	108
MG 2103	231BRCK	MMPC	02-18-04[2]	3.98	4.08	<.9	<.9	107	110
MG 2109	231BRCK	MMPC	05-04-04	6.4	M	1.9	1.4	220	213
MG 2111	231BRCK	MMPC	06-07-04	14.5	10	.5	E.4	86.4	89.3
BE 1733	231BRCKF	MMPC	05-05-04	2.0	M	.4	E.3	38.2	35.9
MG 2001	231BRCK		05-06-04	2.4	M	.4	E.2	445	429
MG 2110	231BRCK		06-03-04	.4	<1.0	.5	.5	481	469
MG 2113	231BRCK		07-27-04	.2	<1.0	.4	.5	6,870	7,020
Private-supply wells - Jacksonwald area									
BE 1769	231BSLT		06-29-04	9.0	M	E.2	<.4	171	169
BE 1771	231BSLT		08-02-04	8.1	M	<.4	<.4	177	158
BE 1768	231DIBS		06-21-04	4.4	M	<.4	<.4	51.9	50.8
BE 1772	231DIBS		08-02-04	17.2	20	2.5	2.6	16.1	15.5
BE 1770	231BRCK	MMPC	08-04-04	3.5	M	<.4	<.4	39.3	35.5
BE 1767	231BRCK		06-21-04	<.1	<1.0	<.4	<.4	414	405

Table 22. Field chemical measurements and results of laboratory analysis of water samples collected from 12 moniotor wells and 46 private-supply wells in and near diabase intrusions, Newark Basin, southeastern Pennsylvania, February 2004-April 2005. Wells listed by geologic unit in each study area.—Continued

U.S. Geological Survey local well number	Geologic unit code	Lithology	Date of sample	Vanadium, water, filtered (µg/L)	Vanadium, water, unfiltered (µg/L)	Selenium, water, filtered (µg/L)	Selenium, water, unfiltered (µg/L)	Strontium, water, filtered (µg/L)	Strontium, water, unfiltered (µg/L)
				(01085)	(01087)	(01145)	(01147)	(01080)	(01082)
Private-supply wells - Kibblehouse area									
MG 2117	231DIBS		10-26-04	15.1	20	E0.3	E0.2	63.0	56.1
MG 2112	231BRCK	MMPC	09-22-04	5.5	M	.4	E.2	346	343
MG 2114	231BRCK	MMPC	09-22-04	5.0	M	.9	E.3	353	344
MG 2115	231BRCK	MMPC	09-23-04	2.1	M	2.3	1.9	217	232
MG 2116	231BRCK	MMPC	09-23-04	2.4	M	E.3	<.4	156	165
MG 2118	231BRCK	MMPC	11-15-04	6.6	M	.4	.8	80.9	70.8
Private-supply wells - New Hope area									
BK 3029	231DIBS		02-16-05	.7	M	.4	.7	155	138
BK 3017	231DIBS		10-07-04	7.1	M	<.4	.5	39.4	22.5
BK 3020	231DIBS		11-22-04[4]	2.3	<20	E.4	E.3	<.40	<.20
BK 3020	231DIBS		01-27-05	3.1	M	1.2	.6	56.3	59.8
BK 3023	231DIBS		12-07-04	2.0	<6	<.4	.5	44.5	35.9
BK 3018	231BRCK	MMPC	10-07-04	7.9	M	.5	.7	179	170
BK 3021	231BRCK	MMPC	12-01-04	8.0	M	<.4	E.3	54.9	56.0
BK 3022	231BRCK	MMPC	12-06-04	3.8	M	E.4	E.2	99.3	89.8
BK 2199	231BRCK	MMPC	02-07-05	8.8	M	.5	.7	148	127
BK 2199	231BRCK	MMPC	02-07-05[2]	9.2	M	.6	.8	148	126
BK 3019	231BRCK		11-17-04	6.5	M	.7	.8	298	284
BK 2153	231BRCK		04-06-05	4.4	M	1.1	1.2	417	357
Private-supply wells - Quakertown area									
BK 3025	231DIBS		01-11-05	8.0	M	E.3	E.4	43.5	40.0
BK 3028	231DIBS		01-13-05	4.6	M	.5	1.0	93.4	84.9
BK 3032	231DIBS		04-13-05	6.3	M	E.3	.4	84.0	70.5
BK 3027	231BRCK	MMPC	01-13-05	1.2	M	E.3	.5	75.0	68.6
BK 3033	231BRCK	MMPC	04-14-05	3.4	M	<.4	.7	139	139
BK 3024	231BRCK		01-10-05	1.4	M	.8	.8	512	507
BK 3026	231BRCK		01-11-05	.7	<2	1.3	1.3	304	302
BK 3031	231BRCK		04-11-05	1.4	<2	E.3	E.3	373	340
BK 3030	231LCKG		04-11-05	.9	<2	E.4	E.4	927	900
Private-supply wells - Dillsburg area, Gettysburg Basin									
YO 1224	231DIBS		12-02-04	5.1	M	E.3	E.2	26.9	27.8

Table 22. Field chemical measurements and results of laboratory analysis of water samples collected from 12 moniotor wells and 46 private-supply wells in and near diabase intrusions, Newark Basin, southeastern Pennsylvania, February 2004-April 2005. Wells listed by geologic unit in each study area.—Continued

U.S. Geological Survey local well number	Geologic unit code	Lithology	Date of sample	Zinc, water, filtered (µg/L)	Zinc, water, unfiltered (µg/L)	Uranium, water, filtered (µg/L)	Uranium, water, unfiltered (µg/L)	$^{11}B/^{10}B$ mass ratio	$\delta^{11}B$ (per mil)	$^{11}B/^{10}B$ mass ratio replicate[1]	$\delta^{11}B$ replicate[1] (per mil)
				(01090)	(01092)	(22703)	(28011)				
Monitor wells - Congo Road area											
BE 1756	231BRCK		03-01-04	--	--	--	--	4.0870464	10.7	--	--
BE 1757	231BRCK		03-02-04	--	--	--	--	4.0750008	7.8	--	--
BE 1758	231BRCK		03-02-04	0.7	<2	19.8	18.8	4.0758524	8.0	4.0781869	8.5
BE 1759	231BRCK		03-04-04	--	--	--	--	--	--	--	--
BE 1759	231BRCK		03-08-04	--	--	--	--	4.1044413	15.0	--	--
BE 1760	231BRCK		03-04-04	--	--	--	--	4.1554167	24.0	--	--
BE 1761	231BRCK		03-08-04	--	--	--	--	4.1408709	24.1	--	--
BE 1762	231BRCK		03-09-04	2.2	2	8.32	9.76	4.0879173	11.0	--	--
MG 2104	231BRCK		03-03-04	--	--	--	--	4.0433276	-0.1	--	--
MG 2105	231BRCK		03-03-04	--	--	--	--	4.0508091	1.8	--	--
MG 2106	231BRCK		03-03-04	--	--	--	--	4.1003984	14.0	4.1012486	14.3
MG 2107	231BRCK		03-05-04	2.3	3	3.21	3.52	4.0552378	2.9	4.0569910	3.3
MG 2108	231BRCK		03-05-04	1.1	4	7.75	8.90	4.1302888	21.4	4.1307442	21.5
Private-supply wells - Congo Road area											
BE 1763	231DIBS		05-04-04	7.6	6	.27	.240	4.1275149	20.7	--	--
BE 1764	231DIBS		05-06-04	4.3	4	.33	.282	4.1284416	21.0	--	--
MG 2026	231DIBS		05-04-04	23.7	20	.06	.047	4.0930670	13.3	--	--
BE 1765	231BRCK	MMPC	05-04-04	1.8	2	.17	.146	4.1301566	21.8	--	--
BE 1766	231BRCK	MMPC	05-06-04	2.3	E1	.30	.245	4.0942387	12.5	--	--
MG 1974	231BRCK	MMPC	07-26-04	9.9	11	2.08	2.08	4.0681004	6.1	--	--
MG 1982	231BRCK	MMPC	05-05-04	8.0	8	11.7	10.2	4.0901033	11.5	4.0894399	11.3
MG 2103	231BRCK	MMPC	02-18-04	17.6	11	2.63	2.61	4.0819244	9.5		
MG 2103	231BRCK	MMPC	02-18-04[2]	--	--	2.73	2.70	4.0808229	9.2	4.0802590	9.1
MG 2109	231BRCK	MMPC	05-04-04	1.9	2	4.09	3.64	[3]4.0991402	[4]14.9	4.1065322	15.6
MG 2111	231BRCK	MMPC	06-07-04	35.4	37	3.51	3.56	4.1001210	14.0	4.0993340	13.9
BE 1733	231BRCKF	MMPC	05-05-04	23.1	67	.89	.790	4.1043569	15.0	4.1041615	15.0
MG 2001	231BRCK		05-06-04	73.7	66	3.88	3.29	4.0643215	5.1	--	--
MG 2110	231BRCK		06-03-04	36.4	35	2.77	3.14	4.0701924	6.6	--	--
MG 2113	231BRCK		07-27-04	8.2	11	.60	.558	4.1399372	23.8	--	--
Private-supply wells - Jacksonwald area										--	--
BE 1769	231BSLT		06-29-04	4.2	3	.16	.152	4.0772869	8.3	--	--
BE 1771	231BSLT		08-02-04	27.5	27	.23	.243	4.0757027	7.9	4.0730347	7.3
BE 1768	231DIBS		06-21-04	10.9	8	.22	.195	4.1395822	23.7	4.1361720	22.9
BE 1772	231DIBS		08-02-04	4.8	6	.91	.949	4.1071725	15.7		
BE 1770	231BRCK	MMPC	08-04-04	9.1	8	E.03	.021	4.1309097	21.6	4.1302460	21.4
BE 1767	231BRCK		06-21-04	1.3	E1	2.28	2.14	4.1042890	15.0		

Table 22. Field chemical measurements and results of laboratory analysis of water samples collected from 12 moniotor wells and 46 private-supply wells in and near diabase intrusions, Newark Basin, southeastern Pennsylvania, February 2004-April 2005. Wells listed by geologic unit in each study area.—Continued

U.S. Geological Survey local well number	Geologic unit code	Lithology	Date of sample	Zinc, water, filtered (µg/L)	Zinc, water, unfiltered (µg/L)	Uranium, water, filtered (µg/L)	Uranium, water, unfiltered (µg/L)	$^{11}B/^{10}B$ mass ratio	$\delta^{11}B$ (per mil)	$^{11}B/^{10}B$ mass ratio replicate[1]	$\delta^{11}B$ replicate[1] (per mil)
				(01090)	(01092)	(22703)	(28011)				
Private-supply wells - Kibblehouse area											
MG 2117	231DIBS		10-26-04	10.6	6	0.07	0.059	4.121940	20.6	--	--
MG 2112	231BRCK	MMPC	09-22-04	9.8	6	5.71	5.97	4.0693095	7.6	--	--
MG 2114	231BRCK	MMPC	09-22-04	584	510	8.49	8.65	4.0574791	4.6	--	--
MG 2115	231BRCK	MMPC	09-23-04	1.4	E1	3.04	3.19	4.0573224	4.6	--	--
MG 2116	231BRCK	MMPC	09-23-04	10.5	10	1.04	1.11	--	--	--	--
MG 2118	231BRCK	MMPC	11-15-04	5.1	5	2.46	2.52	4.0799713	10.1	--	--
Private-supply wells - New Hope area										--	--
BK 3029	231DIBS		02-16-05	24.7	23	.25	.277	--	--	--	--
BK 3017	231DIBS		10-07-04	241	77	.30	.278	4.1208832	20.1	--	--
BK 3020	231DIBS		11-22-04[4]	1.1	2	.28	.268	--	--	--	--
BK 3020	231DIBS		01-27-05	97.5	99	.41	.420	4.118228	18.1	4.1150676	18.6
BK 3023	231DIBS		12-07-04	1.6	E1	.13	.146	4.1228320	20.5	4.1211326	20.1
BK 3018	231BRCK	MMPC	10-07-04	24.6	26	1.37	1.41	4.1139583	18.7	--	--
BK 3021	231BRCK	MMPC	12-01-04	4.9	3	.48	.464	4.0984246	14.5	4.1016873	15.3
BK 3022	231BRCK	MMPC	12-06-04	3.5	4	.54	.555	--	--	--	--
BK 2199	231BRCK	MMPC	02-07-05	284	260	1.82	1.66	4.0675482	7.4	--	--
BK 2199	231BRCK	MMPC	02-07-05[2]	276	343	1.83	1.59	--	--	--	--
BK 3019	231BRCK		11-17-04	1.7	E1	4.59	4.63	4.1110406	17.9	--	--
BK 2153	231BRCK		04-06-05	3.5	7	7.44	8.09	4.0495434	3.0	--	--
Private-supply wells - Quakertown area											
BK 3025	231DIBS		01-11-05	61.5	54	.08	.072	4.1072969	16.4	4.1061775	16.1
BK 3028	231DIBS		01-13-05	5.6	4	1.44	1.49	--	--	--	--
BK 3032	231DIBS		04-13-05	13.4	11	.16	.166	4.1265543	22.0	--	--
BK 3027	231BRCK	MMPC	01-13-05	11.2	8	1.66	1.49	4.0648740	6.4	--	--
BK 3033	231BRCK	MMPC	04-14-05	4.6	3	2.36	2.25	--	--	--	--
BK 3024	231BRCK		01-10-05	5.8	5	9.95	9.02	4.0423453	1.2	--	--
BK 3026	231BRCK		01-11-05	3.1	3	1.64	1.55	--	--	--	--
BK 3031	231BRCK		04-11-05	8.1	3	1.05	1.19	4.1276994	22.3	--	--
BK 3030	231LCKG		04-11-05	7.6	7	2.60	2.92	4.0863976	11.7	--	--
Private-supply wells - Dillsburg area, Gettysburg Basin											
YO 1224	231DIBS		12-02-04	1.6	3	.04	.037	4.0870451	12.0	--	--

[1] Laboratory replicate, unless noted as field replicate.

[2] Field replicate.

[3] Additional field replicate result had mass ratio = 4.1026687, $\delta^{11}B$ = 14.6 per mil.

[4] Sample was collected after water-treatment system (water softener).

Appendix 1.

Mines and prospects in the Newark Basin

Mines and Prospects in the Newark Basin

Several types of mineral deposits are described in this report. A mine is a locality that has a written or recorded history of actual or attempted commercial development and ore production. A prospect is a locality where some excavation or mineral exploration activity has occurred. An occurrence is a locality where anomalously high metal values or interesting or unusual metal-bearing minerals occur, but no mining or prospecting for metals has taken place (Robinson and Sears, 1988, p. 266). Areas in the Newark Basin where mines are described below are shown on figure 1-1.

Congo Road Area

Several copper prospects and occurrences and iron mines are located in the vicinity of the Congo Road area (fig. 1-2). Three copper prospects and occurrences are located in the box on figure III-B-3 (June/July ground water sample locations) in Towle and Kelly (2000, p. 79), and four copper prospects and occurrences are located just to the northeast, north, southwest, and south of the box. In the June/July ground-water sample area (Towle and Kelly, 2000, p. 79) are: (1) Congo W copper prospect, (2) Congo NW copper prospect, and (3) the Brendlinger mine. To the north is Bauman's mine; to the northeast is the Congo NE copper prospect; to the south is the Layfield occurrence; and to the southwest is the Gilbertsville occurrence. Mines, prospects, and mineral occurrences in the vicinity of the Congo Road area are listed in table 1-1.

Congo W copper prospect (Congo copper prospect of Spencer, 1908, p. 65; Wherry, 1908a, p. 728, locality 22). Benge and Wherry (1906, p. 41) give the location of this prospect as B.M. Yost's farm 0.5 mi west of Congo. Spencer (1908, p. 65) provided the following description. "*A shallow pit has been sunk in search of copper ore in a road-metal quarry beside the wagon road half a mile west of the Congo post office near the end of the arm of the diabase which extends toward the southwest from the main triangular area. In the walls of this pit may be seen a veinlet about an inch wide, composed mainly of hornblende and feldspar containing scattered bunches of chalcopyrite.*" Wherry (1908a, p. 732) described the chalcopyrite as large irregular grains embedded in seams of fibrous hornblende; Wherry analyzed the ore and found it to contain 0.3 ounces gold and 1.7 ounces of silver per ton.

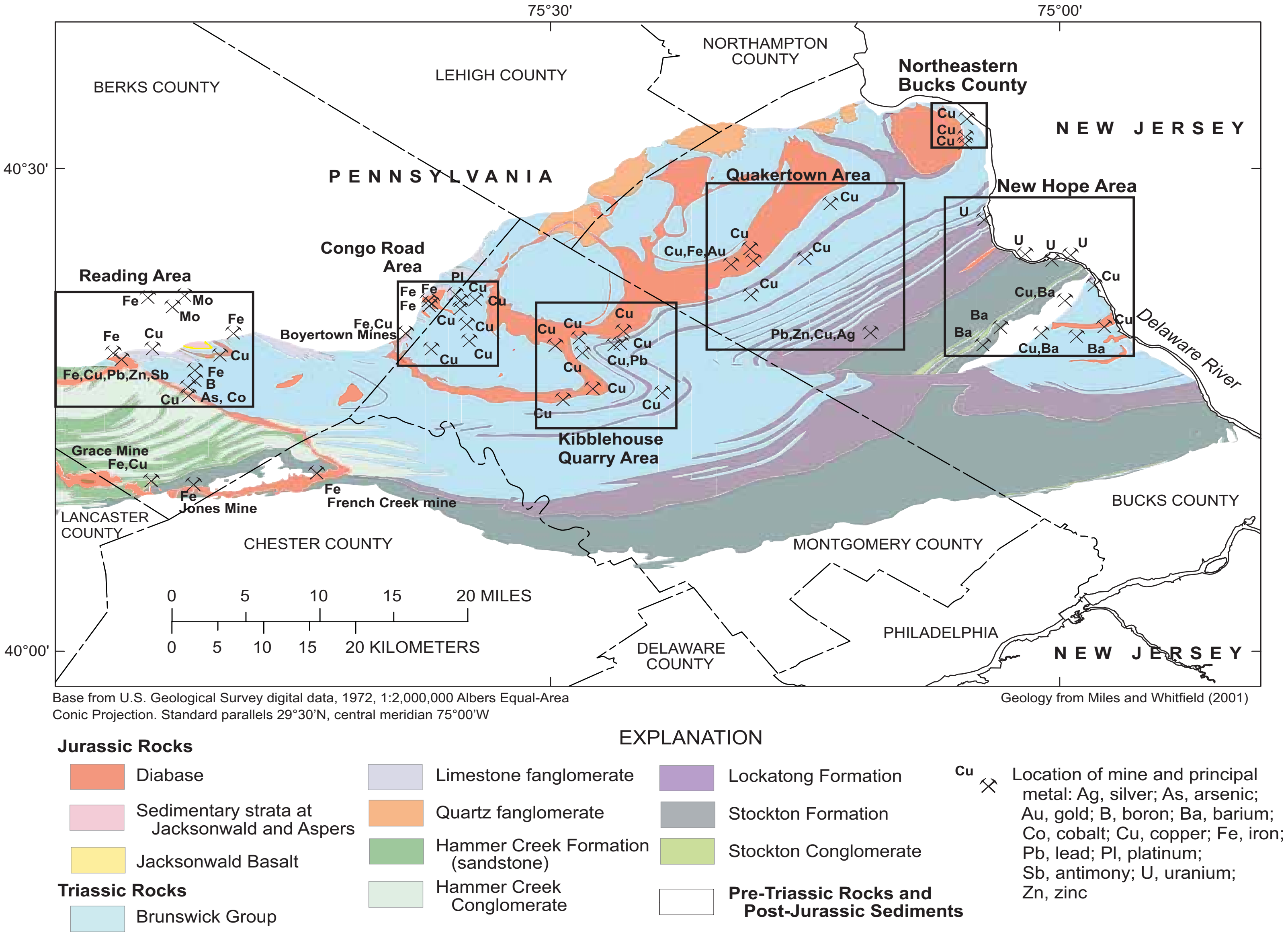
Congo NW copper occurrence (Congo 1 of Robinson and Sears, 1988, p. 274). Wherry (1908a, p. 728, location 21) described this prospect as a roadside exposure 0.5 mi northwest of Congo.

Congo NE copper occurrence (Congo 3 of Robinson and Sears, 1988, p. 274). Wherry (1908a, p. 728, location 19) described this prospect as a hillside exposure 0.75 mi northeast of Congo.

Bauman's mine (Congo 2 of Robinson and Sears, 1988, p. 274). Wherry (1908a, p. 728, location 20) calls this Bauman's platinum mine. Kemp (1902, p. 59) states that platinum was detected by assay in a black shale near Sassamansville. According to information provided by A.W. Johnston, "*A vein from this vicinity containing quartz, pyrites, and oxidized lead minerals yielded one-half ounce per ton of platinum and either gold or palladium.*"

Table 1-1. Mines, prospects, and mineral occurrences in the Congo Road area, Berks and Montgomery Counties, Pennsylvania. Locations are shown on figure 1-2.

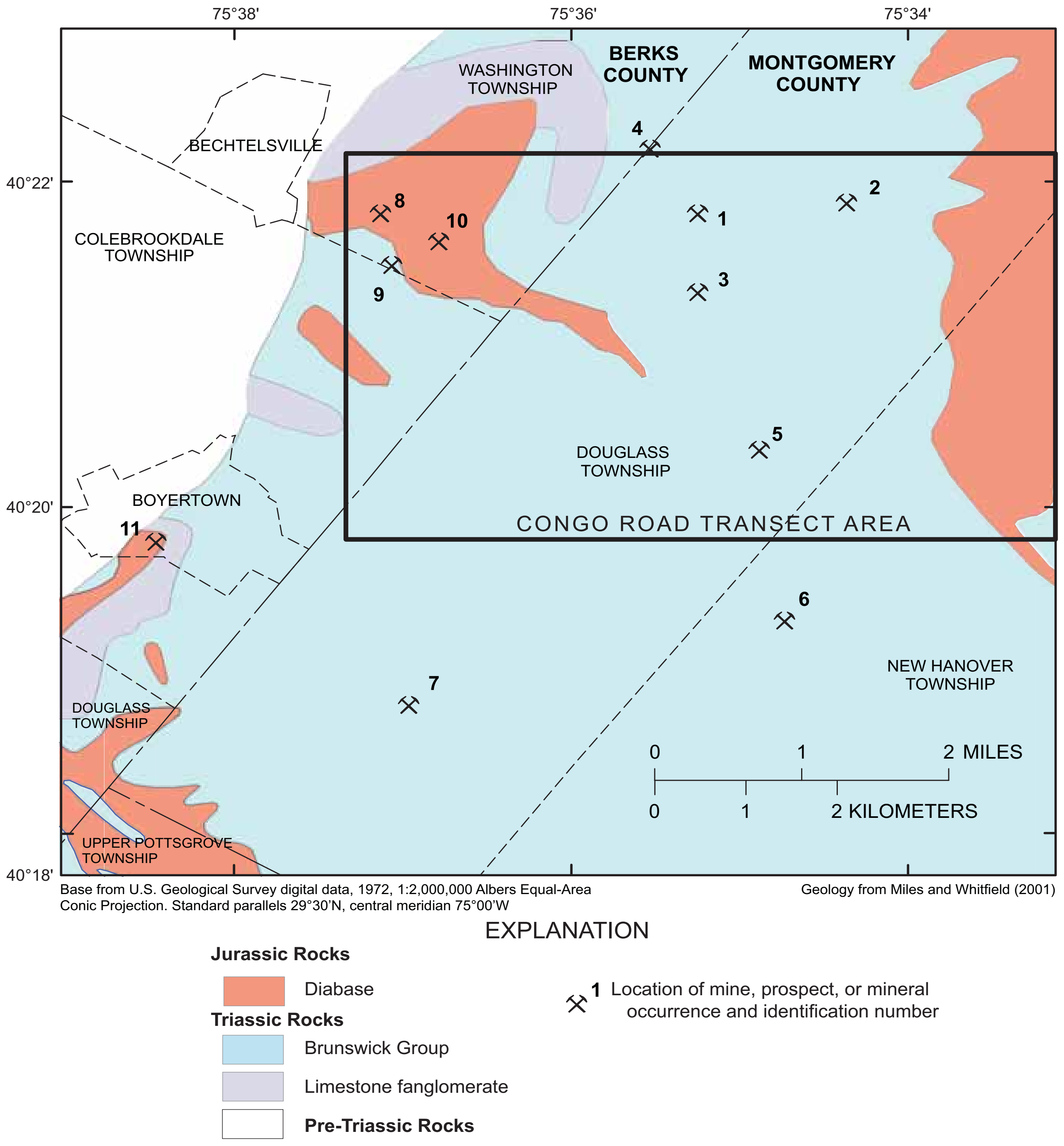
Map number	Name	Type of locality	Type of deposit	Primary metals
1	Congo W	prospect	diabase host/vein	Cu, Au, Ag
2	Congo NE	occurrence	diabase host/vein	Cu
3	Congo NW	occurrence	diabase host/vein	Cu
4	Bauman's mine	prospect	hornfels	Pl
5	Brendlinger mine	prospect	hornfels	Cu
6	Layfield occurrence	occurrence	sedimentary host	Cu
7	Gilbertsville occurrence	occurrence	sedimentary host	Cu
8	Fegley mine	mine	vein/replacement	Fe
9	Gilbert mine	mine	vein/replacement	Fe
10	Unnamed shaft	mine	vein/replacement	Fe
11	Boyertown mines	mine	vein/replacement	Fe, Cu



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic Projection. Standard parallels 29°30'N, central meridian 75°00'W

Geology from Miles and Whitfield (2001)

Figure 1-1. Locations of selected mines, prospects, and mineral occurrences in the Newark Basin, Pennsylvania.



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic Projection. Standard parallels 29°30'N, central meridian 75°00'W

Geology from Miles and Whitfield (2001)

Figure 1-2. Mines, prospects, and mineral occurrences in the Congo Road area, Berks and Montgomery Counties, Pennsylvania. Mine names are given in table 1-1.

Brendlinger mine Wherry (1908a, p. 728, location 23) gives the location of this mine as 1 mi southwest of Sassmansville. Copper was first discovered here by John Henry Sprogel in 1717 (Wherry, 1908b, p. 313-314). The ore was assayed by a German chemist and was "*found to contain, in four ounces, one ounce of metallic copper and four grains of gold.*" Newhouse (1933, p. 626) reported chalcocite, pyrite, chalcopyrite, and hematite from the Brendlinger mine.

Layfield copper occurrence (misspelled as Langfield by Gordon, 1922, p. 215). Lyman (1898, p. 417, location Cdz) gives the location of this occurrence as 3 mi east of Gilbertsville and describes it as an exposure on north side of the road of "*malachite traces in 5 feet of dark, dull red, sandy, hard shales.*"

Gilbertsville copper occurrence Lyman (1898, p. 417, location Bda) gives the location of this occurrence as 1.5 mi south of Gilbertsville and describes it a roadside exposure with "*malachite traces in 2.5 feet of grayish-red sandy shales.*"

Fegley mine The Fegley mine is in diabase about 2 mi northwest of Congo. It produced a small quantity of iron ore. Spencer (1908, p. 64-65) provided the following description. "*Iron ore is said to have been extracted from workings known as the Fegley mine, situated well within the diabase area on the north side of the little brook about one-fourth mile north of the Gilbert shaft. A large fragment of diabase was found, on one side of which there was a coating of ore 1 inch thick composed of crystalline magnetite intergrown with a minor amount of feldspar. Appearance suggests that the magnetite was segregated into a crevice traversing the diabase.*"

Gilbert mine and unnamed shaft The Gilbert mine was located just south of the Fegley mine. D'Invilliers (1883, p. 206), in describing the diabase at the Washington/Colebrookdale township boundary, stated "*Several shafts have been put down in this hill for iron ore and some very excellent material obtained from the Gilbert mine located here, though no regularity is reported in the deposit.*" Spencer (1908, p. 63) was not able to find the shafts. Hawkes and others (1953, p. 140) did not find the shafts or evidence of mining but did find a caved shaft (the unnamed shaft) 1,000 ft east of the map location and theorize that the location may have been missplotted. Hawkes and others (1953, pl. 17) found a magnetic anomaly at the map location of the Gilbert shaft during their aeromagnetic survey of the Boyertown area.

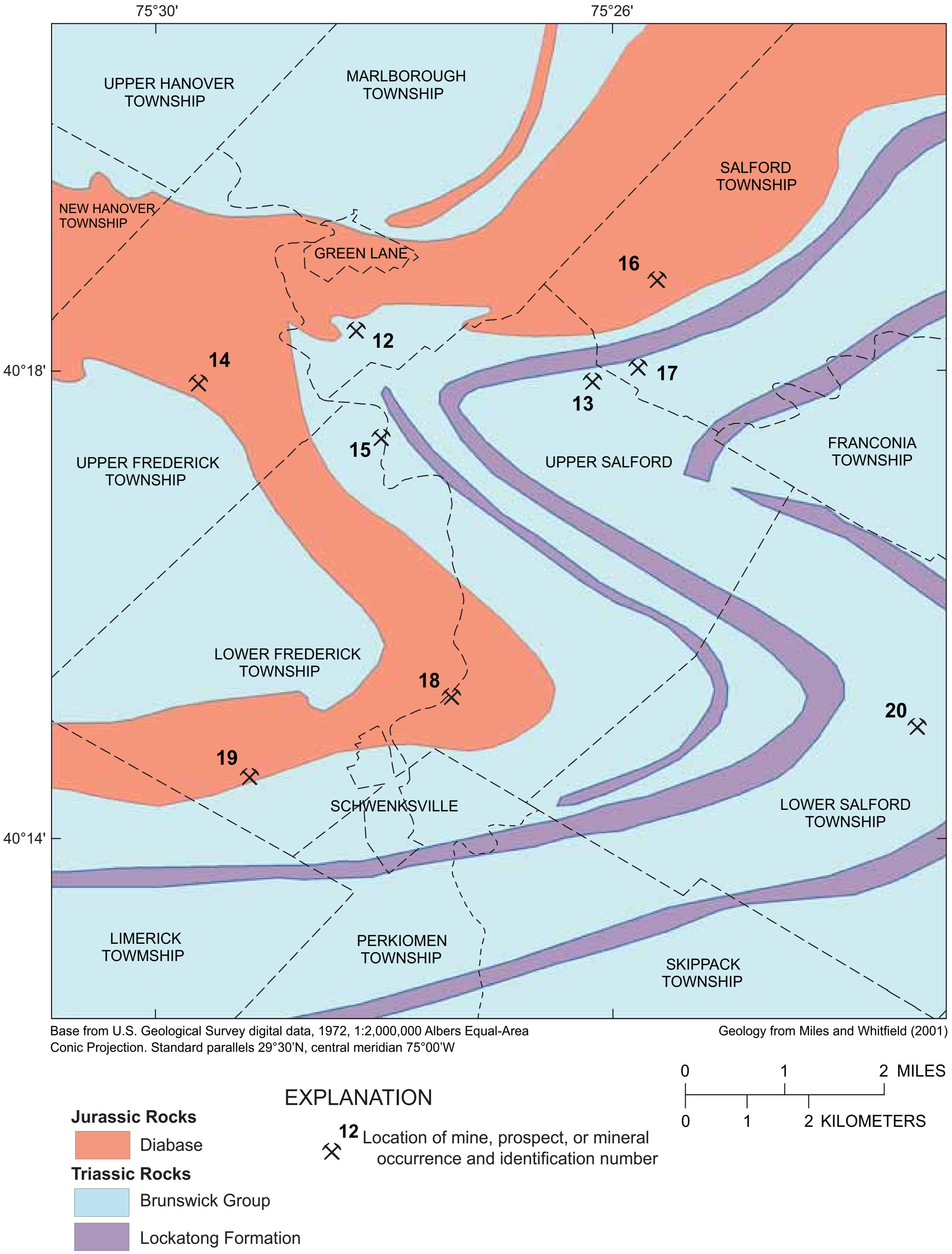
Boyertown mines Five separate magnetite ore bodies were mined at Boyertown. Spencer (1908, p. 43-61) provides the most detailed description of these deposits. D'Invilliers (1883, p. 304-333) provides descriptions of the individual mines and analyses of the ore. Hawkes and others (1953) provide the results of a geologic study of the Boyertown vicinity that utilized diamond drilling and ground magnetic and aeromagnetic surveys. Spencer (1908, p. 47) reported that the mines were abandoned and flooded at the time of his visit (1906 or 1907). Rose (1970, p. 8) estimated ore production from the Boyertown mines at about 1,000,000 tons. Reported minerals from the Boyertown mines include magnetite, stilbite, cuprite, pyrite (D'Invilliers, 1883), chalcopyrite (Eyerman, 1889, p. 6), hematite (Newhouse, 1933, p. 626), and malachite (Smith and others, 1988, p. 328-329). Analyses of ore from the dumps by Smith and others (1988, p. 328) gave 0.16 percent Cu, 145 parts per million Co, and 80 parts per million As.

Kibblehouse Quarry Area

Several mineral deposits occur east of the Congo Road area (fig. 1-3). They include the Kibblehouse quarry and several copper mines and occurrences (table 1-2). Copper mines and occurrences in the vicinity of the Kibblehouse quarry include Kober's mine, Karl's mine, Young's mine, the Hendricks Station occurrence, and the Sumneytown occurrences. Kober's mine, Karl's mine, and Young's mine are in shattered rock along the crest of a fold that becomes a fault farther to the east. The primary copper minerals are chalcopyrite and bornite and their alteration products malachite and azurite.

Table 1-2. Mines, prospects, and mineral occurrences in the vicinity of the Kibblehouse quarry. Locations are shown on figure 1-3.

Map number	Name	Type of locality	Type of deposit	Primary metals
12	Kibblehouse quarry	occurrence	hornfels	Cu
13	Kober's mine	mine	hornfels/fault zone	Cu, Pb
14	Karl's mine	mine	vein/hornfels	Cu
15	Young's mine	mine	hornfels	Cu
16	Sumneytown occurrences	occurrence	hornfels	Cu
17	Hendricks Station occurrence	occurrence	hornfels	Cu
18	Schwenksville occurrences	occurrence	hornfels	Cu
19	Old Perkiomen mine	mine	hornfels	Cu
20	Lederachsville occurrence	occurrence	sediment host	Cu



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic Projection. Standard parallels 29°30'N, central meridian 75°00'W

Geology from Miles and Whitfield (2001)

Figure 1-3. Mines, prospects, and mineral occurrences in the Kibblehouse quarry area, Montgomery County, Pennsylvania. Mine names are given in table 1-2.

Kibblehouse quarry The best exposure of hornfels mineralization in the Congo Road area is the active Kibblehouse quarry, which is about 7.5 mi east-southeast of the industrial facility. It is considered a hornfels copper deposit by Robinson and Sears (1988, p. 273). The Kibblehouse quarry is in Brunswick Group shale, which has been baked to a hornfels. It is about 1,100 ft south of diabase. A great deal of attention has been focused on the minerals occurring in the hornfels. A list of selected minerals found at the Kibblehouse quarry is given in table 1-3. A more complete list is found in Geyer and others (1976, p. 189-192).

Table 1-3. Selected minerals reported from the Kibblehouse quarry.

Mineral	Chemical formula[1]	Notes[2]
Arsenic minerals		
alloclasite	$(Co,Fe)AsS$	Smith (1978, p. 20-21) identified alloclasite intergrown with cobaltite and associated with sphalerite, cobaltite, and arsenopyrite in calcite veins cutting hornfels; glaucodot of Geyer and others (1976)
arsenopyrite	$FeAsS$	found with traces of brown sphalerite; associated with cobaltite and alloclasite (Montgomery, 1974, p. 4)
cobaltite	[3]$(Ni,Co,Fe)AsS$	common, abundant; bright silvery octahedrons in green-gray hornfels, larger crystals up to 1/4 inch in calcite veins with sooty rims of gersdorfite (Smith, 1978, p. 91-93)
erytherite	$Co_3(AsO_4)\bullet 8H_2O$	pink coatings with cobaltite
gersdorffite	$NiAsS$	gray metallic with cobaltite; Smith (1978, p. 20-21) found it associated with cobaltite
safflorite	[3]$(Co,Fe,Ni)As_2$	identified by Speer and others (1978, p. 131-132)
Boron minerals		
datolite	$Ca_2B_2Si_2O_8(OH)_2$	very pale green with glassy lustre; in half inch wide vein-like areas crosscutting hornfels; associated with calcite and galena; also associated with calcite, axinite, cobaltite, erythrite, and prehnite (Montgomery, 1973a, p. 8)
ferro-axinite	$Ca_2Fe^{2+}Al_2BSi_4O_{15}(OH)$	in calcite veins with cobaltite; associated with calcite, axinite, cobaltite, erythrite, and prehnite (Montgomery, 1968 p. 9; 1973a, p. 8)
Copper minerals		
azurite	$Cu_3(CO3)_2(OH)_2$	bright blue spots
chalcopyrite	$CuFeS_2$	small brassy grains; some crystals
chrysocolla	$(Cu,Al)_2H_2SI_2O_5(OH)_4\bullet nH_20$	small blue-green masses
copper (native)	Cu	uncommon; in small sheets and masses in and on hornfels (Montgomery, 1973b, p. 4)
malachite	$Cu_2^{2+}(CO_3)(OH)_2$	small needles and coatings
Fluorine minerals		
[4][fluor]apophyllite(?)	$KCa_4Si_8O_{20}(F,OH)\bullet 8H_2O$	presence questioned by Montgomery (1973a, p. 8)
fluorite	CaF_2	uncommon, small purple crystals
Other metal minerals		
galena	PbS	small cubes 1-2 mm across associated with datolite (Montgomery, 1973a, p. 8)
magnetite	$Fe^{2+}Fe_2^{3+}O_4$	massive
pyrite	FeS_2	microcrystals on natrolite and chabazite
sphalerite	ZnS	tiny brown-red cleavages associated with arsenopyrite
titanite	$CaTiSiO_5$	

[1] From Fleischer and Mandarino (1995).

[2] Description from Geyer and others (1976, p. 189-192) unless otherwise noted.

[3] Based on chemical analysis presented by Speer and others (1978, p. 131-132).

[4] Reported by Montgomery (1969, p. 90) as being collected by A.V. Heyl of U.S. Geological Survey in the 1930s.

Analyses of material from the Kibblehouse quarry for Cu, Co, and As by Smith and others (1988, p. 326-327) gave the following results:

1. 1.1 pounds showing visible cobaltite: 0.04 percent Cu, 490 parts per million Co, and 740 parts per million As
2. 6.8 pounds showing trace Cu (chalcopyrite, chryscolla, and malachite): 1.29 percent Cu, 45 parts per million Co, and 70 parts per million As
3. 4 pounds from pyrite vein: 0.04 percent Cu, 105 parts per million Co, and 1,100 parts per million As

Kober's mine Kober's mine (also known as the Upper Salford mine) is a hornfels copper deposit. Wherry (1908a, p. 728, location 15) gives the location as 0.75 mi northeast of Woxall. Several conflicting accounts of this mine exist. Kober's mine was located on the farm of Abraham Kober. Lyman (1898, p. 419, location Ddi) lists four shafts or pits: (1) a 40-ft deep shaft, (2) a 24-ft deep shaft 12 yards northeast of the first, (3) a 50-ft deep shaft 12 yard southwest of the first intersecting a vein 2 ft wide, and (4) a pit 9 ft deep 100 yards south of the first with traces of malachite. These shafts were sunk about 1875 (Wherry, 1908a, p. 734). An account by Carter (1884, p. 12) relates that ore was first discovered on the surface in a small outcrop and development began in 1878. At a depth of 15 ft, a vein 8 in. thick was discovered. The farm was then leased to Samuel Milligan who continued development and reached a vein 3 ft thick. Milligan mined 4 tons of copper ore, but thereafter ore was not encountered in paying quantities, and mining ended in 1880. Minerals reported from the Kober mine include copper minerals azurite (Wheatley, 1882, p. 36), chalcopyrite, bornite, native copper (Carter, 1884, p. 12), malachite, and chrysocolla; the iron mineral, pyrite (Lyman, 1898, p. 419); zeolite minerals stilbite and natrolite (Benge and Wherry, 1906, p. 110); and lead minerals galena and pyromorphite (Eyerman, 1911, p. 19).

Karl's mine This mine is the A. Charles copper mine of Lyman (1898, p. 418, location Ddb). Karl's mine is a hornfels copper deposit. Wherry (1908a, p. 734, location 16) gives the location as 0.5 mi northwest of Woxall. The mine was operated as an open cut 20 yards long by 4 yards wide dug horizontally into a hillside in 1885 and 1889 (Lyman, 1898, p. 418). It intersected a 7-in. wide vertical vein of quartz and clay in a dark, reddish gray, calcareous, very hard shale. Lyman (1898, p. 418, location Ddd) also reports an unsuccessful "hole" with "copper traces" dug by A. Charles 1/8 mi east of Karl's mine. Minerals reported from Karl's mine include malachite, chalcopyrite, hematite (Lyman, 1898, p. 418-419), chalcocite (Benge and Wherry, 1907, p. 42), and stilbite (Benge and Wherry, 1908, p. 108).

Young's mine Young's mine is a hornfels copper deposit on the west side of Perkiomen Creek mined by a stock company around 1901 or 1903 (Rose, 1970, p. 12). Wherry (1908a, p. 728, location 18) gives the location as 3/8 mi north of Hendricks. A 150-ft deep shaft was sunk on thin hydrothermal copper veins (Heyl, 1980, p. 31). Benge and Wherry (1906, p. 110) reported possible gold and copper minerals bornite, chalcopyrite, chrysocolla, cuprite, and malachite and associated pyrite.

Sumneytown occurrences Two copper occurrences east of Sumneytown are listed as roadside exposures of malachite. At the occurrence 1 mi east of Sumneytown, Lyman (1898, p. 419, location Ddl) described "*copper traces in 1/2 foot of dark reddish- and greenish-gray very hard shales*." At the occurrence 1.5 mi east of Sumneytown, Lyman (1898, p. 419, location Dde) described "*malachite traces in a foot of dark reddish-gray hard shales, and in 1/2 foot of the same, the two layers separated by unexposed layers*."

Hendricks Station occurrences The Hendricks Station occurrences are a hornfels copper deposit in and above a railroad cut 0.5 mi north of Hendricks. They are the two localities described by Lyman (1898, p. 419, locations Ddo and Ddr) as "*on the Perkiomen Railroad halfway between Hendricks' and Kratz stations; malachite traces and pyrites specks* [SIC] *in 6 inches of grayish-green, rather soft shales*" and "*on the Perkiomen railroad 200 yards north of Ddo; and apparently the same bed, traces of malachite*." (Wherry, 1908a, p. 734-35) noted several parallel faults present at this locality. Benge and Wherry (1906, p. 42 and 110) also reported the occurrence of bornite and chalcopyrite.

Schwenksville occurrences Lyman (1898, p. 418) reported three occurrences of copper minerals east of Schwenksville. Lyman (1898, p. 418, location Ddh) described one as on the "*east bank of the Perkiomen, opposite Schwenksville; malachite specks in 1.5 feet of reddish-gray hard shale*." Lyman (1898, p. 418, location Dda and Ddb) described the other two occurrences as on the "*roadside, 1/8 mile east of Schwenksville, and east of the Perkiomen; malachite traces in 4-foot exposure of greenish- and reddish-gray hard shales with white specks. A hole formerly dug on each side of the road, both on the same bed, but with more malachite traces on the north side.*"

Old Perkiomen mine The Old Perkiomen mine (also known as the Schwenksville prospect) is on a hill north of Mine Run east of Schwenksville. Early prospecting for copper ore began about 1717. A company to mine copper was first organized in 1722 but was unsuccessful. Further development took place beginning in 1740 by Christopher Geist, a German mining engineer. He drove a tunnel 2,000 ft from the Perkiomen Creek to connect with three shafts and a drainage tunnel on Mine Run. The mined ore was shipped to England. Mining ceased about 1770 (Wherry, 1908b, p. 312-313). Minerals reported from this mine include bornite, chrysocolla, fluorite, malachite (Benge and Wherry, 1906, p. 110), cuprite (Wherry, 1908a, p. 733), and chalcopyrite (Rose, 1970, p. 12).

Lederachsville occurrence Benge and Wherry (1906, p. 42) reported traces of malachite in shale in a quarry 1.5 mi east of Lederachsville.

Quakertown Area

Mines, prospects, and mineral occurrences in the Quakertown area (fig. 1-4) are listed in table 1-4. Most of these are copper localities. The New Galena mines were worked for lead ore.

Keller's Church prospect The Keller's Church copper prospect is shown on the maps of Wherry (1908a, location 7) and Rose (1970, p. 2, location 8) but is not described.

Hagersville (Keelersville) occurrence The Hagersville copper occurrence also is known as the Keelersville occurrence (Rose, 1970, p. 2, location 9). Lyman (1898, p. 419, location Fcl) described the occurrence as a roadside exposure 1.5 mi south of Keelersville showing "*malachite traces and pyrites in 1.5 ft of grayish-green hard shales.*"

Rocky Ridge occurrence The Rock Ridge occurrence is listed as a copper prospect by Rose (1970, p. 2). It is a railroad cut in diabase (Wherry 1908a, location 9) about 2 mi southeast of Quakertown. Benge and Wherry (1907, p. 42) reported the occurrence of prehnite and stilbite.

Rock Hill quarry The Rock Hill quarry was worked for crushed stone. Minerals occurring in the diabase include prehnite, pyroxene (augite), calcite (Benge and Wherry, 1907, p. 42), and actinolite (Willard and others, 1959, p. 156). Benge and Wherry (1906, p. 110) that "t*races of gold are present in the Rock Hill belt of trap, and in the sand formed by its decomposition*."

Diehl's Mine Wherry (1908a, p. 732, location 10) described a locality called Diehl's gold mine. The mine was developed in a large diabase pegmatite containing traces of chalcopyrite (Smith, 1973, p. 50). It was on Josiah Diehl's farm where a shaft 90 ft deep was sunk (Willard and others, 1959, p. 218). A local newspaper reported a find of 3.5 ounces of gold per ton in an unusually coarse-grained diabase. The report turned out to be a fraud, but an analysis of the rock reported by Wherry (1908a, p. 732) showed it to contain trace gold. Benge and Wherry (1906, p. 8 and 106) reported the occurrence of stilbite and heulandite; Smith (1978, p. 37-41) reported the occurrence of fluorapatite, chalcopyrite, and magnetite.

Sellersville occurrence (Rose, 1970, p. 2, location 12) Eyerman (1889, p. 6) reported "*Associated with azurite and malachite, chalcopyrite was observed by me, some years ago, at the so-called Copper Mine a few miles from Sellersville*."

New Galena mines Galena was discovered in 1856, and mining started about 1861; the mines were worked as late as 1891. The history of the mines is presented by Miller (1924, p. 16-21). A number of pits, shafts, and cross-cuts were sunk at the New Galena mine (also known as the New Britain mine, Dickeson mine. Doan's mine, and Pine Run mine). The primary lead ore minerals were galena, cerussite, and anglesite; the primary zinc ore was sphalerite. Copper minerals present are chalcopyrite, malachite, chrysocolla, covellite, and bornite. The presence of the lead molybdate wulfenite also was reported (Smith, 1977, p. 238-245). Genth (1875, p. 2-3) reported that the ore from the mines contained 2.5 grains of gold and 10-15 ounces of silver per ton.

Northeastern Bucks County

Mines, prospects, and mineral occurrences in northeastern Bucks County (fig. 1-5) are listed in table 1-5. All of the localities listed are hornfels copper occurrences.

Lodi occurrence Wherry (1908a, p. 728) noted a copper occurrence 1 mi southwest of Lodi. The occurrence is shown on the maps of Wherry (1908a, location 1) and Rose (1970, p. 2, location 1) but is not described.

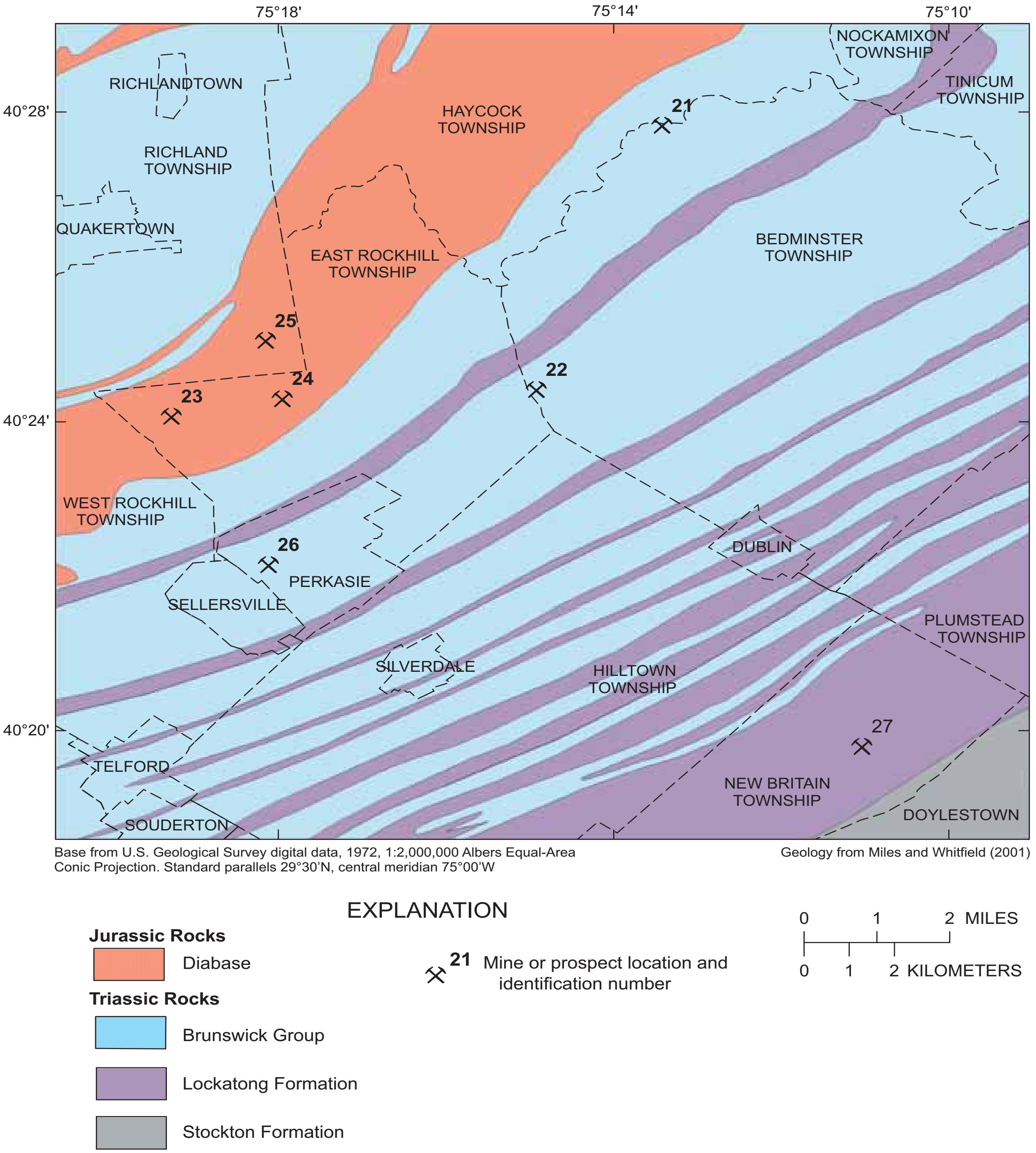
Tettemer's mine About 1875, a shaft was sunk in search of copper ore on Jacob Tettemer's farm 1 mi west of Uhlertown (Lyman, 1898, p. 420). Wherry (1908a, p. 733, location 2) noted that the 80-ft deep shaft encountered only "*the barest traces of ore*." Benge and Wherry (1906, p. 42) reported the occurrence of chalcocite and malachite.

Uhlertown occurrence Wherry (1908a, p. 728, location 3) noted a copper occurrence 1 mi southwest of Uhlertown. The occurrence is shown on the maps of Wherry (1908a) and Rose (1970, p. 2, location 3, "near Uhlerstown") but is not described.

Table 1-4. Mines, prospects, and mineral occurrences in the Quakertown area, Bucks County, Pennsylvania. Locations are shown on figure 1-4.

[--, not determined]

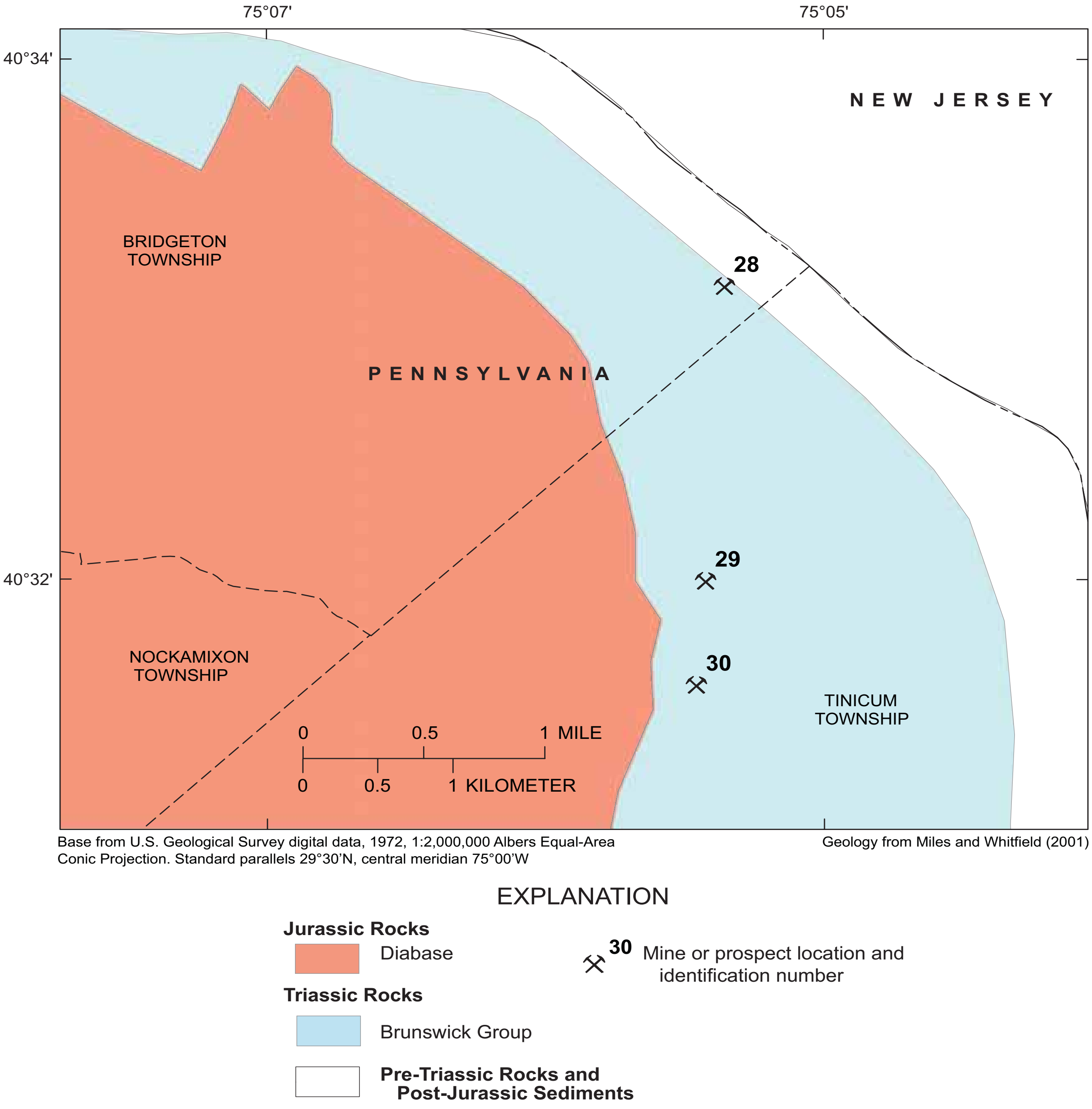
Map number	Name	Type of locality	Type of deposit	Primary metals
21	Keller's Church prospect	prospect	hornfels	Cu
22	Hagersville (Keelersville) occurrence	occurrence	sedimentary host	Cu
23	Rocky Ridge occurrence	occurrence	diabase host	Cu
24	Rock Hill quarry	occurrence	diabase host	--
25	Diehl's mine	mine	diabase host	Cu, Fe, Au
26	Sellersville occurrence	occurrence	sedimentary host	Cu
27	New Galena mines	mine	sedimentary host	Pb, Zn, Cu, Ag



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic Projection. Standard parallels 29°30'N, central meridian 75°00'W

Geology from Miles and Whitfield (2001)

Figure 1-4. Mines, prospects, and mineral occurrences in the Quakertown area, Bucks County, Pennsylvania. Mine names are given in table 1-4.



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic Projection. Standard parallels 29°30'N, central meridian 75°00'W

Geology from Miles and Whitfield (2001)

Figure 1-5. Mines, prospects, and mineral occurrences in northeastern Bucks County, Pennsylvania. Mine names are given in table 1-5.

Table 1-5. Mines, prospects, and mineral occurrences in northeastern Bucks County, Pennsylvania. Locations are shown on figure 1-5.

Map number	Name	Type of locality	Type of deposit	Primary metal
28	Lodi occurrence	occurrence	hornfels	Cu
29	Tettemer's mine	mine	hornfels	Cu
30	Uhlertown occurrence	occurrence	hornfels	Cu

New Hope Area

Mines, prospects, and mineral occurrences in the New Hope-Buckingham area (fig. 1-6) are listed in table 1-6. Several of the localities listed are uranium occurrences. Barium is the primary metal at some of the localities.

Hendricks Island McCauley (1961, p. 6 and 57, prospect 1) described a radioactive zone 1 to 2 ft thick and 150 ft long in yellow to brown ferruginious siltstone in an abandoned quarry.

Prallsville McCauley (1961, p. 6-7 and 57, prospect 2) described a radioactive zone in a coarse-grained, gray, arkosic sandstone speckled with iron oxide. Johnson and McLaughlin (1957) reported a uranium content ranging from 0.9 to 1.28 percent.

Raven Rock Quarry McCauley (1961, p. 6 and 57, prospect 3) described radioactivity in a deeply weathered limonite zone 4 to 6 ft wide, and 100 ft long in a coarse-grained, arkosic sandstone speckled with iron oxide 30 ft from the base of the eastern wall of the quarry.

Delaware Quarry Klemic (1962, p. 283) reported a number of uranium occurrences in the rocks along the Delaware River. Black argillite of the Lockatong Formation exposed in the Delaware Quarry is uraniferous.

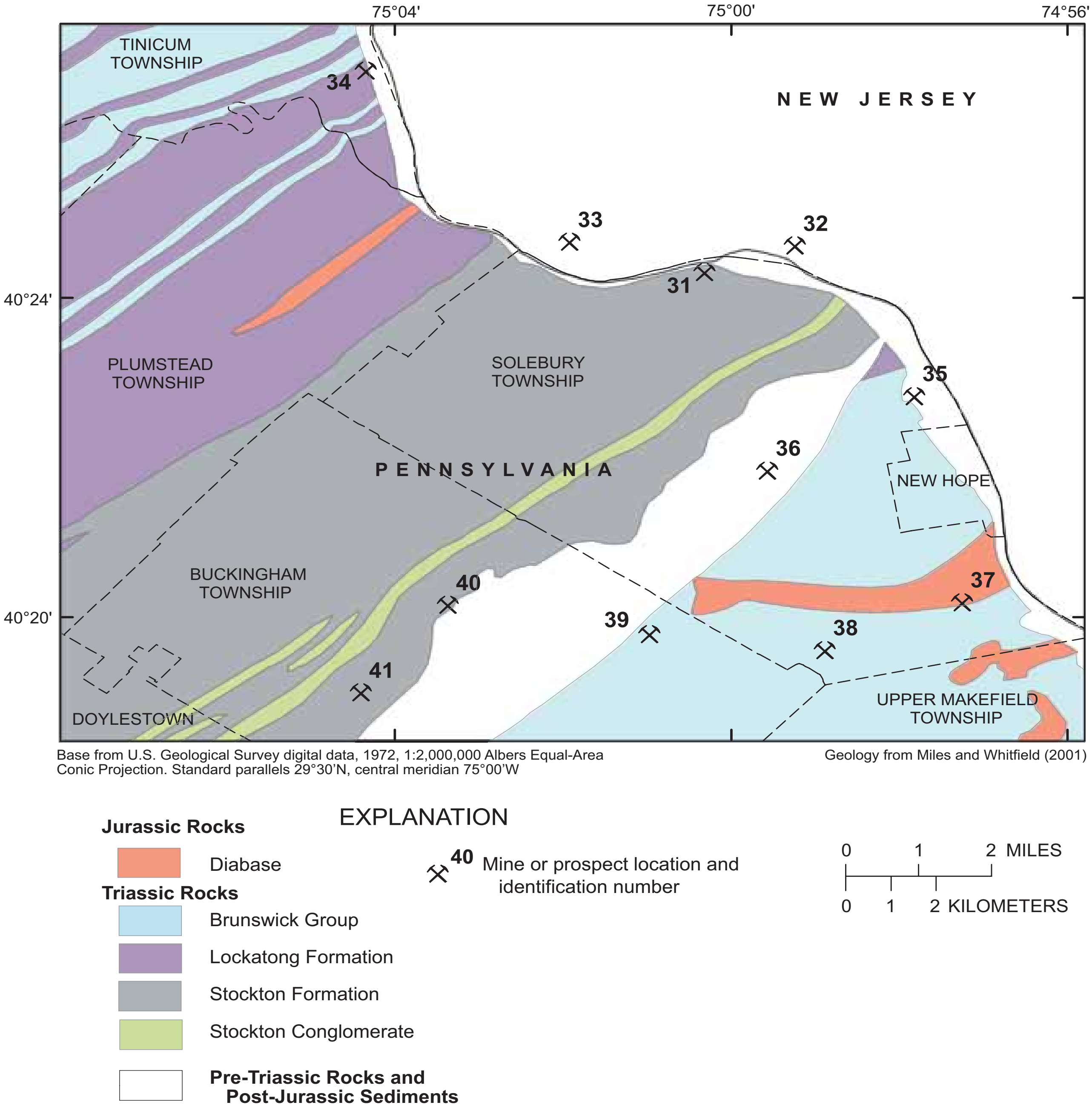
New Hope occurrences Several localities are listed as the New Hope occurrence. Rose (1970, location 20) gave only one location for the New Hope occurrence. Wherry (1908a, p. 728) listed copper localities as a roadside exposure 1 mi west of New Hope (locality 28) and a prospect 1.5 mi west of New Hope (locality 29); however, neither locality was described. Benge and Wherry (1906, p. 8 and 109) gave the location of a New Hope occurrence as a trolley cut and hillside exposure just south of New Hope near Dark Hollow Run and reported andradite, epidote, vesuvianite (Rogers, 1858, p. 685), and tourmaline (Eyerman, 1889, p. 26).

Ingham Spring prospect The Ingham Spring prospect was worked by several small pits. Barite occurs as a filling in breciated sandstone (Willard and others, 1959, p. 211-212). Chalcopyrite, pyrite (Benge and Wherry, 1907, p. 9), and hematite (Willard and others, 1959, p. 211-212) are associated with the barite.

Solebury mine Copper was discovered on Bowman's Hill by the Dutch prior to 1650. Most of the development of the mine is attributed to John Neely around 1845; however, the mine produced little ore (Wherry, 1908b, p. 311). Minerals reported from the Solebury mine include malachite (Benge and Wherry, 1906, p. 8), bornite, and chryscolla (Wherry, 1908a, p. 735).

Table 1-6. Mines, prospects, and mineral occurrences in the New Hope area, Bucks County, Pennsylvania. Locations are shown on figure 1-6.

Map number	Name	Type of locality	Type of deposit	Primary metals
31	Hendrick's Island	occurrence	sedimentary host	U
32	Prallsville	occurrence	sedimentary host	U
33	Raven Rock quarry	occurrence	sedimentary host	U
34	Delaware quarry	occurrence	sedimentary host	U
35	New Hope occurrences	occurrence	hornfels	Cu
36	Ingham Spring prospect	prospect	vein	Ba, Cu
37	Solebury mine	mine	vein/hornfels	Cu
38	Buckmanville mine	mine	fault zone	Ba
39	Occurrence west of Buckmanville	prospect	vein	Ba, Cu
40	Buckingham occurrence	occurrence	vein	Ba
41	Bushington occurrence	occurrence	vein	Ba



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic Projection. Standard parallels 29°30'N, central meridian 75°00'W

Geology from Miles and Whitfield (2001)

Figure 1-6. Mines, prospects, and mineral occurrences in the New Hope area, Bucks County, Pennsylvania. Mine names are given in table 1-6.

Buckmanville mine The Buckmanville mine, about 0.75 mi southwest of Buckmanville, was worked by 14 small open pits to 25 ft deep. The exposed material is in a breccia of diabase and sandstone fragments cemented by crystalline barite, quartz crystals, and occasional specks of chalcopyrite (Willard and others, 1959, p. 210-211). The barite is associated with a fault, which is traceable by deposits of barite (Wherry, 1908a, p. 735). Tooker (1949) attributed the barite deposit to hydrothermal fluids associated with intruding diabase. Other minerals associated with the Buckmanville mine include malachite (Benge and Wherry, 1906, p. 10), magnetite, hematite, and pyrite (Tooker, 1949).

Barite occurrence west of Buckmanville Wherry (1908a, p. 728, location 32) noted barite in exposures 3 mi west of Buckmanville but did not provide a description.

Buckingham occurrence The Buckingham barite occurrence (Rose, 1970, p. 2, location 25) is a roadside exposure 1 mi east of the Buckingham railroad station (Benge and Wherry, 1906, p. 9).

Bushington occurrence The Bushington barite occurrence (Rose, 1970, p. 2, location 26) is a roadside exposure 0.5 mi northeast of Bushington (Benge and Wherry, 1906, p. 9). Benge and Wherry (1906, p. 9) noted an abandoned iron mine in the vicinity.

Reading Area

Mines, prospects, and mineral occurrences in the Reading area (fig. 1-7) are listed in table 1-7.

Valentine Hartman's Mine Gordon (1922, p. 152) put the location of the Valentine Hartman mine on the west bank of Antietam Creek 0.75 mi west of Spies Church. Gordon (1922 p. 152) noted that the locality also is known as “Zion Church” and “Reading.” D’Invilliers (1883, p. 399) reported that molybdenite was found on Valentine Hartman’s farm in crystallized and foliated masses. Analyses of the molybdenite by Wetherill (1853, p. 345) indicate that the Mo content is 56-60 percent.

Jacksonwald occurrence Jacksonwald Exposures of the Jacksonwald basalt along Antietam Creek 1 mi south of Jacksonwald have produced calcite, datolite, prehnite and quartz in amygdaloidal cavities in basalt and zeolite minerals chabazite, heulandite, and stilbite along joint planes in the basalt (Wherry, 1910, p. 12, 24).

Antietam Reservoir This locality also is known as Ohlinger dam (D’Invilliers, 1883, p. 399). Smith (1987, p. 194-196) reports several occurrences of molybdenite in flakes up to 3/4 in. across in pegmatite dikes this area. Smith (1987, p. 195) postulates that the source of the molybdenite was igneous intrusion and hydrothermal solutions. Some of the molybdenite is associated with powellite, pyrrhotite, pyrite, and jarosite.

Stonersville occurrence (Rose, 1970, p. 2, location 11) Spencer (1908, p. 42) reported that “*specimens* [of magnetite] *have been plowed up in the fields near Spring Creek, between the northern arm* [of the diabase] *and Stonersville*.”

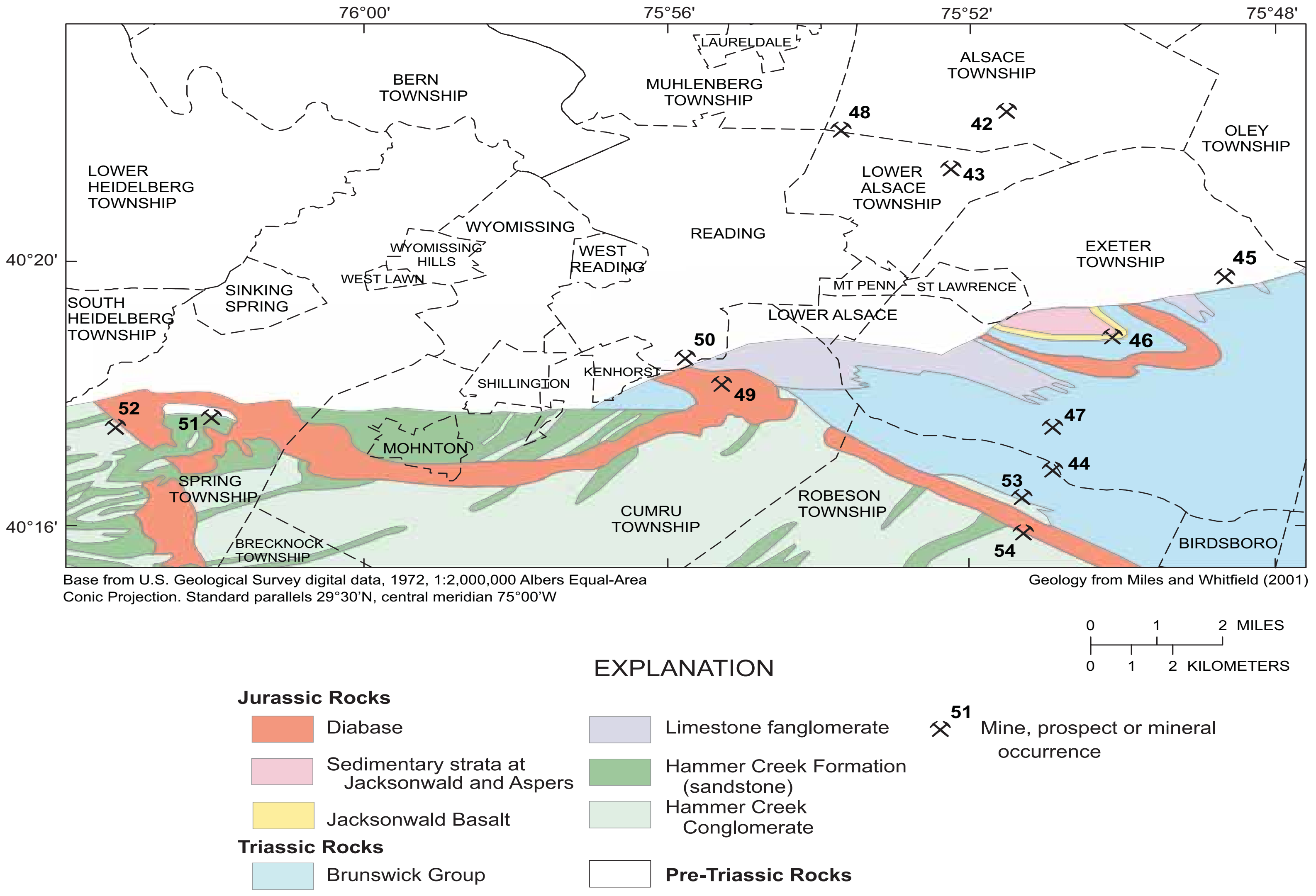
Snydersville occurrence (Rose, 1970, p. 2, location 12) Eyerman (1889, p. 45) reported that malachite was found “*at Snydersville*”.

Esterly mine The Esterly mine was 2 mi south of Jacksonwald on the W. Esterly farm. A small deposit of magnetite was worked by an inclined slope 125 ft deep and a shaft 150 ft deep (Spencer, 1908, p. 41-43). Estimated production was 4,000-5,000 tons of ore (Rose, 1970, p. 10).

Table 1-7. Mines, prospects, and mineral occurrences near Reading, Berks County, Pennsylvania. Locations are shown on figure 1-7.

[--, not determined]

Map number	Name	Type of locality	Type of deposit	Primary metals
46	Valentine Hartman's mine	mine	--	Mo
47	Antietam Reservoir	occurrence	--	Mo
48	Jacksonwald occurrence	occurrence	diabase host/vein	B
49	Stonersville occurrence	prospect	skarn	Fe
50	Snydersville occurrence	occurrence	hornfels	Cu
51	Esterly mine	mine	skarn	Fe
52	Mt. Penn mine	mine	--	Fe
53	Fritz Island mine	mine	skarn	Fe, Cu, Pb, Zn, Sb
54	Raudenbush mine	mine	skarn	Fe
55	Wheatfield mine	mine	skarn	Fe, Cu
56	Ruth mine	mine	skarn	Fe
57	Dyer quarry (Glickerville)	occurrence	diabase host/vein	Cu, As, Co
58	Trap Rock quarry	occurrence	diabase host/vein	Cu



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic Projection. Standard parallels 29°30'N, central meridian 75°00'W

Geology from Miles and Whitfield (2001)

Figure 1-7. Mines, prospects, and mineral occurrences near Reading, Berks County, Pennsylvania. Mine names are given in table 1-7.

Mt. Penn iron mine The Mt. Penn iron mine in Reading was called the Penn's Mount ore-vein by Rogers (1858, p. 716), who stated "*The vein has been wrought at its surface, outcropping in the Reading Fair ground, and for one-third of a mile E., by Eckert and Brother, the Phoenixville Iron Company, and others*." The deposit was worked from surface pits and shafts, including one 142 ft deep. The mine was abandoned by 1883 (D'Invilliers, 1883, p. 277).

Fritz Island mine The Fritz Island mine was called the Island mine by Rogers (1858, p. 716). The mine was on the north end of Fritz Island in the Schuylkill River 2 mi south of Reading. The mine was worked for iron ore by an open pit and two inclined slopes; one was 231 ft deep, and one was 122 ft deep by 1883. Average daily production in 1883 was 25-30 tons (D'Invilliers, 1883, p. 334-342). Total production estimated by Rose (1970, p. 10) was 250,000 tons of ore. An extensive list of minerals reported from the Fritz Island mine includes copper minerals pyrite (Rogers, 1858, p. 716), azurite, chalcopyrite, malachite (Genth, 1875), bornite, chalcocite (D'Invilliers, 1883); iron minerals magnetite (Genth, 1875) and hematite (D'Invilliers, 1883); the lead mineral galena (D'Invilliers, 1883); the antimony mineral stibnite (Genth, 1875); the boron mineral datolite (D'Invilliers, 1883); zeolite minerals chabazite, thompsonite, mesolite, gismondine (Genth, 1875), and stilbite; and apophyllite (D'Invilliers, 1883).

Raudenbush mine The Raudenbush mine was worked for iron ore by a 280-ft inclined slope and several shallow shafts, one of them 50 ft deep (D'Invilliers, 1883, p. 342-343). Rogers (1858, p. 716-717) estimated production at 5,000 tons per year. Total production was less than 150,000 tons of ore (Rose, 1970, p. 10). The ore was magnetite that replaced limestone at the base of a diabase hill just south of Angelica Creek. Other minerals reported from the Raudenbush mine are stilbite (Genth, 1875) and pyrrhotite (D'Invilliers, 1883, p. 400).

Wheatfield mine The Wheatfield mine was named from the discovery of iron ore in William Fisher's wheat field about 1851 (D'Invilliers, 1883, p. 344-350). The mine was worked by open pits and inclined slopes. D'Invilliers (1883, p. 348) estimated production at 300,000 tons by 1883. It was last worked in 1906 (Spencer, 1908, p. 29-36). Minerals reported from the Wheatfield mine include pyrrhotite (D'Invilliers, 1883, p. 400), magnetite, stilbite (Genth, 1875), hematite, and pyrite, (Lapham and Geyer 1959, p. 21).

Ruth mine The Ruth mine (called the Henry Ruth mine by Rogers, 1858, p. 717) was an open cut mined for magnetite that replaced limestone. Iron ore was mined from about 1847 to 1863, at which time the deposit was deemed exhausted. D'Invilliers (1883, p. 350-352) believed the ore vein to be an extension of the veins at the nearby Wheatfield mine and estimated total production of about 10,000 tons.

Dyer quarry The John T. Dyer quarry (Glickerville quarry of Gordon, 1922, p. 158) in diabase is worked for crushed stone. It is on Indian Corn Creek 0.75 mile southwest of Glickerville, now known as Gibraltar. Minerals reported from the Dyer quarry include arsenic minerals arsenopyrite, erythrite (Gordon, 1922, p. 158), cobaltite (Geyer and others, 1976, p. 39-40), and possible loellingite (Smith, 1987, p. 53, 92); copper minerals bornite, chalcopyrite (Geyer and others, 1976, p. 39-40), chrysocolla, tenorite (melaconite) (Gordon, 1922, p. 158), and pyrite (Smith, 1987, p. 53, 92); zeolite minerals chabazite, epidesmine, heulandite, laumontite, natrolite, and stilbite (Gordon, 1922, p. 158); iron minerals hematite and magnetite (Geyer and others, 1976, p. 39-40); the zinc mineral sphalerite (Smith, 1978, p. 53, 92); and the silicate minerals apophyllite and prehnite (Gordon, 1922, p. 158).

Trap Rock quarry Diabase quarries at Trap Rock, on Hay Creek about 1 mi south of Birdsboro, are called "Birdsboro" by Gordon (1922, p. 158). This the locality that Smith (1910) referred to as "*a railroad cut east of Reading*." Minerals reported from this locality include zeolite minerals chabazite, laumontite, scolecite, stilbite (Smith, 1910), natrolite, and thompsonite (Gordon, 1922, p. 158) and silicate minerals apophyllite and prehnite (Smith 1910).

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