Geologic Cross Section *C–C′* Through the Appalachian Basin From Erie County, North-Central Ohio, to the Valley and Ridge Province, Bedford County, South-Central Pennsylvania

By Robert T. Ryder, Michael H. Trippi, Christopher S. Swezey, Robert D. Crangle, Jr., Rebecca S. Hope,
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Introduction

Geologic cross section *C–C′* is the third in a series of cross sections constructed by the U.S. Geological Survey (USGS) to document and improve understanding of the geologic framework and petroleum systems of the Appalachian basin. Cross section *C–C′* provides a regional view of the structural and stratigraphic framework of the Appalachian basin from north-central Ohio to the Valley and Ridge province in south-central Pennsylvania, a distance of approximately 260 miles (mi) (fig. 1). This cross section is a companion to cross sections *E–E′* and *D–D′* (Ryder and others, 2008, 2009) that are located about 50 to 125 mi and 25 to 50 mi, respectively, to the southwest (fig. 1). Cross sections *C–C′*, *D–D′*, and *E–E′* update earlier geologic cross sections through the central Appalachian basin by Renfro and Feray (1970), Bennison (1976, 1978), Bally and Snelson (1980), and a stratigraphic cross section by Colton (1970). Although other published cross sections through parts of the basin show more structural detail (for example, de Witt, 1974; Berg and others, 1980; Faill, 1987; Nickelsen, 1988; Shumaker, 2002; Slucher and others, 2006) and stratigraphic detail (for example, Piotrowski and Krajewski, 1977a,b; Ryder and others, 1992; de Witt and others, 1993; Hettinger, 2001; Riley and others, 2006), these other cross sections are of more limited extent geographically and (or) stratigraphically.

Cross section *C–C′* contains much information that is useful for evaluating energy resources in the Appalachian basin. Although specific petroleum systems are not identified on the cross section, many of their key elements (such as source rocks, reservoir rocks, seals, and traps) can be inferred from lithologic units, unconformities, and geologic structures shown on the cross section. Other aspects of petroleum systems (such as the timing of petroleum generation and preferred migration pathways) may be evaluated by burial history, thermal history, and fluid flow models based on what is shown on the cross section. Cross section *C–C′* also provides a general framework (stratigraphic units and general rock types) for the coal-bearing section, although the cross section lacks the detail to illustrate key elements of coal systems (such as paleoclimate, coal quality, and coal rank). In addition, cross section *C–C′* may be used as a reconnaissance tool to identify plausible geologic structures and strata for the subsurface storage of liquid waste (for example, Colton, 1961; Lloyd and Reid, 1990) or for the sequestration of carbon dioxide (for example, Smith and others, 2002; Lucier and others, 2006).

Construction of the Cross Section

Cross section *C–C′* is oriented northwest-southeast, approximately normal to the structural grain of the region. Several abrupt bends in the section, however, are required to accommodate key drill holes that penetrate the entire section of Paleozoic sedimentary rocks. Cross section *C–C′* follows the general line of section used by Ryder and others (1992) in their stratigraphic study of Cambrian and Ordovician rocks, but four drill holes have been added (two at the northwestern end and two near the middle) and two drill holes have been omitted at and near the southeastern end (fig. 1; table 1).

Cross section *C–C′* is based on geological and geophysical data from 11 deep drill holes, several of which penetrate the Paleozoic sedimentary rocks of the basin and bottom in Mesoproterozoic crystalline basement rocks of the Grenville province. The locations of the tops of each stratigraphic unit penetrated in the 11 deep drill holes were converted from depth in feet (ft) below the kelly bushing (KB) to depth below ground level (GL), and then were plotted on the cross section with respect to mean sea level (MSL). Detailed depth information for the tops of the stratigraphic units in each well is reported in appendix A. In addition

Table 1. Drill holes used to construct cross section *C-C′*.

[Drill-hole locations are shown in figure 1. Source of all lithologic logs is Geological Sample Log Company, Pittsburgh, Pa. Abbreviations are as follows: Co., County; min, minute; NA, not available; No., Number; Pa., Pennsylvania; W. Va., West Virginia]

Drill hole number	Name used in text	Location	American Petroleum Institute number	Latitude (decimal degrees)	Longitude (decimal degrees)	Lithologic log	Cored intervals (in feet) and stratigraphic unit	Total depth (in feet)	Age of oldest rocks drilled (stratigraphic unit)
				Ohio					
1	Sun Oil Co. No. 1 Krysik-Wakefield	Florence Township, Erie Co., Ohio (Kipton, Ohio, 7.5-min quadrangle)	34–043–20011	41.304	-82.350	Yes	NA	4,463	Mesoproterozoic (metamorphic and igneous rock).
2	East Ohio Gas No. 1 A & A Born	Henrietta Township, Lorain Co., Ohio (Kipton, Ohio, 7.5-min quadrangle)	34–093–20794	41.289	-82.321	Yes	NA	4,591	Mesoproterozoic (metamorphic and igneous rock).
3	Wiser Oil No. 1–A F.L. Smith Estate	Hinckley Township, Medina Co., Ohio (West Richfield, Ohio, 7.5-min quadrangle)	34–103–21143	41.229	-81.703	Yes	5,760–5,844, Wells Creek formation, Knox Dolomite (Copper Ridge dolomite), Knox Dolomite (B zone and Krysik sandstone); 5,860–5,890, Knox Dolomite (B zone and Krysik sandstone)	7,040	Mesoproterozoic (metamorphic and igneous rock).
4	Belden & Blake Co., Limited Partnership #9 No. 1–381 B. Westfall	Marlboro Township, Stark Co., Ohio (Hartville, Ohio, 7.5-min quadrangle)	34–151–21081	40.952	-81.263	Yes	NA	7,961	Late Cambrian (Maryville Limestone of Conasauga Group).
5	Management Control No. 3 Frank Murray	Hanover Township, Columbiana Co., Ohio (Lisbon, Ohio, 7.5-min quadrangle)	34–029–20648	40.786	-80.870	Yes	NA	10,242	Late Cambrian (Mount Simon Sandstone).
				West Virginia					
6	Humble Oil No. 1 S. Minesinger	Clay District, Hancock Co., W. Va.-Ohio-Pa. (East Liverpool South, W. Va., 7.5-min quadrangle)	47–029–00080	40.540	-80.556	Yes	6,315–6,368; Lockport Dolomite	10,387	Early Ordovician (Beekmantown Dolomite).

Table 1. Drill holes used to construct cross section *C-C′*.—Continued

[Drill-hole locations are shown in figure 1. Source of all lithologic logs is Geological Sample Log Company, Pittsburgh, Pa. Abbreviations are as follows: Co., County; min, minute; NA, not available; No., Number; Pa., Pennsylvania; W. Va., West Virginia]

Drill hole number	Name used in text	Location	American Petroleum Institute number	Latitude (decimal degrees)	Longitude (decimal degrees)	Lithologic log	Cored intervals (in feet) and stratigraphic unit	Total depth (in feet)	Age of oldest rocks drilled (stratigraphic unit)
				Pennsylvania					
7	St. Joe Petroleum Corp. No. 1 Richard J. Ashcroft	Greene Township, Beaver Co., Pa. (Hookstown, Pa., 7.5-min quadrangle)	37–007–20060	40.602	-80.434	Yes	NA	7,590	Late Ordovician (Queenston Shale).
8	William E. Snee, et al No. 1 E.C. Ricks	Wharton Township, Fayette Co., Pa. (Brownfield, Pa., 7.5-min quadrangle)	37–051–20056	39.843	-79.654	Yes	NA	12,041	Late Ordovician(?) (Tuscarora Formation-Juniata Formation transition zone).
9	Amoco Producing Co. No. 1 Leonard Svetz	Middlecreek Township, Somerset Co., Pa. (Kingwood, Pa., 7.5-min quadrangle)	37-111-20045	39.978	-79.334	Yes	NA	21,460	Late Cambrian (lower sandy member of Gatesburg Formation).
10	Kerr-McGee Corp. No. 1 Schellsburg	Napier Township, Bedford Co., Pa. (Bedford, Pa., 7.5-min quadrangle)	37-009-20034	40.104	-78.616	Yes	NA	11,850	Late Cambrian (upper sandy member of Gatesburg Formation).
11	Atlantic Richfield Co. No. 1 Fred Steele	Snake Spring Township, Bedford Co., Pa. (Everett West, Pa., 7.5-min quadrangle)	37-009-20060	40.016	-78.422	Yes	14,728–14,758, upper sandy member of Gatesburg Formation	15,500	Early to Middle Cambrian (Waynesboro Formation).

to the 11 deep drill holes used to construct the cross section (table 1), some of the details of middle and upper Paleozoic stratigraphy and structure along cross section *C–C′* were obtained from 13 supplementary drill holes. These supplementary drill holes are located on the cross section as follows: (1) two drill holes between drill holes 4 and 5 in Ohio; (2) two drill holes between drill holes 5 and 6 in Ohio; (3) three drill holes between drill holes 7 and 8 in southwestern Pennsylvania (Harper and Laughrey, 1987); (4) one drill hole between drill holes 8 and 9 in southwestern Pennsylvania; and (5) five drill holes between drill holes 9 and 10 in south-central Pennsylvania.

The correlation of stratigraphic intervals between drill holes was based on a variety of geophysical (wireline) and lithologic logs. The most commonly used geophysical logs were the gamma ray-neutron and gamma ray-density log suites (Trippi and Crangle, 2009), whereas the most commonly used lithologic logs were those produced by the Geological Sample Log Company (table 1). Gamma-ray logs used for correlations were digitized as Log ASCII files (LAS), converted to graphic images, and then plotted next to their respective drill holes (Trippi and Crangle, 2009). The lithology assigned to each stratigraphic interval was simplified to just a few rock types and lithologic modifiers.

The data from the drill holes were supplemented by data about bedrock geology and topography. For example, some details of the Pennsylvanian stratigraphy in eastern Ohio were obtained from bedrock geologic maps by Larsen and Rea (1990), Slucher and Larsen (1990, 1996a,b), Caudill and Slucher (1991, revised 1996), Larsen and Slucher (1996), Slucher (1996a,b), and Swinford and Shrake (1996 a,b). Similar details of the Pennsylvanian stratigraphy in northernmost West Virginia were obtained from the geologic map by Grimsley (1907). Also, where applicable, selected stratigraphic units in the cross section were tied to correlative outcropping units using the geologic maps of Ohio (Slucher and others, 2006) and Pennsylvania (Berg and others, 1980) and, locally, using quadrangle maps by the Ohio Division of Geological Survey (for example, Slucher and Larsen, 1996a) and by the Pennsylvania Bureau of Topographic and Geologic Survey (for example, Flint, 1965; Wagner, Craft, and others, 1975). The topographic profile for the cross section was created from a Shuttle Radar Topography Mission (SRTM) 90-m-grid digital elevation model (DEM) for parts of Ohio, Pennsylvania, West Virginia, Maryland, and Virginia (Consultative Group on International Agricultural Research—Consortium for Spatial Information, 2011). This topographic profile is approximate and should not be used to determine accurate surface elevations.

Although some correlations shown on section *C–C′* are based on our own interpretations, many correlations are adopted or modified from previous publications, and stratigraphic nomenclature follows existing terminology wherever possible. Useful references for stratigraphic correlations and (or) nomenclature include the following: Colton (1970); Berg and others (1983), Patchen and others (1985), Milici and de Witt (1988), Swezey (2002), and Slucher (2004) for the entire Paleozoic section; Wagner (1966), Janssens (1973), Riley and Baranoski (1991a,b), Ryder and others (1992), Wickstrom and others (1992), Riley and others (1993, 2006), Laughrey and others (2003), and Harris and others (2004) for Cambrian and Ordovician rocks; Clifford (1973), Janssens (1977), Smosna and others (1977), Ryder (2000, 2004), and Hettinger (2001) for Silurian rocks; Piotrowski and Krajewski (1977a,b), Piotrowski and Harper (1979), Majchszak (1980a,b), de Witt and others (1993), Harper (1999), Harper and others (1999), and Filer (2002, 2003) for Devonian rocks; and Berryhill and Swanson (1962), Berryhill and others, (1971), Wagner, Craft, and others (1975), Edmunds and others (1979, 1999), Harper and Laughrey (1987), Berg (1999), Brezinski (1999), and Stamm (2004) for Mississippian and Pennsylvanian rocks. A correlation chart for all of the stratigraphic units identified along section *C–C′* is shown in figure 2.

Only selected unconformities are shown in cross section *C–C′*. The regional unconformities shown on section *C–C′* and in figure 2 include (1) the Middle Ordovician Knox unconformity (Harris and Repetski, 1982; Mussman and others, 1988), (2) the Upper Ordovician to Lower Silurian Cherokee unconformity (Dennison and Head, 1975; Hettinger, 2001), (3) the Middle to Upper Devonian unconformity (de Witt and others, 1993), (4) the Middle Mississippian sub-Loyalhanna unconformity (Harper and Laughrey, 1987; Brezinski, 1999), and (5) the Lower Pennsylvanian unconformity (Edmunds and others, 1979; Rice and Schwietering, 1988; Beuthin, 1994). The correlation of these unconformities with the North American sequences of Sloss (1988) is shown on figure 2 and by Swezey (2002).

Basement-involved structures along cross section *C–C′* were modified from structure-contour maps by Shumaker (1996), Baranoski (2002), and locally from interpretations of seismic data by Scanlin and Engelder (2003) and Kulander and Ryder (2005). High-amplitude, complex, thin-skinned ramp anticlines (Schellsburg dome, Wills Mountain, and Evitts Mountain) were compiled on section *C–C′* from interpretations by Knowles (1966), Gwinn (1970), and Berg and others (1980). The Schellsburg dome in Pennsylvania is an extension of the Deer Park anticline in Maryland (Shumaker and Wilson, 1985), and it is the first anticline west of the Allegheny structural front (fig. 1). In contrast, the Wills Mountain and Evitts Mountain anticlines are the first two anticlines east of the Allegheny structural front. Low-amplitude, structurally complex, thin-skinned anticlines west of the Allegheny structural front (Negro Mountain, Laurel Hill, and Chestnut Ridge) are based on selected drill holes and interpretations by Berg and others (1980), Shumaker (2002), and Scanlin and Engelder (2003). The Chestnut Ridge anticline, which was drilled by well 8, marks the western limit of the major thin-skinned anticlines shown on the cross section. Low-amplitude anticlines located northwest of the Chestnut Ridge anticline (for example, Amity and Belle Vernon) are defined on section *C–C′*

by selected drill holes and structure-contour maps on the top of the Devonian Ridgeley Sandstone (Cate, 1961) and on top of selected Pennsylvanian coal beds (Hickok and Moyer, 1940; Wagner, Heyman, and others, 1975; Dodge, 1985; Shaulis, 1985; Skema, 1987). In Ohio, the homoclinal regional dip on section *C–C′* and accompanying local faults are defined by structure-contour maps on the top of the Devonian Berea Sandstone and Onondaga Limestone (Gray, 1982a,b).

Structural Framework

The Wills Mountain anticline marks the western margin of the Valley and Ridge province (fig. 1), where a thick panel of Cambrian to Ordovician carbonate rocks was decoupled from underlying strata and was thrust about 2 mi westward up a major tectonic (footwall) ramp. This ramp connected the basal zone of detachment (footwall flat) in the Cambrian Waynesboro Formation with higher zones of detachment (hangingwall flat) in the Upper Ordovician Antes Shale, Silurian Wills Creek Formation, and Devonian Marcellus Formation (thrust terminology from McClay, 1992). The net shortening in the Wills Mountain anticline is about 6 to 7 mi when folding and secondary thrust faulting are accounted for. A net structural relief of about 1.5 mi (8,000 ft) was created by the duplicated Cambrian Warrior Formation in the anticline. Following Gwinn (1970), Rodgers (1970), and Faill (1998) (and using the terminology therein), the juncture between the western limb of the Wills Mountain anticline and the adjoining eastern limb of the Schellsburg dome is defined as the Allegheny structural front, which is the structural feature that separates the Valley and Ridge province to the east from the Appalachian Plateau province to the west (figs. 1, 3). The Allegheny structural front as recognized in south-central Pennsylvania differs from the traditional Allegheny structural front as recognized in Maryland and West Virginia (for example, Kulander and Dean, 1986), where steeply dipping lower Paleozoic carbonate and siliciclastic rocks of the western limb of the Wills Mountain anticline are juxtaposed directly against less deformed upper Paleozoic rocks of the Appalachian Plateau province rather than against rocks of the intervening Schellsburg dome.

The Schellsburg dome experienced a lesser amount of lateral shortening than the Wills Mountain anticline. For example, the thick allochthonous panel of Cambrian to Ordovician carbonate rocks in the Schellsburg dome (that was decoupled from the underlying strata and thrust about 1.5 mi westward up a footwall ramp and over a parautochthonous panel of Cambrian to Ordovician carbonate rocks) displays a net shortening of about 4 mi. Together, the Schellsburg dome and Wills Mountain anticline in south-central Pennsylvania show about the same amount of net lateral shortening as the Deer Park and Wills Mountain anticlines combined in Maryland and West Virginia. The footwall ramp of the Schellsburg dome, which is shown on the easternmost part of the cross section beneath drill hole 10, connects the basal zone of detachment (footwall flat) in the Cambrian Waynesboro Formation with a higher zone of detachment (hangingwall flat) in the Ordovician Antes Shale. As a result of this lateral shortening, a net structural relief of about 1.4 mi (7,500 ft) was created by the duplicated Warrior Formation in the anticline. This interpretation of the Schellsburg dome structure, where the hangingwall flat occurs in the Antes Shale (fig. 3), follows Gwinn (1970). An alternate interpretation of the structure is shown by Berg and others (1980), where the hangingwall flat occurs in the Silurian Wills Creek Formation and Salina Group.

Basement-involved and thin-skinned structures (terminology from Rodgers, 1963) are shown on cross section *C–C′* and their geometry, style, and timing are briefly discussed below. A more detailed treatment of structural styles and patterns that characterize the central Appalachian basin is presented by Faill (1998) and Scanlin and Engelder (2003). The basement structures are largely extensional, and several of them may have evolved during the Neoproterozoic to earliest Cambrian rifting of the eastern continental margin of North America (Rankin and others, 1989; Thomas, 1991). This rifting event was followed by the opening of the Iapetus Ocean and the construction of a passive margin along the eastern margin of North America (Rankin and others, 1989; Thomas, 1991). A Middle Cambrian rifting event, more moderate in scale than the Neoproterozoic rifting event, formed the Rome trough about 200 mi inland from the evolving passive margin (Beardsley and Cable, 1983; Read, 1989a,b; Shumaker, 1996).

In contrast, the major thin-skinned structures are contractional in origin and probably developed during the Late Mississippian to Permian continental collision (Alleghanian orogeny) between eastern North America and Africa (Rodgers, 1988; Hatcher and others, 1989). The crustal contraction that accompanied the Late Mississippian to Permian collision caused large horizontal displacements of thick, competent panels of Paleozoic strata along thin, incompetent Paleozoic strata. In places, the Alleghanian orogeny reactivated basement faults and locally inverted the Rome trough (Harris, 1978; Shumaker and Wilson, 1996; Scanlin and Engelder, 2003; Kulander and Ryder, 2005). Typical Appalachian thin-skinned structures are bedding-plane detachment zones, footwall ramps, ramp anticlines, and imbricate thrust faults (Rodgers, 1963; Gwinn, 1964, 1970; Wilson and Shumaker, 1985; Woodward, 1985; Kulander and Dean, 1986; Faill and Nickelsen, 1999).

Basement Rocks and Associated Structures

The basement rocks along cross section *C–C′* consist largely of igneous and metamorphic rocks of the subsurface extension of the Grenville province (Rankin and others, 1993). Most isotopic ages of these rocks range between 950 and 1,350 million years old (mega-annum, or Ma), and many ages cluster around 1,000 to 1,100 Ma (Rankin and others, 1993) (fig. 2). Lidiak and others (1966) reported a potassium-argon (K-Ar) age of 935 Ma for gneiss and schist in the No. 1 Bruns drill hole (Sandusky County, Ohio), which is located about 50 mi west of drill hole 1, and in the No. 1 Arting drill hole (Huron County, Ohio), which is located about 20 mi southeast of drill hole 1 (fig. 1). As shown on nearby geologic cross section *E–E′* (Ryder and others, 2008) (fig. 1), Lidiak and others (1966) reported a rubidium-strontium (Rb-Sr) age of 860 Ma for biotite granite in drill hole 5 and a K-Ar age of 850 Ma for granodiorite gneiss in drill hole 11. Although the ages reported by Lidiak and others (1966) are younger than the 950 Ma upper limit of Mesoproterozoic basement rocks suggested by Rankin and others (1993), rocks with these ages are grouped in this report with rocks of the Grenville province on the basis of their similar lithology and structural style. The basement rock in drill hole 1 of this cross section is described as a medium-grained granite that contains predominantly orthoclase, quartz, and accessory biotite and plagioclase (McCormick, 1961). Moreover, the basement rocks in drill holes 12, 13, and 14 in nearby cross section *E–E′* are described, respectively, as granite gneiss, gneiss and granite, and quartz-oligoclase-biotite gneiss that contains graphite and sillimanite (King and others, 1998). Van Schmus and others (1996) reported a samarium-neodymium (Sm-Nd) age of 1,272 Ma for gabbro basement in drill hole 4 on cross section *E–E′* (see Wickstrom and others, 1985; Ryder and others, 2008) (fig. 1) but could not explain the absence of Mesoproterozoic penetrative deformation and associated resetting of the apparent age.

The western margin of the subsurface extension of the Grenville province is marked by the Grenville front (fig. 1), along which intensely deformed Mesoproterozoic metamorphic and igneous rocks (commonly characterized by west-verging thrust faults; Culotta and others, 1990) are juxtaposed against mildly deformed 1,470 Ma rocks of the eastern granite-rhyolite province to the west (Van Schmus and others, 1996). The basement-involved Bowling Green fault zone, located about 70 mi west of the northwestern end of the cross section, forms the approximate boundary between the Mesoproterozoic basement rocks and rocks of the granite-rhyolite province (fig. 1; Wickstrom and others, 1992; Baranoski, 2002). The Coshocton zone, a 50- to 100-mi-wide zone of east-verging penetrative deformation in the Mesoproterozoic basement, is located approximately between 5 mi east of well 4 and 8 mi east of well 7 in the eastern Ohio and westernmost Pennsylvania part of cross section *C–C′*. This zone was identified by Culotta and others (1990) from deep seismic reflections on COCORP profiles and was interpreted by them to mark the site of a suture zone within the Grenville province.

The basement of the Appalachians is a homoclinal ramp that dips gently from an interior craton to the external margin of a fold-and-thrust belt, which is typical of many foreland basins. Along cross section *C–C′*, this basement ramp deepens progressively southeastward from about 3,600 ft below mean sea level (MSL) at drill holes 1 and 2 to about 25,000 ft below MSL beneath the Allegheny structural front at drill hole 10. This gradual eastward deepening of the basement ramp along section *C–C′* is interrupted by the Rome trough (fig. 1), a Middle Cambrian rift system that drops the basement rocks to as much as 28,000 ft below MSL. The western limit of the Rome trough is defined here as the down-to-the-east normal fault located about 35 mi east of drill hole 7 (Shumaker, 1996; Baranoski, 2002), and the eastern limit of the Rome trough is defined as the down-to-the-west normal fault several miles east of drill hole 9 (Shumaker, 1996; Kulander and Ryder, 2005). Our interpretation of the boundary faults of the Rome trough differs from that of Scanlin and Engelder (2003), who place the western boundary fault near the Belle Vernon anticline (about 23 mi west of drill hole 8) and the eastern boundary fault near the Chestnut Ridge anticline (beneath drill hole 8). Along cross section *C–C′*, the Rome trough is about 40 to 45 mi wide and has a structural relief on basement that ranges from several hundred feet at its western margin to an estimated 8,000 ft at its eastern margin. Although many of the basement faults of the Rome trough shown in cross section *C–C′* have been recognized in previous studies (Wagner, 1976; Shumaker, 1996; Scanlin and Engelder, 2003; Kulander and Ryder, 2005), the overall structural interpretation presented here for the deep lower Paleozoic section in section *C–C′* is speculative because deep-drill-hole data are absent. The northern extension of the Central West Virginia arch, a large northeast-trending basement block identified by Kulander and Dean (1986), flanks the eastern margin of the Rome trough in south-central Pennsylvania and dips gently eastward beneath the Allegheny structural front and the western part of the Valley and Ridge province.

In northeastern Ohio, the basement ramp locally is modified by a northwest-trending zone of en echelon faults that is subparallel to cross section *C–C′* (fig. 1). From northwest to southeast, these faults have the following names: Middleburg fault, Akron fault, Suffield fault system, Smith Township fault, and Highlandtown fault (Baranoski, 2002) (fig. 1). Based on interpretations by Gray (1982a,b) and Baranoski (2002), the basement along cross section *C–C′* shows a vertical separation of about 50 ft across the Middleburg fault (near drill hole 3) and about 100 ft across the Suffield fault system (about 9 mi west of drill hole 4). Additional evidence for basement offset along the Suffield fault system is presented by Root and Onasch (1999) and is based on seismic records.

The northwest-trending fault zone in northeastern Ohio continues into Pennsylvania as the northwest-trending Pittsburgh-Washington cross-strike structural discontinuity (Lavin and others, 1982; Parrish and Lavin, 1982) (fig. 1). This structural discontinuity is inferred to be a deeply rooted basement fault zone along which strike-slip to dip-slip offset has occurred (Lavin and others, 1982; Harper, 1989). The Pittsburgh-Washington cross-strike structural discontinuity crosses section *C–C′* line in three places: (1) between drill holes 6 and 7, (2) about midway between drill holes 7 and 8, and (3) about 5 mi west of drill hole 9 (fig. 1). Seismic records interpreted by Scanlin (2000) support the presence and the probable recurrent nature of this ancient fault zone in basement rocks beneath the Laurel Hill anticline.

Other structures that involve basement rocks include various inflections in the basement ramp. Minor inflection points or hinge zones in the basement ramp occur between drill holes 2 and 3, between drill holes 3 and 4, and at drill hole 5 in north-central Ohio. The north-central Ohio inflection point between drill holes 2 and 3 may represent the northern extension of the Cambridge arch (Cambridge cross-strike structural discontinuity of Baranoski, 2002) (fig. 1), which is a north-trending basement arch identified by Root (1996) from seismic data and from isopach patterns in selected Paleozoic strata. Furthermore, the hinge zone between drill holes 3 and 4 probably represents offset along the Suffield fault, whereas the hinge zone at drill hole 5 probably represents a simple flexure. Also, a major 33-mi-wide hinge zone extends from drill hole 7 near the West Virginia-Pennsylvania border to about midway between drill holes 7 and 8 and approximately coincides with the Ohio-West Virginia hinge zone of Ryder and others (1992) that marks the western margin of the Rome trough (fig. 1). This wide hinge zone was caused by multiple down-to-the-east normal faults.

Most normal (extensional) faults associated with the Rome trough rift system were reactivated several times during the Paleozoic to produce either renewed subsidence or small-scale basin inversion (Shumaker and Wilson, 1996). For example, small-scale basin inversion has been documented along segments of the Rome trough in northern West Virginia and southwestern Pennsylvania where basement-involved normal (extensional) faults were reactivated as reverse (contractional) faults to create mildly inverted grabens (Scanlin and Engelder, 2003; Kulander and Ryder, 2005). Most of the small-scale inversion probably resulted from contraction during the Late Mississippian to Permian Alleghanian orogeny.

The Laurel Hill anticline, which crests near well 9 on cross section *C–C′* (figs. 1, 3), is interpreted in this study to be an example of the basin inversion during the Alleghanian orogeny that controlled the initial phases of anticlinal growth. The structural geometries shown by seismic lines that cross the anticline indicate that the Laurel Hill anticline is deeply rooted in lower Paleozoic strata and Mesoproterozoic basement rocks (Scanlin and Engelder, 2003). The movement that produced this anticline probably was caused by a reversal in motion during Alleghanian deformation of the preexisting, down-to-the-west normal fault that serves as the eastern boundary of the Rome trough. Furthermore, the deep-seated Laurel Hill anticline was modified by west-verging faults (footwall ramps) that offset the crest of the anticline at about 15,700 and 18,600 ft in drill hole 9 and are connected with a detachment zone (hangingwall flat) in the Ordovician Antes Shale (fig. 3). These small, west-verging footwall ramps originated where the basal zone of detachment in the Cambrian Waynesboro Formation was juxtaposed against more competent carbonate beds of the Cambrian Warrior Formation. As shown on cross section *C–C′* and by Scanlin and Engelder (2003), the upper third of the Laurel Hill anticline is detached along the Silurian Salina Group and the Middle Devonian Marcellus Formation and shows characteristics that are clearly of thin-skinned origin. We suggest that this initial deep-seated relief on the Laurel Hill anticline interrupted the westward-propagating Salina and Marcellus detachments (footwall flats) (fig. 3) to form thin-skinned structures in the upper third of the anticline. In contrast to our interpretation that involves basin inversion, Scanlin and Engelder (2003) interpreted the deep-seated part of the Laurel Hill anticline to be an east-facing coastal declivity created by several down-to-the-east basement faults. In either case, deep structural relief is called upon to interrupt zones of bedding-plane detachment to form upper-level, thin-skinned structures in the anticline.

The Chestnut Ridge anticline (located at drill hole 8) may be another example on cross section *C–C′* where both basement and thin-skinned tectonics probably have contributed to the origin of first-order anticlines in the Appalachian Plateau province. The influence of basement tectonics on the evolution of the Chestnut Ridge anticline is shown by the deeply rooted character of the anticline (Scanlin and Engelder, 2003), whereas the influence of thin-skinned tectonics on the anticline is shown by bedding-plane detachment and disharmonic folding in the Silurian Salina Group (Shumaker, 2002; Scanlin and Engelder, 2003). We propose the following two-stage origin for the Chestnut Ridge anticline: (1) the deeply rooted part of the Chestnut Ridge anticline is the result of reverse-motion reactivation (during the Alleghanian orogeny) along a Rome trough basement fault zone that originally had a down-to-the-west normal sense of separation; and (2) the locations of the thin-skinned structures in the Chestnut Ridge anticline are controlled by deep-seated structural relief, which interrupted westward-propagating zones of bedding-plane detachment in the Salina Group, and possibly in the Marcellus Formation and Antes Shale. Scanlin and Engelder (2003) also favor a two-stage origin for the Chestnut Ridge anticline, but suggested that the deep-seated structural relief associated with the anticline was caused by an upthrown basement fault block at the eastern margin of the Rome trough (as defined by Scanlin and Engelder, 2003) rather than by an upthrown basement fault block within the Rome trough.

Other anticlines on cross section *C–C′* that may have originated by reverse-motion reactivation along basement-involved normal faults in the Rome trough are the Fayette, Brownsville, Belle Vernon, and Amity anticlines (fig. 1). Although Scanlin (2000) and Scanlin and Engelder (2003) have interpreted basement faults beneath all of these anticlines, they have not documented recurrent fault movement.

Thin-Skinned Structures

Thin-skinned structures in the Valley and Ridge province part of cross section *C–C′* include the Wills

Mountain anticline and the Evitts Mountain anticline (Gwinn, 1970; de Witt, 1974; Shumaker and Wilson, 1985; Faill, 1998). These prominent anticlines have high amplitudes and are westward verging. Major thin-skinned structures in the eastern part of the Appalachian Plateau province in cross section *C–C′* include the Schellsburg dome at the northeastern end of the Deer Park anticline, the Negro Mountain anticline, the Laurel Hill anticline, and the Chestnut Ridge anticline (Gwinn, 1964, 1970; Rodgers, 1970; Scanlin and Engelder, 2003). These thin-skinned anticlines in the eastern part of the Appalachian Plateau province have moderate to high amplitudes, and several have complex triangle zones accompanied by east- and west-verging imbricate faults (Shumaker and Wilson, 1985; Shumaker, 2002; Scanlin and Engelder, 2003). All thin-skinned anticlines shown on cross section *C–C′* originated during the Late Mississippian to Permian Alleghanian orogeny (Rodgers, 1970; Faill, 1998; Faill and Nickelsen, 1999).

The Schellsburg dome at the northern end of the Deer Park anticline, the Wills Mountain anticline, and the Evitts Mountain anticline constitute a group of three west-verging, allochthonous blocks of Cambrian and Ordovician carbonate rocks that are separated by major footwall ramps (thrust faults) that have branched off a basal detachment in the Cambrian Waynesboro Formation (Gwinn, 1970; Berg and others, 1980) (fig. 3). These allochthonous blocks, which represent about 14 to 15 mi of lateral shortening, are juxtaposed against a subhorizontal parautochthonous block of Cambrian, Ordovician, and Silurian rocks (fig. 3).

The master footwall ramp or thrust fault of the Schellsburg dome (which makes up the western allochthonous block shown on figure 3) is estimated to be about 16,500 ft below MSL on the eastern limb of the dome, where allochthonous siliciclastic rocks of the Cambrian Waynesboro Formation are juxtaposed against parautochthonous carbonate rocks of the Lower and Middle Ordovician Beekmantown Group and Upper Cambrian Gatesburg Formation. As shown by Gwinn (1970), and previously discussed in this report, the master footwall ramp of the Schellsburg dome flattens into a hangingwall flat in the Antes Shale (fig. 3). Moreover, zones of bedding-plane detachment may form roof thrusts in the Ordovician Antes Shale (about 7,400 ft depth in drill hole 10) and the Silurian Tonoloway and Wills Creek Formations (about 1,000 ft depth in drill hole 10). The proposed roof thrust in the Antes Shale merges with the hangingwall flat beneath the western limb of the dome, whereas the roof thrust in the Tonoloway and Wills Creek Formations continues west of the dome as a major detachment zone in the Silurian Salina Group. Furthermore, a bedding-plane roof thrust probably also exists in the Middle Devonian Marcellus Formation at the Schellsburg dome based on the regional Middle Devonian shale detachment proposed by Evans (1994). Additional structural complications in the Schellsburg dome, shown on section *C–C′*, are back-limb thrust faults that branch off the major basal detachment in the Waynesboro Formation. One of these back-limb thrust faults offsets the bedding plane (roof thrust) in the Antes Shale near the crest of the dome (fig. 3) and offsets the Silurian Rose Hill Formation in the core of the dome at about 1,000 ft below MSL in drill hole 10. Other back-limb thrust faults are located about 2 to 7 mi east of the crest of the Schellsburg dome (fig. 3).

The master footwall ramp or thrust fault of the Wills Mountain anticline (which makes up the middle allochthonous block shown on figure 3) branches off the basal detachment and propagates upsection at least as far as the Upper Devonian Scherr Formation. Although undrilled along cross section *C–C′*, the master thrust of the Wills Mountain anticline (fig. 3) is estimated to be about 5,500 ft beneath the exposed crest of the anticline and involves carbonate rocks of the Ordovician Beekmantown Group juxtaposed against siliciclastic rocks of the younger Ordovician Bald Eagle and Juniata Formations. In the Kerr-McGee No. 1 Martin drill hole (fig. 1), about 9 mi southwest of cross section *C–C′*, the master thrust of the Wills Mountain anticline places the Ordovician Beekmantown Group over the younger Ordovician Reedsville Shale at a depth of 6,200 ft (Knowles, 1966). West of the Wills Mountain anticline, the master thrust in the No. 1 Martin drill hole flattens into a bedding-plane fault (hangingwall flat) in the Reedsville Shale (Knowles, 1966) and then probably rises over the crest of the Deer Park anticline as a roof thrust. The Wills Mountain anticline in the vicinity of cross section *C–C′* is cut by several back-limb thrust faults that branch off the basal detachment. The largest of these back-limb thrusts, as shown on cross section *C–C′* and by Berg and others (1980), cuts through Cambrian and Ordovician carbonate rocks as far upsection as the Reedsville Shale, where it flattens into a bedding-plane fault at the crest of the anticline (fig. 3). Furthermore, this bedding-plane thrust may act as a roof thrust that joins the master footwall ramp of the Wills Mountain anticline. Also, a secondary imbricate thrust (shown on cross section *C–C′* and by Berg and others, 1980) branches off the primary back-limb thrust fault in the Ordovician Beekmantown Group and ends about 9,000 ft farther upsection in the Ordovician Juniata Formation (fig. 3).

The master footwall ramp or thrust fault of the Evitts Mountain anticline (which makes up the eastern allochthonous block shown on figure 3) is located at about 6,800 ft depth in drill hole 11, where a highly deformed complex of thin, repeated thrust slices (horse blocks) of the Cambrian Waynesboro and Pleasant Hill Formations are juxtaposed against the Ordovician Beekmantown Group. A net structural relief of 3.5 to 4 mi is caused by the duplicated Waynesboro Formation in the anticline. An additional structure, a frontal imbricate thrust (fig. 3), branches off the master thrust fault of the Evitts Mountain anticline and places the Upper Cambrian Gatesburg Formation against the Beekmantown Group at about 12,600 ft depth in drill hole 11. This frontal imbricate thrust also places the Ordovician Black River Group against the younger Reedsville Shale at the surface west of drill hole 11.

From its juncture with the master thrust of the Schellsburg dome, the basal detachment in the

Cambrian Waynesboro Formation continues farther west for about 40 mi beneath the parautochthonous block (Berg and others, 1980) to the eastern margin of the Rome trough (fig. 3). West-verging thrust faults branch upward from this basal detachment and subdivide the parautochthonous block into several minor thrust blocks. The westernmost of the minor thrust faults is located beneath the Laurel Hill anticline, where the basal detachment abuts Cambrian carbonate rocks and ramps upsection to join a higher detachment (hangingwall flat) in the Ordovician Antes Shale. Another interpreted minor thrust fault is located in the parautochthonous block beneath the Negro Mountain anticline, where it may have influenced folds and thrust faults associated with the Salina and Marcellus detachment zones.

The major detachment zone (hangingwall flat) in the Salina Group west of the Schellsburg dome is interpreted on section *C–C′* to continue westward for another 115 to 145 mi, where the detachment zone underlies complex thin-skinned structures such as triangle zones, imbricate thrusts, and disharmonic folding in the cores of the Negro Mountain, Laurel Hill, and Chestnut Ridge anticlines (Scanlin and Engelder, 2003). As previously noted, complex thin-skinned deformation in the cores of the Laurel Hill and Chestnut Ridge anticlines is probably related in part to pre-existing or penecontemporaneous zones of positive, northeast-trending structural relief caused by reactivated basement faults. Although the Negro Mountain anticline probably also is related to deep-seated structural relief, the relief very likely was caused by an imbricate fault that branched off the basal detachment rather than by a reactivated basement-involved fault.

As shown on cross section *C–C′*, the Salina detachment in the Negro Mountain, Laurel Hill, and Chestnut Ridge anticlines is interpreted according to the three-tiered model for plateau anticlines proposed by Scanlin and Engelder (2003, adapted from Gwinn, 1964). This model consists of a detachment zone at the base of the anticline, a middle imbricate zone, and an upper wedge zone. Scanlin and Engelder (2003) proposed that the zone of regional detachment is located in shale and evaporite beds near the base of the Salina Group instead of being located in halite- and anhydrite-bearing beds in the middle part of the Salina Group, as favored by Gwinn (1964). Because the shale-bearing part of the Salina Group is not identified in this study, the regional detachment is placed by default in the halite-bearing middle part of the Salina Group. Furthermore, the interpretation by Gwinn (1964) of the structure of the Chestnut Ridge anticline has been revised by Shumaker (2002) using new well-log, dipmeter, and seismic data. According to this revised interpretation (and as shown on cross section *C–C′*), the structurally low and relatively undeformed axial zone (or triangle zone) interpreted by Gwinn (1964) is replaced by a highly faulted, deep syncline located between the central and western structural highs of the Chestnut Ridge anticline.

Bedding-plane detachment in the Marcellus Formation (interpreted to be present at Schellsburg dome) also is interpreted to be present at the Negro Mountain, Laurel Hill, and Chestnut Ridge anticlines. For example, an interpretation by Shumaker (2002) placed a detachment in the Marcellus Formation at the Chestnut Ridge anticline, and an interpretation by Evans (1994) placed a regional detachment in the Marcellus Formation extending from the Allegheny structural front to at least westernmost Pennsylvania. Following these interpretations, small imbricate thrust faults are shown on cross section *C–C′* that branch off the Marcellus Formation detachment zone at Negro Mountain, Laurel Hill, and Chestnut Ridge anticlines and further contribute to the structural complexity of these anticlines.

The small, northeast-trending Fayette, Brownsville, Belle Vernon, and Amity anticlines, which are located west of the Chestnut Ridge anticline, probably were caused by minor thrust faults that branch upward from the Salina detachment zone. Although not shown on the cross section, several of the minor thrust faults beneath the small anticlines may branch upward from the Marcellus detachment zone. Moreover, these partially detached anticlines are interpreted here to have been controlled by deeply rooted structural relief associated with reactivated basement faults. The Salina and Marcellus detachments probably continue westward from the Amity anticline, possibly as far west as eastern Ohio (Evans, 1994; Faill, 1998).

Stratigraphic Framework

The sedimentary rocks shown on cross section *C–C′* span most of the Paleozoic Era, and their thickness ranges from about 4,600 ft at drill holes 1 and 2 to nearly 27,000 ft at the Allegheny structural front at drill hole 10. Lithology, nomenclature, and depositional and tectonic settings of the sedimentary rocks along cross section *C–C′* are briefly outlined and discussed in the following text. A more detailed treatment is available in regional geological summaries by Colton (1970), Milici and de Witt (1988), Read (1989a,b), and Faill (1997a,b, 1998).

Much of the eastward thickening of strata in the Appalachian basin was caused by regional tectonism. During the Neoproterozoic to Early Cambrian, as the proto-Atlantic (Iapetus) Ocean opened and formed a rifted continental margin, cooling and thermal contraction of the lithosphere caused subsidence, which provided accommodation or preservation space for sediments to build an eastward-facing passive continental margin (Bond and others, 1988; Read, 1989a). During several later periods in the Paleozoic, subsidence caused by thrust loading provided additional accommodation or preservation space for sediments to accumulate in Appalachian foreland basins (Quinlan and Beaumont, 1984). Eustatic changes also have played a role in the eastward thickening of Appalachian strata (Bond and others, 1988). For example, a rise in sea level can cause load-induced subsidence (by sediments and the overlying water column) and provide accommodation space for additional sediments on the outer continental shelf, whereas a fall in sea level can cause erosion of the inner continental shelf. These eustatic changes were caused by changes in global climate and (or) changes in regional tectonic activity.

Lower Cambrian to Upper Ordovician Siliciclastic and Carbonate Strata

Lower Cambrian to Upper Ordovician siliciclastic and carbonate strata are characterized by dolomite, anhydritic dolomite, limestone, and lesser amounts of gray shale, red shale, and sandstone (fig. 2). These strata thin dramatically from about 6,700 ft in the western part of the Rome trough in south-central Pennsylvania to about 1,300 ft in north-central Ohio. In the eastern part of the Rome trough in south-central Pennsylvania, Lower Cambrian to Upper Ordovician strata are estimated to thicken to as much as 15,000 ft, of which about 6,000 ft are penetrated in drill hole 9. In the eastern part of cross section *C–C′* (Rome trough to the Valley and Ridge province), the Lower Cambrian to Upper Ordovician siliciclastic and carbonate strata consist of the following units (in ascending order): the Chilhowee Group, Tomstown Formation, Waynesboro Formation, Pleasant Hill Formation, Warrior Formation, Gatesburg Formation, Beekmantown Group, Loysburg Formation, Black River Group, and Trenton Group (fig. 2). The nomenclature of the Chilhowee Group, Tomstown Formation, and Waynesboro Formation in this cross section follows that of Fauth (1968) and Root (1968) in south-central Pennsylvania, Kulander and Dean (1986) in northernmost West Virginia, Southworth and others (2009) in northern Virginia, and Brezinski (1992) in Maryland. The equivalent Cambrian to Upper Ordovician strata in the western part of the cross section consist of the following units (in ascending order): Mount Simon Sandstone, Conasauga Group, Kerbel Formation, Knox Dolomite (which includes the informally used Copper Ridge dolomite, Rose Run sandstone, and Beekmantown dolomite), Wells Creek formation (informal usage), Black River Group, and Trenton Limestone (fig. 2). The Rome Formation of Janssens (1973) is now considered to be an obsolete stratigraphic term in eastern and central Ohio (Harris and others, 2004; Baranoski and others, 2007) and is not used in cross section *C–C′*.

The distribution and lithology of Cambrian rocks in the eastern part of cross section *C–C′* are very speculative because deep drill holes are largely absent. Lithology and thickness data for Cambrian rocks in this area are limited to (1) drill hole 9, where the upper part of the Gatesburg Formation is penetrated; (2) drill hole 11, where the upper part of the Waynesboro Formation through the Gatesburg Formation is penetrated; and (3) outcrop studies in the vicinity of drill hole 11 (Wilson, 1952). Supplementary data for these Cambrian rocks were obtained from drill holes 9 and 13 on nearby cross section *D–D′* and from drill holes 11 through 14 on cross section *E–E′* (fig. 1). Drill hole 9 (cross section *D–D′*) near the western margin of the Rome trough penetrated the uppermost Copper Ridge Dolomite and the Rose Run Sandstone (together equivalent stratigraphically to the Gatesburg Formation in cross section *C–C′*), whereas drill hole 13 (cross section *D–D′*) in the Valley and Ridge province penetrated the upper part of the Waynesboro Formation, the Elbrook Formation (equivalent stratigraphically to the Pleasant Hill and Warrior Formations on cross section *C–C′*), and the Copper Ridge Dolomite (equivalent stratigraphically to the Gatesburg Formation on cross section *C–C′*). By comparison, drill holes 11 through 14 in cross section *E–E′* (located 100 to 130 mi southwest of section *C–C′*) penetrated the entire Cambrian section in the Rome trough. Cambrian units between the western margin of the Rome trough and the western end of cross section *C–C′* are reasonably well documented by drill holes 1 through 5.

On cross section *C–C′*, the Lower Cambrian Chilhowee Group, the Lower Cambrian Tomstown Formation, and the Lower and Middle Cambrian Waynesboro Formation are estimated to have a combined thickness of as much as 3,500 ft in the Rome trough and between 1,400 and 2,300 ft on the northern extension of the Central West Virginia arch and in the Valley and Ridge province. The 50- to 250-ft-thick basal sandstone between the western margin of the Rome trough and drill hole 1 is recognized as the Middle and Upper Cambrian Mount Simon Sandstone in Ohio and the Potsdam Formation in Pennsylvania.

The Lower Cambrian Chilhowee Group (a basal sandstone that rests unconformably on Mesoproterozoic basement rocks of the Grenville province) and the overlying Lower Cambrian Tomstown Formation are the two oldest sedimentary units on cross section *C–C′*. Although neither unit has been penetrated by a drill hole in cross section *C–C′*, a combined thickness of about 500 to 800 ft is estimated from outcrops and regional trends. Following Root (1968), the Chilhowee through Tomstown interval is interpreted here to continue east of cross section *C–C′* and crop out in south-central Pennsylvania along the Blue Ridge structural front (fig. 1). Westward, the Chilhowee through Tomstown interval is interpreted on cross section *C–C′* to pinch out across basement fault blocks near the center of the Rome trough.

The Chilhowee Group is interpreted as a transgressive marine deposit with its sediment source to the west. The overlying carbonate strata of the Tomstown Formation also are interpreted as transgressive marine deposits that accumulated on a marine shelf and carbonate ramp after the adjacent craton was submerged by the Iapetus Ocean (Read, 1989a,b).

The Chilhowee through Tomstown interval possibly is capped by a disconformity (fig. 2), which is overlain by the Waynesboro Formation (Ryder and others, 1992). The age of the Waynesboro Formation is uncertain. Although an Early Cambrian age is commonly cited for the Waynesboro Formation (Butts, 1945; Palmer, 1971; Kulander and Dean, 1986; Brezinski, 1992), fossil evidence is very sparse and a Middle Cambrian age is plausible for part of the formation (Stose, 1909; Woodward, 1949; Root, 1968; Read, 1989a,b). An Early and Middle Cambrian age is assigned to the Waynesboro Formation in this report, based on probable Middle Cambrian fossils in the Rome Formation (equivalent to the Waynesboro Formation) in the Rome trough of western West Virginia (Donaldson and others, 1988). Beneath drill hole 9 in the Rome trough, we speculate that the Waynesboro Formation consists of approximately 2,600 ft of gray shale with local beds of red shale, sandstone, and dolomite.

At 5,620 ft depth in drill hole 11, the upper 120 ft of the Waynesboro Formation are characterized by red and green shale, dolomite, and sandstone. At this locality, the strata of the Waynesboro Formation rest in fault contact on the Cambrian Pleasant Hill Formation. The Pleasant Hill and Waynsboro have been repeated by thrust faults into three horse blocks. The Waynesboro Formation and the underlying horse blocks of the Pleasant Hill Formation probably were derived from the basal detachment and the master thrust or footwall ramp of the Evitts Mountain anticline, tectonically transported westward along the footwall ramp (with a net vertical displacement of as much as 20,000 ft), and juxtaposed against the Beekmantown Group. Along the basal detachment between drill holes 9 and 11, the Waynesboro Formation consists of a westward-tapering wedge (as much as 1,500 ft thick) of clastic red beds and carbonate strata that overlie the Tomstown Formation and pinch out near the crest of the northern extension of the Central West Virginia arch. The lithology of the Waynesboro Formation at this locality probably consists of red, green, and gray shale, sandstone, and dolomite, based on the lithology of the Waynesboro Formation in drill hole 11 and in outcrop studies by Root (1968) in south-central Pennsylvania, by Woodward (1949) in eastern West Virginia, Southworth and others (2009) in northern Virginia, and Brezinski (1992) in Maryland.

On the basis of cross sections *D–D′* and *E–E′* (see fig. 1 for locations), the Waynesboro Formation probably changes in lithology from gray, shale-dominated strata with local beds of sandstone and carbonate rock in the central part of the Rome trough to argillaceous sandstone with local beds of red shale and dolomite in the western part of the Rome trough. The argillaceous sandstone of the Waynesboro Formation in the western part of the Rome trough rests directly either on Mesoproterozoic basement rocks of the Grenville province or on a thin section of the Chilhowee Group, thins progressively westward across successive fault blocks in the Rome trough, and terminates against a fault beneath the No. 1 McMichael drill hole. The argillaceous sandstone of the Waynesboro Formation very likely intertongues with gray shale of the Waynesboro and carbonate rocks of the Pleasant Hill Formation and the lower part of the Warrior Formation in the vicinity of the Brownsville anticline. West of the Rome trough, the Waynesboro Formation is replaced by the Middle and Upper Cambrian Potsdam Formation in Pennsylvania and equivalent Mount Simon Sandstone in Ohio, both of which are younger than the Waynesboro (see the western margin of the Rome trough on cross section *C–C′* and drill holes 1, 2, 3, and 5).

In outcrops in eastern West Virginia and in the subsurface of the Rome trough in western West Virginia, the Waynesboro Formation is interpreted as a shallow-water, nearshore-marine deposit (Woodward, 1949; Donaldson and others, 1988). The marked contrasts that exist between the thin, clastic, red bed- and carbonate-dominated Waynesboro Formation of the northern extension of the Central West Virginia arch and the thick, gray, shale-dominated Waynesboro Formation of the Rome trough probably indicate a change from continental-shelf to rift-basin sedimentation. The Waynesboro strata shown on cross section *C–C′* probably began as shallow-marine-shelf deposits that accumulated on a uniformly subsiding continental margin and then shifted rather abruptly to more locally derived shallow-marine deposits that accumulated in the separate rift basins with adjoining high basement blocks that constitute the Rome trough. The Mount Simon Sandstone and Potsdam Formation are interpreted as transgressive deposits.

The Pleasant Hill Formation is interpreted to rest conformably on the Waynesboro Formation, except along the crest of the northern extension of the Central West Virginia arch. A complete section of the Middle Cambrian Pleasant Hill Formation is penetrated in drill hole 11 at the eastern end of cross section *C–C′*, where the Pleasant Hill Formation is about 400 to 500 ft thick (this thickness is probably apparent because of dipping strata) and consists of a limestone that becomes more argillaceous in the lower 100 ft. Previously mentioned horse blocks of the Pleasant Hill Formation underlie this complete section in drill hole 11. These horse blocks range in thickness from 490 to 630 ft and consist of similar limestone and argillaceous limestone units. West of drill hole 11, the Pleasant Hill Formation is interpreted to be present throughout the Valley and Ridge province and the northern extension of the Central West Virginia arch, and it extends about 35 mi into the Rome trough. The combined thickness of the Pleasant Hill Formation through Trenton Group is 8,500 ft near the Allegheny structural front (based on the section near drill hole 10) and about 9,000 ft in the middle of the Rome trough, under the Lambert syncline. In the eastern part of the Rome trough, this interval may be as thick as 11,000 ft.

The Pleasant Hill Formation in drill hole 11 is conformably overlain by the Middle and Upper Cambrian Warrior Formation, which is 1,400 ft thick and consists primarily of sandy dolomite with a 380-ft-thick upper limestone unit. The sandy dolomite of the Warrior Formation in Pennsylvania (and the equivalent Conasauga Group in Ohio and northernmost West Virginia) stretches across all of cross section *C–C′*; however, the limestone unit at the top of the Warrior Formation in drill hole 11 only extends to within 9 mi of the crest of the northern extension of the Central West Virginia arch, where the Warrior Formation is truncated by an unconformity. In the region between drill hole 11 and the eastern margin of the Rome trough, the contact between the Warrior and Pleasant Hill Formations remains conformable except near the crest of the arch.

Moreover, the Warrior Formation is estimated to thicken abruptly from about 200 ft on the crest of the arch, where repeated episodes of uplift have occurred, to as much as 3,600 ft in the adjoining eastern part of the Rome trough. In addition to the thickening, a dolomitic sandstone unit is interpreted to be present at the base of the Warrior Formation on the basis of the presence of a 450-ft-thick unnamed sandstone unit in the middle part of the Maryville Limestone in cross section *E–E′* (drill holes 13 and 14). This basal sandstone unit of the Warrior Formation conformably overlies the Pleasant Hill Formation in the Rome trough as far west as the Brownsville anticline (middle part of the Rome trough), where the Pleasant Hill pinches out into the Waynesboro Formation. Westward from the pinch out edges of the Pleasant Hill Formation and the basal sandstone of the Warrior Formation to about as far as the western margin of the Rome trough, the main dolomite body of the Warrior Formation conformably overlies the Waynesboro Formation. As interpreted here, the lower part of the Warrior Formation locally intertongues with the upper part of the Waynesboro Formation. The sandy dolomite of the Warrior Formation continues beyond the Rome trough into westernmost Pennsylvania, where it is estimated to be about 1,000 ft thick beneath drill hole 7. An equivalent sequence of sandy dolomite and shale assigned to the Conasauga Group is present in northernmost West Virginia (beneath drill hole 6) and eastern Ohio (drill holes 1–5).

The Middle Cambrian age of the Pleasant Hill Formation and Middle to Late Cambrian age of the Warrior Formation, based on trilobite fauna (Wilson, 1952), indicate that these units are equivalent to the Conasauga Group in adjoining cross sections *D–D′* and *E–E′*. The Conasauga Group in cross sections *D–D′* and *E–E′* is subdivided (in ascending order) into the Pumpkin Valley Shale, Rutledge Limestone, Rogersville Shale, Maryville Limestone, and Nolichucky Shale or equivalent units (Ryder and others, 2008, 2009). In cross section *C–C′*, the Pleasant Hill and Warrior Formations are tentatively recognized as stratigraphic equivalents of the Maryville Limestone and Nolichucky Shale of the Conasauga Group; however, in addition, the presence of lower Middle Cambrian fauna and abundant shale beds in the Pleasant Hill Formation (Wilson, 1952) suggests that part of the Pleasant Hill Formation may be equivalent to the Rogersville Shale. The absence of the Pumpkin Valley Shale and the Rutledge Shale of the Conasauga Group on cross section *C–C′* may be due either to stratigraphic pinchout or to a facies change with the upper part of the Waynesboro Formation. Along the Blue Ridge front in south-central Pennsylvania, Maryland, and northeastern West Virginia, the Pleasant Hill and Warrior Formations are considered to be equivalent to the Middle and Upper Cambrian Elbrook Formation (Root, 1968; Brezinski, 1996).

On cross section *C–C′*, the Conasauga Group in northernmost West Virginia (beneath drill hole 6) and Ohio (drill holes 1–5) is subdivided into the Maryville Limestone and the overlying Nolichucky Shale in Ohio and its stratigraphic equivalent in West Virginia. The Maryville Limestone in Ohio, as used in this report and by Harris and others (2004) and Baranoski and others (2007), was formerly named the Rome Formation of Janssens (1973). Similarly, the Nolichucky Shale in Ohio was formerly named the Conasauga Formation of Janssens (1973). Both the Maryville Limestone and Nolichucky Shale in Ohio are now recognized as formations in the Conasauga Group (fig. 2).

The Conasauga Group and the overlying strata through the Trenton Limestone (Group) are interpreted as deposits of a post-rift passive-margin sequence, where Middle Ordovician continental-scale erosion (Knox unconformity) occurred during a drop in eustatic sea level and (or) tectonic uplift that preceded the Taconic orogeny (Read, 1989a,b). The Conasauga Group in the Rome trough in central West Virginia is interpreted as tidal-flat to shallow-water marine deposits (Donaldson and others, 1988). Moreover, the basal sandstone in the Warrior Formation (the unnamed sandstone member in the middle part of the Maryville Limestone in cross sections *D–D′* and *E–E′*) probably was derived from a cratonic source to the north and northwest.

A complete 2,580-ft-thick section of the Upper Cambrian Gatesburg Formation was penetrated in drill hole 11. In this drill hole, the Gatesburg Formation rests conformably on the Warrior Formation and consists (in ascending order) of the following members: (1) the lower sandy member, which is an 870-ft-thick sandy dolomite with quartzarenite sandstone interbeds as thick as 5 ft; (2) the Ore Hill Limestone Member, which is a 190-ft-thick limestone with dolomite interbeds; (3) the upper sandy member, which is a 1,350-ft-thick sandy dolomite with quartzarenite sandstone interbeds as thick as 5 ft; and (4) the Mines Dolomite Member, which is a 165-ft-thick, chert-bearing dolomite. These members of the Gatesburg Formation and their cited thicknesses are consistent with the members reported in nearby outcrops (Wilson, 1952), except for the following: (1) the Stacy Dolomite Member (Wilson, 1952) at the base of the Gatesburg Formation is unrecognizable in drill hole 11 and has been combined with the lower sandy member in drill hole 11; and (2) the upper sandy member is about 600 ft thinner in outcrop than in drill hole 11. The Late Cambrian age of the Gatesburg Formation is based largely on trilobite fauna in the Ore Hill Limestone Member (Wilson, 1952).

The four members of the Gatesburg Formation recognized in drill hole 11 are correlated westward across the Valley and Ridge province (where the Mines Dolomite Member and the uppermost part of the upper sandy member were penetrated in drill hole 10) to the eastern part of the Rome trough (where the Mines Dolomite Member, the upper sandy member, equivalent beds of the Ore Hill Limestone Member, and the very uppermost part of the lower sandy member were penetrated in drill hole 9). In drill hole 9, the dominant lithology of the upper sandy member is quartzarenite sandstone rather than sandy dolomite as reported in drill hole 11 and adjoining outcrops. The facies change from predominantly dolomite to predominantly sandstone is interpreted to occur on cross section *C–C′*

within 10 mi to the west of the master footwall ramp (thrust fault) of the Schellsburg dome. The Ore Hill Limestone and Mines Dolomite Members pinch out on cross section *C–C′* in southwestern Pennsylvania about 11 and 27 miles, respectively, west of drill hole 9. Beyond these pinchout limits of the Ore Hill Limestone and Mines Dolomite Members, the Gatesburg Formation continues to the Pennsylvania border as the dolomite-dominated lower sandy member and the sandstone-dominated upper sandy member. The lower sandy member of the Gatesburg Formation rests conformably on the Warrior Formation between drill holes 7 and 11, except near the crest of the northern extension of the Central West Virginia arch. The unconformity at the top of the Warrior Formation on the northern extension of the Central West Virginia arch and the previously mentioned unconformities at the base of the Warrior and Pleasant Hill Formations are shown on cross section *C–C′* and are interpreted as having formed during recurrent uplift of the arch during the formation of the Rome trough.

In northernmost West Virginia, beneath drill hole 6, Upper Cambrian rocks of the Gatesburg Formation change in nomenclature to the Copper Ridge Dolomite (equivalent stratigraphically to the lower sandy member of the Gatesburg Formation) and to the overlying Rose Run Sandstone (equivalent stratigraphically to the upper sandy member of the Gatesburg Formation). In Ohio, the stratigraphically equivalent Copper Ridge dolomite and Rose Run sandstone are defined as informal units within the Knox Dolomite (Slucher, 2004). The Copper Ridge dolomite continues to the western end of cross section *C–C′*, whereas the Rose Run sandstone pinches out in eastern Ohio about 14 mi west of drill hole 4. The Upper Cambrian rocks thin gradually westward across cross section *C–C′*, from the previously noted thickness of 2,580 ft for the Gatesburg Formation in drill hole 11 to about 150 ft for the Copper Ridge dolomite in drill hole 1.

The sandy members of the Gatesburg Formation and the Rose Run Sandstone (or sandstone) are interpreted as shallow-marine to peritidal deposits (Wilson, 1952; Riley and others, 1993). Also, the quartzarenite composition of the sandstone units suggests that they were derived from the craton (Riley and others, 1993).

In drill holes 1 and 2, a 100-ft-thick, silty to argillaceous and (or) sandy(?) dolomite unit in the middle of the Copper Ridge dolomite is correlated with the B zone of Calvert (1964) in Ohio. As described by Janssens (1973), the B zone is a glauconitic siltstone and very fine grained sandstone that forms a persistent marker bed over much of central Ohio. Janssens (1973) further reported that locally (such as in drill hole 1) the B zone contains a thin sandstone known informally as the Krysik sandstone. The B zone and the Krysik sandstone extend at least as far eastward in cross section *C–C′* as drill hole 5 and probably underlie drill holes 6 and 7 near the Ohio-West Virginia border and the West Virginia-Pennsylvania border.

The Cambrian Gatesburg Formation in cross section *C–C′* is overlain conformably by the Lower and Middle Ordovician Beekmantown Group, which is a thick, widespread dolomite unit that is commonly anhydritic and contains (at least in the western half of the study area) the Middle Ordovician Knox unconformity (Wagner, 1966; Ryder and others, 1992). The Beekmantown Group is about 2,800 ft thick in the Valley and Ridge province (drill hole 10) and about 3,700 ft thick in the eastern part of the Rome trough (drill hole 9). Westward across the Rome trough, the Beekmantown Group thins to about 1,500 ft at the western margin of the trough. In northernmost West Virginia and northeastern Ohio, stratigraphically equivalent units of the Beekmantown Group (Beekmantown Dolomite, or informal Beekmantown dolomite and the overlying Wells Creek formation) continue to thin in a westward direction. The Beekmantown Dolomite (as used in northernmost West Virginia) changes nomenclature in Ohio to the Beekmantown dolomite, which is an informal unit of the Knox Dolomite (Janssens, 1973; Slucher, 2004). The Beekmantown Group and Beekmantown Dolomite (or dolomite) are interpreted as restricted-marine deposits that accumulated on a passive continental margin (Harris, 1973; Read, 1989a,b).

The informal Middle Ordovician Wells Creek formation (fig. 2) is an argillaceous dolomite that replaces (by a facies change) the upper anhydritic dolomite of the Beekmantown Group in the vicinity of the West Virginia-Pennsylvania border. The Wells Creek Formation was introduced in Ohio by Patchen and others (1985) and Wickstrom and others (1992) on the basis of the Wells Creek Dolomite, which was named by Lusk (1927) after a locality in western Tennessee. Wilson and Stearns (1968) discontinued the term in Tennessee when their geologic mapping failed to identify the Wells Creek Dolomite at the type locality. On cross section *C–C′*, however, the term Wells Creek formation is used (following Wickstrom and others, 1992), but its status is informal because its presence in the type area is uncertain. The upper anhydritic dolomite of the Beekmantown Group (equivalent to the Wells Creek formation) is also the approximate stratigraphic equivalent of the upper member of the Bellefonte Formation of the Beekmantown Group as used by Wagner (1966) and Berg and others (1983). In drill holes 5 and 6, a thin, unnamed sandstone unit, which is probably equivalent to the St. Peter Sandstone, is located at the base of the Wells Creek formation.

The Middle Ordovician Knox unconformity is probably absent between the northern extension of the Central West Virginia arch and the eastern end of cross section *C–C′*, based on studies by Wagner (1966), Harris and Repetski (1982), and Mussman and others (1988); however, the unconformity is very likely present between the upper and middle anhydritic dolomite units in the upper part of the Beekmantown Group at about 17,800 ft depth in drill hole 9. The Knox unconformity continues from drill hole 9 to the western end of the cross section and accounts for at least part of the regional thinning of the underlying Cambrian and Lower Ordovician strata. In Ohio, the unconformity cuts downsection and places the Wells Creek formation on successively older rocks as follows: the

Beekmantown dolomite is truncated by the unconformity about 4 mi east of drill hole 4; the Rose Run sandstone is truncated by the unconformity about 14 mi west of drill hole 4; and the B zone and Krysik sandstone interval is partially truncated by the unconformity in drill hole 1 to within 70 ft of the base of the interval.

The Beekmantown Group (in Pennsylvania) and the Wells Creek formation (in Ohio and West Virginia) are overlain conformably by a widespread Upper Ordovician limestone-dominated interval that extends across the entire cross section. This limestone interval varies in thickness from about 1,100 ft in the Valley and Ridge province (drill hole 10) to about 1,450 ft above the eastern part of the Rome trough (drill hole 9). West of the Rome trough, the thickness of the limestone interval thins gradually to about 900 ft in northernmost West Virginia (drill hole 6) and to about 600 ft in north-central Ohio (drill hole 1). On the basis of the nomenclature used in the Valley and Ridge outcrop belt (Rones, 1969; Laughrey and others, 2003) and in the subsurface near drill hole 10 (Wagner, 1966), the limestone interval in drill holes 9 and 10 is divided into the following units (in ascending order): (1) the Middle to Upper Ordovician Loysburg Formation, (2) the Upper Ordovician Black River Group, and (3) the Upper Ordovician Trenton Group. The Black River and Trenton Groups (Trenton Limestone in West Virginia and Ohio) are recognized across the entire cross section, whereas the Loysburg Formation only extends as far west as drill hole 6 in northernmost West Virginia. The Loysburg Formation pinches out into the Black River Group near the Ohio-West Virginia border. Formations in the Black River Group (Hatter, Snyder, and Linden Hall Formations) and in the Trenton Group (Nealmont, Salona, and Coburn Formations) in Pennsylvania have been identified by Wagner (1966), Rones (1969), and Laughrey and others (2003); however, because the formation contacts were not identified in the drill holes, labels showing the relative positions of these formations are shown but their contacts are not drawn on cross section *C–C′*.

Across Ohio, northernmost West Virginia, and western Pennsylvania, the Black River Group and Trenton Limestone (or Group) are characterized by a homogeneous lithology (Riley and others, 2006). In this part of the cross section, the Black River Group consists largely of carbonate mudstone and wackestone, whereas the Trenton Limestone (Group) consists largely of fossiliferous, argillaceous limestone (wackestone, packstone, and grainstone). Also, as shown on the cross section and in figure 2, two widespread potassium bentonite beds (α and β marker beds of Stith, 1979; Millbrig and Deicke Bentonite Beds of Huff and Kolata, 1990; Kolata and others, 1996) are located in the uppermost part of the Black River Group in Ohio. In the eastern part of the cross section, the Millbrig Bentonite Bed (α marker) either defines the Black River-Trenton contact or is located 10 to 20 ft below the contact (a relation that cannot be shown at the scale of the cross section). Near the Ohio-West Virginia border, the contact between the characteristic carbonate mudstone of the Black River Group and the characteristic fossiliferous argillaceous grainstone of the Trenton Group is located about 110 ft below the Millbrig Bentonite Bed, thus shifting the location of the Black River-Trenton contact from a younger stratigraphic position farther west to an older stratigraphic position at this location. This downsection shift of the Black River-Trenton contact is first documented in drill hole 6, where the Trenton Limestone is about 260 ft thick and consists of a lower unit of fossiliferous wackestone and packstone and an upper unit of argillaceous fossiliferous grainstone. These two units in the Trenton Limestone correlate, respectively, with the Nealmont Formation and the Salona and Coburn Formations, undivided, in central Pennsylvania (Wagner, 1966; Laughrey and others, 2003). The zone across which initial eastward thickening of the Trenton Limestone takes place, because of the downsection shift of the Black River-Trenton contact, coincides approximately with a northeast-trending ramp margin proposed by Riley and others (2006). East of this proposed ramp margin, the limestone of the Black River and Trenton Groups becomes more argillaceous and fossiliferous. In central Pennsylvania about 50 mi north of cross section *C–C′*, the Black River-Trenton contact has shifted even farther downsection (by about 100 ft), so that both the Millbrig and Deicke Bentonite Beds, as well as many other bentonite beds, are present in the Trenton Group (Cullen-Lollis and Huff, 1986; Kolata and others, 1996; Laughrey and others, 2003). The Loysburg-Black River-Trenton interval in central Pennsylvania is characterized by the following lithologic units: (1) the Loysburg Formation, which consists of interbedded to interlaminated calcareous and dolomitic mudstone with minor amounts of wackestone, packstone, and grainstone (Rones, 1969; Laughrey and others, 2003); (2) the Black River Group, which consists of calcareous mudstone commonly interbedded with skeletal wackestone, packstone, and grainstone (Rones, 1969; Laughrey and others, 2003); and (3) the Trenton Group consists of skeletal wackestone, packstone, and grainstone interbedded with argillaceous calcareous mudstone and dark-gray to black shale (Thompson, 1963; Laughrey and others, 2003).

The dolomitic limestone of the Loysburg Formation is interpreted as peritidal deposits, whereas the limestone of the Black River and Trenton Groups is interpreted as subtidal-carbonate-ramp and deeper water carbonate-ramp to shelf-margin deposits, respectively (Laughrey and others, 2003; Riley and others, 2006). The potassium bentonite beds are thought to be derived from extensive volcanic ash falls that occurred during the Late Ordovician phase of the Taconic orogeny (Huff and Kolata, 1990; Huff and others, 1992).

Upper Ordovician to Lower Silurian Siliciclastic Strata

The Upper Ordovician to Lower Silurian siliciclastic strata are characterized by gray shale, red shale, sandstone, and black shale (fig. 2). As shown on cross section *C–C′*, the combined thickness of the strata ranges from about 5,000 ft in the vicinity of the Allegheny structural front (near drill hole 10) (also see isopach maps by Diecchio, 1985) to about 1,300 ft near drill holes 1 and 2. In the south-central Pennsylvania part of cross section *C–C′*, the Upper Ordovician to Lower Silurian siliciclastic strata consist of the following units (in ascending order): the Antes Shale, Reedsville Shale, Bald Eagle Formation, Juniata Formation, Tuscarora Formation (or Medina Group in western Pennsylvania), and Rose Hill Formation (Berg and others, 1983; Ryder and others, 1992) (fig. 2). In Ohio, the Upper Ordovician to Lower Silurian siliciclastic strata change nomenclature as follows: (1) the Utica Shale replaces the Antes Shale (Ryder and others, 1992), (2) the informally used Cincinnati group replaces the Reedsville Shale (Slucher, 2004), (3) the informal Medina sandstone, Cabot Head Shale, and informal "Clinton"[1] sandstone interval replaces the Tuscarora Formation or Medina Group (Ryder, 2004), and (4) the unnamed and undivided Lower Silurian carbonate and shale unit and the overlying Rochester Shale replace the Rose Hill Formation (Ryder, 2004) (fig. 2). The change in nomenclature from the Juniata Formation in southwestern Pennsylvania to the Queenston Shale in western Pennsylvania (Berg and others, 1983) and Ohio (Ryder and others, 1992; Slucher, 2004) occurs approximately 30 miles west of drill hole 8.

The Upper Ordovician to Lower Silurian siliciclastic strata are interpreted as being derived from an eastern orogenic source and deposited in a rapidly subsiding foreland basin. This foreland basin and its sedimentary deposits are associated with the continent-island arc collision of the Taconic orogeny (Colton, 1970; Milici and de Witt, 1988; Drake and others, 1989; Pavlides, 1989; Faill, 1997a).

The Upper Ordovician Antes (or Utica) Shale is a black shale unit that extends across cross section *C–C′* and ranges in thickness from about 300 ft in drill hole 2 to about 700 ft in the eastern part of the Rome trough (drill hole 9). Upper Ordovician strata that overlie the Antes (or Utica) Shale consist of the Reedsville Shale (or Cincinnati group) (gray shale, siltstone, and minor sandstone with increasing amounts of limestone in Ohio), the Bald Eagle Formation (sandstone, siltstone, and gray shale), and the Juniata Formation (or Queenston Shale) (red beds). The widespread Cherokee unconformity is present at the top of the Juniata Formation (or Queenston Shale) (Hettinger, 2001; Ryder, 2004). According to Dennison and Head (1975), the Cherokee unconformity resulted from a fall in eustatic sea level that probably was independent of the Taconic orogeny and the resultant classic angular unconformity between Upper Ordovician and Lower Silurian rocks in eastern Pennsylvania (Pavlides and others, 1968).

The Antes (or Utica) Shale is interpreted as an anoxic deposit that accumulated in the distal part of the Taconic foreland basin during initial deepening of the carbonate platform (the underlying Black River Group and Trenton Group (or Limestone)) (Castle, 2001), whereas the overlying Reedsville Shale (or Cincinnati group), Bald Eagle Formation, and the Juniata Formation (or Queenston Shale) are interpreted as shallow-marine and intertidal deposits that accumulated on a prograding clastic wedge (Diecchio, 1985; Castle, 2001).

Lower Silurian siliciclastic strata overlie the Juniata Formation (or Queenston Shale) red beds from the Allegheny structural front and adjoining Valley and Ridge province westward into north-central Ohio. The eastern part of the Lower Silurian siliciclastic strata is named the Tuscarora Formation, which is about 450 to 500 ft thick (including a 100-ft-thick Tuscarora-Juniata transition zone) where it intersects cross section *C–C′* in south-central Pennsylvania (drill holes 8–10). The Tuscarora Formation grades westward into siliciclastic strata of the Lower Silurian Medina Group in western Pennsylvania (drill hole 7) and of the Lower Silurian "Clinton" sandstone and the underlying Cabot Head Shale and Medina sandstone in Ohio (drill holes 3–5) and along the northernmost West Virginia border (drill hole 6). The Medina sandstone, Cabot Head Shale, and "Clinton" sandstone have a combined thickness of approximately 200 ft (Ryder, 2000, 2004). The Tuscarora Formation has a greater percentage of net sandstone and is typically coarser grained than the Medina Group or the combined Medina sandstone-Cabot Head Shale-"Clinton" sandstone. Between drill holes 2 and 3, the "Clinton" sandstone pinches out westward due to a facies change and is replaced by the Cabot Head Shale. Furthermore, in this same locality, the Medina sandstone is replaced by the Lower Silurian Brassfield Limestone, which continues to the northwestern end of the cross section. The Tuscarora-Medina-"Clinton" interval is interpreted as a combined shallow-marine-shelf, shoreface, and fluvial-to-estuarine deposit (Castle, 1998; Hettinger, 2001; Ryder, 2004) that accumulated as molasse during the Early Silurian late-stage uplift of the Taconian orogenic belt (Dorsch and others, 1994).

The 250- to 750-ft-thick Lower Silurian Rose Hill Formation conformably overlies the Medina Group or the Tuscarora Sandstone in drill holes 7 through 10. The Rose Hill Formation consists of gray shale, red shale, dolomite, and limestone (Hettinger, 2001; Ryder, 2004). About midway between drill holes 7 and 8, the lower part of the Rose Hill Formation changes to a predominantly dolomite interval that continues westward to the Pennsylvania-West Virginia border between drill holes 6 and 7 and into Ohio as far as between drill holes 3 and 4. In northernmost West Virginia (drill hole 7) and northeastern Ohio (drill hole 5), the Rose Hill Formation is replaced by the Lower Silurian Rochester Shale and an underlying unit of thin dolomite, limestone, and interbedded gray shale identified on cross

[1]The "Clinton" sandstone in Ohio was miscorrelated by drillers with strata in the type Clinton Group of New York when in fact it is equivalent to the underlying type Medina Group of New York. Although this miscorrelation has caused confusion in nomenclature, the term continues to be used widely in the literature and by the oil and gas industry. Early drillers correctly identified the informal Medina sandstone in Ohio as a partial equivalent of the type Medina Group of New York.

section *C–C′* as “Lower Silurian carbonates and shales, undivided” (Ryder, 2000, 2004) (fig. 2). The combined Lower Silurian carbonates and shales unit and the Rochester Shale overlie the “Clinton” sandstone and thin to about 150 ft thick in drill hole 5 and to about 50 ft thick in drill hole 1. Kleffner (1985), Brett and others (1990), Hettinger (2001), and Slucher (2004) recognized an unconformity at the base of the Lower Silurian Dayton Limestone, which is included in the Lower Silurian carbonates and shales unit. This unconformity extends across much of northeastern Ohio and probably also extends into the Rose Hill Formation at least as far east as somewhere between drill holes 10 and 11. A thin, continuous, locally hematitic sandstone (known as the Lower Silurian Keefer Sandstone) conformably overlies the Rose Hill Formation and Rochester Shale across northernmost West Virginia and Pennsylvania (fig. 2). The Rose Hill Formation is interpreted as a shallow-marine-shelf deposit (Smosna and Patchen, 1978).

Lower Silurian to Middle Devonian Carbonate and Evaporite Strata

Lower Silurian to Middle Devonian strata consist of a lithologically varied interval of limestone, dolomite, sandstone, gray shale, chert, anhydrite, and halite (fig. 2). The combined thickness of these stratigraphic units ranges from about 2,500 to 3,000 ft, respectively, in drill holes 9 and 8, to about 1,150 ft in drill hole 1. In the vicinity of the Allegheny structural front and adjoining Valley and Ridge province (drill hole 10), the thickness of the Lower Silurian to Middle Devonian strata is about 2,150 ft (Heyman, 1977). In the far eastern part of the section in Pennsylvania, the typical stratigraphic units in this interval are as follows (in ascending order): McKenzie Member of the Mifflintown Formation, Bloomsburg Formation, Wills Creek Formation, Tonoloway Formation, Keyser Formation, New Creek Limestone, Corriganville Limestone, Mandata Shale, Shriver Formation, Ridgeley Sandstone, Needmore Shale, and Onondaga Formation (Berg and others, 1983) (fig. 2). These stratigraphic units extend westward through the rest of Pennsylvania into northernmost West Virginia and Ohio, but are assigned different names in different parts of the section. The McKenzie Limestone Member of the Mifflintown Member is equivalent to the Lockport Formation from western Pennsylvania westward. The Wills Creek Formation is equivalent to the lower part of the Salina Group from western Pennsylvania westward. The Tonoloway Formation is replaced by the upper part of the Salina Group from southwestern Pennsylvania westward. The Silurian part of the Keyser Formation (Keyser Limestone in West Virginia) correlates with the Silurian Bass Islands Dolomite in Ohio. The Shriver Formation is replaced by the Licking Creek Limestone in south-central Pennsylvania. The Keyser Formation, New Creek Limestone, Corriganville Limestone, Mandata Shale, and Licking Creek Limestone in Pennsylvania are mapped as formations in the Helderberg Group in northernmost West Virginia; the New Creek Limestone, Corriganville Limestone, Mandata Shale, and Licking Creek Limestone in Pennsylvania correlate with the Helderberg Limestone in Ohio. The Ridgeley Sandstone in Pennsylvania correlates with the Oriskany Sandstone in northernmost West Virginia and Ohio. The upper part of the Needmore Shale is replaced by the Huntersville Chert in south-central Pennsylvania. The Needmore, Huntersville, and Onondaga Formation (or Limestone) in Pennsylvania and West Virginia correlate with the Onondaga Limestone in northeastern Ohio or with the interval that includes the Bois Blanc Formation, Detroit River Group, Columbus Limestone, and Delaware Limestone in north-central Ohio (fig. 2).

The Lower and Upper Silurian Lockport Dolomite in Ohio rests conformably on either the Rochester Shale or the Lower Silurian Keefer Sandstone, whereas the equivalent McKenzie Member of the Mifflintown Formation in Pennsylvania rests conformably on just the Keefer Sandstone (fig. 2). The Lockport Dolomite consists largely of fine to medium crystalline dolomite, several widespread vuggy rubble zones, and local bioherms (Multer, 1963; Santini and Coogan, 1983; Noger and others, 1996). By comparison, the McKenzie Member consists of carbonate mudstone and fossiliferous wackestone to grainstone interbedded with greenish-gray to black shale (Knowles, 1966; de Witt, 1974). In drill hole 10, the McKenzie Member is divided into upper and lower parts by a thin red-bed unit that probably correlates with the Rabble Run Member of the Mifflintown Formation (Hoskins, 1961). The facies change from limestone and shale of the McKenzie Member to crystalline and vuggy dolomite of the Lockport Dolomite occurs in southwestern Pennsylvania about 20 mi northwest of drill hole 8.

The McKenzie Member of the Mifflintown Formation is conformably overlain by the Upper Silurian Bloomsburg Formation, which is characterized by grayish-red shale, mudstone, and sandstone (Hoskins, 1961; Knowles, 1966; de Witt, 1974). The Bloomsburg Formation is 30 to 60 ft thick and extends from outcrops on the flanks of the Wills Creek anticline, through drill holes 8 and 9, to a pinchout approximately 8 mi west of drill hole 8.

The Upper Silurian Salina Group and the equivalent Wills Creek and overlying Tonoloway Formations constitute a well-defined unit that extends across all of cross section *C–C′* and ranges in thickness from about 1,000 ft near the Allegheny structural front (drill hole 10), to about 1,850 ft in southwestern Pennsylvania (drill hole 8), to about 600 ft in north-central Ohio (drill holes 1 and 2). The Salina Group consists largely of anhydritic dolomite, shale, anhydrite, and halite with the halite-bearing part concentrated in drill holes 3 through 9 near the western and southern margins of the Salina salt basin as defined by Colton (1970), Clifford (1973), Frey (1973), and Smosna and others (1977). Halite-bearing intervals in drill holes 3 through 9 are interpreted from geophysical and lithologic logs and from halite beds previously identified by Clifford (1973) and Heyman (1977). Most halite-bearing intervals shown on section *C–C′*, such as the approximately 600-ft-thick interval in drill hole 5, are not composed entirely of halite but instead are intervals of interbedded halite, dolomite, shale, and anhydrite. As shown by Frey (1973) and Scanlin and Engelder (2003), the halite and shale intervals in the Salina Group are commonly overthickened because of flowage into the cores of thin-skinned anticlines.

Eastward from a location about 18 mi west of drill hole 8, the lower part of the Salina Group is replaced by argillaceous dolomite and gray shale or mudstone of the Upper Silurian Wills Creek Formation. Farther eastward, beginning at about drill hole 9, the remainder of the Salina Group is replaced by argillaceous to anhydritic limestone and dolomite of the Upper Silurian Tonoloway Formation. From a location between drill hole 1 to within about 20 mi of drill hole 8, the Salina Group rests conformably on the Lockport Dolomite. Between drill hole 8 and the eastern end of the cross section, the Wills Creek Formation rests conformably on the Bloomsburg Formation.

The Late Silurian to earliest Devonian Keyser Formation contains the youngest Silurian sediments in the cross section; most of the Keyser Formation is of Silurian age, based on conodont studies (Denkler and Harris, 1988; Baez Rodríguez, 2005). In south-central and southwestern Pennsylvania, the Keyser Formation consists of argillaceous carbonate mudstone and fossiliferous grainstone (Knowles, 1966; de Witt, 1974) that grade into dolomite in western Pennsylvania. In northernmost West Virginia, the dolomite is known as the Keyser Limestone of the Helderberg Group. The majority of the Keyser Formation (or Limestone) in Pennsylvania and northernmost West Virginia is equivalent to the Upper Silurian Bass Islands Dolomite in Ohio, an argillaceous dolomite (80 feet thick or less) that extends to the western end of the cross section.

The overall depositional setting of the Lower and Middle Devonian carbonate and evaporite rocks was a shallow basin with closed circulation where evaporites were surrounded by a carbonate shelf with normal sea water where limestone was deposited (Smosna and others, 1977). Dolomites and evaporite beds of the Upper Silurian Salina Group that conformably overlie the Lockport Dolomite signal an abrupt change on the carbonate shelf from normal circulation to greatly restricted circulation caused by a change to a very arid climate (Cecil and others, 2004). The Salina Group is interpreted as a shallow-water and sabkha (supratidal) deposit (Tomastik, 1997). Because halite beds in the Salina Group terminate abruptly against the Cambridge structural discontinuity (about 25 mi south of cross section *C–C′*; fig. 1), Root (1996) suggested that this structure (during the time of Salina deposition) was a topographic sill that separated hypersaline, halite-precipitating sea water on the east from less saline water on the west. An alternate explanation for the abrupt termination of the halite beds is offered by Farmerie and Coogan (1995), who suggested that the halite beds originally extended westward across the Cambridge structural discontinuity and later were dissolved by downward-percolating ground water from a Lower Devonian erosion surface (the unconformity at the base of the Oriskany Sandstone, discussed later in this section). Both explanations, however, require positive relief on the Cambridge structural discontinuity during the Silurian.

Lower Devonian limestones in cross section *C–C′* constitute a composite unit that ranges in thickness from about 300 ft in drill hole 10, to about 200 ft in drill hole 6, and to a pinch-out edge midway between drill holes 2 and 3. In Pennsylvania and northernmost West Virginia, the New Creek and Corriganville Limestones near the base of the composite unit consist of wackestone, packstone, and skeletal grainstone, and the Licking Creek Limestone at the top of the composite unit consists of slightly fossiliferous calcareous mudstone with local chert (de Witt, 1974; Harper, 1999). The Corriganville is overlain by the thin, dark-gray to black Mandata Shale (Harper, 1999). In the far eastern part of the section, the Shriver Formation overlies the Mandata, but the Shriver grades several miles east of drill hole 9 to the Licking Creek Limestone. The Shriver Formation consists of silty limestone and siliceous shale with abundant chert (Knowles, 1966; de Witt, 1974; Harper, 1999). The equivalent Helderberg Limestone in Ohio rests unconformably on the Bass Islands Dolomite (Patchen and others, 1985; Slucher, 2004) and extends westward to a point between drill holes 2 and 3, where it is truncated by an unconformity at the base of the Oriskany Sandstone. These Helderberg strata are generally interpreted as normal marine deposits that accumulated in an intracratonic basin and on flanking carbonate shelves (Smosna, 1988).

The clean, quartzose Lower Devonian Ridgeley Sandstone (or equivalent Oriskany Sandstone) overlies the Helderberg Limestone (or Group), and extends across most of cross section *C–C′* (see also Abel and Heyman, 1981, for the Pennsylvania part of the section). Regional unconformities at the top and base of the Ridgeley (or Oriskany) Sandstone probably were caused by falls in eustatic sea level (Dennison and Head, 1975). Of the two unconformities, Dennison and Head (1975) considered the upper one to represent the longer period of emergence and perhaps the greater decrease in water depth. This post-Oriskany unconformity probably truncated the Oriskany Sandstone between drill holes 2 and 3 near the pinchout mapped by Opritza (1996). West of where the Oriskany pinches out, the two unconformities merge and cut progressively downsection across the Helderberg Limestone and the uppermost part of the Bass Islands Dolomite. The Oriskany Sandstone has been interpreted as a shallow-marine deposit (Bruner, 1988; Harper and Patchen, 1996), although Cecil (2004a,b) suggested an earlier eolian provenance for the Oriskany Sandstone and adjacent chert beds (Shriver Formation and Huntersville Chert).

In drill holes 1 and 2, a 50- to 60-ft-thick sandstone and cherty carbonate unit unconformably overlies the Salina Group and is unconformably overlain by the Middle Devonian Detroit River Group (as suggested by regional correlations of Dow, 1962; Slucher, 2004).

In this report, the sandstone and cherty carbonate unit is correlated with the Lower Devonian Bois Blanc Formation, which is recognized in northern Ohio by Dow (1962), Janssens (1968), Rickard (1984), Sparling (1988), and Slucher (2004); however, several other possibilities exist. For example, the sandstone and cherty carbonate unit might correlate with the Lower Devonian Sylvania Sandstone in northwestern Ohio and southwestern Ontario (Carman, 1936; Dow, 1962; Slucher, 2004) or with the Lower Devonian Hillsboro Sandstone in central and southwestern Ohio (Hansen, 1999; Slucher, 2004). To further complicate the correlation, the Sylvania and Hillsboro Sandstones might be stratigraphically equivalent units.

In the Pennsylvania and northernmost West Virginia part of cross section *C–C′*, the Ridgeley (or Oriskany) Sandstone is overlain unconformably by a thin, black shale, which is mapped as the Middle Devonian Needmore Shale (de Witt, 1974; Harper and Patchen, 1996). This shale, in turn, is conformably overlain by a chert-dominated, silty limestone (calcareous mudstone), which is mapped as the Middle Devonian Huntersville Chert (Diecchio and others, 1984; Flaherty, 1996; Harper and Patchen, 1996). Furthermore, the Huntersville Chert is overlain by a thin, argillaceous limestone, which is mapped as the Middle Devonian Onondaga Limestone (Flaherty, 1996; Harper and Patchen, 1996). East of drill hole 10, the Huntersville Chert is replaced by the black shale of the Needmore Shale (de Witt, 1974; Flaherty, 1996; Harper and Patchen, 1996). Near the Ohio-West Virginia border, the Huntersville Chert intertongues with argillaceous, slightly fossiliferous limestone that extends into Ohio as the Onondaga Limestone (fig. 2). Moreover, the thin Onondaga Limestone at the top of the Huntersville Chert in Pennsylvania and northernmost West Virginia becomes the uppermost part of the Onondaga Limestone in Ohio. In east-central Ohio, between drill holes 2 and 3, the Onondaga Limestone is replaced by the Middle Devonian Columbus Limestone and the overlying Middle Devonian Delaware Limestone. The Columbus and Delaware Limestones may be separated by an unconformity (Hansen, 1999; Slucher, 2004).

Middle Devonian to Lower Mississippian Siliciclastic Strata

Middle Devonian to Lower Mississippian siliciclastic strata include black shale, gray shale, sandstone, red beds, and minor argillaceous limestone (fig. 2). The Middle Devonian to Lower Mississippian strata shown in cross section *C–C′* thin dramatically westward from as much as about 7,900 ft in south-central Pennsylvania (beneath the No. 1 Lehman drill hole) to about 4,300 ft in western Pennsylvania (drill hole 7), and to about 1,850 ft in north-central Ohio (drill hole 3). From several miles east of drill hole 9 to the flanks of the Schellsburg dome near drill hole 10 in south-central Pennsylvania, the Middle Devonian to Lower Mississippian siliciclastic strata include the following units (and their equivalents, in ascending order): (1) the Middle Devonian Hamilton Group (Marcellus Formation and Mahantango Formation); (2) the Middle Devonian Tully Limestone; (3) the Upper Devonian Harrell Formation, Brallier Formation, Scherr Formation, Foreknobs Formation (Harper, 1993) (equivalent to the Greenland Gap Group of Dennison (1970) in cross section *D–D′* (Ryder and others, 2009)), and Catskill Formation (Harper, 1993) (Hampshire Formation as used by de Witt (1974)); (4) the Upper Devonian and Lower Mississippian Rockwell Formation (Harper, 1993); and (5) the Lower Mississippian Burgoon Sandstone (equivalent to the Price Formation in cross section *D–D′* (Ryder and others, 2009)) (Brezinski, 1999). The Scherr Formation, Foreknobs Formation, and Catskill Formation cross an arbitrary boundary near drill hole 9 and the Laurel Hill anticline, beyond which the formations are mapped as the Elk Group, Bradford Group, and Venango Group, respectively. The Elk, Bradford, and Venango Groups, which were first mentioned as informal sand groups (Wilmarth, 1938), were formalized into stratigraphic nomenclature by Harper and Laughrey (1987), Harper (1993), and Harper and others (1999).

In western Pennsylvania, northernmost West Virginia, and eastern to north-central Ohio, the Middle Devonian to Lower Mississippian strata include the following units (in ascending order): the Middle Devonian Hamilton Group (Marcellus Shale and Mahantango Formation; equivalent to the Plum Brook Shale and overlying Prout Limestone) and Tully Limestone; the Upper Devonian Genesee Formation and Sonyea Formation (which are in turn stratigraphically equivalent to the Harrell Formation to the east); the Upper Devonian West Falls Formation (which includes the Rhinestreet Shale and Angola Shale Members), Java Formation (and the partially equivalent Olentangy Shale), Huron Member of the Ohio Shale (or partially equivalent Dunkirk Shale Member of the Perrysburg Formation) (as shown by de Witt and others, 1993), Chagrin Shale (which is equivalent to the upper part of the Brallier Formation, the Scherr, Foreknobs, and Hampshire Formations, and the lower part of the Rockwell Formation to the east and to the Cussewago Sandstone, Bedford Shale, and Ohio Shale to the west); the Upper Devonian Berea Sandstone and the Lower Mississippian Sunbury Shale (which are equivalent to the lower part of the Rockwell Formation); the Lower Mississippian Cuyahoga Formation; and the Lower Mississippian Shenango Formation. The top of the 30- to 40-ft-thick Tully Limestone, which is located between the Mahantango Formation and the Harrell Formation or Genesee Formation, marks the top of the Middle Devonian on cross section *C–C′*.

The Upper Devonian to Lower Mississippian siliciclastic strata are interpreted as sediments derived from an easterly orogenic source and deposited in a rapidly subsiding foreland basin. This foreland basin and its sedimentary deposits (the Catskill delta complex of Woodrow and Sevon (1985) and Harper (1999); and the Price-Rockwell delta complex of Boswell, Heim, and others (1996) are associated with the Acadian orogeny (Colton, 1970; Milici and de Witt, 1988; Osberg and others, 1989; Faill, 1997b).

The stratigraphy of the Middle and Upper Devonian black shales has been studied in great detail because of the role of black shales as hydrocarbon source rocks and reservoirs (Roen and Kepferle, 1993). In the vicinity of the Allegheny structural front and the adjoining Valley and Ridge province, the lowermost of the Devonian black shales is the Middle Devonian Marcellus Formation, which rests conformably on the Middle Devonian Onondaga Formation. Also in this region, the Marcellus Formation and the Onondaga Formation are commonly separated by the widespread Tioga Ash Bed (Inners, 1979; Way and others, 1986; Harper and Patchen, 1996) (Tioga Bentonite of Dennison and Head, 1975) (fig. 2). The Marcellus Formation (or Shale) and the overlying gray shale of the Mahantango Formation of the Hamilton Group extend across Pennsylvania, northernmost West Virginia, and eastern Ohio in cross section *C–C′* (Patchen and others, 1985; Slucher, 2004). The Marcellus Shale pinches out between drill holes 2 and 3, but the Mahantango Formation of the Hamilton Group continues into north-central Ohio as a gray shale and limestone unit recognized as the undivided Middle Devonian Plum Brook Shale and the Prout Limestone (Rickard, 1984; Slucher, 2004).

The Harrell Formation and the overlying Brallier Formation (from several miles east of drill hole 9 to the flanks of the Schellsburg dome near drill hole 10) consist of dark-gray shale and gray, silty shale or siltstone, respectively. The Harrell Formation rests unconformably (Middle to Late Devonian unconformity described in the following paragraph) on the Tully Limestone and crosses an arbitrary boundary near drill hole 8 into the Genesee and Sonyea Formations. The Brallier Formation conformably overlies the Harrell Formation to within 4 to 5 mi east of drill hole 8, where it conformably overlies the Sonyea Formation. About 25 mi west of drill hole 8, the Brallier Formation crosses an arbitrary boundary into rocks of the Chagrin Shale. The Chagrin Shale (1) continues westward from the arbitrary boundary; (2) intertongues with and climbs over the Rhinestreet and Angola Shale Members of the West Falls Formation, the Java Formation, and the Huron Member of the Ohio Shale; and (3) is replaced by the Three Lick Bed of the Ohio Shale at the western end of the cross section (drill holes 1 and 2). The Harrell Formation is interpreted as an offshore-marine (basin) deposit, whereas the Brallier Formation is interpreted as a marine-basin-slope to turbidite-slope to delta-front deposit (Lundegard and others, 1985; Harper, 1999). The black shales of the Marcellus Formation, Rhinestreet Shale Member, Huron Member, and Dunkirk Member are interpreted as anoxic deposits (Boswell, 1996; Harper, 1999).

A regional Middle to Late Devonian unconformity, described and mapped by de Witt and others (1993), is present throughout all of cross section *C–C′* at the top of the Tully Limestone and at the top of the Hamilton Group where the Tully Limestone is absent (fig. 2). Westward from drill hole 6, where the partially eroded Tully Limestone is overlain by the Upper Devonian Genesee Formation, successively younger Upper Devonian strata downlap on the Middle to Late Devonian unconformity. For example, in drill hole 5, the Upper Devonian Sonyea Formation rests unconformably on the Hamilton Group, whereas farther west, in drill holes 3 and 4, the Upper Devonian Rhinestreet Shale Member of the West Falls Formation rests unconformably on the Hamilton Group. Furthermore, in drill holes 1 and 2, the upper part of the Upper Devonian Olentangy Shale, which is equivalent to the Java Formation, rests unconformably on the Plum Brook Shale and the Prout Limestone.

The Scherr and Foreknobs Formations (which are present from several miles east of drill hole 9 to the flanks of the Schellsburg dome near drill hole 10) consist of sandstone, silty and argillaceous sandstone, and siltstone, whereas the overlying Catskill Formation in the same region consists of red beds of silty sandstone, siltstone, and silty shale. In the vicinity of the Negro Mountain anticline, several red bed tongues of the Catskill Formation extend into the upper part of the Foreknobs Formation. In southwestern Pennsylvania, the equivalent Elk, Bradford, and Venango Groups were used by Harper and Laughrey (1987), Harper (1993), and Harper and others (1999) and correlate approximately with the informal Elk, Bradford, and Venango "plays" recognized by Donaldson and others (1996); Boswell, Thomas, and others (1996); and Boswell, Heim, and others (1996). Most of the sandstone beds of the Scherr and Foreknobs Formations are interpreted as shallow-marine to shoreline, fluvial-deltaic, delta-front, and tidal-flat deposits (Slingerland and Loulé, 1988; Harper, 1999; Dennison, 2005), whereas the red beds are interpreted as subaerially exposed alluvial-plain, fluvial, and fluvial-deltaic deposits (Dennison and others, 1988; Harper, 1999). Sandstones in the Elk and Bradford plays are interpreted as prodeltaic-turbidite and distal-shelf deposits that formed in deeper water (Donaldson and others, 1996; Boswell, Thomas, and others, 1996), whereas sandstones of the Venango play are interpreted as marine-shoreline and wave-dominated delta deposits (Boswell, Heim, and others, 1996).

The Elk Group extends westward from drill hole 9 for about 12 mi, where it changes facies into the upper part of the Brallier Formation. The approximate westward limit of the Elk Group, as interpreted on cross section *C–C′*, coincides reasonably well with a sandstone boundary on the percent siltstone and sandstone maps of Filer (2002, 2003). The Bradford Group extends beyond the Elk Group to a location about 13 mi west of drill hole 8. Red beds that constitute the middle part of the Venango Group are present in drill holes 8 and 9 and extend to about 14 mi beyond drill hole 8. The entire Venango Group extends across much of southwestern Pennsylvania as a 400- to 600-ft-thick sandstone-dominated unit that changes facies into the upper part of the Chagrin Shale about 10 mi east of drill hole 7.

The Catskill Formation (which extends from several miles east of drill hole 9 to the Schellsburg dome) is overlain by the Rockwell Formation, a 400- to 650-ft-thick argillaceous sandstone unit (Kammer and Bjerstedt, 1986; Bjerstedt and Kammer, 1988; Berg, 1999). West of the arbitrary boundary near drill hole 9, the Rockwell Formation is replaced (in ascending order) by the following sandstone and shale units: (1) the upper part of the Venango Group; (2) the Upper Devonian Oswayo Formation; (3) the informal Upper Devonian Murrysville zone of Harper and Laughrey (1987); (4) the Lower Mississippian Cuyahoga Group; and (5) the Lower Mississippian Shenango Formation, which includes the informal Squaw sandstone at the base (Harper and Laughrey, 1987; Berg, 1999). The Oswayo Formation continues to drill hole 8 and several miles beyond, where the formation changes facies to the Riceville Formation. The Murrysville zone of Harper and Laughrey (1987) continues farther west of drill hole 8 to about the Amity anticline, where it changes to the Berea and Cussewago Sandstones (undivided) of Harper and Laughrey (1987). West of drill hole 6, the Cussewago Sandstone continues into Ohio until just past drill hole 5, whereas the Berea Sandstone and the overlying Lower Mississippian Sunbury Shale (as recognized by Pepper and others, 1954; Pashin and Ettensohn, 1995; Tomastik, 1996) continue across eastern Ohio to the end of the cross section (drill holes 1 and 2).

The unconformity shown on cross section *C–C′* at the base of the Berea, Cussewago, and Murrysville zone of Harper and Laughrey (1987) is based largely on the interpretations of Kammer and Bjerstedt (1986), Bjerstedt and Kammer (1988), and Boswell and Jewell (1988) in northern West Virginia (see cross section *D–D′*) and south-central Pennsylvania. Although not recognized by Pashin and Ettensohn (1995) or Slucher (2004) in eastern Ohio, the unconformity at the base of the Berea Sandstone is interpreted in this report to extend a short distance into eastern Ohio to the vicinity of drill hole 5.

Most of the Berea Sandstone in cross section *C–C′* is interpreted as fluvial-deltaic, shallow-marine, and barrier-island deposits derived from the north and east (Pepper and others, 1954; Tomastik, 1996). Sequence-stratigraphic interpretations by Pashin and Ettensohn (1995) suggested that the Berea Sandstone is essentially a lowstand wedge consisting of sand-rich estuary deposits. The sub-Berea unconformity shown on cross section *C–C′* may be related to a eustatic drop in sea level possibly associated with glaciation (Pashin and Ettensohn, 1995).

The Cuyahoga Group in southwestern Pennsylvania (drill holes 7–9) and northernmost West Virginia (drill hole 6) is overlain by the Shenango Formation (Harper and Laughrey, 1987); these two units have a combined thickness of 300 to 350 ft. The Cuyahoga Group correlates with the Cuyahoga Formation in drill hole 5, but the Shenango Formation is absent because of truncation. The Cuyahoga Formation extends across most of northeastern Ohio and crops out between drill holes 2 and 4. East of drill hole 9, the Murrysville zone, Cuyahoga Group, and Shenango Formation correlate with the upper half of the Rockwell Formation. In south-central Pennsylvania (between the Laurel Hill anticline near drill hole 9 and the Schellsburg dome near drill hole 10), the Rockwell Formation is overlain conformably by the 100- to 150-ft-thick Lower Mississippian Burgoon Sandstone (Kammer and Bjerstedt, 1986; Berg, 1999; Brezinski, 1999). Furthermore, in southwestern Pennsylvania (near drill holes 7 and 8), the Shenango Formation (equivalent to the uppermost part of the Rockwell Formation) also is overlain conformably by the Burgoon Sandstone (Harper and Laughrey, 1987). The Burgoon Sandstone (which is known informally as the Big Injun sandstone) extends westward to several miles west of drill hole 6, where the sandstone is truncated by the Lower Pennsylvanian unconformity. This location of the truncated margin of the Burgoon Sandstone is consistent with the northeast-trending truncated margin of the Burgoon shown by Brezinski (1999). The Burgoon Sandstone is interpreted as a braided-fluvial deposit (Berg, 1999; Brezinski, 1999).

Upper Mississippian Carbonate Strata

Upper Mississippian carbonate strata consist of (1) calcareous sandstone and sandy limestone of the Loyalhanna Formation and (2) fossiliferous limestone of the Greenbrier Formation and Wymps Gap Member of the Mauch Chunk Formation. The Upper Mississippian Loyalhanna Formation (fig. 2) rests unconformably (Loyalhanna unconformity) on the Lower Mississippian Burgoon Sandstone from the Schellsburg dome near drill hole 10 (de Witt, 1974), across the Laurel Hill anticline near drill hole 9 (Flint, 1965), to a pinchout near the Pennsylvania-West Virginia border between the No. 10 Matthews and No. 1 McMichael drill holes (Harper and Laughrey, 1987; also located on cross section *C–C′*). South of cross section *C–C′*, the Loyalhanna Formation merges with a 100-ft-thick quartzose sandstone that is informally named the “Greenbrier Big Injun sandstone” (Vargo and Matchen, 1996) at the base of the Upper Mississippian Greenbrier Formation. The Greenbrier Formation on cross section *C–C′* is limited to a small area in and around the No. 1 Duvall drill hole (Harper and Laughrey, 1987; also located on cross section *C–C′*) about 23 mi west of drill hole 8. This locality represents the approximate northernmost extent of the Greenbrier Formation into southwestern Pennsylvania (Smosna, 1996). To the east, the top part of the Greenbrier Formation thins abruptly to a tongue and is replaced by the Wymps Gap Member of the Mauch Chunk Formation (fig. 2) in the Laurel Hill (drill hole 9), Chestnut Ridge, and Negro Mountain anticlines (Hickok and Moyer, 1940; Flint, 1965; Stamm, 2004).

The sandstone-dominated Loyalhanna Formation, which is commonly characterized by units of medium-scale crossbedding, has been interpreted as an eolian deposit (Butts, 1924; Ahlbrandt, 1995; Wynn, 2003), as a marine or coastal sand flat deposit (Flint, 1965;

Adams, 1970; Carney and Smosna, 1989), or as a combination of eolian, sabkha, and wadi deposits (Krezoski and others, 2005). The Greenbrier Formation and the Wymps Gap Member are interpreted as predominantly shallow-water, open-marine deposits (Flint, 1965; Carney and Smosna, 1989; Brezinski, 1999).

Upper Mississippian, Pennsylvanian, and Permian Siliciclastic Strata

The Upper Mississippian, Pennsylvanian, and Permian siliciclastic strata on cross section *C–C′* consist of sandstone, red and gray shale, limestone, and coal (fig. 2). The Upper Mississippian and Pennsylvanian siliciclastic strata are as thick as 1,550 ft, whereas the Permian siliciclastic strata are only as thick as 150 ft (because they are deeply eroded). These Mississippian to Permian strata include the following units (in ascending order): the Mississippian Mauch Chunk Formation; the Pennsylvanian Pottsville Group, Allegheny Group, Conemaugh Group, and Monongahela Group; and the Pennsylvanian to Permian Dunkard Group (see figure 2 for all units except the Monongahela and Dunkard Groups).

The Upper Mississippian to Permian siliciclastic strata are interpreted as predominantly nonmarine sediments derived from an easterly source and deposited in a rapidly subsiding foreland basin. This foreland basin and its sedimentary deposits are associated with the Alleghanian orogeny (Colton, 1970; Milici and de Witt, 1988; Hatcher and others, 1989; Faill, 1997b, 1998).

Along the Pennsylvania part of cross section *C–C′*, the Upper Mississippian Mauch Chunk Formation consists of a 50- to 400-ft-thick unit of gray and red shale, sandstone, and fossiliferous limestone (the previously discussed Wymps Gap Member) that conformably overlies the Loyalhanna Formation (Flint, 1965; de Witt, 1974; Harper and Laughrey, 1987). Westward, the Mauch Chunk Formation thins to a 30-ft-thick shale in northernmost West Virginia (drill hole 6), beyond which the formation is truncated by the overlying Pennsylvanian Pottsville Formation near the Ohio-West Virginia border.

The Lower and Middle Pennsylvanian Pottsville Group (which consists of sandstone; conglomeratic sandstone; sandy, gray shale; gray shale; and minor coal) unconformably overlies the Mauch Chunk Formation in Pennsylvania and the Cuyahoga Formation in Ohio. The widespread unconformity at the base of the Pottsville Group is known by various names that include the basal Pennsylvanian unconformity (Brezinski, 1999), the sub-Pennsylvanian unconformity (Beuthin, 1994), the Mississippian-Pennsylvanian unconformity (Rice and Schwietering, 1988), and the Lower Pennsylvanian unconformity (this report). The Pottsville Group is 150 to 200 ft thick on cross section *C–C′* in Pennsylvania where it crops out along both flanks of the Chestnut Ridge anticline near drill hole 8 and the Laurel Hill anticline near drill hole 9 (Hickok and Moyer, 1940; Flint, 1965) and along the western flank of the Schellsburg dome near drill hole 10. West of drill hole 8, the Pottsville Group extends through the subsurface of southwestern Pennsylvania (drill holes 6 and 7) and part of northeastern Ohio (drill hole 5) and resurfaces in outcrops in northeastern Ohio near drill hole 4. The Pottsville Group may also crop out along the deeply incised valley of the Ohio River along the Ohio-West Virginia border. In northeastern Ohio, the Pottsville Group is difficult to identify as a separate unit (Slucher and Rice, 1994) where it is commonly mapped with the overlying Allegheny Group (for example, Slucher, 1996a; Slucher and Larsen, 1996a; Swinford and Shrake, 1996b). In northeastern Ohio, the Pottsville Group is tentatively recognized in drill hole 4 as a 400-ft-thick unit of sandstone and shale. Between about 4 mi west of drill hole 4 and about 8 mi west of drill hole 3, scattered and discontinuous units of conglomeratic sandstone are mapped as the Sharon Conglomerate of the Pottsville Group (Fuller, 1955). Pottsville Group strata are interpreted as being primarily fluvial in origin (Presley, 1979; Edmunds and others, 1979, 1999; Rice and Schwietering, 1988), but thin beds of shale and limestone with brackish-water and marine fauna have been reported in western Pennsylvania (Edmunds and others, 1979, 1999) and in northeastern Ohio (Slucher and Rice, 1994).

The Middle Pennsylvanian Allegheny Group (which consists of gray shale, sandstone, coal, and local thin limestone) conformably overlies the Pottsville Group. Along cross section *C–C′*, the Allegheny Group extends more or less continuously as a 150- to 350-ft-thick unit in Pennsylvania, except where the group has been eroded along the crest of the Laurel Hill anticline in drill hole 9 (Flint, 1965), along the crest of the Chestnut Ridge anticline in drill hole 8 (Hickok and Moyer, 1940), and on the western flank of the Schellsburg dome near drill hole 10. The Allegheny Group extends into northeastern Ohio (with approximately the same thickness) to a belt of scattered outcrops about 1 to 4 mi east of drill hole 4. Prominent coal beds in the Allegheny Group (Lower and Middle Kittanning coal beds and Upper Freeport coal bed) have been identified along parts of the cross section in Pennsylvania (Hickok and Moyer, 1940; Flint, 1965; Wagner, Heyman, and others, 1975) and in Ohio (Larsen and Rea, 1990; Slucher and Larsen, 1990). Strata of the Allegheny Group are interpreted as alluvial-plain, delta-plain, marginal-marine, and peat-swamp deposits (Edmunds and others, 1979, 1999).

Conformably overlying the Allegheny Group is the Upper Pennsylvanian Conemaugh Group (which consists of gray and red shale, sandstone, and coal). The Conemaugh Group forms a relatively continuous 450- to 550-ft-thick unit that crosses western Pennsylvania from near drill hole 8 to about 12 mi east of drill hole 7. Between drill holes 8 and 10, incomplete sections of the Conemaugh Group are preserved in synclinal structures. West of drill hole 7, the Conemaugh Group occurs as discontinuous sections in scattered outcrops across northernmost West Virginia (drill hole 6) and easternmost Ohio (drill hole 5) and extends as far west as 6 mi west of drill hole 5. The Conemaugh

Group is overlain conformably by the Upper Pennsylvanian Monongahela Group, which is overlain in turn by the Upper Pennsylvanian to Lower Permian Dunkard Group. The Dunkard Group is the youngest Paleozoic strata preserved in the Appalachian basin (Berryhill and others, 1971; Harper and Laughrey, 1987; Edmunds, 1999). Both the Monongahela and Dunkard Groups consist largely of gray to red shale, sandstone, limestone, and coal. Several limestone beds as much as 40 ft thick are reported in the Monongahela Group in a region on cross section *C–C′* about midway between the No. 1 Duvall drill hole and the No. 10 McDonald drill hole (Wagner, Craft, and others, 1975). The thickest and most widespread of the coal beds in the Monongahela to Dunkard interval is the Pittsburgh coal bed, which is located at the base of the Monongahela Group (Berryhill and Swanson, 1962). The Pittsburgh coal bed is as much as 9 to 10 ft thick in the Uniontown syncline (Hickok and Moyer, 1940; Tewalt and others, 1997) and thins to 1 to 2 ft near the outcrop limit of the Monongahela Group southeast of drill holes 7 and 8 (Tewalt and others, 1997).

Donaldson (1974), Edmunds and others (1979, 1999), and Edmunds (1999) interpreted the siliciclastic and carbonate strata in the Monongahela Group and Dunkard Group as alluvial-plain, delta-plain, lacustrine, and marginal-lacustrine deposits, whereas Cecil and others (1985) interpreted the coal beds as topogenous, planar-swamp deposits that accumulated under humid climate conditions.

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Appendix A.—Table Summarizing Drill Holes, Stratigraphic Units, and Depths of Stratigraphic Units in Cross Section *C–C′*

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	**1**	**2**	**3**	**4**	**5**
American Petroleum Institute number	**34–043–20011**	**34–093–20794**	**34–103–21143**	**34–151–21081**	**34–029–20648**
Lease name	**No. 1 Krysik-Wakefield**	**No. 1 A and A Born**	**No. 1–A F.L. Smith Estate**	**No. 1–381 B. Westfall**	**No. 3 Frank Murray**
Permanent datum	**Ground level**	**NA**	**Ground level**	**Ground level**	**Ground level**
Ground level elevation (ft)	**822.45**	**848**	**1,185.5**	**1,137.3**	**1,183.3**
Kelly bushing elevation (ft)	**828.45**	**848**	**1,200**	**1,144.3**	**1,193**
Measured from	**KB (6 ft APD)**	**GL**	**KB (14.5 ft APD)**	**KB (7 ft APD)**	**KB (9.7 ft APD)**
Drill depth (ft)	**4,463**	**4,591**	**7,040**	**7,961**	**10,242**
KB elevation - GL elevation (ft)	**6.0**	**0.0**	**14.5**	**7.0**	**9.7**
Formation 1	Berea Sandstone	Sunbury Shale	Sharon Conglomerate of Pottsville Group	Pottsville Group	Conemaugh Group
System or series	Upper Devonian	Lower Mississippian	Lower Pennsylvanian	Lower Pennsylvanian	Middle to Upper Pennsylvanian
Formation top (relative to KB) (ft)	-6	0	-14.5	-7	-9.7
Formation top (relative to GL) (ft)	0	0	0	0	0
Formation top (relative to SL) (ft)	822.45	848	1,185.5	1,137.3	1,193
Formation 2	Bedford Shale	Berea Sandstone	Cuyahoga Formation	Cuyahoga Formation	Allegheny Group
System or series	Upper Devonian	Upper Devonian	Lower Mississippian	Lower Mississippian	Middle Pennsylvanian
Formation top (relative to KB) (ft)	-10	-40	-55	-340	-20
Formation top (relative to GL) (ft)	-4	-40	-40.5	-333	-10.3
Formation top (relative to SL) (ft)	818.45	808	1,145	804.3	1,173
Formation 3	Cleveland Member of Ohio Shale	Bedford Shale	Sunbury Shale	Sunbury Shale	Pottsville Group
System or series	Upper Devonian	Upper Devonian	Lower Mississippian	Lower Mississippian	Lower Pennsylvanian
Formation top (relative to KB) (ft)	-60	-100	-380	-635	-190
Formation top (relative to GL) (ft)	-54	-100	-365.5	-628	-180.3
Formation top (relative to SL) (ft)	768.45	748	820	509.3	1,003
Formation 4	Three Lick Bed of Ohio Shale	Cleveland Member of Ohio Shale	Berea Sandstone	Berea Sandstone	Cuyahoga Formation (upper part)
System or series	Upper Devonian	Upper Devonian	Upper Devonian	Upper Devonian	Lower Mississippian
Formation top (relative to KB) (ft)	-107	-150	-390	-657	-450
Formation top (relative to GL) (ft)	-101	-150	-375.5	-650	-440.3
Formation top (relative to SL) (ft)	721.45	698	810	487.3	743

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	**6**	**7**	**8**	**9**	**10**	**11**
American Petroleum Institute number	**47–029–00080**	**37–007–20060**	**37–051–20056**	**37–111–20045**	**37–009–20034**	**37–009–20060**
Lease name	**No. 1 S. Minesinger**	**No. 1 Richard J. Ashcroft**	**No. 1 E.C. Ricks**	**No. 1 Leonard Svetz**	**No. 1 Schellsburg**	**No. 1 Fred Steele**
Permanent datum	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**
Ground level elevation (ft)	**1,039**	**1,120**	**2,523**	**2,450**	**1,650**	**1,162**
Kelly bushing elevation (ft)	**1,052**	**1,130**	**2,539**	**2,473**	**1,663**	**1,189**
Measured from	**KB (13 ft APD)**	**KB (10 ft APD)**	**KB (16 ft APD)**	**KB (23 ft APD)**	**KB (13 ft APD)**	**GL**
Drill depth (ft)	**10,387**	**7,590**	**12,041**	**21,460**	**11,850**	**15,500**
KB elevation - GL elevation (ft)	**13.0**	**10.0**	**16.0**	**23.0**	**13.0**	**27.0**
Formation 1	Conemaugh Group	Conemaugh Group	Burgoon Sandstone (Big Injun sandstone)	Mauch Chunk Formation (upper part)	Shriver Formation	Beekmantown Group
System or series	Middle to Upper Pennsylvanian	Middle to Upper Pennsylvanian	Lower Mississippian	Upper Mississippian	Lower Devonian	Lower to Middle Ordovician
Formation top (relative to KB) (ft)	-13	-10	-16	-23	-13	0
Formation top (relative to GL) (ft)	0	0	0	0	0	0
Formation top (relative to SL) (ft)	1,039	1,120	2,523	2,450	1,650	1,162
Formation 2	Allegheny Group	Allegheny Group	Shenango Formation	Wymps Gap Limestone Member	Mandata Shale	Mines Dolomite Member of Gatesburg Formation
System or series	Middle Pennsylvanian	Middle Pennsylvanian	Lower Mississippian	Upper Mississippian	Lower Devonian	Upper Cambrian
Formation top (relative to KB) (ft)	-25	-230	-130	-235	-50	-870
Formation top (relative to GL) (ft)	-12	-220	-114	-212	-37	-870
Formation top (relative to SL) (ft)	1,027	900	2,409	2,238	1,613	292
Formation 3	Pottsville Group	Pottsville Group	Shenango Formation (Squaw sandstone)	Mauch Chunk Formation (lower part)	Corriganville and New Creek Limestones (undivided)	Gatesburg Formation (upper sandy member)
System or series	Lower Pennsylvanian	Lower Pennsylvanian	Lower Mississippian	Middle Mississippian	Lower Devonian	Upper Cambrian
Formation top (relative to KB) (ft)	-368	-565	-215	-310	-93	-1,065
Formation top (relative to GL) (ft)	-355	-555	-199	-287	-80	-1,065
Formation top (relative to SL) (ft)	684	565	2,324	2,163	1,570	97
Formation 4	Mauch Chunk Formation	Mauch Chunk Formation	Cuyahoga Group	Loyalhanna Formation	Keyser Formation	Ore Hill Limestone Member of Gatesburg Formation
System or series	Middle to Upper Mississippian	Middle to Upper Mississippian	Lower Mississippian	Middle Mississippian	Upper Silurian to Lower Devonian	Upper Cambrian
Formation top (relative to KB) (ft)	-560	-720	-340	-365	-160	-2,400
Formation top (relative to GL) (ft)	-547	-710	-324	-342	-147	-2,400
Formation top (relative to SL) (ft)	492	410	2,199	2,108	1,503	-1,238

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	**1**	**2**	**3**	**4**	**5**
American Petroleum Institute number	**34–043–20011**	**34–093–20794**	**34–103–21143**	**34–151–21081**	**34–029–20648**
Lease name	**No. 1 Krysik-Wakefield**	**No. 1 A and A Born**	**No. 1–A F.L. Smith Estate**	**No. 1–381 B. Westfall**	**No. 3 Frank Murray**
Permanent datum	**Ground level**	**NA**	**Ground level**	**Ground level**	**Ground level**
Ground level elevation (ft)	**822.45**	**848**	**1,185.5**	**1,137.3**	**1,183.3**
Kelly bushing elevation (ft)	**828.45**	**848**	**1,200**	**1,144.3**	**1,193**
Measured from	**KB (6 ft APD)**	**GL**	**KB (14.5 ft APD)**	**KB (7 ft APD)**	**KB (9.7 ft APD)**
Drill depth (ft)	**4,463**	**4,591**	**7,040**	**7,961**	**10,242**
KB elevation - GL elevation (ft)	**6.0**	**0.0**	**14.5**	**7.0**	**9.7**
Formation 5	Huron Member of Ohio Shale	Three Lick Bed of Ohio Shale	Bedford Shale	Bedford Shale	Cuyahoga Formation (unnamed sandstone)
System or series	Upper Devonian	Upper Devonian	Upper Devonian	Upper Devonian	Lower Mississippian
Formation top (relative to KB) (ft)	-255	-190	-440	-684	-498
Formation top (relative to GL) (ft)	-249	-190	-425.5	-677	-488.3
Formation top (relative to SL) (ft)	573.45	658	760	460.3	695
Formation 6	Olentangy Shale (upper part)	Huron Member of Ohio Shale	Cleveland Member of Ohio Shale	Chagrin Shale	Cuyahoga Formation (lower part)
System or series	Upper Devonian	Upper Devonian	Upper Devonian	Upper Devonian	Lower Mississippian
Formation top (relative to KB) (ft)	-518	-290	-513	-697	-540
Formation top (relative to GL) (ft)	-512	-290	-498.5	-690	-530.3
Formation top (relative to SL) (ft)	310.45	558	687	447.3	653
Formation 7	Prout Limestone and Plum Brook Shale (undivided)	Olentangy Shale (upper part)	Chagrin Shale	Huron Member of Ohio Shale	Sunbury Shale
System or series	Middle Devonian	Upper Devonian	Upper Devonian	Upper Devonian	Lower Mississippian
Formation top (relative to KB) (ft)	-553	-610	-536	-1,942	-712
Formation top (relative to GL) (ft)	-547	-610	-521.5	-1,935	-702.3
Formation top (relative to SL) (ft)	275.45	238	664	-797.7	481
Formation 8	Delaware Limestone	Prout Limestone and Plum Brook Shale (undivided)	Huron Member of Ohio Shale	Java Formation	Berea Sandstone
System or series	Middle Devonian	Middle Devonian	Upper Devonian	Upper Devonian	Upper Devonian
Formation top (relative to KB) (ft)	-635	-650	-1,398	-2,380	-723
Formation top (relative to GL) (ft)	-629	-650	-1,383.5	-2,373	-713.3
Formation top (relative to SL) (ft)	193.45	198	-198	-1,235.7	470

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	**6**	**7**	**8**	**9**	**10**	**11**
American Petroleum Institute number	**47–029–00080**	**37–007–20060**	**37–051–20056**	**37–111–20045**	**37–009–20034**	**37–009–20060**
Lease name	**No. 1 S. Minesinger**	**No. 1 Richard J. Ashcroft**	**No. 1 E.C. Ricks**	**No. 1 Leonard Svetz**	**No. 1 Schellsburg**	**No. 1 Fred Steele**
Permanent datum	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**
Ground level elevation (ft)	**1,039**	**1,120**	**2,523**	**2,450**	**1,650**	**1,162**
Kelly bushing elevation (ft)	**1,052**	**1,130**	**2,539**	**2,473**	**1,663**	**1,189**
Measured from	**KB (13 ft APD)**	**KB (10 ft APD)**	**KB (16 ft APD)**	**KB (23 ft APD)**	**KB (13 ft APD)**	**GL**
Drill depth (ft)	**10,387**	**7,590**	**12,041**	**21,460**	**11,850**	**15,500**
KB elevation - GL elevation (ft)	**13.0**	**10.0**	**16.0**	**23.0**	**13.0**	**27.0**
Formation 5	Burgoon Sandstone	Burgoon Sandstone (Big Injun sandstone)	Murrysville zone of Harper and Laughrey (1987)	Burgoon Sandstone	Tonoloway Formation	Gatesburg Formation (lower sandy member)
System or series	Lower Mississippian	Lower Mississippian	Upper Devonian to Lower Mississippian	Lower Mississippian	Upper Silurian	Upper Cambrian
Formation top (relative to KB) (ft)	-592	-748	-500	-450	-410	-2,593
Formation top (relative to GL) (ft)	-579	-738	-484	-427	-397	-2,593
Formation top (relative to SL) (ft)	460	382	2,039	2,023	1,253	-1,431
Formation 6	Shenango Formation (upper part)	Shenango Formation	Oswayo Formation	Shenango Formation	Wills Creek Formation	Warrior Formation (limestone member)
System or series	Lower Mississippian	Lower Mississippian	Upper Devonian	Lower Mississippian	Upper Silurian	Middle and Upper Cambrian
Formation top (relative to KB) (ft)	-636	-834	-605	-570	-1,038	-3,460
Formation top (relative to GL) (ft)	-623	-824	-589	-547	-1,025	-3,460
Formation top (relative to SL) (ft)	416	296	1,934	1,903	625	-2,298
Formation 7	Shenango Formation (Squaw sandstone)	Shenango Formation (Squaw sandstone)	Venango Group (upper part) (sandy)	Shenango Formation (Squaw sandstone)	Bloomsburg Formation	Warrior Formation (dolomite member)
System or series	Lower Mississippian	Lower Mississippian	Upper Devonian	Lower Mississippian	Upper Silurian	Middle Cambrian
Formation top (relative to KB) (ft)	-692	-908	-670	-600	-1,430	-3,842
Formation top (relative to GL) (ft)	-679	-898	-654	-577	-1,417	-3,842
Formation top (relative to SL) (ft)	360	222	1,869	1,873	233	-2,680
Formation 8	Cuyahoga Formation (upper part)	Cuyahoga Group (upper part)	Venango Group (middle part) (shale)	Cuyahoga Group	McKenzie Member (upper part) of Mifflintown Formation	Pleasant Hill Formation
System or series	Lower Mississippian	Lower Mississippian	Upper Devonian	Lower Mississippian	Upper Silurian	Middle Cambrian
Formation top (relative to KB) (ft)	-722	-922	-807	-688	-1,460	-4,860
Formation top (relative to GL) (ft)	-709	-912	-791	-665	-1,447	-4,860
Formation top (relative to SL) (ft)	330	208	1,732	1,785	203	-3,698

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	**1**	**2**	**3**	**4**	**5**
American Petroleum Institute number	**34–043–20011**	**34–093–20794**	**34–103–21143**	**34–151–21081**	**34–029–20648**
Lease name	**No. 1 Krysik-Wakefield**	**No. 1 A and A Born**	**No. 1–A F.L. Smith Estate**	**No. 1–381 B. Westfall**	**No. 3 Frank Murray**
Permanent datum	**Ground level**	**NA**	**Ground level**	**Ground level**	**Ground level**
Ground level elevation (ft)	**822.45**	**848**	**1,185.5**	**1,137.3**	**1,183.3**
Kelly bushing elevation (ft)	**828.45**	**848**	**1,200**	**1,144.3**	**1,193**
Measured from	**KB (6 ft APD)**	**GL**	**KB (14.5 ft APD)**	**KB (7 ft APD)**	**KB (9.7 ft APD)**
Drill depth (ft)	**4,463**	**4,591**	**7,040**	**7,961**	**10,242**
KB elevation - GL elevation (ft)	**6.0**	**0.0**	**14.5**	**7.0**	**9.7**
Formation 9	Columbus Limestone	Delaware Limestone	Java Formation	Angola Shale Member of West Falls Formation	Cussewago Sandstone
System or series	Middle Devonian	Middle Devonian	Upper Devonian	Upper Devonian	Upper Devonian
Formation top (relative to KB) (ft)	-668	-735	-1,650	-2,512	-765
Formation top (relative to GL) (ft)	-662	-735	-1,635.5	-2,505	-755.3
Formation top (relative to SL) (ft)	160.45	113	-450	-1,367.7	428
Formation 10	Detroit River Group	Columbus Limestone	Angola Shale Member of West Falls Formation	Rhinestreet Shale Member of West Falls Formation	Chagrin Shale (upper part) (sandy shale)
System or series	Middle Devonian	Middle Devonian	Upper Devonian	Upper Devonian	Upper Devonian
Formation top (relative to KB) (ft)	-788	-765	-1,688	-2,590	-789
Formation top (relative to GL) (ft)	-782	-765	-1,673.5	-2,583	-779.3
Formation top (relative to SL) (ft)	40.45	83	-488	-1,445.7	404
Formation 11	Bois Blanc Formation(?)	Detroit River Group	Rhinestreet Shale Member of West Falls Formation	Mahantango Formation of Hamilton Group	Chagrin Shale (middle part) (silty shale)
System or series	Lower Devonian	Middle Devonian	Upper Devonian	Middle Devonian	Upper Devonian
Formation top (relative to KB) (ft)	-850	-890	-1,748	-2,700	-1,305
Formation top (relative to GL) (ft)	-844	-890	-1,733.5	-2,693	-1,295.3
Formation top (relative to SL) (ft)	-21.55	-42	-548	-1,555.7	-112
Formation 12	Bass Islands Dolomite	Bois Blanc Formation(?)	Mahantango Formation of Hamilton Group	Marcellus Shale of Hamilton Group	Chagrin Shale (lower part) (shale)
System or series	Upper Silurian	Lower Devonian	Middle Devonian	Middle Devonian	Upper Devonian
Formation top (relative to KB) (ft)	-910	-955	-1,785	-2,820	-2,507
Formation top (relative to GL) (ft)	-904	-955	-1,770.5	-2,813	-2,497.3
Formation top (relative to SL) (ft)	-81.55	-107	-585	-1,675.7	-1,314

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	**6**	**7**	**8**	**9**	**10**	**11**
American Petroleum Institute number	**47–029–00080**	**37–007–20060**	**37–051–20056**	**37–111–20045**	**37–009–20034**	**37–009–20060**
Lease name	**No. 1 S. Minesinger**	**No. 1 Richard J. Ashcroft**	**No. 1 E.C. Ricks**	**No. 1 Leonard Svetz**	**No. 1 Schellsburg**	**No. 1 Fred Steele**
Permanent datum	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**
Ground level elevation (ft)	**1,039**	**1,120**	**2,523**	**2,450**	**1,650**	**1,162**
Kelly bushing elevation (ft)	**1,052**	**1,130**	**2,539**	**2,473**	**1,663**	**1,189**
Measured from	**KB (13 ft APD)**	**KB (10 ft APD)**	**KB (16 ft APD)**	**KB (23 ft APD)**	**KB (13 ft APD)**	**GL**
Drill depth (ft)	**10,387**	**7,590**	**12,041**	**21,460**	**11,850**	**15,500**
KB elevation - GL elevation (ft)	**13.0**	**10.0**	**16.0**	**23.0**	**13.0**	**27.0**
Formation 9	Cuyahoga Formation (unnamed sandstone)	Cuyahoga Group (unnamed sandstone)	Venango Group (lower part) (sandy)	Murrysville zone of Harper and Laughrey (1987)	Rabble Run Member of Bloomsburg Formation	Waynesboro Formation (sandstone member)
System or series	Lower Mississippian	Lower Mississippian	Upper Devonian	Upper Devonian to Lower Mississippian	Upper Silurian	Lower to Middle Cambrian
Formation top (relative to KB) (ft)	-810	-1,060	-1,158	-803	-1,575	-5,355
Formation top (relative to GL) (ft)	-797	-1,050	-1,142	-780	-1,562	-5,355
Formation top (relative to SL) (ft)	242	70	1,381	1,670	88	-4,193
Formation 10	Cuyahoga Formation (lower part)	Cuyahoga Group (lower part)	Chadakoin Formation	Oswayo Formation	McKenzie Member (lower part) of Mifflintown Formation	Waynesboro Formation
System or series	Lower Mississippian	Lower Mississippian	Upper Devonian	Upper Devonian	Lower Silurian	Lower to Middle Cambrian
Formation top (relative to KB) (ft)	-860	-1,082	-1,387	-865	-1,590	-5,500
Formation top (relative to GL) (ft)	-847	-1,072	-1,371	-842	-1,577	-5,500
Formation top (relative to SL) (ft)	192	48	1,152	1,608	73	-4,338
Formation 11	Sunbury Shale equivalent of Harper and Laughrey (1987)	Sunbury Shale equivalent of Harper and Laughrey (1987)	Bradford Group	Venango Group (upper part) (sandy)	Keefer Formation and Rochester Member of Mifflintown Formation (undivided)	Pleasant Hill Formation (top of zone of imbricate thrust faults)
System or series	Lower Mississippian	Lower Mississippian	Upper Devonian	Upper Devonian	Lower Silurian	Middle Cambrian
Formation top (relative to KB) (ft)	-888	-1,146	-1,830	-1,000	-1,848	-5,617
Formation top (relative to GL) (ft)	-875	-1,136	-1,814	-977	-1,835	-5,617
Formation top (relative to SL) (ft)	164	-16	709	1,473	-185	-4,455
Formation 12	Berea and Cussewago Sandstones (undivided) as used by Harper and Laughrey (1987)	Berea and Cussewago Sandstones (undivided) as used by Harper and Laughrey (1987)	Brallier Formation	Venango Group (middle part) (shale)	Rose Hill Formation (upper part)	Pleasant Hill Formation (thrust fault at top)
System or series	Upper Devonian	Upper Devonian	Upper Devonian	Upper Devonian	Lower Silurian	Middle Cambrian
Formation top (relative to KB) (ft)	-912	-1,172	-2,560	-1,228	-1,920	-6,100
Formation top (relative to GL) (ft)	-899	-1,162	-2,544	-1,205	-1,907	-6,100
Formation top (relative to SL) (ft)	140	-42	-21	1,245	-257	-4,938

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	**1**	**2**	**3**	**4**	**5**
American Petroleum Institute number	**34–043–20011**	**34–093–20794**	**34–103–21143**	**34–151–21081**	**34–029–20648**
Lease name	**No. 1 Krysik-Wakefield**	**No. 1 A and A Born**	**No. 1–A F.L. Smith Estate**	**No. 1–381 B. Westfall**	**No. 3 Frank Murray**
Permanent datum	**Ground level**	**NA**	**Ground level**	**Ground level**	**Ground level**
Ground level elevation (ft)	**822.45**	**848**	**1,185.5**	**1,137.3**	**1,183.3**
Kelly bushing elevation (ft)	**828.45**	**848**	**1,200**	**1,144.3**	**1,193**
Measured from	**KB (6 ft APD)**	**GL**	**KB (14.5 ft APD)**	**KB (7 ft APD)**	**KB (9.7 ft APD)**
Drill depth (ft)	**4,463**	**4,591**	**7,040**	**7,961**	**10,242**
KB elevation - GL elevation (ft)	**6.0**	**0.0**	**14.5**	**7.0**	**9.7**
Formation 13	Salina Group	Bass Islands Dolomite	Marcellus Shale of Hamilton Group	Onondaga Limestone	Dunkirk Shale Member of Perrysburg Formation
System or series	Upper Silurian	Upper Silurian	Middle Devonian	Middle Devonian	Upper Devonian
Formation top (relative to KB) (ft)	-970	-1,005	-1,892	-2,830	-2,880
Formation top (relative to GL) (ft)	-964	-1,005	-1,877.5	-2,823	-2,870.3
Formation top (relative to SL) (ft)	-141.55	-157	-692	-1,685.7	-1,687
Formation 14	Lockport Dolomite	Salina Group	Onondaga Limestone	Oriskany Sandstone	Java Formation
System or series	Lower to Upper Silurian	Upper Silurian	Middle Devonian	Lower Devonian	Upper Devonian
Formation top (relative to KB) (ft)	-1,590	-1,087	-1,900	-3,100	-2,900
Formation top (relative to GL) (ft)	-1,584	-1,087	-1,885.5	-3,093	-2,890.3
Formation top (relative to SL) (ft)	-761.55	-239	-700	-1,955.7	-1,707
Formation 15	Rochester Shale	Lockport Dolomite	Oriskany Sandstone	Helderberg Limestone	Angola Shale Member of West Falls Formation
System or series	Lower Silurian	Lower to Upper Silurian	Lower Devonian	Lower Devonian	Upper Devonian
Formation top (relative to KB) (ft)	-1,780	-1,700	-2,180	-3,120	-3,070
Formation top (relative to GL) (ft)	-1,774	-1,700	-2,165.5	-3,113	-3,060.3
Formation top (relative to SL) (ft)	-951.55	-852	-980	-1,975.7	-1,877
Formation 16	Lower Silurian carbonates and shales (undivided)	Rochester Shale	Helderberg Limestone	Bass Islands Dolomite	Rhinestreet Shale Member of West Falls Formation
System or series	Lower Silurian	Lower Silurian	Lower Devonian	Upper Silurian	Upper Devonian
Formation top (relative to KB) (ft)	-1,800	-1,880	-2,200	-3,278	-3,332
Formation top (relative to GL) (ft)	-1,794	-1,880	-2,185.5	-3,271	-3,322.3
Formation top (relative to SL) (ft)	-971.55	-1,032	-1,000	-2,133.7	-2,139

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	**6**	**7**	**8**	**9**	**10**	**11**
American Petroleum Institute number	**47–029–00080**	**37–007–20060**	**37–051–20056**	**37–111–20045**	**37–009–20034**	**37–009–20060**
Lease name	**No. 1 S. Minesinger**	**No. 1 Richard J. Ashcroft**	**No. 1 E.C. Ricks**	**No. 1 Leonard Svetz**	**No. 1 Schellsburg**	**No. 1 Fred Steele**
Permanent datum	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**
Ground level elevation (ft)	**1,039**	**1,120**	**2,523**	**2,450**	**1,650**	**1,162**
Kelly bushing elevation (ft)	**1,052**	**1,130**	**2,539**	**2,473**	**1,663**	**1,189**
Measured from	**KB (13 ft APD)**	**KB (10 ft APD)**	**KB (16 ft APD)**	**KB (23 ft APD)**	**KB (13 ft APD)**	**GL**
Drill depth (ft)	**10,387**	**7,590**	**12,041**	**21,460**	**11,850**	**15,500**
KB elevation - GL elevation (ft)	**13.0**	**10.0**	**16.0**	**23.0**	**13.0**	**27.0**
Formation 13	Chagrin Shale (upper part) (sandy shale)	Chagrin Shale (upper part) (sandy shale)	Sonyea Formation	Venango Group (lower part) (sandy)	Rose Hill Formation (sandstone)	Waynesboro Formation (sandstone member)
System or series	Upper Devonian	Upper Devonian	Upper Devonian	Upper Devonian	Lower Silurian	Lower to Middle Cambrian
Formation top (relative to KB) (ft)	-972	-1,244	-6,580	-1,490	-2,480	-6,510
Formation top (relative to GL) (ft)	-959	-1,234	-6,564	-1,467	-2,467	-6,510
Formation top (relative to SL) (ft)	80	-114	-4,041	983	-817	-5,348
Formation 14	Chagrin Shale (middle part) (silty shale)	Chagrin Shale (middle part) (silty shale)	Genesee Formation	Chadakoin Formation	Rose Hill Formation (lower part)	Pleasant Hill Formation (thrust fault at top)
System or series	Upper Devonian	Upper Devonian	Upper Devonian	Upper Devonian	Lower Silurian	Middle Cambrian
Formation top (relative to KB) (ft)	-1,535	-1,796	-7,018	-1,852	-2,532	-6,700
Formation top (relative to GL) (ft)	-1,522	-1,786	-7,002	-1,829	-2,519	-6,700
Formation top (relative to SL) (ft)	-483	-666	-4,479	621	-869	-5,538
Formation 15	Chagrin Shale (lower part) (shale)	Chagrin Shale (lower part) (shale)	Tully Limestone	Bradford Group	Castanea Member of Tuscarora Formation	Beekmantown Group (lower anhydritic dolomite?) (thrust fault at top)
System or series	Upper Devonian	Upper Devonian	Middle Devonian	Upper Devonian	Lower Silurian	Lower Ordovician
Formation top (relative to KB) (ft)	-2,583	-2,935	-7,240	-1,950	-2,680	-7,327
Formation top (relative to GL) (ft)	-2,570	-2,925	-7,224	-1,927	-2,667	-7,327
Formation top (relative to SL) (ft)	-1,531	-1,805	-4,701	523	-1,017	-6,165
Formation 16	Dunkirk Shale Member of Perrysburg Formation	Dunkirk Shale Member of Perrysburg Formation	Mahantango Formation of Hamilton Group	Elk Group	Tuscarora Formation	Beekmantown Group (dolomite in lower part)
System or series	Upper Devonian	Upper Devonian	Middle Devonian	Upper Devonian	Lower Silurian	Lower Ordovician
Formation top (relative to KB) (ft)	-3,390	-3,724	-7,345	-3,200	-2,728	-8,050
Formation top (relative to GL) (ft)	-3,377	-3,714	-7,329	-3,177	-2,715	-8,050
Formation top (relative to SL) (ft)	-2,338	-2,594	-4,806	-727	-1,065	-6,888

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	1	2	3	4	5
American Petroleum Institute number	34–043–20011	34–093–20794	34–103–21143	34–151–21081	34–029–20648
Lease name	No. 1 Krysik-Wakefield	No. 1 A and A Born	No. 1–A F.L. Smith Estate	No. 1–381 B. Westfall	No. 3 Frank Murray
Permanent datum	Ground level	NA	Ground level	Ground level	Ground level
Ground level elevation (ft)	822.45	848	1,185.5	1,137.3	1,183.3
Kelly bushing elevation (ft)	828.45	848	1,200	1,144.3	1,193
Measured from	KB (6 ft APD)	GL	KB (14.5 ft APD)	KB (7 ft APD)	KB (9.7 ft APD)
Drill depth (ft)	4,463	4,591	7,040	7,961	10,242
KB elevation - GL elevation (ft)	6.0	0.0	14.5	7.0	9.7
Formation 17	Cabot Head Shale	Lower Silurian carbonates and shales (undivided)	Bass Islands Dolomite	Salina Group (upper part)	Sonyea Formation
System or series	Lower Silurian	Lower Silurian	Upper Silurian	Upper Silurian	Upper Devonian
Formation top (relative to KB) (ft)	-1,830	-1,900	-2,265	-3,305	-3,470
Formation top (relative to GL) (ft)	-1,824	-1,900	-2,250.5	-3,298	-3,460.3
Formation top (relative to SL) (ft)	-1,001.55	-1,052	-1,065	-2,160.7	-2,277
Formation 18	Brassfield Limestone	Cabot Head Shale	Salina Group (upper part)	Salina Group (halite zone)	Mahantango Formation of Hamilton Group
System or series	Lower Silurian	Lower Silurian	Upper Silurian	Upper Silurian	Middle Devonian
Formation top (relative to KB) (ft)	-1,908	-1,925	-2,309	-3,503	-3,530
Formation top (relative to GL) (ft)	-1,902	-1,925	-2,294.5	-3,496	-3,520.3
Formation top (relative to SL) (ft)	-1,079.55	-1,077	-1,109	-2,358.7	-2,337
Formation 19	Queenston Shale	Brassfield Limestone	Salina Group (halite zone?)	Salina Group (lower part)	Marcellus Shale of Hamilton Group
System or series	Upper Ordovician	Lower Silurian	Upper Silurian	Upper Silurian	Middle Devonian
Formation top (relative to KB) (ft)	-1,968	-2,012	-2,630	-3,900	-3,690
Formation top (relative to GL) (ft)	-1,962	-2,012	-2,615.5	-3,893	-3,680.3
Formation top (relative to SL) (ft)	-1,139.55	-1,164	-1,430	-2,755.7	-2,497
Formation 20	Cincinnati group	Queenston Shale	Salina Group (lower part)	Lockport Dolomite	Onondaga Limestone
System or series	Upper Ordovician	Upper Ordovician	Upper Silurian	Lower to Upper Silurian	Middle Devonian
Formation top (relative to KB) (ft)	-2,211	-2,070	-2,760	-4,163	-3,708
Formation top (relative to GL) (ft)	-2,205	-2,070	-2,745.5	-4,156	-3,698.3
Formation top (relative to SL) (ft)	-1,382.55	-1,222	-1,560	-3,018.7	-2,515

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	**6**	**7**	**8**	**9**	**10**	**11**
American Petroleum Institute number	**47–029–00080**	**37–007–20060**	**37–051–20056**	**37–111–20045**	**37–009–20034**	**37–009–20060**
Lease name	**No. 1 S. Minesinger**	**No. 1 Richard J. Ashcroft**	**No. 1 E.C. Ricks**	**No. 1 Leonard Svetz**	**No. 1 Schellsburg**	**No. 1 Fred Steele**
Permanent datum	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**
Ground level elevation (ft)	**1,039**	**1,120**	**2,523**	**2,450**	**1,650**	**1,162**
Kelly bushing elevation (ft)	**1,052**	**1,130**	**2,539**	**2,473**	**1,663**	**1,189**
Measured from	**KB (13 ft APD)**	**KB (10 ft APD)**	**KB (16 ft APD)**	**KB (23 ft APD)**	**KB (13 ft APD)**	**GL**
Drill depth (ft)	**10,387**	**7,590**	**12,041**	**21,460**	**11,850**	**15,500**
KB elevation - GL elevation (ft)	**13.0**	**10.0**	**16.0**	**23.0**	**13.0**	**27.0**
Formation 17	Java Formation	Java Formation	Marcellus Formation of Hamilton Group	Brallier Formation	Rose Hill Formation (upper part) (fault at top)	Mines Dolomite Member of Gatesburg Formation
System or series	Upper Devonian	Upper Devonian	Middle Devonian	Upper Devonian	Lower Silurian	Upper Cambrian
Formation top (relative to KB) (ft)	-3,420	-3,746	-7,620	-4,310	-2,810	-10,360
Formation top (relative to GL) (ft)	-3,407	-3,736	-7,604	-4,287	-2,797	-10,360
Formation top (relative to SL) (ft)	-2,368	-2,616	-5,081	-1,837	-1,147	-9,198
Formation 18	Angola Shale Member of West Falls Formation	Angola Shale Member of West Falls Formation	Onondaga Formation	Harrell Formation (Sonyea Formation equivalent)	Rose Hill Formation (sandstone)	Gatesburg Formation (upper sandy member)
System or series	Upper Devonian	Upper Devonian	Middle Devonian	Upper Devonian	Lower Silurian	Upper Cambrian
Formation top (relative to KB) (ft)	-3,595	-3,945	-7,780	-6,970	-2,996	-10,610
Formation top (relative to GL) (ft)	-3,582	-3,935	-7,764	-6,947	-2,983	-10,610
Formation top (relative to SL) (ft)	-2,543	-2,815	-5,241	-4,497	-1,333	-9,448
Formation 19	Rhinestreet Shale Member of West Falls Formation	Rhinestreet Shale Member of West Falls Formation	Huntersville Chert	Harrell Formation (Genesee Formation equivalent)	Rose Hill Formation (lower part)	Ore Hill Limestone Member of Gatesburg Formation
System or series	Upper Devonian	Upper Devonian	Middle Devonian	Upper Devonian	Lower Silurian	Upper Cambrian
Formation top (relative to KB) (ft)	-3,966	-4,435	-7,795	-7,490	-3,050	-11,300
Formation top (relative to GL) (ft)	-3,953	-4,425	-7,779	-7,467	-3,037	-11,300
Formation top (relative to SL) (ft)	-2,914	-3,305	-5,256	-5,017	-1,387	-10,138
Formation 20	Sonyea Formation	Sonyea Formation	Needmore Shale	Tully Limestone	Castanea Member of Tuscarora Formation	Gatesburg Formation (lower sandy member)
System or series	Upper Devonian	Upper Devonian	Middle Devonian	Middle Devonian	Lower Silurian	Upper Cambrian
Formation top (relative to KB) (ft)	-4,262	-4,680	-7,905	-7,668	-3,140	-11,400
Formation top (relative to GL) (ft)	-4,249	-4,670	-7,889	-7,645	-3,127	-11,400
Formation top (relative to SL) (ft)	-3,210	-3,550	-5,366	-5,195	-1,477	-10,238

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	**1**	**2**	**3**	**4**	**5**
American Petroleum Institute number	**34–043–20011**	**34–093–20794**	**34–103–21143**	**34–151–21081**	**34–029–20648**
Lease name	**No. 1 Krysik-Wakefield**	**No. 1 A and A Born**	**No. 1–A F.L. Smith Estate**	**No. 1–381 B. Westfall**	**No. 3 Frank Murray**
Permanent datum	**Ground level**	**NA**	**Ground level**	**Ground level**	**Ground level**
Ground level elevation (ft)	**822.45**	**848**	**1,185.5**	**1,137.3**	**1,183.3**
Kelly bushing elevation (ft)	**828.45**	**848**	**1,200**	**1,144.3**	**1,193**
Measured from	**KB (6 ft APD)**	**GL**	**KB (14.5 ft APD)**	**KB (7 ft APD)**	**KB (9.7 ft APD)**
Drill depth (ft)	**4,463**	**4,591**	**7,040**	**7,961**	**10,242**
KB elevation - GL elevation (ft)	**6.0**	**0.0**	**14.5**	**7.0**	**9.7**
Formation 21	Utica Shale	Cincinnati group	Lockport Dolomite	Rochester Shale	Oriskany Sandstone
System or series	Upper Ordovician	Upper Ordovician	Lower to Upper Silurian	Lower Silurian	Lower Devonian
Formation top (relative to KB) (ft)	-2,820	-2,308	-3,148	-4,433	-4,000
Formation top (relative to GL) (ft)	-2,814	-2,308	-3,133.5	-4,426	-3,990.3
Formation top (relative to SL) (ft)	-1,991.55	-1,460	-1,948	-3,288.7	-2,807
Formation 22	Trenton Limestone	Utica Shale	Rochester Shale	Lower Silurian carbonates and shales (undivided)	Helderberg Limestone
System or series	Upper Ordovician	Upper Ordovician	Lower Silurian	Lower Silurian	Lower Devonian
Formation top (relative to KB) (ft)	-3,192	-2,988	-3,315	-4,580	-4,045
Formation top (relative to GL) (ft)	-3,186	-2,988	-3,300.5	-4,573	-4,035.3
Formation top (relative to SL) (ft)	-2,363.55	-2,140	-2,115	-3,435.7	-2,852
Formation 23	Black River Group (Millbrig Bentonite Bed at top)	Trenton Limestone	Lower Silurian carbonates and shales (undivided)	“Clinton” sandstone, Cabot Head Shale, and Medina sandstone (undivided)	Bass Islands Dolomite
System or series	Upper Ordovician	Upper Ordovician	Lower Silurian	Lower Silurian	Upper Silurian
Formation top (relative to KB) (ft)	-3,270	-3,310	-3,383	-4,625	-4,255
Formation top (relative to GL) (ft)	-3,264	-3,310	-3,368.5	-4,618	-4,245.3
Formation top (relative to SL) (ft)	-2,441.55	-2,462	-2,183	-3,480.7	-3,062
Formation 24	Deicke Bentonite Bed	Black River Group (Millbrig Bentonite Bed at top)	“Clinton” sandstone, Cabot Head Shale, and Medina sandstone (undivided)	Queenston Shale	Salina Group (upper part)
System or series	Upper Ordovician	Upper Ordovician	Lower Silurian	Upper Ordovician	Upper Silurian
Formation top (relative to KB) (ft)	-3,297	-3,395	-3,400	-4,810	-4,273
Formation top (relative to GL) (ft)	-3,291	-3,395	-3,385.5	-4,803	-4,263.3
Formation top (relative to SL) (ft)	-2,468.55	-2,547	-2,200	-3,665.7	-3,080

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	6	7	8	9	10	11
American Petroleum Institute number	47–029–00080	37–007–20060	37–051–20056	37–111–20045	37–009–20034	37–009–20060
Lease name	No. 1 S. Minesinger	No. 1 Richard J. Ashcroft	No. 1 E.C. Ricks	No. 1 Leonard Svetz	No. 1 Schellsburg	No. 1 Fred Steele
Permanent datum	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level
Ground level elevation (ft)	1,039	1,120	2,523	2,450	1,650	1,162
Kelly bushing elevation (ft)	1,052	1,130	2,539	2,473	1,663	1,189
Measured from	KB (13 ft APD)	KB (10 ft APD)	KB (16 ft APD)	KB (23 ft APD)	KB (13 ft APD)	GL
Drill depth (ft)	10,387	7,590	12,041	21,460	11,850	15,500
KB elevation - GL elevation (ft)	13.0	10.0	16.0	23.0	13.0	27.0
Formation 21	Genesee Formation	Genesee Formation	Ridgeley Sandstone	Mahantango Formation of Hamilton Group	Tuscarora Formation	Beekmantown Group (dolomite in lower part?) (thrust fault at top)
System or series	Upper Devonian	Upper Devonian	Lower Devonian	Middle Devonian	Lower Silurian	Lower Ordovician
Formation top (relative to KB) (ft)	-4,317	-4,745	-7,929	-7,685	-3,200	-12,775
Formation top (relative to GL) (ft)	-4,304	-4,735	-7,913	-7,662	-3,187	-12,775
Formation top (relative to SL) (ft)	-3,265	-3,615	-5,390	-5,212	-1,537	-11,613
Formation 22	Tully Limestone	Tully Limestone	Licking Creek Limestone	Marcellus Formation of Hamilton Group	Tuscarora Formation-Juniata Formation transition zone	Mines Dolomite Member of Gatesburg Formation
System or series	Middle Devonian	Middle Devonian	Lower Devonian	Middle Devonian	Upper Ordovician(?)	Upper Cambrian
Formation top (relative to KB) (ft)	-4,376	-4,816	-8,023	-8,263	-3,540	-13,920
Formation top (relative to GL) (ft)	-4,363	-4,806	-8,007	-8,240	-3,527	-13,920
Formation top (relative to SL) (ft)	-3,324	-3,686	-5,484	-5,790	-1,877	-12,758
Formation 23	Mahantango Formation of Hamilton Group	Mahantango Formation of Hamilton Group	Mandata Shale	Onondaga Formation	Juniata Formation	Gatesburg Formation (upper sandy member)
System or series	Middle Devonian	Middle Devonian	Lower Devonian	Middle Devonian	Upper Ordovician	Upper Cambrian
Formation top (relative to KB) (ft)	-4,380	-4,870	-8,252	-8,340	-3,620	-14,238
Formation top (relative to GL) (ft)	-4,367	-4,860	-8,236	-8,317	-3,607	-14,238
Formation top (relative to SL) (ft)	-3,328	-3,740	-5,713	-5,867	-1,957	-13,076
Formation 24	Marcellus Shale of Hamilton Group	Marcellus Formation of Hamilton Group	Corriganville and New Creek Limestones (undivided)	Huntersville Chert	Bald Eagle Formation	Ore Hill Limestone Member of Gatesburg Formation
System or series	Middle Devonian	Middle Devonian	Lower Devonian	Middle Devonian	Upper Ordovician	Upper Cambrian
Formation top (relative to KB) (ft)	-4,572	-4,980	-8,272	-8,360	-4,885	-15,000
Formation top (relative to GL) (ft)	-4,559	-4,970	-8,256	-8,337	-4,872	-15,000
Formation top (relative to SL) (ft)	-3,520	-3,850	-5,733	-5,887	-3,222	-13,838

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	**1**	**2**	**3**	**4**	**5**
American Petroleum Institute number	**34–043–20011**	**34–093–20794**	**34–103–21143**	**34–151–21081**	**34–029–20648**
Lease name	**No. 1 Krysik-Wakefield**	**No. 1 A and A Born**	**No. 1–A F.L. Smith Estate**	**No. 1–381 B. Westfall**	**No. 3 Frank Murray**
Permanent datum	**Ground level**	**NA**	**Ground level**	**Ground level**	**Ground level**
Ground level elevation (ft)	**822.45**	**848**	**1,185.5**	**1,137.3**	**1,183.3**
Kelly bushing elevation (ft)	**828.45**	**848**	**1,200**	**1,144.3**	**1,193**
Measured from	**KB (6 ft APD)**	**GL**	**KB (14.5 ft APD)**	**KB (7 ft APD)**	**KB (9.7 ft APD)**
Drill depth (ft)	**4,463**	**4,591**	**7,040**	**7,961**	**10,242**
KB elevation - GL elevation (ft)	**6.0**	**0.0**	**14.5**	**7.0**	**9.7**
Formation 25	Wells Creek formation	Deicke Bentonite Bed	Queenston Shale	Cincinnati group	Salina Group (halite zone)
System or series	Middle Ordovician	Upper Ordovician	Upper Ordovician	Upper Ordovician	Upper Silurian
Formation top (relative to KB) (ft)	-3,815	-3,412	-3,592	-5,300	-4,462
Formation top (relative to GL) (ft)	-3,809	-3,412	-3,577.5	-5,293	-4,452.3
Formation top (relative to SL) (ft)	-2,986.55	-2,564	-2,392	-4,155.7	-3,269
Formation 26	Knox Dolomite (Copper Ridge dolomite (B zone and Krysik sandstone))	Wells Creek formation	Cincinnati group	Utica Shale	Salina Group (lower part)
System or series	Upper Cambrian	Middle Ordovician	Upper Ordovician	Upper Ordovician	Upper Silurian
Formation top (relative to KB) (ft)	-3,850	-3,937	-3,960	-6,130	-5,030
Formation top (relative to GL) (ft)	-3,844	-3,937	-3,945.5	-6,123	-5,020.3
Formation top (relative to SL) (ft)	-3,021.55	-3,089	-2,760	-4,985.7	-3,837
Formation 27	Knox Dolomite (Copper Ridge dolomite (lower part))	Knox Dolomite (Copper Ridge dolomite (B zone and Krysik sandstone))	Utica Shale	Trenton Limestone	Lockport Dolomite
System or series	Upper Cambrian	Upper Cambrian	Upper Ordovician	Upper Ordovician	Lower to Upper Silurian
Formation top (relative to KB) (ft)	-3,920	-4,000	-4,750	-6,430	-5,280
Formation top (relative to GL) (ft)	-3,914	-4,000	-4,735.5	-6,423	-5,270.3
Formation top (relative to SL) (ft)	-3,091.55	-3,152	-3,550	-5,285.7	-4,087
Formation 28	Kerbel Formation	Knox Dolomite (Copper Ridge dolomite (lower part))	Trenton Limestone	Black River Group (Millbrig Bentonite Bed at top)	Rochester Shale
System or series	Upper Cambrian	Upper Cambrian	Upper Ordovician	Upper Ordovician	Lower Silurian
Formation top (relative to KB) (ft)	-3,994	-4,035	-5,060	-6,533	-5,615
Formation top (relative to GL) (ft)	-3,988	-4,035	-5,045.5	-6,526	-5,605.3
Formation top (relative to SL) (ft)	-3,165.55	-3,187	-3,860	-5,388.7	-4,422

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	**6**	**7**	**8**	**9**	**10**	**11**
American Petroleum Institute number	**47–029–00080**	**37–007–20060**	**37–051–20056**	**37–111–20045**	**37–009–20034**	**37–009–20060**
Lease name	**No. 1 S. Minesinger**	**No. 1 Richard J. Ashcroft**	**No. 1 E.C. Ricks**	**No. 1 Leonard Svetz**	**No. 1 Schellsburg**	**No. 1 Fred Steele**
Permanent datum	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**
Ground level elevation (ft)	**1,039**	**1,120**	**2,523**	**2,450**	**1,650**	**1,162**
Kelly bushing elevation (ft)	**1,052**	**1,130**	**2,539**	**2,473**	**1,663**	**1,189**
Measured from	**KB (13 ft APD)**	**KB (10 ft APD)**	**KB (16 ft APD)**	**KB (23 ft APD)**	**KB (13 ft APD)**	**GL**
Drill depth (ft)	**10,387**	**7,590**	**12,041**	**21,460**	**11,850**	**15,500**
KB elevation - GL elevation (ft)	**13.0**	**10.0**	**16.0**	**23.0**	**13.0**	**27.0**
Formation 25	Onondaga Limestone	Onondaga Formation	Keyser Formation	Needmore Shale	Reedsville Shale	Gatesburg Formation (lower sandy member)
System or series	Middle Devonian	Middle Devonian	Upper Silurian to Lower Devonian	Middle Devonian	Upper Ordovician	Upper Cambrian
Formation top (relative to KB) (ft)	-4,661	-5,056	-8,340	-8,480	-5,520	-15,178
Formation top (relative to GL) (ft)	-4,648	-5,046	-8,324	-8,457	-5,507	-15,178
Formation top (relative to SL) (ft)	-3,609	-3,926	-5,801	-6,007	-3,857	-14,016
Formation 26	Huntersville Chert	Huntersville Chert	Salina Group (upper part)	Ridgeley Sandstone	Antes Shale	
System or series	Middle Devonian	Middle Devonian	Upper Silurian	Lower Devonian	Upper Ordovician	
Formation top (relative to KB) (ft)	-4,700	-5,090	-8,600	-8,500	-7,270	
Formation top (relative to GL) (ft)	-4,687	-5,080	-8,584	-8,477	-7,257	
Formation top (relative to SL) (ft)	-3,648	-3,960	-6061	-6,027	-5,607	
Formation 27	Needmore Shale	Needmore Shale	Salina Group (halite zone)	Licking Creek Limestone	Trenton Group (Coburn, Salona, and Nealmont Formations, undivided)	
System or series	Middle Devonian	Middle Devonian	Upper Silurian	Lower Devonian	Upper Ordovician	
Formation top (relative to KB) (ft)	-4,863	-5,230	-8,956	-8,555	-7,614	
Formation top (relative to GL) (ft)	-4,850	-5,220	-8,940	-8,532	-7,601	
Formation top (relative to SL) (ft)	-3,811	-4,100	-6,417	-6,082	-5,951	
Formation 28	Oriskany Sandstone	Ridgeley Sandstone	Salina Group (lower part)	Mandata Shale	Millbrig Bentonite Bed	
System or series	Lower Devonian	Lower Devonian	Upper Silurian	Lower Devonian	Upper Ordovician	
Formation top (relative to KB) (ft)	-4,872	-5,237	-9,786	-8,800	-8,010	
Formation top (relative to GL) (ft)	-4,859	-5,227	-9,770	-8,777	-7,997	
Formation top (relative to SL) (ft)	-3,820	-4,107	-7,247	-6,327	-6,347	

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	1	2	3	4	5
American Petroleum Institute number	34–043–20011	34–093–20794	34–103–21143	34–151–21081	34–029–20648
Lease name	No. 1 Krysik-Wakefield	No. 1 A and A Born	No. 1–A F.L. Smith Estate	No. 1–381 B. Westfall	No. 3 Frank Murray
Permanent datum	Ground level	NA	Ground level	Ground level	Ground level
Ground level elevation (ft)	822.45	848	1,185.5	1,137.3	1,183.3
Kelly bushing elevation (ft)	828.45	848	1,200	1,144.3	1,193
Measured from	KB (6 ft APD)	GL	KB (14.5 ft APD)	KB (7 ft APD)	KB (9.7 ft APD)
Drill depth (ft)	4,463	4,591	7,040	7,961	10,242
KB elevation - GL elevation (ft)	6.0	0.0	14.5	7.0	9.7
Formation 29	Nolichucky Shale of Conasauga Group	Kerbel Formation	Black River Group (Millbrig Bentonite Bed at top)	Deicke Bentonite Bed	Lower Silurian carbonates and shales (undivided)
System or series	Upper Cambrian	Upper Cambrian	Upper Ordovician	Upper Ordovician	Lower Silurian
Formation top (relative to KB) (ft)	-4,025	-4,104	-5,143	-6,559	-5,730
Formation top (relative to GL) (ft)	-4,019	-4,104	-5,128.5	-6,552	-5,720.3
Formation top (relative to SL) (ft)	-3,196.55	-3,256	-3,943	-5,414.7	-4,537
Formation 30	Maryville Limestone of Conasauga Group	Nolichucky Shale of Conasauga Group	Deicke Bentonite Bed	Wells Creek formation	“Clinton” sandstone, Cabot Head Shale, and Medina sandstone (undivided)
System or series	Upper Cambrian	Upper Cambrian	Upper Ordovician	Middle Ordovician	Lower Silurian
Formation top (relative to KB) (ft)	-4,085	-4,141	-5,154	-7,220	-5,783
Formation top (relative to GL) (ft)	-4,079	-4,141	-5,139.5	-7,213	-5,773.3
Formation top (relative to SL) (ft)	-3,256.55	-3,293	-3,954	-6,075.7	-4,590
Formation 31	Mount Simon Sandstone	Maryville Limestone of Conasauga Group	Wells Creek formation	Knox Dolomite (Rose Run sandstone)	Queenston Shale
System or series	Upper Cambrian	Upper Cambrian	Middle Ordovician	Upper Cambrian	Upper Ordovician
Formation top (relative to KB) (ft)	-4,353	-4,203	-5,740	-7,273	-5,997
Formation top (relative to GL) (ft)	-4,347	-4,203	-5,725.5	-7,266	-5,987.3
Formation top (relative to SL) (ft)	-3,524.55	-3,355	-4,540	-6,128.7	-4,804

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	**6**	**7**	**8**	**9**	**10**	**11**
American Petroleum Institute number	**47–029–00080**	**37–007–20060**	**37–051–20056**	**37–111–20045**	**37–009–20034**	**37–009–20060**
Lease name	**No. 1 S. Minesinger**	**No. 1 Richard J. Ashcroft**	**No. 1 E.C. Ricks**	**No. 1 Leonard Svetz**	**No. 1 Schellsburg**	**No. 1 Fred Steele**
Permanent datum	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**
Ground level elevation (ft)	**1,039**	**1,120**	**2,523**	**2,450**	**1,650**	**1,162**
Kelly bushing elevation (ft)	**1,052**	**1,130**	**2,539**	**2,473**	**1,663**	**1,189**
Measured from	**KB (13 ft APD)**	**KB (10 ft APD)**	**KB (16 ft APD)**	**KB (23 ft APD)**	**KB (13 ft APD)**	**GL**
Drill depth (ft)	**10,387**	**7,590**	**12,041**	**21,460**	**11,850**	**15,500**
KB elevation - GL elevation (ft)	**13.0**	**10.0**	**16.0**	**23.0**	**13.0**	**27.0**
Formation 29	Licking Creek Limestone of Helderberg Group	Licking Creek Limestone	Wills Creek Formation	Corriganville and New Creek Limestones (undivided)	Deicke Bentonite Bed	
System or series	Lower Devonian	Lower Devonian	Upper Silurian	Lower Devonian	Upper Ordovician	
Formation top (relative to KB) (ft)	-4,938	-5,300	-9,990	-8,820	-8,050	
Formation top (relative to GL) (ft)	-4,925	-5,290	-9,974	-8,797	-8,037	
Formation top (relative to SL) (ft)	-3,886	-4,170	-7,451	-6,347	-6,387	
Formation 30	Mandata Shale of Helderberg Group	Mandata Shale	Bloomsburg Formation	Keyser Formation (upper part)	Black River Group (Linden Hall, Snyder, and Hatter Formations, undivided)	
System or series	Lower Devonian	Lower Devonian	Upper Silurian	Upper Silurian to Lower Devonian	Upper Ordovician	
Formation top (relative to KB) (ft)	-5,062	-5,436	-10,510	-8,900	-8,140	
Formation top (relative to GL) (ft)	-5,049	-5,426	-10,494	-8,877	-8,127	
Formation top (relative to SL) (ft)	-4,010	-4,306	-7,971	-6,427	-6,477	
Formation 31	Corriganville and New Creek Limestones (undivided) of Helderberg Group	Corriganville and New Creek Limestones (undivided)	McKenzie Member of Mifflintown Formation	Tonoloway Formation (intertongues with Salina Group equivalent including halite in lower 200 ft?)	Loysburg Formation	
System or series	Lower Devonian	Lower Devonian	Lower to Upper Silurian	Upper Silurian	Middle to Upper Ordovician	
Formation top (relative to KB) (ft)	-5,080	-5,445	-10,540	-9,080	-8,510	
Formation top (relative to GL) (ft)	-5,067	-5,435	-10,524	-9,057	-8,497	
Formation top (relative to SL) (ft)	-4,028	-4,315	-8,001	-6,607	-6,847	

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	**1**	**2**	**3**	**4**	**5**
American Petroleum Institute number	**34–043–20011**	**34–093–20794**	**34–103–21143**	**34–151–21081**	**34–029–20648**
Lease name	**No. 1 Krysik-Wakefield**	**No. 1 A and A Born**	**No. 1–A F.L. Smith Estate**	**No. 1–381 B. Westfall**	**No. 3 Frank Murray**
Permanent datum	**Ground level**	**NA**	**Ground level**	**Ground level**	**Ground level**
Ground level elevation (ft)	**822.45**	**848**	**1,185.5**	**1,137.3**	**1,183.3**
Kelly bushing elevation (ft)	**828.45**	**848**	**1,200**	**1,144.3**	**1,193**
Measured from	**KB (6 ft APD)**	**GL**	**KB (14.5 ft APD)**	**KB (7 ft APD)**	**KB (9.7 ft APD)**
Drill depth (ft)	**4,463**	**4,591**	**7,040**	**7,961**	**10,242**
KB elevation - GL elevation (ft)	**6.0**	**0.0**	**14.5**	**7.0**	**9.7**
Formation 32	Metamorphic and igneous rocks	Mount Simon Sandstone	Knox Dolomite (Copper Ridge dolomite (upper part))	Knox Dolomite (Copper Ridge dolomite (upper part))	Cincinnati group
System or series	Mesoproterozoic	Upper Cambrian	Upper Cambrian	Upper Cambrian	Upper Ordovician
Formation top (relative to KB) (ft)	-4,450	-4,466	-5,800	-7,340	-6,725
Formation top (relative to GL) (ft)	-4,444	-4,466	-5,785.5	-7,333	-6,715.3
Formation top (relative to SL) (ft)	-3,621.55	-3,618	-4,600	-6,195.7	-5,532
Formation 33		Metamorphic and igneous rocks	Knox Dolomite (Copper Ridge dolomite (B zone and Krysik sandstone))	Knox Dolomite (Copper Ridge dolomite (B zone and Krysik sandstone))	Utica Shale
System or series		Mesoproterozoic	Upper Cambrian	Upper Cambrian	Upper Ordovician
Formation top (relative to KB) (ft)		-4,585	-5,840	-7,522	-7,492
Formation top (relative to GL) (ft)		-4,585	-5,825.5	-7,515	-7,482.3
Formation top (relative to SL) (ft)		-3,737	-4,640	-6,377.7	-6,299
Formation 34			Knox Dolomite (Copper Ridge dolomite (lower part))	Knox Dolomite (Copper Ridge dolomite (lower part))	Trenton Limestone
System or series			Upper Cambrian	Upper Cambrian	Upper Ordovician
Formation top (relative to KB) (ft)			-6,021	-7,656	-7,782
Formation top (relative to GL) (ft)			-6,006.5	-7,649	-7,772.3
Formation top (relative to SL) (ft)			-4,821	-6,511.7	-6,589

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	**6**	**7**	**8**	**9**	**10**	**11**
American Petroleum Institute number	**47–029–00080**	**37–007–20060**	**37–051–20056**	**37–111–20045**	**37–009–20034**	**37–009–20060**
Lease name	**No. 1 S. Minesinger**	**No. 1 Richard J. Ashcroft**	**No. 1 E.C. Ricks**	**No. 1 Leonard Svetz**	**No. 1 Schellsburg**	**No. 1 Fred Steele**
Permanent datum	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**
Ground level elevation (ft)	**1,039**	**1,120**	**2,523**	**2,450**	**1,650**	**1,162**
Kelly bushing elevation (ft)	**1,052**	**1,130**	**2,539**	**2,473**	**1,663**	**1,189**
Measured from	**KB (13 ft APD)**	**KB (10 ft APD)**	**KB (16 ft APD)**	**KB (23 ft APD)**	**KB (13 ft APD)**	**GL**
Drill depth (ft)	**10,387**	**7,590**	**12,041**	**21,460**	**11,850**	**15,500**
KB elevation - GL elevation (ft)	**13.0**	**10.0**	**16.0**	**23.0**	**13.0**	**27.0**
Formation 32	Keyser Limestone (upper part) of Helderberg Group	Keyser Formation (upper part)	Rochester Member of Mifflintown Formation	Wills Creek Formation	Beekmantown Group (upper anhydritic dolomite)	
System or series	Upper Silurian to Lower Devonian	Upper Silurian to Lower Devonian	Lower Silurian	Upper Silurian	Middle Ordovician	
Formation top (relative to KB) (ft)	-5,153	-5,522	-10,755	-10,183	-8,700	
Formation top (relative to GL) (ft)	-5,140	-5,512	-10,739	-10,160	-8,687	
Formation top (relative to SL) (ft)	-4,101	-4,392	-8,216	-7,710	-7,037	
Formation 33	Keyser Limestone (middle part) of Helder-berg Group (Bass Islands Dolomite equivalent)	Keyser Formation (middle part) (Bass Islands Dolomite equivalent)	Keefer Formation	Bloomsburg Formation	Beekmantown Group (dolomite in upper part)	
System or series	Upper Silurian	Upper Silurian	Lower Silurian	Upper Silurian	Middle Ordovician	
Formation top (relative to KB) (ft)	-5,172	-5,540	-10,790	-10,615	-9,200	
Formation top (relative to GL) (ft)	-5,159	-5,530	-10,774	-10,592	-9,187	
Formation top (relative to SL) (ft)	-4,120	-4,410	-8,251	-8,142	-7,537	
Formation 34	Keyser Limestone (lower part) of Helderberg Group (not equivalent to Bass Island Dolomite, pinches out in Ohio?)	Keyser Formation (lower part) (not equivalent to Bass Island Dolomite, pinches out in Ohio?)	Rose Hill Formation (upper part)	McKenzie Member of Mifflintown Formation	Beekmantown Group (lower anhydritic dolomite)	
System or series	Upper Silurian	Upper Silurian	Lower Silurian	Lower to Upper Silurian	Lower Ordovician	
Formation top (relative to KB) (ft)	-5,238	-5,620	-10,820	-10,650	-10,670	
Formation top (relative to GL) (ft)	-5,225	-5,610	-10,804	-10,627	-10,657	
Formation top (relative to SL) (ft)	-4,186	-4,490	-8,281	-8,177	-9,007	

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	**1**	**2**	**3**	**4**	**5**
American Petroleum Institute number	**34–043–20011**	**34–093–20794**	**34–103–21143**	**34–151–21081**	**34–029–20648**
Lease name	**No. 1 Krysik-Wakefield**	**No. 1 A and A Born**	**No. 1–A F.L. Smith Estate**	**No. 1–381 B. Westfall**	**No. 3 Frank Murray**
Permanent datum	**Ground level**	**NA**	**Ground level**	**Ground level**	**Ground level**
Ground level elevation (ft)	**822.45**	**848**	**1,185.5**	**1,137.3**	**1,183.3**
Kelly bushing elevation (ft)	**828.45**	**848**	**1,200**	**1,144.3**	**1,193**
Measured from	**KB (6 ft APD)**	**GL**	**KB (14.5 ft APD)**	**KB (7 ft APD)**	**KB (9.7 ft APD)**
Drill depth (ft)	**4,463**	**4,591**	**7,040**	**7,961**	**10,242**
KB elevation - GL elevation (ft)	**6.0**	**0.0**	**14.5**	**7.0**	**9.7**
Formation 35			Nolichucky Shale equivalent of Conasauga Group	Nolichucky Shale equivalent of Conasauga Group	Black River Group (Millbrig Bentonite Bed at top)
System or series			Upper Cambrian	Upper Cambrian	Upper Ordovician
Formation top (relative to KB) (ft)			-6,080	-7,730	-7,922
Formation top (relative to GL) (ft)			-6,065.5	-7,723	-7,912.3
Formation top (relative to SL) (ft)			-4,880	-6,585.7	-6,729
Formation 36			Maryville Limestone of Conasauga Group	Maryville Limestone of Conasauga Group	Deicke Bentonite Bed
System or series			Upper Cambrian	Upper Cambrian	Upper Ordovician
Formation top (relative to KB) (ft)			-6,121	-7,789	-7,960
Formation top (relative to GL) (ft)			-6,106.5	-7,782	-7,950.3
Formation top (relative to SL) (ft)			-4,921	-6,644.7	-6,767
Formation 37			Mount Simon Sandstone		Wells Creek formation
System or series			Upper Cambrian		Middle Ordovician
Formation top (relative to KB) (ft)			-6,520		-8,596
Formation top (relative to GL) (ft)			-6,505.5		-8,586.3
Formation top (relative to SL) (ft)			-5,320		-7,403
Formation 38			Metamorphic and igneous rocks		Wells Creek formation (unnamed sandstone) (St. Peter Sandstone equivalent)
System or series			Mesoproterozoic		Middle Ordovician
Formation top (relative to KB) (ft)			-6,573		-8,652
Formation top (relative to GL) (ft)			-6,558.5		-8,642.3
Formation top (relative to SL) (ft)			-5,373		-7,459

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	**6**	**7**	**8**	**9**	**10**	**11**
American Petroleum Institute number	**47–029–00080**	**37–007–20060**	**37–051–20056**	**37–111–20045**	**37–009–20034**	**37–009–20060**
Lease name	**No. 1 S. Minesinger**	**No. 1 Richard J. Ashcroft**	**No. 1 E.C. Ricks**	**No. 1 Leonard Svetz**	**No. 1 Schellsburg**	**No. 1 Fred Steele**
Permanent datum	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**
Ground level elevation (ft)	**1,039**	**1,120**	**2,523**	**2,450**	**1,650**	**1,162**
Kelly bushing elevation (ft)	**1,052**	**1,130**	**2,539**	**2,473**	**1,663**	**1,189**
Measured from	**KB (13 ft APD)**	**KB (10 ft APD)**	**KB (16 ft APD)**	**KB (23 ft APD)**	**KB (13 ft APD)**	**GL**
Drill depth (ft)	**10,387**	**7,590**	**12,041**	**21,460**	**11,850**	**15,500**
KB elevation - GL elevation (ft)	**13.0**	**10.0**	**16.0**	**23.0**	**13.0**	**27.0**
Formation 35	Salina Group (upper part)	Salina Group (upper part)	Rose Hill Formation (dolomite)	Keefer Formation and Rochester Member of Mifflintown Formation (undivided)	Beekmantown Group (dolomite in lower part)	
System or series	Upper Silurian	Upper Silurian	Lower Silurian	Lower Silurian	Lower Ordovician	
Formation top (relative to KB) (ft)	-5,270	-5,655	-11,220	-10,883	-11,010	
Formation top (relative to GL) (ft)	-5,257	-5,645	-11,204	-10,860	-10,997	
Formation top (relative to SL) (ft)	-4,218	-4,525	-8,681	-8,410	-9,347	
Formation 36	Salina Group (halite zone)	Salina Group (halite zone)	Rose Hill Formation (lower part)	Rose Hill Formation (upper part)	Mines Dolomite Member of Gatesburg Formation	
System or series	Upper Silurian	Upper Silurian	Lower Silurian	Lower Silurian	Upper Cambrian	
Formation top (relative to KB) (ft)	-5,418	-5,810	-11,254	-10,945	-11,520	
Formation top (relative to GL) (ft)	-5,405	-5,800	-11,238	-10,922	-11,507	
Formation top (relative to SL) (ft)	-4,360	-4,680	-8,715	-8,472	-9,857	
Formation 37	Salina Group (lower part)	Salina Group (lower part)	Castanea Member of Tuscarora Formation	Rose Hill Formation (dolomite)	Gatesburg Formation (upper sandy member)	
System or series	Upper Silurian	Upper Silurian	Lower Silurian	Lower Silurian	Upper Cambrian	
Formation top (relative to KB) (ft)	-5,950	-6,452	-11,438	-11,304	-11,703	
Formation top (relative to GL) (ft)	-5,937	-6,442	-11,422	-11,281	-11,690	
Formation top (relative to SL) (ft)	-4,898	-5,322	-8,899	-8,831	-10,040	
Formation 38	Lockport Dolomite	Lockport Dolomite	Tuscarora Formation	Rose Run Formation (lower part)		
System or series	Lower to Upper Silurian	Lower to Upper Silurian	Lower Silurian	Lower Silurian		
Formation top (relative to KB) (ft)	-6,290	-6,660	-11,550	-11,340		
Formation top (relative to GL) (ft)	-6,277	-6,650	-11,534	-11,317		
Formation top (relative to SL) (ft)	-5,238	-5,530	-9,011	-8,867		

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	**1**	**2**	**3**	**4**	**5**
American Petroleum Institute number	**34–043–20011**	**34–093–20794**	**34–103–21143**	**34–151–21081**	**34–029–20648**
Lease name	**No. 1 Krysik-Wakefield**	**No. 1 A and A Born**	**No. 1–A F.L. Smith Estate**	**No. 1–381 B. Westfall**	**No. 3 Frank Murray**
Permanent datum	**Ground level**	**NA**	**Ground level**	**Ground level**	**Ground level**
Ground level elevation (ft)	**822.45**	**848**	**1,185.5**	**1,137.3**	**1,183.3**
Kelly bushing elevation (ft)	**828.45**	**848**	**1,200**	**1,144.3**	**1,193**
Measured from	**KB (6 ft APD)**	**GL**	**KB (14.5 ft APD)**	**KB (7 ft APD)**	**KB (9.7 ft APD)**
Drill depth (ft)	**4,463**	**4,591**	**7,040**	**7,961**	**10,242**
KB elevation - GL elevation (ft)	**6.0**	**0.0**	**14.5**	**7.0**	**9.7**
Formation 39					Knox Dolomite (Beekmantown dolomite)
System or series					Lower Ordovician
Formation top (relative to KB) (ft)					-8,671
Formation top (relative to GL) (ft)					-8,661.3
Formation top (relative to SL) (ft)					-7,478
Formation 40					Knox Dolomite (Rose Run sandstone)
System or series					Upper Cambrian
Formation top (relative to KB) (ft)					-8,890
Formation top (relative to GL) (ft)					-8,880.3
Formation top (relative to SL) (ft)					-7,697
Formation 41					Knox Dolomite (Copper Ridge dolomite (upper part))
System or series					Upper Cambrian
Formation top (relative to KB) (ft)					-9,050
Formation top (relative to GL) (ft)					-9,040.3
Formation top (relative to SL) (ft)					-7,857
Formation 42					Knox Dolomite (Copper Ridge dolomite (B zone and Krysik sandstone))
System or series					Upper Cambrian
Formation top (relative to KB) (ft)					-9,180
Formation top (relative to GL) (ft)					-9,170.3
Formation top (relative to SL) (ft)					-7,987

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	**6**	**7**	**8**	**9**	**10**	**11**
American Petroleum Institute number	**47–029–00080**	**37–007–20060**	**37–051–20056**	**37–111–20045**	**37–009–20034**	**37–009–20060**
Lease name	**No. 1 S. Minesinger**	**No. 1 Richard J. Ashcroft**	**No. 1 E.C. Ricks**	**No. 1 Leonard Svetz**	**No. 1 Schellsburg**	**No. 1 Fred Steele**
Permanent datum	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**
Ground level elevation (ft)	**1,039**	**1,120**	**2,523**	**2,450**	**1,650**	**1,162**
Kelly bushing elevation (ft)	**1,052**	**1,130**	**2,539**	**2,473**	**1,663**	**1,189**
Measured from	**KB (13 ft APD)**	**KB (10 ft APD)**	**KB (16 ft APD)**	**KB (23 ft APD)**	**KB (13 ft APD)**	**GL**
Drill depth (ft)	**10,387**	**7,590**	**12,041**	**21,460**	**11,850**	**15,500**
KB elevation - GL elevation (ft)	**13.0**	**10.0**	**16.0**	**23.0**	**13.0**	**27.0**
Formation 39	Keefer Sandstone	Keefer Sandstone	Tuscarora Formation-Juniata Formation transition zone	Castanea Member of Tuscarora Formation		
System or series	Lower Silurian	Lower Silurian	Upper Ordovician(?)	Lower Silurian		
Formation top (relative to KB) (ft)	-6,580	-7,058	-11,907	-11,525		
Formation top (relative to GL) (ft)	-6,567	-7,048	-11,891	-11,502		
Formation top (relative to SL) (ft)	-5,528	-5,928	-9,368	-9,052		
Formation 40	Rochester Shale	Rose Hill Formation (Rochester Shale equivalent)	Juniata Formation	Tuscarora Formation		
System or series	Lower Silurian	Lower Silurian	Upper Ordovician	Lower Silurian		
Formation top (relative to KB) (ft)	-6,600	-7,065	-12,045	-11,556		
Formation top (relative to GL) (ft)	-6,587	-7,055	-12,029	-11,533		
Formation top (relative to SL) (ft)	-5,548	-5,935	-9,506	-9,083		
Formation 41	Lower Silurian carbonates and shales (undivided)	Rose Hill Formation (Lower Silurian carbonates and shales, undivided, equivalent)		Tuscarora Formation-Juniata Formation transition zone		
System or series	Lower Silurian	Lower Silurian		Upper Ordovician(?)		
Formation top (relative to KB) (ft)	-6,755	-7,226		-11,875		
Formation top (relative to GL) (ft)	-6,742	-7,216		-11,852		
Formation top (relative to SL) (ft)	-5,703	-6,096		-9,402		
Formation 42	“Clinton” sandstone, Cabot Head Shale, and Medina sandstone (undivided)	Medina Group		Juniata Formation		
System or series	Lower Silurian	Lower Silurian		Upper Ordovician		
Formation top (relative to KB) (ft)	-6,828	-7,320		-12,010		
Formation top (relative to GL) (ft)	-6,815	-7,310		-11,987		
Formation top (relative to SL) (ft)	-5,776	-6,190		-9,537		

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	**1**	**2**	**3**	**4**	**5**
American Petroleum Institute number	**34–043–20011**	**34–093–20794**	**34–103–21143**	**34–151–21081**	**34–029–20648**
Lease name	**No. 1 Krysik-Wakefield**	**No. 1 A and A Born**	**No. 1–A F.L. Smith Estate**	**No. 1–381 B. Westfall**	**No. 3 Frank Murray**
Permanent datum	**Ground level**	**NA**	**Ground level**	**Ground level**	**Ground level**
Ground level elevation (ft)	**822.45**	**848**	**1,185.5**	**1,137.3**	**1,183.3**
Kelly bushing elevation (ft)	**828.45**	**848**	**1,200**	**1,144.3**	**1,193**
Measured from	**KB (6 ft APD)**	**GL**	**KB (14.5 ft APD)**	**KB (7 ft APD)**	**KB (9.7 ft APD)**
Drill depth (ft)	**4,463**	**4,591**	**7,040**	**7,961**	**10,242**
KB elevation - GL elevation (ft)	**6.0**	**0.0**	**14.5**	**7.0**	**9.7**
Formation 43					Knox Dolomite (Copper Ridge dolomite (lower part))
System or series					Upper Cambrian
Formation top (relative to KB) (ft)					-9,310
Formation top (relative to GL) (ft)					-9,300.3
Formation top (relative to SL) (ft)					-8,117
Formation 44					Nolichucky Shale equivalent of Conasauga Group
System or series					Upper Cambrian
Formation top (relative to KB) (ft)					-9,420
Formation top (relative to GL) (ft)					-9,410.3
Formation top (relative to SL) (ft)					-8,227
Formation 45					Maryville Limestone of Conasauga Group
System or series					Upper Cambrian
Formation top (relative to KB) (ft)					-9,486
Formation top (relative to GL) (ft)					-9,476.3
Formation top (relative to SL) (ft)					-8,293
Formation 46					Mount Simon Sandstone
System or series					Upper Cambrian
Formation top (relative to KB) (ft)					-10,078
Formation top (relative to GL) (ft)					-10,068.3
Formation top (relative to SL) (ft)					-8,885

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	**6**	**7**	**8**	**9**	**10**	**11**
American Petroleum Institute number	**47–029–00080**	**37–007–20060**	**37–051–20056**	**37–111–20045**	**37–009–20034**	**37–009–20060**
Lease name	**No. 1 S. Minesinger**	**No. 1 Richard J. Ashcroft**	**No. 1 E.C. Ricks**	**No. 1 Leonard Svetz**	**No. 1 Schellsburg**	**No. 1 Fred Steele**
Permanent datum	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**
Ground level elevation (ft)	**1,039**	**1,120**	**2,523**	**2,450**	**1,650**	**1,162**
Kelly bushing elevation (ft)	**1,052**	**1,130**	**2,539**	**2,473**	**1,663**	**1,189**
Measured from	**KB (13 ft APD)**	**KB (10 ft APD)**	**KB (16 ft APD)**	**KB (23 ft APD)**	**KB (13 ft APD)**	**GL**
Drill depth (ft)	**10,387**	**7,590**	**12,041**	**21,460**	**11,850**	**15,500**
KB elevation - GL elevation (ft)	**13.0**	**10.0**	**16.0**	**23.0**	**13.0**	**27.0**
Formation 43	Queenston Shale	Queenston Shale		Bald Eagle Formation		
System or series	Upper Ordovician	Upper Ordovician		Upper Ordovician		
Formation top (relative to KB) (ft)	-7,014	-7,560		-13,000		
Formation top (relative to GL) (ft)	-7,001	-7,550		-12,977		
Formation top (relative to SL) (ft)	-5,962	-6,430		-10,527		
Formation 44	Reedsville Shale			Reedsville Shale		
System or series	Upper Ordovician			Upper Ordovician		
Formation top (relative to KB) (ft)	-7,826			-13,382		
Formation top (relative to GL) (ft)	-7,813			-13,359		
Formation top (relative to SL) (ft)	-6,774			-10,909		
Formation 45	Utica Shale			Antes Shale (Utica Shale equivalent)		
System or series	Upper Ordovician			Upper Ordovician		
Formation top (relative to KB) (ft)	-8,670			-14,720		
Formation top (relative to GL) (ft)	-8,657			-14,697		
Formation top (relative to SL) (ft)	-7,618			-12,247		
Formation 46	Trenton Limestone			Trenton Group (Coburn, Salona, and Nealmont Formations, undivided)		
System or series	Upper Ordovician			Upper Ordovician		
Formation top (relative to KB) (ft)	-8,954			-15,349		
Formation top (relative to GL) (ft)	-8,941			-15,326		
Formation top (relative to SL) (ft)	-7,902			-12,876		

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	**1**	**2**	**3**	**4**	**5**
American Petroleum Institute number	**34–043–20011**	**34–093–20794**	**34–103–21143**	**34–151–21081**	**34–029–20648**
Lease name	**No. 1 Krysik-Wakefield**	**No. 1 A and A Born**	**No. 1–A F.L. Smith Estate**	**No. 1–381 B. Westfall**	**No. 3 Frank Murray**
Permanent datum	**Ground level**	**NA**	**Ground level**	**Ground level**	**Ground level**
Ground level elevation (ft)	**822.45**	**848**	**1,185.5**	**1,137.3**	**1,183.3**
Kelly bushing elevation (ft)	**828.45**	**848**	**1,200**	**1,144.3**	**1,193**
Measured from	**KB (6 ft APD)**	**GL**	**KB (14.5 ft APD)**	**KB (7 ft APD)**	**KB (9.7 ft APD)**
Drill depth (ft)	**4,463**	**4,591**	**7,040**	**7,961**	**10,242**
KB elevation - GL elevation (ft)	**6.0**	**0.0**	**14.5**	**7.0**	**9.7**
Formation 47					
System or series					
Formation top (relative to KB) (ft)					
Formation top (relative to GL) (ft)					
Formation top (relative to SL) (ft)					
Formation 48					
System or series					
Formation top (relative to KB) (ft)					
Formation top (relative to GL) (ft)					
Formation top (relative to SL) (ft)					
Formation 49					
System or series					
Formation top (relative to KB) (ft)					
Formation top (relative to GL) (ft)					
Formation top (relative to SL) (ft)					
Formation 50					
System or series					
Formation top (relative to KB) (ft)					
Formation top (relative to GL) (ft)					
Formation top (relative to SL) (ft)					
Formation 51					
System or series					
Formation top (relative to KB) (ft)					
Formation top (relative to GL) (ft)					
Formation top (relative to SL) (ft)					

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	**6**	**7**	**8**	**9**	**10**	**11**
American Petroleum Institute number	**47–029–00080**	**37–007–20060**	**37–051–20056**	**37–111–20045**	**37–009–20034**	**37–009–20060**
Lease name	**No. 1 S. Minesinger**	**No. 1 Richard J. Ashcroft**	**No. 1 E.C. Ricks**	**No. 1 Leonard Svetz**	**No. 1 Schellsburg**	**No. 1 Fred Steele**
Permanent datum	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**
Ground level elevation (ft)	**1,039**	**1,120**	**2,523**	**2,450**	**1,650**	**1,162**
Kelly bushing elevation (ft)	**1,052**	**1,130**	**2,539**	**2,473**	**1,663**	**1,189**
Measured from	**KB (13 ft APD)**	**KB (10 ft APD)**	**KB (16 ft APD)**	**KB (23 ft APD)**	**KB (13 ft APD)**	**GL**
Drill depth (ft)	**10,387**	**7,590**	**12,041**	**21,460**	**11,850**	**15,500**
KB elevation - GL elevation (ft)	**13.0**	**10.0**	**16.0**	**23.0**	**13.0**	**27.0**
Formation 47	Millbrig Bentonite Bed			Millbrig Bentonite Bed		
System or series	Upper Ordovician			Upper Ordovician		
Formation top (relative to KB) (ft)	-9,110			-15,580		
Formation top (relative to GL) (ft)	-9,097			-15,557		
Formation top (relative to SL) (ft)	-8,058			-13,107		
Formation 48	Deicke Bentonite Bed			Deicke Bentonite Bed		
System or series	Upper Ordovician			Upper Ordovician		
Formation top (relative to KB) (ft)	-9,158			-15,615		
Formation top (relative to GL) (ft)	-9,145			-15,592		
Formation top (relative to SL) (ft)	-8,106			-13,142		
Formation 49	Black River Group			Trenton Group (Salona and Nealmont Formations, undivided) (fault at top)		
System or series	Upper Ordovician			Upper Ordovician		
Formation top (relative to KB) (ft)	-9,215			-15,710		
Formation top (relative to GL) (ft)	-9,202			-15,687		
Formation top (relative to SL) (ft)	-8,163			-13,237		
Formation 50	Loysburg Formation equivalent			Millbrig Bentonite Bed		
System or series	Middle to Upper Ordovician			Upper Ordovician		
Formation top (relative to KB) (ft)	-9,625			-15,780		
Formation top (relative to GL) (ft)	-9,612			-15,757		
Formation top (relative to SL) (ft)	-8,573			-13,307		
Formation 51	Wells Creek formation			Deicke Bentonite Bed		
System or series	Middle Ordovician			Upper Ordovician		
Formation top (relative to KB) (ft)	-9,850			-15,820		
Formation top (relative to GL) (ft)	-9,837			-15,797		
Formation top (relative to SL) (ft)	-8,798			-13,347		

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	**1**	**2**	**3**	**4**	**5**
American Petroleum Institute number	**34–043–20011**	**34–093–20794**	**34–103–21143**	**34–151–21081**	**34–029–20648**
Lease name	**No. 1 Krysik-Wakefield**	**No. 1 A and A Born**	**No. 1–A F.L. Smith Estate**	**No. 1–381 B. Westfall**	**No. 3 Frank Murray**
Permanent datum	**Ground level**	**NA**	**Ground level**	**Ground level**	**Ground level**
Ground level elevation (ft)	**822.45**	**848**	**1,185.5**	**1,137.3**	**1,183.3**
Kelly bushing elevation (ft)	**828.45**	**848**	**1,200**	**1,144.3**	**1,193**
Measured from	**KB (6 ft APD)**	**GL**	**KB (14.5 ft APD)**	**KB (7 ft APD)**	**KB (9.7 ft APD)**
Drill depth (ft)	**4,463**	**4,591**	**7,040**	**7,961**	**10,242**
KB elevation - GL elevation (ft)	**6.0**	**0.0**	**14.5**	**7.0**	**9.7**
Formation 52					
System or series					
Formation top (relative to KB) (ft)					
Formation top (relative to GL) (ft)					
Formation top (relative to SL) (ft)					
Formation 53					
System or series					
Formation top (relative to KB) (ft)					
Formation top (relative to GL) (ft)					
Formation top (relative to SL) (ft)					
Formation 54					
System or series					
Formation top (relative to KB) (ft)					
Formation top (relative to GL) (ft)					
Formation top (relative to SL) (ft)					
Formation 55					
System or series					
Formation top (relative to KB) (ft)					
Formation top (relative to GL) (ft)					
Formation top (relative to SL) (ft)					

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	6	7	8	9	10	11
American Petroleum Institute number	47–029–00080	37–007–20060	37–051–20056	37–111–20045	37–009–20034	37–009–20060
Lease name	No. 1 S. Minesinger	No. 1 Richard J. Ashcroft	No. 1 E.C. Ricks	No. 1 Leonard Svetz	No. 1 Schellsburg	No. 1 Fred Steele
Permanent datum	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level
Ground level elevation (ft)	1,039	1,120	2,523	2,450	1,650	1,162
Kelly bushing elevation (ft)	1,052	1,130	2,539	2,473	1,663	1,189
Measured from	KB (13 ft APD)	KB (10 ft APD)	KB (16 ft APD)	KB (23 ft APD)	KB (13 ft APD)	GL
Drill depth (ft)	10,387	7,590	12,041	21,460	11,850	15,500
KB elevation - GL elevation (ft)	13.0	10.0	16.0	23.0	13.0	27.0
Formation 52	Wells Creek formation (unnamed sandstone) (St. Peter Sandstone equivalent)			Black River Group (Linden Hall, Snyder, and Hatter Formations, undivided)		
System or series	Middle Ordovician			Upper Ordovician		
Formation top (relative to KB) (ft)	-9,925			-15,970		
Formation top (relative to GL) (ft)	-9,912			-15,947		
Formation top (relative to SL) (ft)	-8,873			-13,497		
Formation 53	Beekmantown Dolomite			Loysburg Formation		
System or series	Lower Ordovician			Middle to Upper Ordovician		
Formation top (relative to KB) (ft)	-9,940			-16,640		
Formation top (relative to GL) (ft)	-9,927			-16,617		
Formation top (relative to SL) (ft)	-8,888			-14,167		
Formation 54				Beekmantown Group (upper anhydritic dolomite)		
System or series				Middle Ordovician		
Formation top (relative to KB) (ft)				-17,000		
Formation top (relative to GL) (ft)				-16,977		
Formation top (relative to SL) (ft)				-14,527		
Formation 55				Beekmantown Group (dolomite in upper part, above Knox unconformity)		
System or series				Middle Ordovician		
Formation top (relative to KB) (ft)				-17,320		
Formation top (relative to GL) (ft)				-17,297		
Formation top (relative to SL) (ft)				-14,847		

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	1	2	3	4	5
American Petroleum Institute number	34–043–20011	34–093–20794	34–103–21143	34–151–21081	34–029–20648
Lease name	No. 1 Krysik-Wakefield	No. 1 A and A Born	No. 1–A F.L. Smith Estate	No. 1–381 B. Westfall	No. 3 Frank Murray
Permanent datum	Ground level	NA	Ground level	Ground level	Ground level
Ground level elevation (ft)	822.45	848	1,185.5	1,137.3	1,183.3
Kelly bushing elevation (ft)	828.45	848	1,200	1,144.3	1,193
Measured from	KB (6 ft APD)	GL	KB (14.5 ft APD)	KB (7 ft APD)	KB (9.7 ft APD)
Drill depth (ft)	4,463	4,591	7,040	7,961	10,242
KB elevation - GL elevation (ft)	6.0	0.0	14.5	7.0	9.7
Formation 56					
System or series					
Formation top (relative to KB) (ft)					
Formation top (relative to GL) (ft)					
Formation top (relative to SL) (ft)					
Formation 57					
System or series					
Formation top (relative to KB) (ft)					
Formation top (relative to GL) (ft)					
Formation top (relative to SL) (ft)					
Formation 58					
System or series					
Formation top (relative to KB) (ft)					
Formation top (relative to GL) (ft)					
Formation top (relative to SL) (ft)					
Formation 59					
System or series					
Formation top (relative to KB) (ft)					
Formation top (relative to GL) (ft)					
Formation top (relative to SL) (ft)					

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	6	7	8	9	10	11
American Petroleum Institute number	47–029–00080	37–007–20060	37–051–20056	37–111–20045	37–009–20034	37–009–20060
Lease name	No. 1 S. Minesinger	No. 1 Richard J. Ashcroft	No. 1 E.C. Ricks	No. 1 Leonard Svetz	No. 1 Schellsburg	No. 1 Fred Steele
Permanent datum	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level
Ground level elevation (ft)	1,039	1,120	2,523	2,450	1,650	1,162
Kelly bushing elevation (ft)	1,052	1,130	2,539	2,473	1,663	1,189
Measured from	KB (13 ft APD)	KB (10 ft APD)	KB (16 ft APD)	KB (23 ft APD)	KB (13 ft APD)	GL
Drill depth (ft)	10,387	7,590	12,041	21,460	11,850	15,500
KB elevation - GL elevation (ft)	13.0	10.0	16.0	23.0	13.0	27.0
Formation 56				Beekmantown Group (dolomite in upper part, below Knox unconformity)		
System or series				Lower Ordovician		
Formation top (relative to KB) (ft)				-17,830		
Formation top (relative to GL) (ft)				-17,807		
Formation top (relative to SL) (ft)				-15,357		
Formation 57				Beekmantown Group (middle anhydritic dolomite)		
System or series				Lower Ordovician		
Formation top (relative to KB) (ft)				-17,930		
Formation top (relative to GL) (ft)				-17,907		
Formation top (relative to SL) (ft)				-15,457		
Formation 58				Beekmantown Group (dolomite in lower part)		
System or series				Lower Ordovician		
Formation top (relative to KB) (ft)				-18,420		
Formation top (relative to GL) (ft)				-18,397		
Formation top (relative to SL) (ft)				-15,947		
Formation 59				Mines Dolomite Member of Gatesburg Formation		
System or series				Upper Cambrian		
Formation top (relative to KB) (ft)				-20,740		
Formation top (relative to GL) (ft)				-20,717		
Formation top (relative to SL) (ft)				-18,267		

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	**1**	**2**	**3**	**4**	**5**
American Petroleum Institute number	**34–043–20011**	**34–093–20794**	**34–103–21143**	**34–151–21081**	**34–029–20648**
Lease name	**No. 1 Krysik-Wakefield**	**No. 1 A and A Born**	**No. 1–A F.L. Smith Estate**	**No. 1–381 B. Westfall**	**No. 3 Frank Murray**
Permanent datum	**Ground level**	**NA**	**Ground level**	**Ground level**	**Ground level**
Ground level elevation (ft)	**822.45**	**848**	**1,185.5**	**1,137.3**	**1,183.3**
Kelly bushing elevation (ft)	**828.45**	**848**	**1,200**	**1,144.3**	**1,193**
Measured from	**KB (6 ft APD)**	**GL**	**KB (14.5 ft APD)**	**KB (7 ft APD)**	**KB (9.7 ft APD)**
Drill depth (ft)	**4,463**	**4,591**	**7,040**	**7,961**	**10,242**
KB elevation - GL elevation (ft)	**6.0**	**0.0**	**14.5**	**7.0**	**9.7**
Formation 60					
System or series					
Formation top (relative to KB) (ft)					
Formation top (relative to GL) (ft)					
Formation top (relative to SL) (ft)					
Formation 61					
System or series					
Formation top (relative to KB) (ft)					
Formation top (relative to GL) (ft)					
Formation top (relative to SL) (ft)					
Formation 62					
System or series					
Formation top (relative to KB) (ft)					
Formation top (relative to GL) (ft)					
Formation top (relative to SL) (ft)					

Appendix A. Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *C–C′*.—Continued

[Abbreviations: APD, above permanent datum; ft, feet; GL, ground level; KB, kelly bushing; NA, not available; SL, sea level]

Drill-hole number	**6**	**7**	**8**	**9**	**10**	**11**
American Petroleum Institute number	**47–029–00080**	**37–007–20060**	**37–051–20056**	**37–111–20045**	**37–009–20034**	**37–009–20060**
Lease name	**No. 1 S. Minesinger**	**No. 1 Richard J. Ashcroft**	**No. 1 E.C. Ricks**	**No. 1 Leonard Svetz**	**No. 1 Schellsburg**	**No. 1 Fred Steele**
Permanent datum	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**
Ground level elevation (ft)	**1,039**	**1,120**	**2,523**	**2,450**	**1,650**	**1,162**
Kelly bushing elevation (ft)	**1,052**	**1,130**	**2,539**	**2,473**	**1,663**	**1,189**
Measured from	**KB (13 ft APD)**	**KB (10 ft APD)**	**KB (16 ft APD)**	**KB (23 ft APD)**	**KB (13 ft APD)**	**GL**
Drill depth (ft)	**10,387**	**7,590**	**12,041**	**21,460**	**11,850**	**15,500**
KB elevation - GL elevation (ft)	**13.0**	**10.0**	**16.0**	**23.0**	**13.0**	**27.0**
Formation 60				Gatesburg Formation (upper sandy member) (Rose Run sandstone equivalent)		
System or series				Upper Cambrian		
Formation top (relative to KB) (ft)				-20,835		
Formation top (relative to GL) (ft)				-20,812		
Formation top (relative to SL) (ft)				-18,362		
Formation 61				Ore Hill Limestone Member equivalent of Gatesburg Formation		
System or series				Upper Cambrian		
Formation top (relative to KB) (ft)				-21,320		
Formation top (relative to GL) (ft)				-21,297		
Formation top (relative to SL) (ft)				-18,847		
Formation 62				Gatesburg Formation (lower sandy member?)		
System or series				Upper Cambrian		
Formation top (relative to KB) (ft)				-21,453		
Formation top (relative to GL) (ft)				-21,430		
Formation top (relative to SL) (ft)				-18,980		

Appendix B.—Scale, Units, and Depths for Gamma-Ray Logging Runs

Appendix B. Scale, units, and depths for gamma-ray logging units.

[Abbreviations are as follows: API, American Petroleum Institute; ft, feet; KB, kelly bushing; nd, no data; TD, total depth; ft, feet]

Well number	Scale and units	Depths of selected logged intervals	Casing shoe location(s)
1	0–200 API units 200–400 backup scale	KB to TD	411 ft below KB.
2	0–15 micro Roentgen per hour	60 ft below KB to TD	nd
3	0–10 micrograms radium equivalents per ton 10–20 backup scale 20–30 backup scale	KB to TD	491 ft below KB.
4	0–200 API units 200–400 backup scale	40 ft below KB to TD	870 ft below KB.
5	0–200 API units 200–400 backup scale	15 ft below KB to TD	925 ft below KB.
6	0–150 API units 0–200 API units 200–400 backup scale	KB to 1,027 ft 1,000 ft below KB to TD	nd
7	0–200 API units 0–200 API units	KB to 1,282 ft 1,272 ft below KB to TD	nd
8	0–250 API units 0–200 API units 0–150 API units	KB to 9,320 ft 9,320 ft below KB to 11,400 ft 11,4000 ft below KB to TD	1,385 ft below KB. 9,388 ft below KB.
9	0–200 API units 0–200 API units 200–400 backup scale 0–200 API units	70 ft below KB to 1,450 ft 1,450 ft below KB to 10,250 ft 10,250 ft below KB to TD	110 ft below KB.
10	0–150 API units 150–300 backup scale	8 ft below KB to TD	3,120 ft below KB.
11	0–200 API units	146 ft below KB to TD	608 ft below KB. 11,338 ft below KB.

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