Geologic Cross Section *D–D′* through the Appalachian Basin from the Findlay Arch, Sandusky County, Ohio, to the Valley and Ridge Province, Hardy County, West Virginia

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Contents

Introduction..1
Construction of the Cross Section..1
Structural Framework..3
Basement Structures..4
Thin-Skinned Structures..6
Stratigraphic Framework..7
Lower Cambrian to Upper Ordovician Siliciclastic and Carbonate Strata..7
Upper Ordovician to Lower Silurian Siliciclastic Strata..11
Lower Silurian to Middle Devonian Carbonate and Evaporite Strata..12
Middle Devonian to Lower Mississippian Siliciclastic Strata..13
Middle and Upper Mississippian Carbonate Strata..16
Upper Mississippian, Pennsylvanian, and Permian Siliciclastic Strata..16
Acknowledgments..17
References Cited..17
Appendix A—Table summarizing drill holes, stratigraphic units, and depths of stratigraphic units in cross section *D–D′*..28
Appendix B—Scale, units, and depths for gamma-ray logging runs..52

Figures

[On map sheets]

1. Map of Ohio, West Virginia, Pennsylvania, and adjoining States showing location of cross section *D–D′* and selected tectonic features
2. Correlation of Paleozoic rocks along cross section *D–D′* in Ohio and West Virginia
3. Figure showing the Broad Top and Plateau sheets of Wilson and Shumaker (1992)

Tables

1. Drill holes used to construct cross section *D–D′*............2

Conversion Factors

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
meter (m)	3.281	foot (ft)
mile (mi)	1.609	kilometer (km)
kilometer (km)	0.6214	mile (mi)

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Introduction

Geologic cross section *D–D′* is the second 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 *D–D′* provides a regional view of the structural and stratigraphic framework of the Appalachian basin from the Findlay arch in northwestern Ohio to the Valley and Ridge province in eastern West Virginia, a distance of approximately 290 miles (mi) (fig. 1 on sheet 1). The information shown on the cross section is based on geological and geophysical data from 13 deep drill holes, several of which penetrate the Paleozoic sedimentary rocks of the basin and bottom in Mesoproterozoic (Grenville-age) crystalline basement rocks. This cross section is a companion to cross section *E–E′* (Ryder and others, 2008) that is located about 25 to 50 mi to the southwest (fig. 1). Cross sections *D–D′* and *E–E′* update earlier geologic cross sections through the central Appalachian basin by Renfro and Feray (1970), Bennison (1978), and Bally and Snelson (1980) and a stratigraphic cross section by Colton (1970). Published cross sections through parts of the basin show more structural detail (for example, Shumaker, 1985; Wilson, 1985a,b,c; Kulander and Dean, 1986; Wilson and Shumaker, 1992) and stratigraphic detail (for example, Ryder, 1991, 1992; de Witt and others, 1993; Hettinger, 2001) but are of more limited extent geographically and stratigraphically.

Although specific petroleum systems in the Appalachian basin 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 information shown on the cross section. Cross section *D–D′* lacks the detail to illustrate key elements of coal systems (such as paleoclimate, coal quality, and coal rank), but it does provide a general geologic framework (stratigraphic units and general rock types) for the coal-bearing section. Also, cross section *D–D′* 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 *D–D′* 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. In general, cross section *D–D′* follows the line of section used by Ryder (1991) in his stratigraphic study of Cambrian and Ordovician rocks.

The locations of the tops of each stratigraphic unit penetrated in the 13 deep drill holes were converted from depth in feet (ft) below kelly bushing (KB) to depth below ground level (GL), and then plotted on the cross section with respect to mean sea level (MSL). Detailed depth information for the tops of the stratigraphic units in each drill hole is reported in appendix A. In addition to the 13 deep drill holes used to construct the cross section (table 1), some of the details of Pennsylvanian stratigraphy were obtained from "shallow" USGS coreholes in northern West Virginia. Data from USGS corehole 6 (Dulong and others, 2002) were projected into the cross section at drill hole 9, whereas data from USGS corehole 10 (Nick Fedorko, West Virginia Geological and Economic Survey (formerly), unpub. data, 2003) were projected into the cross section between drill holes 10 and 11. In addition, data were obtained from shallow coreholes in eastern Ohio near drill holes 6 to 8 (Couchot and others, 1980) and from selected wells in northern West Virginia between drill holes 10 and 11 (Boswell and others, 1987; Lewis, 1983; West Virginia Geological and Economic Survey, 2005) and between drill holes 11 and 12 (Schwietering,

Table 1. Drill holes used to construct cross section *D–D′*.

Drill-hole no.	Name used in text	Location	American Petroleum Institute no.	Latitude (decimal degrees)	Longitude (decimal degrees)	Lithologic log	Cored intervals (ft) and formation	Total depth (ft)	Age of oldest rocks drilled (formation)
				Ohio					
1	East Ohio Gas Company No. 1–2171 V. and I. Haff	Townsend Township, Sandusky Co., Ohio (Clyde 7.5-min quadrangle)	34–143–20077	41.37085	-82.9066	Yes[1]		3,123	Mesoproterozoic (metamorphic and igneous rocks).
2	Pure Oil Company No. 1 I.M. Wheeler	Greenfield Township, Huron Co., Ohio (Willard 7.5-min quadrangle)	34–077–20025	41.1061	-82.7044	No		3,865	Late Cambrian (Maryville Limestone of Conasauga Group).
3	Empire Reeves Steel No. D–1 Empire Reeves Steel Division	Madison Township, Richland Co., Ohio (Mansfield North 7.5-min quadrangle)	34–139–20448	40.77921	-82.519	Yes[1] (samples end at 4,990 ft)		5,085	Mesoproterozoic (metamorphic and igneous rocks).
4	Great Lakes Gas Corporation No. 1 Alonzo Drake, Jr.	Wayne Township, Wayne Co., Ohio (Wooster 7.5-min quadrangle)	34–169–21419	40.8605	-81.9057	Yes[1]		6,897	Mesoproterozoic (metamorphic and igneous rocks).
5	Parker and Chapman No. 1 Dan E. Troyer	Saltcreek Township, Holmes Co., Ohio (Fredericksburg 7.5-min quadrangle)	34–075–21283	40.65712	-81.7723	Yes[1]		7,369	Late Cambrian (Maryville Limestone of Conasauga Group).
6	Stocker & Sitler, Inc. No. 2 (1–2669) Huebner	Rush Township, Tuscarawas Co., Ohio (Gnadenhutton 7.5-min quadrangle)	34–157–21030	40.30405	-81.4245	Yes[1]		8,277	Late Cambrian (Copper Ridge dolomite).
7	Red Hill Development No. 1 Thomas Zechman	Moorefield Township, Harrison Co., Ohio (Piedmont 7.5-min quadrangle)	34–067–20737	40.195	-81.1972	No		10,625	Mesoproterozoic (metamorphic and igneous rocks).
8	Sanford E. McCormick No. 1 Roy Birney	Green Township, Harrison Co., Ohio (Cadiz 7.5-min quadrangle)	34–067–20103	40.26188	-80.9664	Yes[1]		10,181	Late Cambrian (Rose Run sandstone).
				West Virginia					
9	Sanford E. McCormick No. 1 John Burley	Liberty District, Marshall Co., W. Va. (Cameron 7.5-min quadrangle)	47–051–00539	39.76167	-80.53	Yes[1]		16,512	Late Cambrian (Copper Ridge Dolomite).
10	Phillips Petroleum Company No. A–1 (A–1251) R.R. Finch	Winfield District, Marion Co., W. Va. (Fairmont East 7.5-min quadrangle)	47–049–00244	39.43194	-80.0122	Yes[1]		17,111	Early and Middle Ordovician (Beekmantown Dolomite).
11	Columbian Fuel Corporation No. USA Q–1, GW–1466, Monongahela National Forest	Union District, Preston Co., W. Va. (Lead Mine 7.5-min quadrangle)	47–077–00119	39.23791	-79.5734	Yes[1]	7,164–7,437 (Tuscarora Sandstone)	9,910	Late Ordovician (Reedsville Shale).
12	Shell Oil Company (Consolidated Gas Supply Corporation) No. 1 Greenland Lodge, Inc.	Union District, Grant Co., W. Va. (Greenland Gap 7.5-min quadrangle)	47–023–00002	39.19472	-79.1417	Yes[1]		13,000	Early and Middle Ordovician (Beekmantown Group) thrust over Ordovician (Beekmantown Group, St. Paul Group, Black River Limestone, and Trenton Limestone).
13	Exxon Corporation No. 1 Charles H. Bean, et al.	Moorefield District, Hardy Co., W. Va. (Old Fields 7.5-min quadrangle)	47–031–00021	39.1375	-78.9903	Yes[2]	9,791–9,821 (Copper Ridge Dolomite); 11,047–11,107 (Elbrook Formation)	16,075	Early and Middle Cambrian (Waynesboro Formation) thrust over Early and Middle Ordovician (Beekmantown Group).

Sources of lithologic logs:
[1]Geological Sample Log Company, Pittsburgh, Pa.
[2]Exxon mud log.

1980a; Geological Sample Log Company Log no. P–2285).

The correlation of stratigraphic intervals between drill holes and (or) coreholes 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; 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 (Crangle, 2007). The lithology assigned to each stratigraphic interval was simplified to just a few rock types and lithologic modifiers. The topographic profile for the cross section was created from a Shuttle Radar Topography Mission (SRTM) 90-meter (m)-grid digital elevation model (DEM) for parts of Ohio, Pennsylvania, West Virginia, Maryland, and Virginia (http://gisdata.usgs.gov/website/seamless/index.asp). This topographic profile is approximate and should not be used to determine accurate surface elevations.

A summary of the stratigraphic units and names identified along section *D–D′* is shown in figure 2 (on sheet 1). Although most correlations shown on section *D–D′* 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), Patchen and others (1985), Milici and de Witt (1988), Swezey (2002), and Slucher (2004) for the entire Paleozoic section; Janssens (1973), Diecchio (1985), Riley and Baranoski (1991a,b), Ryder (1991, 1992), Wickstrom and others (1992), Riley and others (1993), and Harris and others (2004) for the Cambrian and Ordovician rocks; Clifford (1973), Janssens (1977), Smosna and others (1977), Hettinger (2001), and Ryder (2004) for the Silurian rocks; Dennison (1970), Majchszak (1980a,b,c), Schwietering (1980a,b), Filer (2002, 2003), Boswell and others (1987), Boswell (1988a,b), Dennison and others (1988), and de Witt and others (1993) for the Devonian rocks; Couchot and others (1980), Majchszak (1984), Matchen and Vargo (1996), Hohn (1996), Vargo and Matchen (1996), and Dulong and others (2002) for the Mississippian and Pennsylvanian rocks.

Only selected unconformities are shown on cross section *D–D′*. Regional unconformities shown on section *D–D′* and in figure 2 include the Middle Ordovician (Knox) unconformity (Harris and Repetski, 1982; Mussman and others, 1988), the Upper Ordovician-Lower Silurian Cherokee unconformity (Dennison and Head, 1975; Diecchio and Brodersen, 1994), the Middle-Upper Devonian unconformity (de Witt and others, 1993), and the Lower Pennsylvanian unconformity (Arkle and others, 1979; Beuthin, 1994). The correlation of these unconformities with North American sequences of Sloss (1988) is shown in figure 2 and in Swezey (2002).

Basement-involved structures along cross section *D–D′* are modified from structure contour maps by Shumaker (1996) and Baranoski (2002) and from seismic-based interpretations by Kulander and Ryder (2005). High-amplitude, complex, thin-skinned ramp anticlines (Etam, Deer Park-Leadmine, Blackwater, Wills Mountain, and Patterson Creek Mountain) near the Allegheny structural front were constructed on section *D–D′* largely on the basis of interpretations by Wilson (1985a,b,c, 1989) and Wilson and Shumaker (1992). Low-amplitude anticlines in central West Virginia are based on a structure contour map by Cardwell (1982) that represents the structure on top of the Devonian Onondaga Limestone-Huntersville Chert. The Chestnut Ridge anticline that was drilled by drill hole 10 marks the approximate westernmost limit of thin-skinned anticlines shown on the cross section. Northwest of the Chestnut Ridge anticline, structural dip along the cross section is largely determined by connecting equivalent formation tops between drill holes. However, in Ohio the regional dip is locally based on structure contour maps by Gray (1982a,b) that represent the structure on top of the Devonian Berea Sandstone and the Devonian Onondaga Limestone. Where applicable, stratigraphic units on the cross section are tied to the outcrop using the geologic maps of Ohio (Slucher and others, 2006) and West Virginia (Cardwell and others, 1968) and, locally, unpublished maps by the West Virginia Geological and Economic Survey (Nick Fedorko, West Virginia Geological and Economic Survey, oral commun., 2005).

Structural Framework

The western margin of the Valley and Ridge province (fig. 1) is located at the western limb of the Wills Mountain anticline. Beneath the Wills Mountain anticline is a thick allochthonous panel of Cambrian-Ordovician carbonate rocks (Broad Top sheet of Wilson and Shumaker, 1992) that decoupled from the underlying strata and was thrust 12 to 15 mi westward over a parautochthonous panel of Cambrian-Ordovician carbonate rocks (Plateau sheet of Wilson and Shumaker, 1992). The footwall ramp, which is shown on the easternmost part of the cross section beneath drill hole 13, connects the basal zone of detachment (footwall flat) in the Lower Cambrian Waynesboro Formation with a higher zone of detachment (hangingwall flat) in the Upper Ordovician Reedsville Shale (thrust fault terminology from McClay, 1992). A net structural relief of about 2 mi was created by the duplicated Cambrian Conasauga Group-Elbrook Formation in the anticline. Another consequence of this major structural dislocation is the juxtaposition of steeply dipping lower Paleozoic carbonate and siliciclastic rocks of the frontal Wills Mountain anticline against less deformed upper Paleozoic rocks of the Allegheny Plateau structural province (Kulander and Dean, 1986). This abrupt juxtaposition of structural styles defines the Allegheny structural front.

Basement-involved and thin-skinned (terminology from Rodgers, 1949) structures are shown on cross section *D–D′*, and their geometry, style, and timing are briefly discussed. More detailed treatments of the structural styles and patterns of the central Appalachian basin are presented by Faill (1997a,b, 1998) and Scanlin and Engelder (2003). The basement structures are largely extensional in origin, and several of them may have evolved during the Neoproterozoic-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 side of North America (Rankin and others, 1989; Thomas, 1991). A Middle Cambrian event, which was more moderate in scale than the Neoproterozoic-earliest Cambrian 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 Late Mississippian-Permian continental collision (Alleghanian orogeny) between eastern North America and Africa (Rodgers, 1988; Hatcher and others, 1989). Crustal contraction that accompanied the collision caused large horizontal displacements of thick panels of Paleozoic strata along thin, incompetent Paleozoic strata. Typical Appalachian thin-skinned structures are bedding-plane detachment zones, footwall ramps, ramp anticlines, and imbricate thrust faults (Rodgers, 1963; Gwinn, 1964; Wilson, 1985a,b,c, 1989; Kulander and Dean, 1986; Wilson and Shumaker, 1992). 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).

Basement Structures

Basement rocks along cross section *D–D′* 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 mega-annum (Ma), and many ages cluster around 1,000 to 1,100 Ma (Rankin and others, 1993) (fig. 2). Lidiak and others (1966) reported a K-Ar age of 935 Ma for gneiss and schist in the No. 1 Bruns drill hole (Sandusky County, Ohio), which is located about 25 mi west of drill hole 1 and in the No. 1 Arting drill hole (Huron County, Ohio), which is located about 7 mi north of drill hole 2 (fig. 1). As shown on nearby cross section *E–E′* (fig. 1), Lidiak and others (1966) reported a 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 these ages reported by Lidiak and others (1966) are younger than the 950 Ma upper limit of Grenville basement rocks suggested by Rankin and others (1993), they are grouped in this report with rocks of the Grenville province. Basement rocks in drill hole 1 of this cross section are described as medium-grained granite that contains predominantly orthoclase and quartz and accessory biotite and plagioclase (McCormick, 1961). Moreover, basement rocks in drill holes 12 to 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 Sm-Nd age of 1,272±32 Ma for gabbro basement in drill hole 3 on cross section *E–E′* (see Wickstrom and others, 1985, for a description of the rocks in the drill hole) but could not explain the absence of Grenville-age (Mesoproterozoic) penetrative deformation and associated resetting of the apparent age. The western margin of the Grenville province is marked by the Grenville front (fig. 1) along which intensely deformed Grenville-age 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 (fig. 1). The basement-involved Bowling Green fault zone, located about 40 mi beyond the western end of the cross section, coincides with the Grenville front (fig. 1; Baranoski and Wickstrom, 1991; Wickstrom and others, 1992; Baranoski, 2002).

The Coshocton zone, a 50-to 60-mi-wide zone of east-verging penetrative deformation in the Grenville basement, is located approximately between drill holes 5 and 9 in the eastern Ohio and westernmost West Virginia part of cross section *D–D′*. On the basis of deep seismic reflections on COCORP profiles, this zone is interpreted by Culotta and others (1990) as the site of an intra-Grenville province suture zone. Younger basement structures discussed in the following paragraphs seem to have no relation with structures in the Coshocton zone.

Typical of many foreland basins, 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. Along section *D–D′*, this basement ramp deepens progressively southeastward from about 3,000 ft below mean sea level (MSL) beneath the eastern flank of the Findlay arch to about 23,500 ft below MSL beneath the Allegheny structural front. This gradual eastward deepening of the basement ramp along section *D–D′* is interrupted by the Rome trough (fig. 1), a Middle Cambrian rift system that drops basement to as much as 26,000 ft below MSL. The western limit of the Rome trough is defined here as the down-to-the-east normal fault located several miles west of drill hole 9 (Shumaker, 1996; Baranoski, 2002), whereas the eastern limit of the Rome trough is defined as the down-to-the-west normal fault (later reactivated) about 5 mi east of drill hole 10 (Shumaker, 1996; Kulander and Ryder, 2005).

Minor inflection points or hinge zones in the basement ramp probably occur near drill holes 3, 5, and 6 in north-central Ohio, and a major 30-mi-wide hinge zone extends between drill hole 8 in eastern Ohio to about midway between the Ohio-West Virginia border and drill hole 9. The north-central Ohio inflection point near drill hole 3 coincides approximately with the Waverly arch (fig. 1), a north-trending basement arch identified by Woodward (1961) from isopach patterns in the

Cambrian-Ordovician Knox Dolomite and mapped by Janssens (1973) and Shearrow (1987). According to Root and Onasch (1999), the Waverly arch is a basement uplift that formed during the Taconic orogeny as a result of contrasting anisotropies across lithotectonic boundaries in the Grenville basement rocks. The 30-mi-wide hinge zone between drill holes 8 and 9 coincides approximately with the Ohio-West Virginia hinge zone of Ryder (1991, 1992) that marks the western margin of the Rome trough (fig. 1). Where section *D–D′* crosses the Rome trough, the trough is about 45 to 50 mi wide and has a structural relief on basement that ranges from several hundred feet at its western margin across down-to-the-east normal (extensional) faults to an estimated 4,000 to 5,000 ft at its eastern margin across down-to-the-west normal (extensional) faults. Most basement faults of the Rome trough in the cross section have been recognized in previous studies (Shumaker, 1996; Baranoski, 2002; Kulander and Ryder, 2005). A basement block, called the central West Virginia arch (Kulander and Dean, 1986), flanks the eastern margin of the Rome trough and dips gently eastward beneath the Allegheny structural front and the western part of the Valley and Ridge province. The eastern part of the arch may be broken into several blocks by down-to-the-east normal (extensional) faults that involve basement beneath and east of the Etam and Wills Mountain anticlines (Jacobeen and Kanes, 1975; Shumaker, 1996).

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-Permian Alleghanian orogeny.

The best example of Alleghanian basin inversion on section *D–D′* is shown by the Chestnut Ridge anticline where well 10 was drilled (fig. 1). This anticline shows evidence of both thin-skinned and basement deformation. As shown on the cross section, the Chestnut Ridge anticline clearly involves the Middle Devonian Huntersville Chert (Cardwell, 1982), probably as a result of thin-skinned detachment in the underlying Upper Ordovician Reedsville Shale (Kulander and Ryder, 2005) and Upper Silurian Salina Group (Gwinn, 1964; Wilson, 1985b). Furthermore, the anticline is interpreted here to be deeply rooted and involve lower Paleozoic strata and Mesoproterozoic basement rocks, judging from the structural geometry shown by a seismic line (Kulander and Ryder, 2005) that crosses the Chestnut Ridge anticline about 5 to 10 mi south of drill hole 10 (fig. 1). Because the deeply rooted part of this anticline occurs below any zones of known bedding-plane detachment, it is interpreted here to be caused by mild basin inversion associated with the reversal in motion of the eastern boundary fault of the Rome trough during the Alleghanian orogeny.

Approximately 8 to 9 mi northeast of cross section *D–D′*, the Chestnut Ridge anticline diverges from the eastern margin boundary fault of the Rome trough and continues into southwestern Pennsylvania (fig. 1). On the basis of seismic data, Scanlin and Engelder (2003) showed that the Chestnut Ridge anticline in southwestern Pennsylvania is underlain by a downdropped western basement block in the Rome trough graben system, but evidence for inversion is lacking. Furthermore, Scanlin and Engelder (2003) showed that thin-skinned structures are more characteristic of the Chestnut Ridge anticline in this area than basement-involved structures, which contrasts with the Chestnut Ridge anticline on section *D–D′*. From where it diverges from the Chestnut Ridge anticline (8–9 mi northeast of section *D–D′*), the eastern margin boundary fault of the Rome trough trends northeastward into southwestern Pennsylvania (Shumaker, 1996; Shumaker and Wilson, 1996) and underlies the Laurel Hill anticline (fig. 1). We suggest that the Laurel Hill anticline was initiated by mild inversion along the eastern margin boundary fault of the Rome trough, during Alleghanian contraction, in a manner akin to the initiation of the Chestnut Ridge anticline on section *D–D′*. Inversion along the eastern boundary fault zone of the Rome trough formed deep-seated structural relief that disrupted westward-propagating zones of bedding-plane detachment in Ordovician and Silurian strata that were approximately synchronous with the inversion. Disrupted detachment zones beneath the Chestnut Ridge and Laurel Hill anticlines were transformed onto complex imbricate faults (both northwest and southeast verging) and triangle zones (Scanlin and Engelder, 2003). Even in areas without structural inversion, the basement-involved fault zones of the Rome trough commonly imposed a northeast-trending positive structural grain on Mesoproterozoic basement rocks and overlying Cambrian strata along which imbricate faults were concentrated (Scanlin and Engelder, 2003).

Another possible example of Alleghanian basin inversion on section *D–D′* is shown by the Hundred anticline located about 7 mi east of drill hole 9. This anticline is interpreted to be deeply rooted on the basis of a seismic line (Kulander and Ryder, 2005) that crosses the colinear Arches Fork anticline approximately 30 mi south of the cross section. The reactivated basement fault shown on the seismic section (Kulander and Ryder, 2005) dips northwestward beneath the Arches Fork anticline, whereas the reactivated basement fault shown on section *D–D′* dips southeastward beneath the Hundred anticline.

Yet another basement structure on section *D–D′* may be the northwest-trending Parkersburg-Lorain syncline, which is present approximately 10 mi west of drill hole 4. This structure is a broad south-plunging syncline on a structure contour map on the top of the Berea Sandstone (Gray, 1982a), but the syncline does not appear on a structure contour map on the top of the

Onondaga (Columbus) Limestone (Gray, 1982b). From its location on section *D–D′*, the Parkersburg-Lorain syncline extends southward to the Ohio-West Virginia border, and from there the Parkersburg syncline extends a short distance into West Virginia (fig. 1). Along most of this trend, the syncline is flanked by the Cambridge arch (Cambridge cross strike structural discontinuity of Baranoski, 2002), which is interpreted as a basement structure (Root, 1996; Baranoski, 2002). Gray (1982a, b), Riley and others (1993), and Baranoski (2002) have suggested that the northern end of the Cambridge arch-cross strike structural discontinuity terminates in Coshocton or Holmes Counties (fig. 1). However, judging from the apparent genetic relation between the arch and the abrupt westward limit of Silurian halite beds that trends northwestward across central Ohio (Clifford, 1973; Farmerie and Coogan, 1995; Root, 1996), both the arch and the Parkersburg-Lorain syncline may extend at least as far north as cross section *D–D′* or even farther.

Thin-Skinned Structures

Thin-skinned structures on cross section *D–D′* include the Broad Top, Patterson Creek Mountain, Wills Mountain, Blackwater, Deer Park-Leadmine, Etam, and Chestnut Ridge anticlines at the eastern end of the cross section. These anticlines are high-amplitude, commonly west-verging structures that formed during the Late Mississippian-Permian Alleghanian orogeny (Gwinn, 1964; Kulander and Dean, 1986; Wilson and Shumaker, 1992). The Wills Mountain (upper part), Patterson Creek Mountain, and Broad Top anticlines (including the Clearville syncline that overlies the western margin of the Broad Top anticline in the subsurface) belong to the Broad Top sheet of Wilson and Shumaker (1992), whereas the Etam, Deer Park-Leadmine, Blackwater, and Wills Mountain (lower part) anticlines belong to the Plateau sheet of Wilson and Shumaker (1992).

In drill hole 12, the master tectonic ramp-thrust fault of the Wills Mountain anticline is located 8,500 ft below MSL where allochthonous Lower Ordovician Beekmantown Group rocks rest in thrust contact on an overturned syncline that involves Lower to Upper Ordovician carbonate rocks and shale (W.J. Perry, Jr., USGS, unpub. data, 1980). The drill hole bottomed in the upright limb of the overturned syncline, which is considered in this report to be a horse block that was derived from the eastern margin of the Plateau sheet and is now lodged between the main allochthonous sheet (Broad Top sheet) and the underlying subhorizontal parautochthonous sheet (Plateau sheet) (see figure 3 on sheet 2). Additional structural complications in the Wills Mountain anticline, shown on section *D–D′* and based on repeated strata in drill hole 12, are imbricate faults (at approximate depths of 3,200 and 6,100 ft below ground level) that branch from the master thrust and the synclinal horse block. These imbricate faults cut the core of the anticline and probably the roof thrust in the Ordovician Reedsville Shale at the crest of the anticline. Also, at the crest of the Wills Mountain anticline, the roof thrust bends sharply westward to conform with the steep western frontal limb of the anticline to merge with the top of the hangingwall flat in the master thrust (in the Reedsville Shale) beneath the Allegheny structural front (Wilson and Shumaker, 1992). Moreover, the master thrust or ramp of the Wills Mountain anticline and the underlying horse block were folded by a deeper thrust-ramp that branched off the basal zone of detachment and joined the hangingwall flat in the Reedsville Shale about 5 mi west of drill hole 12. This deeper thrust fault-ramp is one of several secondary thrusts that subdivide the parautochthonous Plateau sheet of Wilson and Shumaker (1992) into five subsheets (see figure 3). According to McClay (1992), thrust-fault-bounded structures such as subsheets 2 to 5 also may be classified as horses. The thrust fault-ramp that folded the master thrust beneath the Wills Mountain anticline is the easternmost of the lower thrust subsheets (5) (see figure 3). This easternmost subsheet was originally named the Wills Mountain block by Wilson (1989), but Wilson and Shumaker (1992) later abandoned the term.

Within and east of the Wills Mountain anticline, several thrust faults branch off the master thrust fault (hangingwall flat) of the Broad Top sheet of Wilson and Shumaker (1992) and divide the sheet into three subsheets (or horses) (see figure 3). The easternmost subsheet (3) forms the Broad Top anticline, the western part of which is shown at the eastern end of cross section *D–D′*. The thrust fault that forms the Broad Top anticline is located in drill hole 13 about 14,000 ft below MSL where several repeated sections of the Waynesboro Formation rest in thrust contact on the Beekmantown Group. This thrust fault that forms the Broad Top anticline joins the upper zone of detachment in the Reedsville Shale (roof thrust) about 1 to 2 mi west of drill hole 13, and also very likely offsets the roof thrust. Subsheet 2 of the Broad Top sheet forms the Patterson Creek Mountain anticline, which is located 2 to 3 mi west of drill hole 13. Imbricate thrusts that splay off the roof thrust in the Reedsville Shale cut Upper Ordovician to Upper Devonian strata in the Patterson Creek Mountain anticline. The western subsheet (1) of the Broad Top sheet forms the majority of the Wills Mountain anticline. Also, subsheet 1 of the Broad Top sheet overrides the previously described synclinal horse block that is lodged between the Broad Top and Plateau sheets.

From its juncture with the master thrust of the Broad Top sheet at the eastern end of section *D–D′*, the basal detachment in the Lower to Middle Cambrian Waynesboro Formation continues farther westward for an estimated 50 to 55 mi beneath the Plateau sheet to near the eastern edge of the Rome trough. West-verging thrust faults branch upward from this basal detachment in the Waynesboro Formation, subdivide the Plateau sheet into the previously mentioned five subsheets, and join a higher detachment in the Reedsville Shale that extends westward from the Wills Mountain anticline. Except for the western subsheet (1), each of these thrust faults-subsheets has carried a panel of Cambrian and

Ordovician carbonate strata westward for 1 to 2 mi across the footwall ramp that connects the basal detachment in the Waynesboro Formation with the higher detachment in the Reedsville Shale. Subsheets 2 to 4 of the Plateau sheet are characterized by ramp anticlines that have folded overlying Paleozoic strata and preexisting faults, in the same manner as the Wills Mountain anticline. The underlying synclinal horse block has been folded by the easternmost subsheet 5 of the Plateau sheet. The Blackwater, Deer Park-Leadmine, and Etam anticlines are interpreted as having been caused by thrusts and associated ramps of subsheets 4, 3, and 2, respectively, of the Plateau sheet. This interpretation is supported by seismic lines that cross the Deer Park-Leadmine and Etam anticlines (Kulander and Ryder, 2005) and by a cross section through the Deer Park anticline (Wilson, 1985a). Most other structural interpretations have suggested that the Blackwater, Deer Park-Leadmine, and Etam anticlines were caused by imbricate faults that branched from detachments in the Reedsville Shale and (or) Salina Group (for example, see Gwinn, 1964).

In the Blackwater anticline, the imbricate fan associated with the Reedsville detachment is probably folded by an underlying ramp anticline that branches from the basal Cambrian detachment. Moreover, the underlying thrust fault that created the underlying ramp anticline is interpreted to cut through the Reedsville detachment and imbricate fan, and to extend as far upsection as the Upper Devonian strata. Following Wilson (1985b), additional detachment zones (in the Silurian Salina Group and Devonian Brallier Formation) branched off the faulted core of the Blackwater anticline. In the Deer Park-Leadmine and Etam anticlines, imbricate fans are interpreted by Wilson (1985b) to account for the overthickening of the Reedsville Shale in the anticline cores (Wilson, 1985a,b). In cross section *D–D′*, the overthickening of the Reedsville Shale in the core of the Deer Park-Leadmine and Etam anticlines is attributed to a smooth roof duplex (thrust fault terminology from McClay, 1992) that extends between the anticlines and is folded by ramp anticlines in the underlying Plateau sheet.

West of the Etam anticline, the detachment zone in the Reedsville Shale is interpreted on section *D–D′* to continue for 60 to 65 mi, where it has produced several additional anticlines and thrust faults. The largest of these anticlines is the previously discussed Chestnut Ridge anticline that is interpreted here to be related to a deeply rooted inversion structure that involves basement rocks. This anticline also has a thin-skinned component that involves the Salina detachment zone (Wilson, 1985c), the Reedsville detachment zone, and possibly imbricate faults with opposing vergence. Also, the small Hiram and Wolf Summit anticlines that flank the Chestnut Ridge anticline and involve the top of the Huntersville Chert (Cardwell, 1982) may have been caused by minor thrust faults that branch upward from the Reedsville Shale and (or) the Salina detachment zones. Perhaps these anticlines were localized by structural inversion that predated or was penecontemporaneous with the Salina-Reedsville detachment zones. Salina detachment probably extends westward from the Blackwater anticline (Wilson, 1985b) to the Ohio-West Virginia border (Milici, 1980) and possibly into eastern Ohio (Faill, 1998).

Stratigraphic Framework

Sedimentary rocks shown on cross section *D–D′* span most of the Paleozoic Era, and their thickness ranges from about 3,200 ft on the eastern flank of the Findlay arch to about 26,000 ft near the Allegheny structural front. Lithology, nomenclature, depositional setting, and tectonic setting of the sedimentary rocks along cross section *D–D′* are briefly outlined and discussed in the following sections. A more detailed treatment is available in the regional geological summaries by Colton (1970), Milici and de Witt (1988), Read (1989a,b), and Faill (1997a,b, 1998). The papers by Faill (1997a,b, 1998) are the most comprehensive syntheses to date regarding the geologic evolution of the central Appalachians. Although the papers by Faill are focused on the Pennsylvania region, much of the geologic history is applicable to the region traversed by cross section *D–D′*.

Much of the eastward thickening of strata in the Appalachian basin was caused by regional tectonism. Initial rifting and subsidence caused by the cooling and thermal contraction of the lithosphere, as the proto-Atlantic Ocean (Iapetus Ocean) opened, provided accommodation-preservation space for sediments to build the eastward-facing passive continental margin of Laurentia (North America) (Bond and others, 1988; Read, 1989b). At a later time, subsidence caused by thrust loading provided additional accommodation space for sediments to accumulate in several 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 caused load-induced subsidence (by sediments and overlying water column) that provided accommodation space for additional sediments on the outer continental shelf, whereas a fall in sea level caused erosion of the inner continental shelf.

Lower Cambrian to Upper Ordovician Siliciclastic and Carbonate Strata

Lower Cambrian to Upper Ordovician siliciclastic and carbonate strata are characterized by dolomite, anhydritic dolomite, and limestone, and lesser amounts of gray shale, red shale, and sandstone. On section *D–D′*, these Lower Cambrian to Upper Ordovician strata thin dramatically from about 9,000 ft in eastern West Virginia to about 1,400 ft in northwestern Ohio. In the Rome trough in northern West Virginia, these strata are as thick as 13,500 ft. In the eastern part of cross section *D–D′* (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 Dolomite (Formation), Waynesboro Formation, Conasauga Group-Elbrook Formation, Copper Ridge Dolomite, Rose Run Sandstone, Beekmantown Group (Dolomite), St. Paul Group, Black River Limestone, and Trenton Limestone (fig. 2). The use of the terms "Chilhowee Group," "Tomstown Dolomite (Formation)," and "Waynesboro Formation" follows the preferred nomenclature for Lower Cambrian strata in northern West Virginia (Cardwell and others, 1968; Kulander and Dean, 1986), northern Virginia (Virginia Division of Mineral Resources, 1993; Southworth and others, 2002), and Maryland (Brezinski, 1992). In southern West Virginia and southern Virginia, equivalent strata are named the Chilhowee Group, Shady Dolomite, and Rome Formation, respectively.

In the Ohio part of the cross section, equivalent Cambrian to Upper Ordovician strata consist of the following units (in ascending order): Mount Simon Sandstone, Conasauga Group, Knox Dolomite (Copper Ridge dolomite, Rose Run sandstone, Beekmantown dolomite), Wells Creek formation, Black River Group, and Trenton Limestone (fig. 2). The Rome Formation of Janssens (1973) in eastern and central Ohio is now considered to be an obsolete stratigraphic term (Harris and others, 2004) and is not used on cross section *D–D′*.

Because Cambrian units in the eastern part of cross section *D–D′* are largely undrilled, their lithology and thickness are based on drill holes 9 and 13 on section *D–D′* and on drill holes 11 to 14 on the nearby cross section *E–E′*. Drill hole 9 near the western margin of the Rome trough penetrated the uppermost Copper Ridge Dolomite and the Rose Run Sandstone, whereas drill hole 13 in the Valley and Ridge province penetrated the upper part of the Waynesboro Formation, the Elbrook Formation, and the Copper Ridge Dolomite. By comparison, drill holes 11 to 14 on section *E–E′*, located 50 to 100 mi south of section *D–D′*, penetrated the entire Cambrian section in the Rome trough. Cambrian units between the western margin of the Rome trough and the Findlay arch are reasonably well documented by drill holes 1 to 8 on cross section *D–D′*.

As interpreted on section *D–D′*, the Lower Cambrian Chilhowee Group and Tomstown Dolomite (Formation) and the Lower and Middle Cambrian Waynesboro Formation have a combined thickness ranging from about 500 to 3,500 ft, and are located in the Rome trough and adjoining areas to the east, such as the central West Virginia arch and the Valley and Ridge province. The 100- to 250-ft-thick basal sandstone between the western margin of the Rome trough and drill hole 1 is recognized as the Middle to Upper Cambrian Mount Simon Sandstone.

The Lower Cambrian Chilhowee Group (which rests unconformably on Mesoproterozoic Grenville basement rocks) and the overlying Lower Cambrian Tomstown Dolomite (Formation) are the two oldest sedimentary units on section *D–D′*. Although neither unit has been penetrated by drill holes on section *D–D′*, a combined thickness of about 400 ft is estimated from cross section *E–E′*. The Chilhowee-Tomstown interval is interpreted to continue east of cross section *D–D′*. Correlative rocks crop out in northern and central Virginia along the Blue Ridge structural front (fig. 1). Westward, the Chilhowee-Tomstown interval is interpreted here to terminate against a prominent basement fault block near the middle of the Rome trough.

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

The Chilhowee-Tomstown interval is possibly capped by a disconformity (Ryder, 1992) (fig. 2), which is overlain by the Waynesboro Formation. The age of the Waynesboro Formation is uncertain. An Early Cambrian age is commonly cited for the Waynesboro Formation (Butts, 1945; Palmer, 1971; Kulander and Dean, 1986; Brezinski, 1992); however, fossil evidence is very sparse so that a Middle Cambrian age is plausible for part of the Waynesboro (Stose, 1909; Woodward, 1949; Read, 1989a,b). On the basis of probable Middle Cambrian fossils in the Rome Formation (equivalent to the Waynesboro) in the Rome trough of western West Virginia (Donaldson and others, 1988), an Early and Middle Cambrian age is assigned to the Waynesboro Formation in this report. Beneath drill hole 10 in the Rome trough, the Waynesboro Formation probably consists of approximately 3,000 ft of gray shale with local beds of sandstone and limestone.

In drill hole 13, between about 12,600 and 14,750 ft, the Waynesboro Formation consists of three 200- to 500-ft-thick zones, characterized by red and green shale and oolitic dolomite that have been repeated by thrust faults (Exxon mud log, unpub. data, 1980; called Rome Formation by Exxon geologists). These faulted Waynesboro strata are probably horse blocks that were derived from the basal detachment, tectonically transported westward along the master thrust fault or ramp of the Broad Top sheet, with a net vertical displacement of about 8,000 to 9,000 ft, and juxtaposed against the Beekmantown Group. Also accompanying this group of horse blocks in drill hole 13 is a 300-ft-thick block of argillaceous dolomite that was originally identified as Tomstown Dolomite (Formation) (Exxon mud log, unpub. data, 1980; called Shady Dolomite by Exxon geologists). On cross section *D–D′*, this dolomite horse block is now interpreted to be part of the Elbrook Formation because it is unlikely that the Tomstown-Shady interval was disrupted by the basal detachment. Along the basal detachment between drill holes 11 and 13, the Waynesboro Formation is a westward tapering wedge (as much as 1,400 ft thick) of red beds and carbonates that overlies the Tomstown Dolomite (Formation) and pinches out near the crest 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 limestone-dolomite, based on the lithology of the Waynesboro Formation in drill hole 13 and in outcrops in eastern West Virginia (Woodward, 1949), northern Virginia (Virginia Division of Mineral Resources, 1993; Southworth and others, 2002), and Maryland (Brezinski, 1992).

On the basis of cross section *E–E′* (see figure 1 for location), the Waynesboro Formation probably changes in lithology from the previously cited gray shale with local beds of sandstone and limestone 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 part of the Waynesboro Formation rests directly on Grenville basement rocks, thins progressively westward across successive fault blocks in the Rome trough, and is juxtaposed against the hinge zone near the Ohio-West Virginia border. Very likely, the argillaceous sandstone of the Waynesboro Formation intertongues with gray shale of the Waynesboro and carbonates of the lower part of the Conasauga Group between the Wolf Summit anticline and drill hole 9. Marked contrasts between the thick, gray shale-dominated Waynesboro Formation of the Rome trough and the thin, red bed-dominated Waynesboro Formation of the northern extension of the central West Virginia arch probably reflect the sequence of extensional basement faulting. The Waynesboro strata shown on section *D–D′* 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 separate rift basins of the Rome trough.

In the outcrop of eastern West Virginia and in the subsurface of the Rome trough, the Waynesboro Formation is interpreted as a shallow-water, nearshore marine deposit (Woodward, 1949; Donaldson and others, 1988). West of the Rome trough, the Waynesboro Formation is replaced by the Middle and Upper Cambrian Mount Simon Sandstone, a transgressive deposit that extends across the Ohio part of section *D–D′* (see drill holes 7, 1–4).

The combined thickness of the Conasauga Group (and equivalent Elbrook Formation) through Trenton Limestone ranges from an estimated 8,100 ft beneath the Allegheny structural front to about 1,100 ft on the eastern flank of the Findlay arch. The Middle and Upper Cambrian Conasauga Group (which consists of complexly interbedded units of limestone, dolomite, gray shale, and sandstone) is between 1,500 and 2,500 ft thick and conformably overlies the Waynesboro Formation except perhaps along the crest of the central West Virginia arch. In the Rome trough, in adjoining cross section *E–E′*, the Conasauga Group is subdivided (in ascending order) into the Pumpkin Valley Shale, Rutledge Limestone, Rogersville Shale, Maryville Limestone, and Nolichucky Shale. The Maryville Limestone, which is largely dolomite, and the Nolichucky Shale extend beyond the western margin of the trough and continue west across Ohio (Harris and others, 2004). The Maryville Limestone in Ohio, as used in this report and by Harris and others (2004), was formerly the Rome Formation of Janssens (1973). Similarly, the Nolichucky Shale in Ohio was formerly 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). Lithologic equivalents of the Rutledge, Rogersville, Maryville, and Nolichucky (as well as an unnamed sandstone unit in the middle part of the Maryville) are projected from section *E–E′* into the undrilled Conasauga Group in cross section *D–D′*. Drill hole 13 at the eastern end of the cross section penetrated an allochthonous 1,600- to 1,700-ft-thick section of the Middle to Upper Cambrian Elbrook Formation (for age, see Brezinski, 1996) that is equivalent to the Conasauga Group and contains lithologic units that are similar to the Rutledge Limestone, Rogersville Shale, and Maryville Limestone (Exxon mud log, unpub. data, 1980).

The Conasauga Group, as well as the overlying strata through the Trenton Limestone, 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 is interpreted as tidal-flat to shallow-marine deposits (Donaldson and others, 1988). Moreover, the unnamed sandstone member in the middle part of the Maryville Limestone was probably derived from a cratonic source to the north.

Between the western margin of the Rome trough and the eastern end of the section, the Conasauga Group is conformably overlain by the 900- to 1,600-ft-thick Upper Cambrian Copper Ridge Dolomite, which is, in turn, conformably overlain by the 250- to 400-ft-thick Upper Cambrian(?) Rose Run Sandstone. The 1,400-ft-thick Copper Ridge Dolomite in drill hole 13 includes a sandy dolomite unit near the top that is equivalent to the Rose Run Sandstone and a middle limestone unit that may be equivalent to the Ore Hill Limestone Member of the Upper Cambrian Gatesburg Formation in central Pennsylvania (Wilson, 1952). The stratigraphic terms “Copper Ridge Dolomite” and “Rose Run Sandstone,” as applied here, replace the terms “Gatesburg Formation,” “lower sandy member,” and “upper sandy member” as used in northern and central West Virginia by Ryder (1991, 1992). The Rose Run Sandstone (sandstone) is interpreted as having been derived from the craton.

The Rose Run Sandstone is overlain conformably by a 2,100- to 3,300-ft-thick dolomite unit, which is commonly anhydritic and contains the Middle Ordovician (Knox) unconformity. In drill holes 9 and 10, the stratigraphic position of the unconformity is used to subdivide the anhydritic dolomite into the Lower Ordovician Beekmantown Dolomite and the overlying Middle Ordovician unnamed anhydritic dolomite (fig. 2). For example, the Beekmantown Dolomite in drill hole 9 is 1,700 ft thick and is unconformably overlain by 200 ft of unnamed shale, which is succeeded by 200 ft of unnamed anhydritic dolomite. By comparison, the Beekmantown Dolomite in and below drill hole 10 is approximately 2,200 ft thick and is unconformably overlain by 1,400 ft of unnamed anhydritic dolomite. Thus, the Beekmantown Group of Ryder (1991, 1992), which included the entire 2,100- to 3,300-ft-thick anhydritic dolomite sequence in drill holes 9 and 10, is modified here by restricting the term “Beekmantown” to the dolomite unit between the Rose Run Sandstone and the Knox unconformity. Judging from studies by Harris and Repetski (1982), the Knox unconformity is probably absent between the eastern part of the central West Virginia arch and the eastern end of section *D–D′*. In such areas where the unconformity is either absent or cannot be identified (for example, between drill holes 11 and 13; see Harris and Repetski, 1982; Mussman and others, 1988), the term “Beekmantown Group” is used for dolomite between the Rose Run Sandstone and the St. Paul Group. For example, the 2,200-ft-thick Beekmantown Group in drill hole 13 consists of a lower part that is equivalent to the Beekmantown Dolomite and an upper part that is equivalent to the unnamed anhydritic dolomite in drill holes 9 and 10. The Copper Ridge Dolomite, Beekmantown Dolomite (Group), and unnamed anhydritic dolomite are interpreted as restricted marine deposits that accumulated on a passive margin (Harris, 1973; Read, 1989a,b).

The Beekmantown Group in drill hole 13 and the unnamed anhydritic dolomite in drill holes 9 and 10 are overlain by several hundred feet of argillaceous and dolomitic limestone that are interpreted here to be the Middle to Upper Ordovician St. Paul Group (Neuman, 1951), which is equivalent to the Loysburg Formation in central Pennsylvania (Wagner, 1966). According to Ryder (1991), the St. Paul Group is anomalously thick (1,000 ft) in drill hole 12 and its lower 500 ft (Row Park Limestone?) has replaced, by a facies change, the upper part of the adjacent Beekmantown Group.

From the western margin of the Rome trough, the Copper Ridge Dolomite, Rose Run Sandstone, and Beekmantown Dolomite continue into Ohio as informal units of the Knox Dolomite (Janssens, 1973; Slucher, 2004). This usage in Ohio differs somewhat from Ryder (1991, 1992), who recognized the Knox Dolomite of Janssens (1973) but gave the Rose Run Sandstone formal status and left the dolomite units unnamed.

In drill hole 7, a 100-ft-thick silty to argillaceous and (or) sandy(?) dolomite unit in the middle of the Copper Ridge dolomite correlates 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. The B zone is extended eastward in cross section *D–D′* beneath drill hole 8 to the hinge zone near the Ohio-West Virginia border. The B zone also extends into central and northwestern Ohio and is truncated between drill holes 1 and 2 by the Middle Ordovician (Knox) unconformity.

At the northwestern end of the cross section, a 50-ft-thick, fine- to coarse-grained sandstone (the Kerbel Formation of Janssens, 1973) is located above the Conasauga Group and below the Knox Dolomite. Eastward, the Kerbel Formation becomes dolomitic, thins to about 30 ft in drill hole 3, and pinches out by a facies change about 10 mi west of drill hole 4.

West of the Rome trough, in the vicinity of the Ohio-West Virginia border, the unnamed anhydritic dolomite above the Middle Ordovician (Knox) unconformity changes lithology to an argillaceous dolomite named the Middle Ordovician Wells Creek formation (fig. 2). The Wells Creek Formation was formally introduced in Ohio by Patchen and others (1985) and Wickstrom and others (1992) on the basis of the Wells Creek Dolomite named by Lusk (1927) after a locality in western Tennessee. Wilson and Stearns (1968) did not use the term in Tennessee when their geologic mapping failed to identify the Wells Creek Dolomite at the type locality. On section *D–D′*, however, we use the term “Wells Creek formation” as used by Wickstrom and others (1992), but informally because of its uncertainty in the type area. In drill hole 8, the Wells Creek formation rests unconformably on the Lower Ordovician Beekmantown dolomite of the Knox Dolomite (Janssens, 1973; Slucher, 2004). In drill hole 7, a thin, unnamed sandstone unit, probably equivalent to the St. Peter Sandstone, is located between the Wells Creek formation and the Middle Ordovician (Knox) unconformity. Farther west, the Middle Ordovician (Knox) unconformity cuts downsection and places the Wells Creek formation on successively older rocks as follows: the Beekmantown dolomite is truncated about 10 mi west of drill hole 6; the Rose Run sandstone is truncated about 9 mi east of drill hole 5; and, as previously noted, the B zone is truncated between drill holes 1 and 2. At drill hole 1, near the northwestern end of the cross section, the Middle Ordovician unconformity places the Wells Creek formation within about 80 ft of the top of the Kerbel Formation.

The Upper Ordovician Black River Limestone (Group), consisting of carbonate mudstone and wackestone, and the overlying Upper Ordovician Trenton Limestone, consisting of fossiliferous argillaceous limestone (wackestone and packstone) and grainstone, are present across all of section *D–D′*. The Black River-Trenton interval thins gradually westward from about 1,000 ft in thrust-faulted zones at the Allegheny structural front and adjoining Valley and Ridge province, to about 800 ft in drill hole 9, to about 650 ft in drill hole 1 near the Findlay arch (fig. 1). The Black River Group (Limestone) rests conformably on the Wells Creek formation or St. Paul Group and, in turn, is overlain conformably by the Trenton Limestone. As shown in figure 2, two widespread K-bentonite beds (Millbrig and Deicke Bentonite Beds of Huff and Kolata, 1990; α and β marker beds of Stith, 1979, respectively) are located in the uppermost part of the Black River Group (Limestone), where the Millbrig Bentonite Bed (α marker) defines the Black River-Trenton contact in Ohio. In West Virginia, the contact between the characteristic carbonate mudstone of the Black River Limestone and the characteristic fossiliferous grainstone and argillaceous packstone of the Trenton Limestone is located about 250 ft below the Millbrig Bentonite Bed (S_2 bentonite bed of Perry, 1964), thus shifting the location of the contact to an older stratigraphic position. This downsection shift of the Black River-Trenton contact probably begins near the Ohio-West Virginia border and is first documented in drill holes 9 and 10.

In these drill holes, the Trenton Limestone is between 450 and 550 ft thick and consists of a lower carbonate mudstone unit and an upper argillaceous grainstone unit that correlate, respectively, with the Nealmont Formation and the Salona-Coburn Formations in central Pennsylvania (Wagner, 1966; Laughrey and others, 2003). Trenton and Black River Limestones involved in the thrust faults in drill holes 12 and 13, including the overturned synclinal horse block in drill hole 12, have a consistent net thickness of about 900 to 1,000 ft and are lithologically similar to the Trenton and Black River Limestones in the Rome trough.

In West Virginia and adjoining Virginia, these limestones are interpreted as carbonate ramp deposits (Read, 1980; Smosna, 1985). The K-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

Upper Ordovician to Lower Silurian siliciclastic strata are characterized by gray shale, red shale, sandstone, and black shale. On cross section *D–D′*, the combined thickness of the strata ranges from about 3,500 ft in the vicinity of the Allegheny structural front (also see isopach maps reported by Diecchio, 1985) to about 1,150 ft on the eastern flank of the Findlay arch. The Upper Ordovician to Lower Silurian siliciclastic strata consist of the following units (in ascending order): the Utica Shale, Reedsville Shale (Perry, 1972; Ryder, 1991, 1992)-Cincinnati group (Slucher, 2004), Oswego Sandstone, Juniata Formation-Queenston Shale, Tuscarora Sandstone-“Clinton” sandstone-Medina sandstone (as used by Ryder, 2000), and Rose Hill Formation-Rochester Shale (fig. 2). The lowermost Lower Silurian of Ohio consists of informal units, the Medina sandstone and the “Clinton” sandstone that were named by early drillers. 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 (McCormac and others, 1996). Although this miscorrelation has caused confusion in nomenclature, the “Clinton” term continues to be widely used in the literature and by the oil and gas industry. Informal subdivisions of the “Clinton” sandstone such as the white, red, and stray Clinton sands (Pepper and others, 1953) are not used here. Early drillers correctly identified the Medina sandstone in Ohio as a partial equivalent of the type Medina Group of New York.

The Upper Ordovician to Lower Silurian 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 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).

The Upper Ordovician Utica Shale extends across the entire cross section *D–D′* and ranges in thickness from about 150 to 450 ft. Upper Ordovician strata that overlie the Utica Shale consist of the Reedsville Shale-Cincinnati group (gray shale, siltstone, and minor sandstone with increasing amounts of limestone in Ohio), the Oswego Sandstone (sandstone, siltstone, and gray shale), and the Juniata Formation-Queenston Shale (red beds).

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

The widespread Cherokee unconformity is present at the top of the Juniata Formation-Queenston Shale. According to Dennison and Head (1975), this 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).

From the Allegheny structural front and adjoining Valley and Ridge to central Ohio, the red beds of the Queenston Shale and Juniata Formation are overlain unconformably (Cherokee unconformity) by a widespread unit of Lower Silurian siliciclastic rocks that ranges in thickness from 400 ft in drill hole 13 to about 150 ft in drill hole 5. The western part of this Lower Silurian siliciclastic unit (in Ohio) consists of the “Clinton” sandstone, Cabot Head Shale, and Medina sandstone, combined, whereas the eastern part of this siliciclastic unit (in West Virginia) consists of the Tuscarora Sandstone (Ryder, 2000, 2004). The Tuscarora Sandstone has a greater percentage of net sandstone and is typically coarser grained than the “Clinton” sandstone-Cabot Head Shale-Medina sandstone interval. Between drill holes 3 and 4, the “Clinton” sandstone pinches out westward due to a facies change and is replaced by the Cabot Head Shale. About 6 mi west of drill hole 5, the Medina sandstone in the lower part of the sandstone unit is replaced by the Lower Silurian Brassfield Limestone, which continues to the northwestern end of the cross section. The Tuscarora-Clinton interval is interpreted as shallow-marine shelf, shoreface, and fluvial-estuarine deposits (Castle, 1998; Ryder, 2004) that accumulated as molasse during Early Silurian late-stage uplift in the Taconic source area (Dorsch and others, 1994).

The 400- to 600-ft-thick Lower Silurian Rose Hill Formation conformably overlies the Tuscarora Sandstone in drill holes 9 to 13. The lower part of the Rose Hill Formation consists of an argillaceous sandstone (locally hematitic) and siltstone unit named the Cacapon Sandstone Member, whereas the upper part of the Rose Hill Formation consists of gray shale, red shale, dolomite, and limestone (Ryder, 2004). West of the Ohio-West Virginia border, 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 section *D–D′* as “Lower Silurian carbonates and shales, undivided” (fig. 2). This unit and the Rochester Shale overlie the “Clinton” sandstone and thin to about 225 ft in drill hole 8 and to about 80 ft 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, undivided” unit. This unconformity extends across much of central and eastern Ohio and probably extends into the Rose Hill Formation at least as far east as drill hole 11. A thin, but continuous, locally hematitic sandstone known as the Upper Silurian Keefer Sandstone conformably overlies the Rose Hill Formation and Rochester Shale across West Virginia and eastern Ohio. 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, anhydrite, sandstone, gray shale, chert, and halite. The combined thickness of these stratigraphic units ranges from about 2,000 ft in drill holes 9 and 10 to about 900 ft near their outcrop limit on the eastern flank of the Findlay arch (fig. 1). In the vicinity of the Allegheny structural front and adjoining Valley and Ridge province, the thickness of the Lower Silurian to Middle Devonian strata is about 2,100 ft (Cardwell and others, 1968; Smosna and others, 1977; Smosna, 1988). Typical stratigraphic units in this interval are as follows (in ascending order): the Lockport Dolomite-McKenzie Limestone, Salina Group-Tonoloway Limestone-Wills Creek Formation, Bass Islands Dolomite, Keyser Limestone, Mandata Shale, Helderberg Limestone, Oriskany Sandstone, and Onondaga Limestone-Huntersville Chert (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 Limestone in West Virginia rests conformably on the Keefer Sandstone (fig. 2). The Lockport Dolomite consists largely of finely crystalline dolomite with local algal bioherms. By comparison, the McKenzie Limestone consists of argillaceous to sandy carbonate mudstone and wackestone that locally are fossiliferous and oolitic. In drill hole 9, the lower third of the Lockport Dolomite consists of limestone that is a westward continuation of the McKenzie Limestone.

The Upper Silurian Salina Group, which consists predominantly of anhydritic dolomite, anhydrite, and halite, extends across most of section *D–D′* where it ranges in thickness from 350 to 500 ft near drill hole 11 in northern West Virginia, to about 1,000 ft in drill hole 8 in eastern Ohio, and to about 600 ft where it crops out near drill hole 1 in northwestern Ohio. The Salina Group is halite bearing in drill holes 4 to 10 near the western and southern margins of the Salina salt basin as defined by Colton (1970), Clifford (1973), and Smosna and others (1977). Halite-bearing intervals in drill holes 4 to 10 are interpreted from geophysical and lithologic logs and, in several cases, from correlations with known halite beds in nearby wells (for example, see Clifford, 1973). Most halite-bearing intervals shown on section *D–D′*, such as the 600-ft-thick interval in drill hole 8, are not entirely halite but rather represent zones of interbedded halite, dolomite, and anhydrite.

Eastward from approximately the Ohio-West Virginia border, the lower 250 to 300 ft of the Salina Group is replaced by argillaceous dolomite of the Upper Silurian Wills Creek Formation and, farther eastward from about 12 mi east of drill hole 11, the remainder of the Salina Group is replaced by anhydritic limestone and dolomite of the Upper Silurian Tonoloway Limestone. In drill holes 1 to 9, the Salina Group and the equivalent Wills Creek Formation rest conformably on the Lockport Dolomite, but in drill holes 10 to 13, the Wills Creek Formation rests conformably on the 10- to 20-ft-thick Upper Silurian Williamsport Sandstone that, in turn, rests with apparent conformity on the McKenzie Limestone.

Between drill holes 4 and 8, the Upper Silurian Bass Islands Dolomite, an argillaceous dolomite (50 ft thick or less), conformably overlies the Salina Group. The Bass Islands Dolomite is absent between about 22 mi west of drill hole 4 and the northwestern end of cross section *D–D′* because the dolomite was truncated by an overlying pre-Middle Devonian unconformity. Between drill holes 10 and 11, the Bass Islands Dolomite changes facies to the Big Mountain Shale, which continues eastward to drill hole 13 in the Valley and Ridge province at the eastern end of cross section *D–D′* (Smosna and others, 1977). About midway between drill holes 8 and 9, the Bass Islands Dolomite is conformably overlain by the Upper Silurian-Lower Devonian Keyser Limestone (upper), which is the uppermost Silurian unit on cross section *D–D′* and continues eastward to drill hole 13.

The overall depositional setting of the Lower Silurian to 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). Dolomite 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. This abrupt change to evaporite deposition was caused by an arid climate (Cecil and others, 2004). The Upper Silurian Salina Group is interpreted as greatly restricted shallow-water and sabkha deposits (Tomastik, 1997). Because halite beds in the Salina Group terminate abruptly against the Cambridge arch, Root (1996) suggested that this structure during the time of Salina deposition was a topographic sill that separated hypersaline, halite-precipitating seawater 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 arch and later were dissolved by downward-percolating ground water from a Lower Devonian erosion surface (pre-Oriskany Sandstone unconformity, discussed below). Either explanation requires that the Cambridge arch was a positive feature during the Silurian.

Strata that overlie the Silurian Salina Group-Tonoloway Limestone between drill holes 10 through 12 include the following (in ascending order): the Upper Silurian Keyser Limestone (lower and the lower part of the upper), the Upper Silurian Bass Islands Dolomite-Big Mountain Shale, the Lower Devonian Keyser Limestone (the uppermost part of the upper), the Lower Devonian Mandata Shale, and the Lower Devonian Helderberg Limestone (fig. 2). The Helderberg Limestone is characterized by chert-bearing, locally fossiliferous limestone with interbeds of shale and sandstone. In outcrops between the Wills Mountain anticline and the eastern end of section *D–D′*, the Helderberg Limestone is replaced by the Lower Devonian Shriver Chert of the Helderberg Group (Smosna, 1988). The remainder of the Helderberg Group below the Shriver Chert consists of the following formations in descending order: (1) the Lower Devonian Mandata Shale, Corriganville Limestone, and New Creek Limestone, (2) the Upper Silurian-Lower Devonian Keyser Limestone (upper), and (3) the Upper Silurian Big Mountain Shale and Keyser Limestone (lower) (Smosna, 1988). The Helderberg strata are generally interpreted as normal marine deposits that accumulated in an intracratonic basin and on flanking carbonate shelves (Dorobek and Read, 1986; Smosna, 1988). In eastern Ohio from about the Ohio-West Virginia border to between drill holes 4 and 5, the Helderberg Limestone rests unconformably on the Bass Islands Dolomite (Patchen and others, 1985; Slucher, 2004).

The clean, quartzose Lower Devonian Oriskany Sandstone overlies the Helderberg Limestone (Group), and extends along cross section *D–D′* from about 6 mi west of drill hole 5 to drill hole 13 in the Valley and Ridge province. Regional unconformities at the top and base of the 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 larger decrease in water depth. This post-Oriskany unconformity probably truncated the Oriskany Sandstone between drill holes 4 and 5 to form the pinchout mapped by Opritza (1996). Westward of the Oriskany Sandstone pinchout, the two unconformities merge and cut progressively downsection across the Helderberg Limestone, the Bass Islands Dolomite, and the uppermost part of the Salina Group. The Oriskany Sandstone has been interpreted as a shallow-marine deposit (Bruner, 1988), although Cecil (2004) has suggested a prior eolian provenance for the Oriskany Sandstone and adjacent chert beds (Shriver and Huntersville Cherts).

A 35- to 45-ft-thick sandstone and cherty carbonate unit that unconformably overlies the Salina Group in drill holes 2 and 3 probably correlates with the Lower Devonian Bois Blanc Formation recognized in northern Ohio by Dow (1962), Janssens (1968), Rickard (1984), Sparling (1988), and Slucher (2004). This unit is slightly younger than the Oriskany Sandstone (fig. 2). The sandstone and cherty carbonate unit is unconformably overlain by the Middle Devonian Columbus Limestone in drill hole 3 and by the Middle Devonian Detroit River Group in drill hole 2, as suggested by regional correlations (Dow, 1962; Slucher, 2004). Studies by Sparling (1988) indicate that the Bois Blanc Formation does not crop out on the Findlay arch. Although the correlation of this sandstone and cherty carbonate unit with the Bois Blanc Formation is favored in this report, several other possibilities exist. Conceivably, this unit also 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 equivalent units.

Near the Ohio-West Virginia border, the Onondaga Limestone unconformably overlies the Oriskany Sandstone and is replaced by an equivalent chert-dominated interval called the Huntersville Chert (fig. 2). As shown in figure 2, the Huntersville Chert extends across northern West Virginia (drill holes 9–11) to the Allegheny structural front and the Valley and Ridge province (drill hole 13), where the chert is replaced by black shale of the Middle Devonian Needmore Shale (Diecchio and others, 1984; Harper and Patchen, 1996). In central Ohio, between drill holes 5 and 6 and the outcrop belt on the eastern flank of the Findlay arch, 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). The lower part of the Columbus Limestone in drill hole 2 and in outcrops along the eastern flank of the Findlay arch is replaced by sandy dolomite and limestone of the Middle Devonian Detroit River Group (Sparling, 1988; Slucher, 2004). Detroit River Group strata pinch out by facies change into the lower part of the Columbus Limestone probably within 25 mi southeast of drill hole 2.

Middle Devonian to Lower Mississippian Siliciclastic Strata

Middle Devonian to Lower Mississippian siliciclastic strata are characterized by gray shale, siltstone, sandstone, and red beds in eastern West Virginia and by black shale, gray shale, and siltstone (with thin sandstone beds near the top) in central Ohio. The Middle Devonian to Lower Mississippian strata shown on section *D–D′* thin dramatically from as much as 8,500 ft in northeastern West Virginia to about 5,000 ft in northern West Virginia and to about 2,200 ft in east-central Ohio. In northeastern West Virginia, the Middle Devonian to Lower Mississippian siliciclastic strata include the following units (in ascending order): the Middle Devonian Hamilton Group; the Upper Devonian Harrell Shale, Brallier Formation, Greenland Gap Group, and Hampshire Formation; and the Lower Mississippian Price Formation (fig. 2). Also, the top of the 30- to 40-ft-thick Tully Limestone, which is located between the Hamilton Group and Harrell Shale, marks the top of the Middle Devonian on the cross section (fig. 2). In eastern Ohio, the Middle Devonian to Lower Mississippian strata include the following units (in ascending order): the Middle Devonian Hamilton Group; the Upper Devonian Genesee Formation, Sonyea Formation, West Falls Formation, Java Formation, Huron Member of the Ohio Shale, Dunkirk Shale Member of the Perrysburg Formation, and Chagrin Shale; the Upper Devonian Berea Sandstone; and the Lower Mississippian Sunbury Shale and Cuyahoga Formation (fig. 2).

The Middle 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) are associated with the Acadian orogeny (Colton, 1970; Milici and de Witt, 1988; Osberg and others, 1989).

The stratigraphy of the Middle and Upper Devonian black shales has been studied in great detail because of their role as petroleum source rocks and reservoirs (Roen and Kepferle, 1993). In the vicinity of the Allegheny structural front and the adjoining Valley and Ridge province, black shale of the Middle Devonian Needmore Shale is overlain by the Tioga Bentonite Bed (Dennison and Head, 1975; Dennison and others, 1988), which is overlain by black shale of the Marcellus Shale (fig. 2). The Marcellus Shale and the overlying gray shale of the Mahantango Formation of the Hamilton Group extend across the West Virginia part of section *D–D′* and into eastern Ohio (Patchen and others, 1985; Slucher, 2004). The Marcellus Shale pinches out between drill holes 5 and 6, but the Mahantango Formation of the Hamilton Group continues into central Ohio as a gray shale that is recognized as the Middle Devonian Olentangy Shale (lower). From about 10 mi west of drill hole 9 to about 10 mi east of drill hole 10, the Hamilton Group is overlain by the Tully Limestone.

A regional Middle-Late Devonian unconformity, described and mapped by de Witt and others (1993), is present at the top of the Hamilton Group-Olentangy Shale (lower) and at the top of the Tully Limestone across most of cross section *D–D′* (fig. 2). Westward from near drill hole 10, where the partially eroded Tully Limestone is overlain by the Upper Devonian Genesee Formation, successively younger Upper Devonian strata downlap against the Middle to Late Devonian unconformity. For example, in drill hole 6, the Upper Devonian Sonyea Formation rests unconformably on the Mahantango Formation of the Hamilton Group, whereas farther west (about midway between drill holes 5 and 6) the Upper Devonian Rhinestreet Shale Member of the West Falls Formation rests unconformably on the Mahantango Formation of the Hamilton Group. Furthermore, in drill holes 3 and 4, the Upper Devonian Olentangy Shale (upper), which is equivalent to the Java Formation, rests unconformably on the Middle Devonian Olentangy Shale (lower), whereas in drill hole 2 and in outcrops on the eastern flank of the Findlay arch, the Olentangy Shale (upper) rests unconformably on the Plum Brook Shale and the Prout Limestone (Rickard, 1984; Slucher, 2004), which are equivalents of the Olentangy Shale (lower).

The dark-gray shale-dominated Upper Devonian Harrell Shale extends westward from near the Allegheny structural front (between drill holes 12 and 13) to within 5 mi of drill hole 10 where the shale crosses an arbitrary boundary into rocks of the Genesee Formation and the lower part of the Sonyea Formation. Similarly, the overlying shale- and siltstone-dominated Upper Devonian Brallier Formation extends westward from near the Allegheny structural front to within 5 mi of drill hole 10, where the lower part of the shale and siltstone crosses an arbitrary boundary into rocks of the Sonyea Formation. The majority of the Brallier Formation in drill hole 10 continues westward as far as the eastern limits of the Rhinestreet and Dunkirk Shale Members, beyond which it rises stratigraphically over Rhinestreet-Dunkirk units and thins to about 1,500 ft in drill hole 9. Midway between drill holes 8 and 9, the Brallier Formation is replaced by the lower two-thirds of the Upper Devonian Chagrin Shale.

The sandstone- and siltstone-dominated Upper Devonian Greenland Gap Group overlies the Brallier Formation between the Allegheny structural front and 12 mi west of drill hole 11. As defined in outcrop by Dennison (1970) and Dennison and others (1988), the Greenland Gap Group is subdivided into the Scherr and Foreknobs Formations. The majority of the sandstone beds in the Greenland Gap Group are interpreted as nearshore marine and distributary channel deposits (Boswell and Jewell, 1988).

The Greenland Gap Formation was introduced by Boswell and others (1987) and Boswell (1988a) to define a westward extension of the Foreknobs Formation part of the Greenland Gap Group that has a higher percentage of shale and siltstone. In cross section *D–D′*, the term “Foreknobs” is added to the Greenland Gap Formation (in parentheses) to emphasize the alternate nomenclature used by Dennison and others (1988) and implied by Filer (2002, 2003). The Greenland Gap (Foreknobs) Formation extends westward from its arbitrary boundary with the Greenland Gap Group to midway between drill holes 8 and 9, where it changes facies (across an arbitrary boundary) and is replaced by the upper part of the Chagrin Shale. The approximate westward limit and the abrupt upward diachronous shifts in lithology (shown by arbitrary cutoffs) in the Greenland Gap (Foreknobs) Formation are based on percent siltstone and sandstone maps and cross sections by Boswell (1988b) and Filer (2002). The Greenland Gap (Foreknobs) Formation in the vicinity of drill hole 10 is underlain by the uppermost part of the Brallier Formation that is equivalent to the Scherr Formation.

The red-bed dominated Hampshire Formation (Dennison and others, 1988) occurs on section *D–D′* between the Allegheny structural front and about 12 mi west of drill hole 11. The red-bed interval continues beyond this location for about 25 mi, where it is assigned to the Hampshire Group (Boswell and others, 1987; Boswell, 1988a). About 10 mi west of drill hole 10, the Hampshire Group pinches out into the Upper Devonian Venango Formation as indicated by Boswell (1988a). The Venango Formation extends to within about 14 mi west of drill hole 9, where it changes facies and is replaced by the westernmost part of the Greenland Gap (Foreknobs) Formation. The red beds are interpreted as subaerially exposed alluvial plain and fluvial deposits (Dennison and others, 1988).

The Brallier Formation, Greenland Gap (Foreknobs) Formation, Hampshire Group, Venango Formation, and equivalent strata such as the West Falls and Java Formations contain somewhat continuous, thin sandstone units (generally 10–50 ft thick) to which drillers have given informal names such as the Elk, Alexander, Benson, Riley, Bradford, Warren, and Fifth sandstones shown in drill hole 10 and in the No. 1 Teets and Sigley wells between drill holes 10 and 11 (Schwietering, 1980a,b; Boswell and others, 1987; Boswell and Jewell, 1988; Dennison and others, 1988; Filer, 1988). The Elk, Alexander, and Benson sandstones are included in the Elk play of Donaldson and others (1996), whereas the Riley and Bradford sandstones are included in the Bradford play of Boswell, Thomas, and others (1996). The Warren and Fifth sandstones are included in the Venango play of Boswell, Heim, and others (1996). Sandstones in the Elk play and Bradford play are interpreted as deeper water prodeltaic turbidites and distal shelf deposits (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).

In eastern Ohio and northwestern West Virginia, thick intervals of black shale that constitute the Rhinestreet Shale Member, Huron Member, and Dunkirk Shale Member intertongue with and pinch out eastward into gray shale and siltstone of the Upper Devonian Brallier Formation (fig. 2). These black shales are interpreted as anoxic marine deposits, but the origin of the anoxic conditions is controversial (Boswell, 1996).

The sandstone-dominated Upper Devonian Oswayo Member of the Price Formation overlies the Hampshire Group between the Etam anticline and about 10 mi west of drill hole 10, where the Hampshire Group pinches out into the Venango Formation. The Oswayo Member changes into the Oswayo Formation across an arbitrary boundary that is aligned with the western limit of the Hampshire Group. The Oswayo Formation conformably overlies the Venango Formation for about 9 mi before the Oswayo changes facies and is replaced by the Riceville Formation (that also conformably overlies the Venango Formation) midway between drill holes 9 and 10. The Oswayo Member (Formation) is interpreted as a transgressive marine sandstone that onlaps the Catskill delta complex (Boswell and others, 1987).

In northern West Virginia, siliciclastic strata of the Upper Devonian and Lower Mississippian Price Formation (Pocono Group of previous terminology; for example, see Cardwell and others, 1968, and Patchen and others, 1985) rest unconformably on strata of the Catskill delta complex that include the Riceville Formation, Oswayo Formation, Oswayo Member of the Price Formation (in drill hole 10), and the Greenland Gap Group. In drill hole 9, the Price Formation consists of the following units (in ascending order): the Upper Devonian Berea Sandstone, Lower Mississippian Sunbury Shale, Weir and Big Injun sandstones (informal units of drillers' usage), and an unnamed shale unit (fig. 2). Farther east, in the Consolidated Gas Supply Sigley well, about midway between drill holes 10 and 11, the Price Formation consists of the following units (in ascending order): the Oswayo Member, Riddlesburg Member, and Rockwell Member (Boswell and others, 1987; Bjerstedt and Kammer, 1988; Boswell, 1988a). As previously discussed, the Oswayo Member of the Price Formation is restricted to that part of the Oswayo interval that overlies the Hampshire Group (Formation).

Along the western flank of the Etam anticline, near drill hole 11, Kammer and Bjerstedt (1986) and Bjerstedt and Kammer (1988) interpreted an unconformity within the Price Formation (at the top of the Oswayo Member) that they identified as the sub-Berea unconformity. Boswell and Jewell (1988) adopted the sub-Berea unconformity of Kammer and Bjerstedt (1986) and Bjerstedt and Kammer (1988) and extended it westward across northern and central West Virginia at the base of the Riddlesburg Shale Member and at the base of the Berea Sandstone. Furthermore, Pashin and Ettensohn (1995) interpreted an unconformity at the base of the Berea Sandstone in northern West Virginia and northern Ohio that coincides with the sub-Berea unconformity.

The sub-Berea unconformity is interpreted to be present across much of cross section *D–D′*. For example, the unconformity is interpreted to underlie the Price Formation beneath the Georges Creek syncline and the adjoining Blackwater anticline. Furthermore, the unconformity is interpreted to underlie the Riddlesburg Member of the Price Formation beneath the Hiram anticline and to underlie the Berea Sandstone from drill holes 9 and 10 to the Ohio-West Virginia line. The sub-Berea unconformity probably continues into eastern Ohio to within 10 to 15 mi of drill hole 8.

The Price Formation in West Virginia and the equivalent Cuyahoga Formation in Ohio range in thickness from between 350 and 1,000 ft across section *D–D′*. In central Ohio, the upper part of the Lower Mississippian Cuyahoga Formation contains the Black Hand Member, which is the Big Injun sandstone of drillers' usage (Majchszak, 1984; Slucher, 2004). The

Cuyahoga interval in central Ohio is conformably overlain by the Lower and Middle Mississippian Logan Formation (Majchszak, 1984; Vargo and Matchen, 1996), a unit that is absent in the West Virginia part of cross section *D–D′* because the unit is truncated by an unconformity near drill hole 5.

Boswell, Heim, and others (1996) referred to the Price Formation as the Price-Rockwell delta complex, which they interpreted as the final phase of deposition in the foreland basin associated with the Late Devonian-Early Mississippian Acadian orogeny. Most of the Berea Sandstone, which is included with the Price interval on section *D–D′*, 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) suggest that the Berea Sandstone is essentially a lowstand wedge, composed of sand-rich estuary deposits. The sub-Berea unconformity shown on cross section *D–D′* may be related to a eustatic drop in sea level possibly associated with glaciation (Pashin and Ettensohn, 1995).

Middle and Upper Mississippian Carbonate Strata

Middle and Upper Mississippian carbonate strata on cross section *D–D′* consist of fossiliferous and oolitic limestone (grainstone, packstone, and wackestone) units with local sandy limestone and sandstone beds at the base. These strata range in thickness from about 100 to 300 ft and are assigned to the Middle and Upper Mississippian Greenbrier Limestone (fig. 2) (Flowers, 1956; Smosna, 1996). The Greenbrier Limestone rests unconformably on the Price Formation in West Virginia (Vargo and Matchen, 1996). This sub-Greenbrier unconformity is shown on section *D–D′* in drill holes 9 and 10, and in outcrops along the Etam anticline, Georges Creek syncline, and Allegheny structural front. In drill hole 10, the base of the Greenbrier Limestone consists of a 100-ft-thick quartzose sandstone that is informally named the Greenbrier Big Injun sandstone (Matchen and Vargo, 1996). The Greenbrier Big Injun extends west of drill hole 10 to a short distance beyond drill hole 9 and, east of drill hole 10, to as far as the Allegheny structural front. About 10 mi east of drill hole 9, the Greenbrier Big Injun sandstone may unconformably overlie the Big Injun sandstone of the Pocono Formation (Pocono Big Injun sandstone described by Matchen and Vargo, 1996).

The sub-Greenbrier unconformity shown on cross section *D–D′* is interpreted, at least in part, to have been caused by uplift and erosion associated with the West Virginia dome (Kammer and Bjerstedt, 1986; Yeilding and Dennison, 1986; Bjerstedt and Kammer, 1988; Boswell and Jewell, 1988). The Greenbrier carbonate strata are interpreted as predominantly shallow-marine deposits (Carney and Smosna, 1989; Al-Tawil and others, 2003).

Upper Mississippian, Pennsylvanian, and Permian Siliciclastic Strata

The Upper Mississippian, Pennsylvanian, and Permian siliciclastic strata on cross section *D–D′* consist of sandstone, red and gray shale, and siltstone. Commonly, these siliciclastic strata contain coal beds and, locally, the strata contain thin beds of limestone. The Upper Mississippian and Pennsylvanian siliciclastic strata are as thick as 1,700 ft, whereas the Permian siliciclastic strata are as thick as 1,200 ft. These siliciclastic strata include the following units (in ascending order): the Mississippian Mauch Chunk Group; the Pennsylvanian Pottsville Group, Allegheny Group, Conemaugh Group, and Monongahela Group; and the Upper Pennsylvanian and Permian Dunkard Group (fig. 2).

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).

Along the West Virginia part of section *D–D′*, a 50- to 600-ft-thick unit of sandstone, gray and red shale, and locally fossiliferous limestone of the Upper Mississippian Mauch Chunk Group conformably overlies the Greenbrier Limestone. The Mauch Chunk Group, in turn, is overlain by a widespread Lower Pennsylvanian unconformity that cuts progressively downsection, between drill holes 8 and 9, through the Upper Mississippian Mauch Chunk Group, the Middle and Upper Mississippian Greenbrier Limestone, and into the upper part of the Lower Mississippian Cuyahoga Formation (Arkle and others, 1979; Rice and Schwietering, 1988; Beuthin, 1994). In east-central Ohio, between drill holes 4 and 5, the unconformity shifts abruptly upsection to rest on the upper part of the Middle and Upper Mississippian Logan Formation (Majchszak, 1984), where it remains to the western limit of Pennsylvanian outcrops.

The Lower and Middle Pennsylvanian Pottsville Group (fig. 2), which consists largely of sandstone and conglomeratic sandstone with minor gray shale and coal beds, overlies the Lower Pennsylvanian unconformity (for example, see USGS corehole 10, Nick Fedorko, unpub. data, 2003). In USGS corehole 10, the Pottsville Group is 350 ft thick and it crops out about 10 mi farther to the east on the western flank of the Etam anticline. Between drill holes 11 and 12, the Pottsville Group underlies the Blackwater anticline and it crops out on the western flank of the Georges Creek syncline and near the Allegheny structural front (Cardwell and others, 1968). West of USGS corehole 10, the Pottsville Group continues across West Virginia (drill holes 9 and 10; USGS corehole 6, Dulong and others, 2002) and into eastern Ohio (drill holes 6–8). The Pottsville Group crops out near drill hole 5 in east-central Ohio. Pottsville Group strata are interpreted as being primarily fluvial in origin (Presley, 1979), but locally thin shale beds with marine fauna have been reported in the vicinity of the cross section (Couchot and others, 1980; Englund and others, 1989).

The Middle Pennsylvanian Allegheny Group, which consists of gray shale, sandstone, thin limestone, and coal beds (such as the Upper Freeport coal bed in drill hole 9), conformably overlies the Pottsville Group (for example, see USGS corehole 10). In the West Virginia part of section *D–D′*, the Allegheny Group ranges in thickness from 190 ft in USGS corehole 10 to about 330 ft in drill hole 9. In USGS corehole 6, which is located about 20 mi south of drill hole 9, the Allegheny Group is about 255 ft thick (Dulong and others, 2002). Allegheny Group strata continue into eastern Ohio (drill holes 6–8) (Couchot and others, 1980) and gradually end in a belt of scattered outcrops between drill holes 5 and 6.

The Middle and Upper Pennsylvanian Conemaugh Group, which consists of gray and red shale, sandstone, and coal (for example, see USGS coreholes 6 and 10), conformably overlies the Allegheny Group. In most drill holes along cross section *D–D′*, the base of the Conemaugh Group is marked by a 50- to 100-ft-thick sandstone that is probably correlative with the Mahoning Sandstone Member of the Glenshaw Formation of the Conemaugh Group (Rice and others, 1994; Hohn, 1996). In USGS coreholes 6 and 10, several marine shale and limestone zones as thick as 19 ft are reported in the Conemaugh Group.

Above the Conemaugh Group are the Upper Pennsylvanian Monongahela Group and the overlying Upper Pennsylvanian to Lower Permian Dunkard Group, which are the youngest Paleozoic strata preserved in the Appalachian basin (Cardwell and others, 1968; Arkle and others, 1979). Both the Monongahela Group and the Dunkard Group consist largely of gray to red shale, sandstone, limestone, and coal beds. The thickest and most widespread of these coal beds in the Monongahela-Dunkard interval is the Pittsburgh coal bed, the base of which marks the base of the Monongahela Group (Berryhill and Swanson, 1962). The Pittsburgh coal bed is as much as 8 ft thick between drill holes 9 and 10 (Linger, 1979) and as much as 7.5 ft thick in drill hole 8 (Couchot and others, 1980). Donaldson (1974) interpreted the siliciclastic and carbonate strata in the Monongahela Group and Dunkard Group as alluvial plain, delta plain, and lacustrine deposits, and Cecil and others (1985) interpreted the coal beds as topogenous, planar swamp deposits that accumulated under humid climate conditions.

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Appendixes A–B

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

[Abbreviations: AGL, above ground level; APD, above permanent datum; API no., American Petroleum Institute drill-hole identification number; equiv., equivalent; GL, ground level; KB, kelly bushing; SL, sea level]

Drill-hole no.	**1**	**2**	**3**	**4**	**5**	**6**
API no. (from State)	**34–143–20077**	**34–077–20025**	**34–139–20448**	**34–169–21419**	**34–075–21283**	**34–157–21030**
Lease name	**No. 1–2171 V. and I. Haff**	**No. 1 I.M. Wheeler**	**No. D–1 Empire Reeves Steel Division**	**No. 1 Alonzo Drake, Jr.**	**No. 1 Dan E. Troyer**	**No. 2 (1–2669) Huebner**
Permanent datum	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**
GL elevation (ft)	**644**	**881**	**1,169**	**1,145**	**1,307**	**1,205**
KB elevation (ft)	**644**	**891**	**1,176**	**1,151**	**1,316**	**1,221**
Measured from	**KB**	**KB (10 ft APD)**	**KB (7 ft APD)**	**KB (6 ft APD)**	**KB**	**KB (16 ft APD)**
Drill depth (ft)	**3,123**	**3,865**	**5,085**	**6,897**	**7,369**	**8,227**
KB elevation - GL elevation	**0**	**10**	**7**	**6**	**9**	**16**
Formation 1	Salina Group	Three Lick Bed	Black Hand Member (Big Injun sandstone)	Logan Formation	Pottsville Group	Conemaugh Group
System or series	Silurian	Upper Devonian	Mississippian	Mississippian	Pennsylvanian	Pennsylvanian
Formation top (relative to KB) (ft)	0	-10	-7	-6	-9	-16
Formation top (relative to GL) (ft)	0	0	0	0	0	0
Formation top (relative to SL) (ft)	644	881	1,169	1,145	1,307	1,205
Formation 2	Lockport Dolomite	Huron Member of Ohio Shale	Cuyahoga Formation	Black Hand Member (Big Injun sandstone)	Black Hand Member (Big Injun sandstone)	Allegheny Group
System or series	Silurian	Upper Devonian	Mississippian	Mississippian	Mississippian	Pennsylvanian
Formation top (relative to KB) (ft)	-500	-113	-86	-240	-430	-282
Formation top (relative to GL) (ft)	-500	-103	-79	-234	-421	-266
Formation top (relative to SL) (ft)	144	778	1,090	911	886	939
Formation 3	Rochester Shale and Lower Silurian carbonates and shales, undivided	Olentangy Shale (upper)	Sunbury Shale	Cuyahoga Formation	Cuyahoga Formation	Pottsville Group
System or series	Silurian	Upper Devonian	Mississippian	Mississippian	Mississippian	Pennsylvanian
Formation top (relative to KB) (ft)	-722	-340	-370	-300	-488	-528
Formation top (relative to GL) (ft)	-722	-330	-363	-294	-479	-512
Formation top (relative to SL) (ft)	-78	551	806	851	828	693
Formation 4	Cabot Head Shale	Prout Limestone	Berea Sandstone	Sunbury Shale	Sunbury Shale	Cuyahoga Formation (upper)
System or series	Silurian	Middle Devonian	Upper Devonian	Mississippian	Mississippian	Mississippian
Formation top (relative to KB) (ft)	-768	-372	-470	-652	-976	-917
Formation top (relative to GL) (ft)	-768	-362	-463	-646	-967	-901
Formation top (relative to SL) (ft)	-124	519	706	499	340	304
Formation 5	Brassfield Limestone	Plum Brook Shale	Bedford Shale	Berea Sandstone	Berea Sandstone	Unnamed sandstone
System or series	Silurian	Middle Devonian	Upper Devonian	Upper Devonian	Upper Devonian	Mississippian
Formation top (relative to KB) (ft)	-798	-385	-502	-740	-1,041	-1,000
Formation top (relative to GL) (ft)	-798	-375	-495	-734	-1,032	-984
Formation top (relative to SL) (ft)	-154	506	674	411	275	221

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

[Abbreviations: AGL, above ground level; APD, above permanent datum; API no., American Petroleum Institute drill-hole identification number; equiv., equivalent; GL, ground level; KB, kelly bushing; SL, sea level]

Drill-hole no.	7	8	9	10	11	12	13
API no. (from State)	34–067–20737	34–067–20103	47–051–00539	47–049–00244	47–077–00119	47–023–00002	47–031–00021
Lease name	No. 1 Thomas Zechman	No. 1 Roy Birney	No. 1 John Burley	No. A–1 (A–1251) R.R. Finch	No. USA Q–1 GW–1466[1]	No. 1 Greenland Lodge, Inc.	No. 1 Charles H. Bean, et al.
Permanent datum	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level
GL elevation (ft)	888	1,110.9	1,423	1,341	2,172	2,344	1,022
KB elevation (ft)	898	1,126.9	1,435	1,362	2,187	2,362	1,043
Measured from	KB (10 ft APD)	KB (16 ft APD)	KB (12 ft AGL)	KB (21 ft AGL)	KB (15 ft AGL)	KB (18 ft AGL)	KB (21 ft AGL)
Drill depth (ft)	10,625	10,181	16,512	17,111	9,910	13,000	16,075
KB elevation - GL elevation	10	16	12	21	15	18	21
Formation 1	Conemaugh Group	Conemaugh Group	Dunkard Group	Allegheny Group	Greenland Gap Group (Foreknobs Formation)	Cacapon Sandstone Member of Rose Hill Formation	Mahantango Formation of Hamilton Group
System or series	Pennsylvanian	Pennsylvanian	Permian	Pennsylvanian	Upper Devonian	Silurian	Middle Devonian
Formation top (relative to KB) (ft)	-10	-16	-12	-21	-15	-18	-21
Formation top (relative to GL) (ft)	0	0	0	0	0	0	0
Formation top (relative to SL) (ft)	888	1,110.9	1,423	1,341	2,172	2,344	1,022
Formation 2	Allegheny Group	Mahoning Sandstone	Monongahela Group	Pottsville Group	Greenland Gap Group (Scherr Formation)	Tuscarora Sandstone	Marcellus Shale of Hamilton Group
System or series	Pennsylvanian	Pennsylvanian	Pennsylvanian	Pennsylvanian	Upper Devonian	Silurian	Middle Devonian
Formation top (relative to KB) (ft)	-300	-430	-873	-130	-1,424	-99	-243
Formation top (relative to GL) (ft)	-290	-414	-861	-109	-1,409	-81	-222
Formation top (relative to SL) (ft)	598	696.9	562	1,232	763	2,263	800
Formation 3	Pottsville Group	Allegheny Group	Conemaugh Group	Mauch Chunk Group	Brallier Formation	Juniata Formation	Needmore Shale
System or series	Pennsylvanian	Pennsylvanian	Pennsylvanian	Mississippian	Upper Devonian	Upper Ordovician	Middle Devonian
Formation top (relative to KB) (ft)	-580	-480	-1,185	-435	-1,740	-495	-335
Formation top (relative to GL) (ft)	-570	-464	-1,173	-414	-1,725	-477	-314
Formation top (relative to SL) (ft)	318	646.9	250	927	447	1,867	708
Formation 4	Cuyahoga Formation (upper)	Pottsville Group	Mahoning Sandstone	Greenbrier Limestone	Harrell Shale	Oswego Sandstone	Oriskany Sandstone
System or series	Mississippian	Pennsylvanian	Pennsylvanian	Mississippian	Upper Devonian	Upper Ordovician	Lower Devonian
Formation top (relative to KB) (ft)	-940	-815	-1,674	-690	-3,923	-1,500	-490
Formation top (relative to GL) (ft)	-930	-799	-1,662	-669	-3,908	-1,482	-469
Formation top (relative to SL) (ft)	-42	311.9	-239	672	-1,736	862	553
Formation 5	Unnamed sandstone	Cuyahoga Formation (upper)	Allegheny Group	Greenbrier Limestone[2]	Mahantango Formation of Hamilton Group	Reedsville Shale	Shriver Chert (Helderberg Group)
System or series	Mississippian	Mississippian	Pennsylvanian	Mississippian	Middle Devonian	Upper Ordovician	Lower Devonian
Formation top (relative to KB) (ft)	-1,110	-1,058	-1,722	-908	-4,250	-1,600	-650
Formation top (relative to GL) (ft)	-1,100	-1,042	-1,710	-887	-4,235	-1,582	-629
Formation top (relative to SL) (ft)	-212	68.9	-287	454	-2,063	762	393

[1]Monongahela National Forest. [2]Also known as Greenbrier Big Injun sandstone.

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

[Abbreviations: AGL, above ground level; APD, above permanent datum; API no., American Petroleum Institute drill-hole identification number; equiv., equivalent; GL, ground level; KB, kelly bushing; SL, sea level]

Drill-hole no.	**1**	**2**	**3**	**4**	**5**	**6**
API no. (from State)	**34–143–20077**	**34–077–20025**	**34–139–20448**	**34–169–21419**	**34–075–21283**	**34–157–21030**
Lease name	**No. 1–2171 V. and I. Haff**	**No. 1 I.M. Wheeler**	**No. D–1 Empire Reeves Steel Division**	**No. 1 Alonzo Drake, Jr.**	**No. 1 Dan E. Troyer**	**No. 2 (1–2669) Huebner**
Permanent datum	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**
GL elevation (ft)	**644**	**881**	**1,169**	**1,145**	**1,307**	**1,205**
KB elevation (ft)	**644**	**891**	**1,176**	**1,151**	**1,316**	**1,221**
Measured from	**KB**	**KB (10 ft APD)**	**KB (7 ft APD)**	**KB (6 ft APD)**	**KB**	**KB (16 ft APD)**
Drill depth (ft)	**3,123**	**3,865**	**5,085**	**6,897**	**7,369**	**8,227**
KB elevation - GL elevation	**0**	**10**	**7**	**6**	**9**	**16**
Formation 6	Queenston Shale	Delaware Limestone	Cleveland Member of Ohio Shale	Bedford Shale	Bedford Shale	Cuyahoga Formation (lower)
System or series	Upper Ordovician	Middle Devonian	Upper Devonian	Upper Devonian	Upper Devonian	Mississippian
Formation top (relative to KB) (ft)	-880	-435	-618	-790	-1,124	-1,062
Formation top (relative to GL) (ft)	-880	-425	-611	-784	-1,115	-1,046
Formation top (relative to SL) (ft)	-236	456	558	361	192	159
Formation 7	Whitewater Formation equiv.(?)	Columbus Limestone	Three Lick Bed	Chagrin Shale	Chagrin Shale	Sunbury Shale
System or series	Upper Ordovician	Middle Devonian	Upper Devonian	Upper Devonian	Upper Devonian	Mississippian
Formation top (relative to KB) (ft)	-960	-470	-710	-933	-1,210	-1,263
Formation top (relative to GL) (ft)	-960	-460	-703	-927	-1,201	-1,247
Formation top (relative to SL) (ft)	-316	421	466	218	106	-42
Formation 8	Cincinnati group	Detroit River Group	Huron Member of Ohio Shale	Huron Member of Ohio Shale	Huron Member of Ohio Shale	Berea Sandstone
System or series	Upper Ordovician	Middle Devonian	Upper Devonian	Upper Devonian	Upper Devonian	Upper Devonian
Formation top (relative to KB) (ft)	-1,075	-547	-800	-1,702	-2,080	-1,282
Formation top (relative to GL) (ft)	-1,075	-537	-793	-1,696	-2,071	-1,266
Formation top (relative to SL) (ft)	-431	344	376	-551	-764	-61
Formation 9	Utica Shale	Bois Blanc Formation(?)	Olentangy Shale (upper)	Olentangy Shale (upper)	Olentangy Shale (upper)	Bedford Shale
System or series	Upper Ordovician	Lower Devonian	Upper Devonian	Upper Devonian	Upper Devonian	Upper Devonian
Formation top (relative to KB) (ft)	-1,525	-620	-1,150	-1,930	-2,392	-1,350
Formation top (relative to GL) (ft)	-1,525	-610	-1,143	-1,924	-2,383	-1,334
Formation top (relative to SL) (ft)	-881	271	26	-779	-1,076	-129
Formation 10	Trenton Limestone	Salina Group	Olentangy Shale (lower)	Olentangy Shale (lower)	Olentangy Shale (lower)	Chagrin Shale (upper)
System or series	Upper Ordovician	Silurian	Middle Devonian	Middle Devonian	Middle Devonian	Upper Devonian
Formation top (relative to KB) (ft)	-1,860	-650	-1,200	-2,098	-2,587	-1,420
Formation top (relative to GL) (ft)	-1,860	-640	-1,193	-2,092	-2,578	-1,404
Formation top (relative to SL) (ft)	-1,216	241	-24	-947	-1,271	-199

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

[Abbreviations: AGL, above ground level; APD, above permanent datum; API no., American Petroleum Institute drill-hole identification number; equiv., equivalent; GL, ground level; KB, kelly bushing; SL, sea level]

Drill-hole no.	7	8	9	10	11	12	13
API no. (from State)	34–067–20737	34–067–20103	47–051–00539	47–049–00244	47–077–00119	47–023–00002	47–031–00021
Lease name	No. 1 Thomas Zechman	No. 1 Roy Birney	No. 1 John Burley	No. A–1 (A–1251) R.R. Finch	No. USA Q–1 GW–1466 [1]	No. 1 Greenland Lodge, Inc.	No. 1 Charles H. Bean, et al.
Permanent datum	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level
GL elevation (ft)	888	1,110.9	1,423	1,341	2,172	2,344	1,022
KB elevation (ft)	898	1,126.9	1,435	1,362	2,187	2,362	1,043
Measured from	KB (10 ft APD)	KB (16 ft APD)	KB (12 ft AGL)	KB (21 ft AGL)	KB (15 ft AGL)	KB (18 ft AGL)	KB (21 ft AGL)
Drill depth (ft)	10,625	10,181	16,512	17,111	9,910	13,000	16,075
KB elevation - GL elevation	10	16	12	21	15	18	21
Formation 6	Cuyahoga Formation (lower)	Unnamed sandstone	Pottsville Group	Price Formation	Marcellus Shale	Utica Shale	Mandata Shale (Helderberg Group)
System or series	Mississippian	Mississippian	Pennsylvanian	Mississippian	Middle Devonian	Upper Ordovician	Lower Devonian
Formation top (relative to KB) (ft)	-1,158	-1,212	-2,050	-997	-4,412	-2,814	-770
Formation top (relative to GL) (ft)	-1,148	-1,196	-2,038	-976	-4,397	-2,796	-749
Formation top (relative to SL) (ft)	-260	-85.1	-615	365	-2,225	-452	273
Formation 7	Sunbury Shale	Cuyahoga Formation (lower)	Mauch Chunk Group	Price Formation (Weir sandstone)	Huntersville Chert	Reedsville Shale	Keyser Limestone (upper) (Helderberg Group)[2]
System or series	Mississippian	Mississippian	Mississippian	Mississippian	Middle Devonian	Upper Ordovician	Lower Devonian
Formation top (relative to KB) (ft)	-1,260	-1,280	-2,250	-1,103	-4,557	-3,098	-790
Formation top (relative to GL) (ft)	-1,250	-1,264	-2,238	-1,082	-4,542	-3,080	-769
Formation top (relative to SL) (ft)	-362	-153.1	-815	259	-2,370	-736	253
Formation 8	Berea Sandstone	Sunbury Shale	Greenbrier Limestone[3]	Price Formation (lower)	Oriskany Sandstone	Utica Shale	Big Mountain Shale (Helderberg Group)
System or series	Upper Devonian	Mississippian	Mississippian	Mississippian	Lower Devonian	Upper Ordovician	Silurian
Formation top (relative to KB) (ft)	-1,290	-1,392	-2,312	-1,135	-4,700	-4,528	-975
Formation top (relative to GL) (ft)	-1,280	-1,376	-2,300	-1,114	-4,685	-4,510	-954
Formation top (relative to SL) (ft)	-392	-265.1	-877	227	-2,513	-2,166	68
Formation 9	Bedford Shale	Berea Sandstone	Price Formation (upper)	Berea Sandstone of Price Formation	Helderberg Limestone	Trenton Limestone	Keyser Limestone (lower) (Helderberg Group)
System or series	Upper Devonian	Upper Devonian	Mississippian	Upper Devonian	Lower Devonian	Upper Ordovician	Silurian
Formation top (relative to KB) (ft)	-1,335	-1,410	-2,470	-1,257	-4,822	-5,090	-1,018
Formation top (relative to GL) (ft)	-1,325	-1,394	-2,458	-1,236	-4,807	-5,072	-997
Formation top (relative to SL) (ft)	-437	-283.1	-1,035	105	-2,635	-2,728	25
Formation 10	Chagrin Shale (upper)	Chagrin Shale (upper)	Big Injun sandstone	Oswayo Member of Price Formation	Mandata Shale	Black River Limestone	Tonoloway Limestone
System or series	Upper Devonian	Upper Devonian	Mississippian	Upper Devonian	Lower Devonian	Middle and Upper Ordovician	Silurian
Formation top (relative to KB) (ft)	-1,438	-1,445	-2,513	-1,292	-5,059	-5,660	-1,110
Formation top (relative to GL) (ft)	-1,428	-1,429	-2,501	-1,271	-5,044	-5,642	-1,089
Formation top (relative to SL) (ft)	-540	-318.1	-1,078	70	-2,872	-3,298	-67

[1]Monongahela National Forest. [2]Includes Corriganville and New Creek Limestones at top. [3]Greenbrier Big Injun sandstone at base.

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

[Abbreviations: AGL, above ground level; APD, above permanent datum; API no., American Petroleum Institute drill-hole identification number; equiv., equivalent; GL, ground level; KB, kelly bushing; SL, sea level]

Drill-hole no.	1	2	3	4	5	6
API no. (from State)	34–143–20077	34–077–20025	34–139–20448	34–169–21419	34–075–21283	34–157–21030
Lease name	No. 1–2171 V. and I. Haff	No. 1 I.M. Wheeler	No. D–1 Empire Reeves Steel Division	No. 1 Alonzo Drake, Jr.	No. 1 Dan E. Troyer	No. 2 (1–2669) Huebner
Permanent datum	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level
GL elevation (ft)	644	881	1,169	1,145	1,307	1,205
KB elevation (ft)	644	891	1,176	1,151	1,316	1,221
Measured from	KB	KB (10 ft APD)	KB (7 ft APD)	KB (6 ft APD)	KB	KB (16 ft APD)
Drill depth (ft)	3,123	3,865	5,085	6,897	7,369	8,227
KB elevation - GL elevation	0	10	7	6	9	16
Formation 11	Black River Group	Lockport Dolomite	Delaware Limestone	Columbus Limestone	Columbus Limestone	Chagrin Shale (sandy facies)
System or series	Upper Ordovician	Silurian	Middle Devonian	Middle Devonian	Middle Devonian	Upper Devonian
Formation top (relative to KB) (ft)	-1,975	-1,210	-1,235	-2,174	-2,682	-1,650
Formation top (relative to GL) (ft)	-1,975	-1,200	-1,228	-2,168	-2,673	-1,634
Formation top (relative to SL) (ft)	-1,331	-319	-59	-1,023	-1,366	-429
Formation 12	Wells Creek formation	Rochester Shale and Lower Silurian carbonates and shales, undivided	Columbus Limestone	Bass Islands Dolomite	Oriskany Sandstone	Chagrin Shale (lower)
System or series	Middle Ordovician	Silurian	Middle Devonian	Silurian	Lower Devonian	Upper Devonian
Formation top (relative to KB) (ft)	-2,500	-1,350	-1,270	-2,370	-2,860	-1,850
Formation top (relative to GL) (ft)	-2,500	-1,340	-1,263	-2,364	-2,851	-1,834
Formation top (relative to SL) (ft)	-1,856	-459	-94	-1,219	-1,544	-629
Formation 13	Knox Dolomite (lower)	Cabot Head Shale	Bois Blanc Formation(?)	Salina Group	Helderberg Limestone	Huron Member of Ohio Shale
System or series	Upper Cambrian	Silurian	Lower Devonian	Silurian	Lower Devonian	Upper Devonian
Formation top (relative to KB) (ft)	-2,515	-1,390	-1,400	-2,454	-2,878	-2,622
Formation top (relative to GL) (ft)	-2,515	-1,380	-1,393	-2,448	-2,869	-2,606
Formation top (relative to SL) (ft)	-1,871	-499	-224	-1,303	-1,562	-1,401
Formation 14	Kerbel Formation	Brassfield Limestone	Salina Group	Lockport Dolomite	Bass Islands Dolomite	Java Formation
System or series	Upper Cambrian	Silurian	Silurian	Silurian	Silurian	Upper Devonian
Formation top (relative to KB) (ft)	-2,600	-1,452	-1,435	-3,144	-2,964	-3,140
Formation top (relative to GL) (ft)	-2,600	-1,442	-1,428	-3,138	-2,955	-3,124
Formation top (relative to SL) (ft)	-1,956	-561	-259	-1,993	-1,648	-1,919
Formation 15	Nolichucky Shale of Conasauga Group	Queenston Shale	Lockport Dolomite	Rochester Shale	Salina Group	Angola Shale Member of West Falls Formation
System or series	Upper Cambrian	Upper Ordovician	Silurian	Silurian	Silurian	Upper Devonian
Formation top (relative to KB) (ft)	-2,656	-1,517	-1,973	-3,317	-2,990	-3,282
Formation top (relative to GL) (ft)	-2,656	-1,507	-1,966	-3,311	-2,981	-3,266
Formation top (relative to SL) (ft)	-2,012	-626	-797	-2,166	-1,674	-2,061

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

[Abbreviations: AGL, above ground level; APD, above permanent datum; API no., American Petroleum Institute drill-hole identification number; equiv., equivalent; GL, ground level; KB, kelly bushing; SL, sea level]

Drill-hole no.	7	8	9	10	11	12	13
API no. (from State)	34–067–20737	34–067–20103	47–051–00539	47–049–00244	47–077–00119	47–023–00002	47–031–00021
Lease name	No. 1 Thomas Zechman	No. 1 Roy Birney	No. 1 John Burley	No. A–1 (A–1251) R.R. Finch	No. USA Q–1 GW–1466 [1]	No. 1 Greenland Lodge, Inc.	No. 1 Charles H. Bean, et al.
Permanent datum	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level
GL elevation (ft)	888	1,110.9	1,423	1,341	2,172	2,344	1,022
KB elevation (ft)	898	1,126.9	1,435	1,362	2,187	2,362	1,043
Measured from	KB (10 ft APD)	KB (16 ft APD)	KB (12 ft AGL)	KB (21 ft AGL)	KB (15 ft AGL)	KB (18 ft AGL)	KB (21 ft AGL)
Drill depth (ft)	10,625	10,181	16,512	17,111	9,910	13,000	16,075
KB elevation - GL elevation	10	16	12	21	15	18	21
Formation 11	Chagrin Shale (upper sandy facies)	Chagrin Shale (upper sandy facies)	Price Formation (middle)	Hampshire Group	Keyser Limestone (upper)	Utica Shale	Wills Creek Formation
System or series	Upper Devonian	Upper Devonian	Mississippian	Upper Devonian	Lower Devonian	Upper Ordovician	Silurian
Formation top (relative to KB) (ft)	-1,675	-1,770	-2,622	-1,470	-5,089	-6,100	-1,720
Formation top (relative to GL) (ft)	-1,665	-1,754	-2,610	-1,449	-5,074	-6,082	-1,699
Formation top (relative to SL) (ft)	-777	-643.1	-1,187	-108	-2,902	-3,738	-677
Formation 12	Chagrin Shale (middle)	Chagrin Shale (middle)	Weir sandstone	Greenland Gap (Foreknobs) Formation[2]	Big Mountain Shale	Trenton Limestone	Williamsport Sandstone
System or series	Upper Devonian	Upper Devonian	Mississippian	Upper Devonian	Silurian	Upper Ordovician	Silurian
Formation top (relative to KB) (ft)	-1,876	-2,005	-2,765	-1,930	-5,270	-6,575	-2,025
Formation top (relative to GL) (ft)	-1,866	-1,989	-2,753	-1,909	-5,255	-6,557	-2,004
Formation top (relative to SL) (ft)	-978	-878.1	-1,330	-568	-3,083	-4,213	-982
Formation 13	Chagrin Shale (lower sandy facies)	Chagrin Shale (lower sandy facies)	Price Formation (lower)	Greenland Gap (Foreknobs) Formation[3]	Keyser Limestone (lower)	Black River Limestone	McKenzie Limestone
System or series	Upper Devonian	Upper Devonian	Mississippian	Upper Devonian	Silurian	Middle and Upper Ordovician	Silurian
Formation top (relative to KB) (ft)	-2,520	-2,570	-2,800	-2,295	-5,310	-7,120	-2,050
Formation top (relative to GL) (ft)	-2,510	-2,554	-2,788	-2,274	-5,295	-7,102	-2,029
Formation top (relative to SL) (ft)	-1,622	-1,443.1	-1,365	-933	-3,123	-4,758	-1,007
Formation 14	Chagrin Shale (lower)	Chagrin Shale (lower)	Sunbury Shale	Greenland Gap (Foreknobs) Formation[4]	Salina Group	St. Paul Group (upper) (Loysburg Formation equiv.)	Keefer Sandstone
System or series	Upper Devonian	Upper Devonian	Mississippian	Upper Devonian	Silurian	Middle and Upper Ordovician	Silurian
Formation top (relative to KB) (ft)	-2,780	-2,875	-2,955	-3,183	-5,470	-7,600	-2,270
Formation top (relative to GL) (ft)	-2,770	-2,859	-2,943	-3,162	-5,455	-7,582	-2,249
Formation top (relative to SL) (ft)	-1,882	-1,748.1	-1,520	-1,821	-3,283	-5,238	-1,227
Formation 15	Huron Member of Ohio Shale	Dunkirk Shale Member of Perrysburg Formation	Berea Sandstone	Greenland Gap (Foreknobs) Formation[5]	Wills Creek Formation	St. Paul Group (lower) (Row Park Limestone?)	Rose Hill Formation (upper)
System or series	Upper Devonian	Upper Devonian	Upper Devonian	Upper Devonian	Silurian	Middle and Upper Ordovician	Silurian
Formation top (relative to KB) (ft)	-3,030	-3,660	-2,976	-3,540	-6,000	-8,110	-2,297
Formation top (relative to GL) (ft)	-3,020	-3,644	-2,964	-3,519	-5,985	-8,092	-2,276
Formation top (relative to SL) (ft)	-2,132	-2,533.1	-1,541	-2,178	-3,813	-5,748	-1,254

[1]Monongahela National Forest. [2]Includes Bayard, Elizabeth, and Warren sandstones. [3]Includes Speechley, Balltown, and Bradford sandstones. [4]Includes Riley sandstone. [5]Includes Benson and Alexander sandstones.

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

[Abbreviations: AGL, above ground level; APD, above permanent datum; API no., American Petroleum Institute drill-hole identification number; equiv., equivalent; GL, ground level; KB, kelly bushing; SL, sea level]

Drill-hole no.	**1**	**2**	**3**	**4**	**5**	**6**
API no. (from State)	**34–143–20077**	**34–077–20025**	**34–139–20448**	**34–169–21419**	**34–075–21283**	**34–157–21030**
Lease name	**No. 1–2171 V. and I. Haff**	**No. 1 I.M. Wheeler**	**No. D–1 Empire Reeves Steel Division**	**No. 1 Alonzo Drake, Jr.**	**No. 1 Dan E. Troyer**	**No. 2 (1–2669) Huebner**
Permanent datum	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**
GL elevation (ft)	**644**	**881**	**1,169**	**1,145**	**1,307**	**1,205**
KB elevation (ft)	**644**	**891**	**1,176**	**1,151**	**1,316**	**1,221**
Measured from	**KB**	**KB (10 ft APD)**	**KB (7 ft APD)**	**KB (6 ft APD)**	**KB**	**KB (16 ft APD)**
Drill depth (ft)	**3,123**	**3,865**	**5,085**	**6,897**	**7,369**	**8,227**
KB elevation - GL elevation	**0**	**10**	**7**	**6**	**9**	**16**
Formation 16	Maryville Limestone of Conasauga Group (upper)	Whitewater Formation equiv.(?)	Rochester Shale	Lower Silurian carbonates and shales, undivided	Lockport Dolomite	Rhinestreet Shale Member of West Falls Formation
System or series	Upper Cambrian	Upper Ordovician	Silurian	Silurian	Silurian	Upper Devonian
Formation top (relative to KB) (ft)	-2,745	-1,612	-2,130	-3,380	-3,584	-3,375
Formation top (relative to GL) (ft)	-2,745	-1,602	-2,123	-3,374	-3,575	-3,359
Formation top (relative to SL) (ft)	-2,101	-721	-954	-2,229	-2,268	-2,154
Formation 17	Unnamed sandstone in Maryville Limestone	Cincinnati group	Lower Silurian carbonates and shales, undivided	“Clinton” sandstone-Cabot Head Shale	Rochester Shale	Sonyea Formation
System or series	Upper Cambrian	Upper Ordovician	Silurian	Silurian	Silurian	Upper Devonian
Formation top (relative to KB) (ft)	-2,860	-1,702	-2,150	-3,413	-3,876	-3,575
Formation top (relative to GL) (ft)	-2,860	-1,692	-2,143	-3,407	-3,867	-3,559
Formation top (relative to SL) (ft)	-2,216	-811	-974	-2,262	-2,560	-2,354
Formation 18	Maryville Limestone of Conasauga Group (lower)	Utica Shale	Cabot Head Shale	Brassfield Limestone	Lower Silurian carbonates and shales, undivided	Mahantango Formation of Hamilton Group
System or series	Upper Cambrian	Upper Ordovician	Silurian	Silurian	Silurian	Middle Devonian
Formation top (relative to KB) (ft)	-2,895	-2,335	-2,187	-3,530	-3,964	-3,615
Formation top (relative to GL) (ft)	-2,895	-2,325	-2,180	-3,524	-3,955	-3,599
Formation top (relative to SL) (ft)	-2,251	-1,444	-1,011	-2,379	-2,648	-2,394
Formation 19	Mount Simon Sandstone	Trenton Limestone	Brassfield Limestone	Queenston Shale	“Clinton” sandstone-Cabot Head Shale-Medina sandstone	Marcellus Shale of Hamilton Group
System or series	Middle and Upper Cambrian	Upper Ordovician	Silurian	Upper Ordovician	Silurian	Middle Devonian
Formation top (relative to KB) (ft)	-2,960	-2,640	-2,272	-3,591	-4,020	-3,635
Formation top (relative to GL) (ft)	-2,960	-2,630	-2,265	-3,585	-4,011	-3,619
Formation top (relative to SL) (ft)	-2,316	-1,749	-1,096	-2,440	-2,704	-2,414
Formation 20	Metamorphic and igneous rocks	Black River Group	Queenston Shale	Cincinnati group	Queenston Shale	Onondaga Limestone
System or series	Mesoproterozoic	Middle and Upper Ordovician	Upper Ordovician	Upper Ordovician	Upper Ordovician	Middle Devonian
Formation top (relative to KB) (ft)	-3,105	-2,690	-2,320	-3,890	-4,198	-3,675
Formation top (relative to GL) (ft)	-3,105	-2,680	-2,313	-3,884	-4,189	-3,659
Formation top (relative to SL) (ft)	-2,461	-1,799	-1,144	-2,739	-2,882	-2,454

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

[Abbreviations: AGL, above ground level; APD, above permanent datum; API no., American Petroleum Institute drill-hole identification number; equiv., equivalent; GL, ground level; KB, kelly bushing; SL, sea level]

Drill-hole no.	7	8	9	10	11	12	13
API no. (from State)	34–067–20737	34–067–20103	47–051–00539	47–049–00244	47–077–00119	47–023–00002	47–031–00021
Lease name	No. 1 Thomas Zechman	No. 1 Roy Birney	No. 1 John Burley	No. A–1 (A–1251) R.R. Finch	No. USA Q–1 GW–1466 [1]	No. 1 Greenland Lodge, Inc.	No. 1 Charles H. Bean, et al.
Permanent datum	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level
GL elevation (ft)	888	1,110.9	1,423	1,341	2,172	2,344	1,022
KB elevation (ft)	898	1,126.9	1,435	1,362	2,187	2,362	1,043
Measured from	KB (10 ft APD)	KB (16 ft APD)	KB (12 ft AGL)	KB (21 ft AGL)	KB (15 ft AGL)	KB (18 ft AGL)	KB (21 ft AGL)
Drill depth (ft)	10,625	10,181	16,512	17,111	9,910	13,000	16,075
KB elevation - GL elevation	10	16	12	21	15	18	21
Formation 16	Java Formation	Java Formation	Riceville Formation	Brallier Formation	Williamsport Sandstone	Beekmantown Group	Cacapon Sandstone Member of Rose Hill Formation
System or series	Upper Devonian	Upper Devonian	Upper Devonian	Upper Devonian	Silurian	Middle Ordovician	Silurian
Formation top (relative to KB) (ft)	-3,410	-3,680	-2,992	-4,606	-6,330	-8,690	-2,610
Formation top (relative to GL) (ft)	-3,400	-3,664	-2,980	-4,585	-6,315	-8,672	-2,589
Formation top (relative to SL) (ft)	-2,512	-2,553.1	-1,557	-3,244	-4,143	-6,328	-1,567
Formation 17	Angola Shale Member of West Falls Formation	Angola Shale Member of West Falls Formation	Venango Formation[2]	Sonyea Formation	McKenzie Limestone	Trenton Limestone (overturned)	Tuscarora Sandstone
System or series	Upper Devonian	Upper Devonian	Upper Devonian	Upper Devonian	Silurian	Upper Ordovician	Silurian
Formation top (relative to KB) (ft)	-3,578	-3,860	-3,132	-6,270	-6,350	-12,640	-2,850
Formation top (relative to GL) (ft)	-3,568	-3,844	-3,120	-6,249	-6,335	-12,622	-2,829
Formation top (relative to SL) (ft)	-2,680	-2,733.1	-1,697	-4,908	-4,163	-10,278	-1,807
Formation 18	Rhinestreet Shale Member of West Falls Formation	Rhinestreet Shale Member of West Falls Formation	Greenland Gap (Foreknobs) Formation[3]	Genesee Formation	Keefer Sandstone	Black River Limestone (overturned)	Juniata Formation
System or series	Upper Devonian	Upper Devonian	Upper Devonian	Upper Devonian	Silurian	Middle and Upper Ordovician	Upper Ordovician
Formation top (relative to KB) (ft)	-3,812	-4,150	-3,330	-6,630	-6,590	-12,080	-3,140
Formation top (relative to GL) (ft)	-3,802	-4,134	-3,318	-6,609	-6,575	-12,062	-3,119
Formation top (relative to SL) (ft)	-2,914	-3,023.1	-1,895	-5,268	-4,403	-9,718	-2,097
Formation 19	Sonyea Formation	Sonyea Formation	Greenland Gap (Foreknobs) Formation[4]	Tully Limestone	Rose Hill Formation (upper)	St. Paul Group (overturned)	Oswego Sandstone
System or series	Upper Devonian	Upper Devonian	Upper Devonian	Middle Devonian	Silurian	Middle and Upper Ordovician	Upper Ordovician
Formation top (relative to KB) (ft)	-4,000	-4,380	-3,940	-6,820	-6,623	-11,715	-3,760
Formation top (relative to GL) (ft)	-3,990	-4,364	-3,928	-6,799	-6,608	-11,697	-3,739
Formation top (relative to SL) (ft)	-3,102	-3,253.1	-2,505	-5,458	-4,436	-9,353	-2,717
Formation 20	Genesee Formation	Genesee Formation	Brallier Formation	Mahantango Formation of Hamilton Group	Cacapon Sandstone Member of Rose Hill Formation	Beekmantown Group (overturned)	Reedsville Shale
System or series	Upper Devonian	Upper Devonian	Upper Devonian	Middle Devonian	Silurian	Middle Ordovician	Upper Ordovician
Formation top (relative to KB) (ft)	-4,060	-4,420	-4,440	-6,840	-6,900	-10,880	-4,138
Formation top (relative to GL) (ft)	-4,050	-4,404	-4,428	-6,819	-6,885	-10,862	-4,117
Formation top (relative to SL) (ft)	-3,162	-3,293.1	-3,005	-5,478	-4,713	-8,518	-3,095

[1]Monongahela National Forest. [2]Includes Gordon sandstone. [3]Includes Bayard, Elizabeth, and Warren sandstones. [4]Includes Speechley, Balltown, and Bradford sandstones.

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

[Abbreviations: AGL, above ground level; APD, above permanent datum; API no., American Petroleum Institute drill-hole identification number; equiv., equivalent; GL, ground level; KB, kelly bushing; SL, sea level]

Drill-hole no.	**1**	**2**	**3**	**4**	**5**	**6**
API no. (from State)	**34–143–20077**	**34–077–20025**	**34–139–20448**	**34–169–21419**	**34–075–21283**	**34–157–21030**
Lease name	**No. 1–2171 V. and I. Haff**	**No. 1 I.M. Wheeler**	**No. D–1 Empire Reeves Steel Division**	**No. 1 Alonzo Drake, Jr.**	**No. 1 Dan E. Troyer**	**No. 2 (1–2669) Huebner**
Permanent datum	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**
GL elevation (ft)	**644**	**881**	**1,169**	**1,145**	**1,307**	**1,205**
KB elevation (ft)	**644**	**891**	**1,176**	**1,151**	**1,316**	**1,221**
Measured from	**KB**	**KB (10 ft APD)**	**KB (7 ft APD)**	**KB (6 ft APD)**	**KB**	**KB (16 ft APD)**
Drill depth (ft)	**3,123**	**3,865**	**5,085**	**6,897**	**7,369**	**8,227**
KB elevation - GL elevation	**0**	**10**	**7**	**6**	**9**	**16**
Formation 21		Wells Creek formation	Cincinnati group	Utica Shale	Cincinnati group	Oriskany Sandstone
System or series		Middle Ordovician	Upper Ordovician	Upper Ordovician	Upper Ordovician	Lower Devonian
Formation top (relative to KB) (ft)		-3,254	-2,520	-4,700	-4,500	-3,890
Formation top (relative to GL) (ft)		-3,244	-2,513	-4,694	-4,491	-3,874
Formation top (relative to SL) (ft)		-2,363	-1,344	-3,549	-3,184	-2,669
Formation 22		Knox Dolomite (B zone)	Utica Shale	Trenton Limestone	Utica Shale	Helderberg Limestone
System or series		Upper Cambrian	Upper Ordovician	Upper Ordovician	Upper Ordovician	Lower Devonian
Formation top (relative to KB) (ft)		-3,288	-3,229	-4,988	-5,360	-3,895
Formation top (relative to GL) (ft)		-3,278	-3,222	-4,982	-5,351	-3,879
Formation top (relative to SL) (ft)		-2,397	-2,053	-3,837	-4,044	-2,674
Formation 23		Knox Dolomite (lower)	Trenton Limestone	Black River Group	Trenton Limestone	Bass Islands Dolomite
System or series		Upper Cambrian	Upper Ordovician	Middle and Upper Ordovician	Upper Ordovician	Silurian
Formation top (relative to KB) (ft)		-3,321	-3,523	-5,078	-5,631	-4,036
Formation top (relative to GL) (ft)		-3,311	-3,516	-5,072	-5,622	-4,020
Formation top (relative to SL) (ft)		-2,430	-2,347	-3,927	-4,315	-2,815
Formation 24		Kerbel Formation	Black River Group	Wells Creek formation	Black River Group	Salina Group
System or series		Upper Cambrian	Middle and Upper Ordovician	Middle Ordovician	Middle and Upper Ordovician	Silurian
Formation top (relative to KB) (ft)		-3,433	-3,595	-5,688	-5,736	-4,075
Formation top (relative to GL) (ft)		-3,423	-3,588	-5,682	-5,727	-4,059
Formation top (relative to SL) (ft)		-2,542	-2,419	-4,537	-4,420	-2,854
Formation 25		Nolichucky Shale of Conasauga Group	Wells Creek formation	Knox Dolomite (upper)	Wells Creek formation	Lockport Dolomite
System or series		Upper Cambrian	Middle Ordovician	Upper Cambrian	Middle Ordovician	Silurian
Formation top (relative to KB) (ft)		-3,476	-4,164	-5,706	-6,370	-4,810
Formation top (relative to GL) (ft)		-3,466	-4,157	-5,700	-6,361	-4,794
Formation top (relative to SL) (ft)		-2,585	-2,988	-4,555	-5,054	-3,589

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

[Abbreviations: AGL, above ground level; APD, above permanent datum; API no., American Petroleum Institute drill-hole identification number; equiv., equivalent; GL, ground level; KB, kelly bushing; SL, sea level]

Drill-hole no.	**7**	**8**	**9**	**10**	**11**	**12**	**13**
API no. (from State)	**34–067–20737**	**34–067–20103**	**47–051–00539**	**47–049–00244**	**47–077–00119**	**47–023–00002**	**47–031–00021**
Lease name	**No. 1 Thomas Zechman**	**No. 1 Roy Birney**	**No. 1 John Burley**	**No. A–1 (A–1251) R.R. Finch**	**No. USA Q–1 GW–1466** [1]	**No. 1 Greenland Lodge, Inc.**	**No. 1 Charles H. Bean, et al.**
Permanent datum	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**
GL elevation (ft)	**888**	**1,110.9**	**1,423**	**1,341**	**2,172**	**2,344**	**1,022**
KB elevation (ft)	**898**	**1,126.9**	**1,435**	**1,362**	**2,187**	**2,362**	**1,043**
Measured from	**KB (10 ft APD)**	**KB (16 ft APD)**	**KB (12 ft AGL)**	**KB (21 ft AGL)**	**KB (15 ft AGL)**	**KB (18 ft AGL)**	**KB (21 ft AGL)**
Drill depth (ft)	**10,625**	**10,181**	**16,512**	**17,111**	**9,910**	**13,000**	**16,075**
KB elevation - GL elevation	**10**	**16**	**12**	**21**	**15**	**18**	**21**
Formation 21	Mahantango Formation of Hamilton Group	Mahantango Formation of Hamilton Group	Dunkirk Shale Member of Perrysburg Formation	Marcellus Shale of Hamilton Group	Tuscarora Sandstone		Utica Shale
System or series	Middle Devonian	Middle Devonian	Upper Devonian	Middle Devonian	Silurian		Upper Ordovician
Formation top (relative to KB) (ft)	-4,118	-4,490	-5,890	-7,103	-7,136		-5,200
Formation top (relative to GL) (ft)	-4,108	-4,474	-5,878	-7,082	-7,121		-5,179
Formation top (relative to SL) (ft)	-3,220	-3,363.1	-4,455	-5,741	-4,949		-4,157
Formation 22	Marcellus Shale of Hamilton Group	Marcellus Shale of Hamilton Group	Java Formation	Huntersville Chert	Juniata Formation		Trenton Limestone
System or series	Middle Devonian	Middle Devonian	Upper Devonian	Middle Devonian	Upper Ordovician		Upper Ordovician
Formation top (relative to KB) (ft)	-4,146	-4,565	-5,910	-7,190	-7,495		-5,495
Formation top (relative to GL) (ft)	-4,136	-4,549	-5,898	-7,169	-7,480		-5,474
Formation top (relative to SL) (ft)	-3,248	-3,438.1	-4,475	-5,828	-5,308		-4,452
Formation 23	Onondaga Limestone	Onondaga Limestone	Angola Shale Member of West Falls Formation	Oriskany Sandstone	Oswego Sandstone		Black River Limestone
System or series	Middle Devonian	Middle Devonian	Upper Devonian	Lower Devonian	Upper Ordovician		Middle and Upper Ordovician
Formation top (relative to KB) (ft)	-4,178	-4,625	-6,290	-7,405	-9,200		-5,970
Formation top (relative to GL) (ft)	-4,168	-4,609	-6,278	-7,384	-9,185		-5,949
Formation top (relative to SL) (ft)	-3,280	-3,498.1	-4,855	-6,043	-7,013		-4,927
Formation 24	Oriskany Sandstone	Oriskany Sandstone	Rhinestreet Shale Member of West Falls Formation	Helderberg Limestone	Reedsville Shale		St. Paul Group (upper)
System or series	Lower Devonian	Lower Devonian	Upper Devonian	Lower Devonian	Upper Ordovician		Middle and Upper Ordovician
Formation top (relative to KB) (ft)	-4,348	-4,805	-6,768	-7,510	-9,405		-6,410
Formation top (relative to GL) (ft)	-4,338	-4,789	-6,756	-7,489	-9,390		-6,389
Formation top (relative to SL) (ft)	-3,450	-3,678.1	-5,333	-6,148	-7,218		-5,367
Formation 25	Helderberg Limestone	Helderberg Limestone	Sonyea Formation	Mandata Shale			Beekmantown Group (upper)
System or series	Lower Devonian	Lower Devonian	Upper Devonian	Lower Devonian			Middle Ordovician
Formation top (relative to KB) (ft)	-4,375	-4,825	-7,133	-7,705			-6,710
Formation top (relative to GL) (ft)	-4,365	-4,809	-7,121	-7,684			-6,689
Formation top (relative to SL) (ft)	-3,477	-3,698.1	-5,698	-6,343			-5,667

[1] Monongahela National Forest.

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

[Abbreviations: AGL, above ground level; APD, above permanent datum; API no., American Petroleum Institute drill-hole identification number; equiv., equivalent; GL, ground level; KB, kelly bushing; SL, sea level]

Drill-hole no.	**1**	**2**	**3**	**4**	**5**	**6**
API no. (from State)	**34–143–20077**	**34–077–20025**	**34–139–20448**	**34–169–21419**	**34–075–21283**	**34–157–21030**
Lease name	**No. 1–2171 V. and I. Haff**	**No. 1 I.M. Wheeler**	**No. D–1 Empire Reeves Steel Division**	**No. 1 Alonzo Drake, Jr.**	**No. 1 Dan E. Troyer**	**No. 2 (1–2669) Huebner**
Permanent datum	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**
GL elevation (ft)	**644**	**881**	**1,169**	**1,145**	**1,307**	**1,205**
KB elevation (ft)	**644**	**891**	**1,176**	**1,151**	**1,316**	**1,221**
Measured from	**KB**	**KB (10 ft APD)**	**KB (7 ft APD)**	**KB (6 ft APD)**	**KB**	**KB (16 ft APD)**
Drill depth (ft)	**3,123**	**3,865**	**5,085**	**6,897**	**7,369**	**8,227**
KB elevation - GL elevation	**0**	**10**	**7**	**6**	**9**	**16**
Formation 26		Maryville Limestone of Conasauga Group (upper)	Knox Dolomite (upper)	Knox Dolomite (B zone)	Knox Dolomite (upper)	Rochester Shale
System or series		Upper Cambrian	Upper Cambrian	Upper Cambrian	Upper Cambrian	Silurian
Formation top (relative to KB) (ft)		-3,563	-4,170	-5,897	-6,418	-5,165
Formation top (relative to GL) (ft)		-3,553	-4,163	-5,891	-6,409	-5,149
Formation top (relative to SL) (ft)		-2,672	-2,994	-4,746	-5,102	-3,944
Formation 27		Unnamed sandstone in Maryville Limestone	Knox Dolomite (B zone)	Knox Dolomite (lower)	Knox Dolomite (B zone)	Lower Silurian carbonates and shales, undivided
System or series		Upper Cambrian	Upper Cambrian	Upper Cambrian	Upper Cambrian	Silurian
Formation top (relative to KB) (ft)		-3,705	-4,325	-5,994	-6,584	-5,270
Formation top (relative to GL) (ft)		-3,695	-4,318	-5,988	-6,575	-5,254
Formation top (relative to SL) (ft)		-2,814	-3,149	-4,843	-5,268	-4,049
Formation 28		Maryville Limestone of Conasauga Group (lower)	Knox Dolomite (lower)	Nolichucky Shale of Conasauga Group	Knox Dolomite (lower)	“Clinton” sandstone-Cabot Head Shale-Medina sandstone
System or series		Upper Cambrian	Upper Cambrian	Upper Cambrian	Upper Cambrian	Silurian
Formation top (relative to KB) (ft)		-3,740	-4,410	-6,078	-6,668	-5,330
Formation top (relative to GL) (ft)		-3,730	-4,403	-6,072	-6,659	-5,314
Formation top (relative to SL) (ft)		-2,849	-3,234	-4,927	-5,352	-4,109
Formation 29			Kerbel Formation	Maryville Limestone of Conasauga Group	Nolichucky Shale of Conasauga Group	Queenston Shale
System or series			Upper Cambrian	Upper Cambrian	Upper Cambrian	Upper Ordovician
Formation top (relative to KB) (ft)			-4,520	-6,147	-6,848	-5,535
Formation top (relative to GL) (ft)			-4,513	-6,141	-6,839	-5,519
Formation top (relative to SL) (ft)			-3,344	-4,996	-5,532	-4,314
Formation 30			Nolichucky Shale of Conasauga Group	Mount Simon Sandstone	Maryville Limestone of Conasauga Group	Cincinnati group
System or series			Upper Cambrian	Middle and Upper Cambrian	Upper Cambrian	Upper Ordovician
Formation top (relative to KB) (ft)			-4,552	-6,617	-6,938	-5,955
Formation top (relative to GL) (ft)			-4,545	-6,611	-6,929	-5,939
Formation top (relative to SL) (ft)			-3,376	-5,466	-5,622	-4,734

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

[Abbreviations: AGL, above ground level; APD, above permanent datum; API no., American Petroleum Institute drill-hole identification number; equiv., equivalent; GL, ground level; KB, kelly bushing; SL, sea level]

Drill-hole no.	7	8	9	10	11	12	13
API no. (from State)	34–067–20737	34–067–20103	47–051–00539	47–049–00244	47–077–00119	47–023–00002	47–031–00021
Lease name	No. 1 Thomas Zechman	No. 1 Roy Birney	No. 1 John Burley	No. A–1 (A–1251) R.R. Finch	No. USA Q–1 GW–1466 [1]	No. 1 Greenland Lodge, Inc.	No. 1 Charles H. Bean, et al.
Permanent datum	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level
GL elevation (ft)	888	1,110.9	1,423	1,341	2,172	2,344	1,022
KB elevation (ft)	898	1,126.9	1,435	1,362	2,187	2,362	1,043
Measured from	KB (10 ft APD)	KB (16 ft APD)	KB (12 ft AGL)	KB (21 ft AGL)	KB (15 ft AGL)	KB (18 ft AGL)	KB (21 ft AGL)
Drill depth (ft)	10,625	10,181	16,512	17,111	9,910	13,000	16,075
KB elevation - GL elevation	10	16	12	21	15	18	21
Formation 26	Bass Islands Dolomite	Bass Islands Dolomite	Genesee Formation	Keyser Limestone (upper)			Beekmantown Group (lower)
System or series	Silurian	Silurian	Upper Devonian	Lower Devonian			Lower Ordovician
Formation top (relative to KB) (ft)	-4,600	-5,090	-7,292	-7,745			-8,025
Formation top (relative to GL) (ft)	-4,590	-5,074	-7,280	-7,724			-8,004
Formation top (relative to SL) (ft)	-3,702	-3,963.1	-5,857	-6,383			-6,982
Formation 27	Salina Group	Salina Group (upper)	Tully Limestone	Bass Islands Dolomite			Copper Ridge Dolomite[2]
System or series	Silurian	Silurian	Middle Devonian	Silurian			Upper Cambrian
Formation top (relative to KB) (ft)	-4,645	-5,153	-7,395	-7,905			-9,110
Formation top (relative to GL) (ft)	-4,635	-5,137	-7,383	-7,884			-9,089
Formation top (relative to SL) (ft)	-3,747	-4,026.1	-5,960	-6,543			-8,067
Formation 28	Lockport Dolomite	Salina Group (halite zone)	Mahantango Formation of Hamilton Group	Keyser Limestone (lower)			Copper Ridge Dolomite (upper)[3]
System or series	Silurian	Silurian	Middle Devonian	Silurian			Upper Cambrian
Formation top (relative to KB) (ft)	-5,480	-5,335	-7,425	-7,950			-9,300
Formation top (relative to GL) (ft)	-5,470	-5,319	-7,413	-7,929			-9,279
Formation top (relative to SL) (ft)	-4,582	-4,208.1	-5,990	-6,588			-8,257
Formation 29	Keefer Sandstone	Salina Group (lower)	Marcellus Shale of Hamilton Group	Salina Group (upper)			Copper Ridge Dolomite[4]
System or series	Silurian	Silurian	Middle Devonian	Silurian			Upper Cambrian
Formation top (relative to KB) (ft)	-5,803	-5,925	-7,530	-8,068			-10,110
Formation top (relative to GL) (ft)	-5,793	-5,909	-7,518	-8,047			-10,089
Formation top (relative to SL) (ft)	-4,905	-4,798.1	-6,095	-6,706			-9,067
Formation 30	Rochester Shale	Lockport Dolomite	Huntersville Chert	Salina Group (halite zone)			Copper Ridge Dolomite (lower)
System or series	Silurian	Silurian	Middle Devonian	Silurian			Upper Cambrian
Formation top (relative to KB) (ft)	-5,830	-6,100	-7,575	-8,130			-10,260
Formation top (relative to GL) (ft)	-5,820	-6,084	-7,563	-8,109			-10,239
Formation top (relative to SL) (ft)	-4,932	-4,973.1	-6,140	-6,768			-9,217

[1]Monongahela National Forest. [2]Mines Dolomite Member of Gatesburg Formation equivalent(?). [3]Rose Run Sandstone equivalent. [4]Ore Hill Limestone Member of Gatesburg Formation equivalent(?).

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

[Abbreviations: AGL, above ground level; APD, above permanent datum; API no., American Petroleum Institute drill-hole identification number; equiv., equivalent; GL, ground level; KB, kelly bushing; SL, sea level]

Drill-hole no.	1	2	3	4	5	6
API no. (from State)	34–143–20077	34–077–20025	34–139–20448	34–169–21419	34–075–21283	34–157–21030
Lease name	No. 1–2171 V. and I. Haff	No. 1 I.M. Wheeler	No. D–1 Empire Reeves Steel Division	No. 1 Alonzo Drake, Jr.	No. 1 Dan E. Troyer	No. 2 (1–2669) Huebner
Permanent datum	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level
GL elevation (ft)	644	881	1,169	1,145	1,307	1,205
KB elevation (ft)	644	891	1,176	1,151	1,316	1,221
Measured from	KB	KB (10 ft APD)	KB (7 ft APD)	KB (6 ft APD)	KB	KB (16 ft APD)
Drill depth (ft)	3,123	3,865	5,085	6,897	7,369	8,227
KB elevation - GL elevation	0	10	7	6	9	16
Formation 31			Maryville Limestone of Conasauga Group (upper)	Metamorphic and igneous rocks		Utica Shale
System or series			Upper Cambrian	Mesoproterozoic		Upper Ordovician
Formation top (relative to KB) (ft)			-4,632	-6,719		-6,730
Formation top (relative to GL) (ft)			-4,625	-6,713		-6,714
Formation top (relative to SL) (ft)			-3,456	-5,568		-5,509
Formation 32			Unnamed sandstone in Maryville Limestone			Trenton Limestone
System or series			Upper Cambrian			Upper Ordovician
Formation top (relative to KB) (ft)			-4,796			-7,040
Formation top (relative to GL) (ft)			-4,789			-7,024
Formation top (relative to SL) (ft)			-3,620			-5,819
Formation 33			Maryville Limestone of Conasauga Group (lower)			Black River Group
System or series			Upper Cambrian			Middle and Upper Ordovician
Formation top (relative to KB) (ft)			-4,822			-7,165
Formation top (relative to GL) (ft)			-4,815			-7,149
Formation top (relative to SL) (ft)			-3,646			-5,944
Formation 34			Mount Simon Sandstone			Wells Creek formation
System or series			Middle and Upper Cambrian			Middle Ordovician
Formation top (relative to KB) (ft)			-4,990			-7,850
Formation top (relative to GL) (ft)			-4,983			-7,834
Formation top (relative to SL) (ft)			-3,814			-6,629
Formation 35			Metamorphic and igneous rocks			Beekmantown dolomite
System or series			Mesoproterozoic			Lower Ordovician
Formation top (relative to KB) (ft)			-5,075			-7,910
Formation top (relative to GL) (ft)			-5,068			-7,894
Formation top (relative to SL) (ft)			-3,899			-6,689

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

[Abbreviations: AGL, above ground level; APD, above permanent datum; API no., American Petroleum Institute drill-hole identification number; equiv., equivalent; GL, ground level; KB, kelly bushing; SL, sea level]

Drill-hole no.	7	8	9	10	11	12	13
API no. (from State)	34–067–20737	34–067–20103	47–051–00539	47–049–00244	47–077–00119	47–023–00002	47–031–00021
Lease name	No. 1 Thomas Zechman	No. 1 Roy Birney	No. 1 John Burley	No. A–1 (A–1251) R.R. Finch	No. USA Q–1 GW–1466 [1]	No. 1 Greenland Lodge, Inc.	No. 1 Charles H. Bean, et al.
Permanent datum	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level
GL elevation (ft)	888	1,110.9	1,423	1,341	2,172	2,344	1,022
KB elevation (ft)	898	1,126.9	1,435	1,362	2,187	2,362	1,043
Measured from	KB (10 ft APD)	KB (16 ft APD)	KB (12 ft AGL)	KB (21 ft AGL)	KB (15 ft AGL)	KB (18 ft AGL)	KB (21 ft AGL)
Drill depth (ft)	10,625	10,181	16,512	17,111	9,910	13,000	16,075
KB elevation - GL elevation	10	16	12	21	15	18	21
Formation 31	Lower Silurian carbonates and shales, undivided	Keefer Sandstone	Oriskany Sandstone	Salina Group (lower)			Elbrook Formation
System or series	Silurian	Silurian	Lower Devonian	Silurian			Middle and Upper Cambrian
Formation top (relative to KB) (ft)	-5,960	-6,425	-7,800	-8,375			-10,735
Formation top (relative to GL) (ft)	-5,950	-6,409	-7,788	-8,354			-10,714
Formation top (relative to SL) (ft)	-5,062	-5,298.1	-6,365	-7,013			-9,692
Formation 32	“Clinton” sandstone-Cabot Head Shale-Medina sandstone	Rochester Shale	Helderberg Limestone	Wills Creek Formation			Elbrook Formation[2]
System or series	Silurian	Silurian	Lower Devonian	Silurian			Middle Cambrian
Formation top (relative to KB) (ft)	-6,022	-6,455	-7,922	-8,841			-11,970
Formation top (relative to GL) (ft)	-6,012	-6,439	-7,910	-8,820			-11,949
Formation top (relative to SL) (ft)	-5,124	-5,328.1	-6,487	-7,479			-10,927
Formation 33	Queenston Shale	Lower Silurian carbonates and shales, undivided	Mandata Shale	Williamsport Sandstone			Elbrook Formation
System or series	Upper Ordovician	Silurian	Lower Devonian	Silurian			Middle and Upper Cambrian
Formation top (relative to KB) (ft)	-6,220	-6,600	-8,093	-9,186			-12,082
Formation top (relative to GL) (ft)	-6,210	-6,584	-8,081	-9,165			-12,061
Formation top (relative to SL) (ft)	-5,322	-5,473.1	-6,658	-7,824			-11,039
Formation 34	Cincinnati group	“Clinton” sandstone-Cabot Head Shale-Medina sandstone	Keyser Limestone (upper)	McKenzie Limestone			Elbrook Formation[2]
System or series	Upper Ordovician	Silurian	Lower Devonian	Silurian			Middle Cambrian
Formation top (relative to KB) (ft)	-6,740	-6,680	-8,110	-9,206			-12,210
Formation top (relative to GL) (ft)	-6,730	-6,664	-8,098	-9,185			-12,189
Formation top (relative to SL) (ft)	-5,842	-5,553.1	-6,675	-7,844			-11,167
Formation 35	Utica Shale	Queenston Shale	Bass Islands Dolomite	Keefer Sandstone			Elbrook Formation[3]
System or series	Upper Ordovician	Upper Ordovician	Silurian	Silurian			Middle Cambrian
Formation top (relative to KB) (ft)	-7,664	-6,908	-8,263	-9,469			-12,350
Formation top (relative to GL) (ft)	-7,654	-6,892	-8,251	-9,448			-12,329
Formation top (relative to SL) (ft)	-6,766	-5,781.1	-6,828	-8,107			-11,307

[1]Monongahela National Forest. [2]Rogersville Shale equivalent(?) (Conasauga Group). [3]Rutledge Limestone equivalent(?) (Conasauga Group) (Pleasant Hill equivalent?).

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

[Abbreviations: AGL, above ground level; APD, above permanent datum; API no., American Petroleum Institute drill-hole identification number; equiv., equivalent; GL, ground level; KB, kelly bushing; SL, sea level]

Drill-hole no.	**1**	**2**	**3**	**4**	**5**	**6**
API no. (from State)	**34–143–20077**	**34–077–20025**	**34–139–20448**	**34–169–21419**	**34–075–21283**	**34–157–21030**
Lease name	**No. 1–2171 V. and I. Haff**	**No. 1 I.M. Wheeler**	**No. D–1 Empire Reeves Steel Division**	**No. 1 Alonzo Drake, Jr.**	**No. 1 Dan E. Troyer**	**No. 2 (1–2669) Huebner**
Permanent datum	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**
GL elevation (ft)	**644**	**881**	**1,169**	**1,145**	**1,307**	**1,205**
KB elevation (ft)	**644**	**891**	**1,176**	**1,151**	**1,316**	**1,221**
Measured from	**KB**	**KB (10 ft APD)**	**KB (7 ft APD)**	**KB (6 ft APD)**	**KB**	**KB (16 ft APD)**
Drill depth (ft)	**3,123**	**3,865**	**5,085**	**6,897**	**7,369**	**8,227**
KB elevation - GL elevation	**0**	**10**	**7**	**6**	**9**	**16**
Formation 36						Rose Run sandstone
System or series						Upper Cambrian
Formation top (relative to KB) (ft)						-8,055
Formation top (relative to GL) (ft)						-8,039
Formation top (relative to SL) (ft)						-6,834
Formation 37						Copper Ridge dolomite (upper)
System or series						Upper Cambrian
Formation top (relative to KB) (ft)						-8,193
Formation top (relative to GL) (ft)						-8,177
Formation top (relative to SL) (ft)						-6,972
Formation 38						
System or series						
Formation top (relative to KB) (ft)						
Formation top (relative to GL) (ft)						
Formation top (relative to SL) (ft)						
Formation 39						
System or series						
Formation top (relative to KB) (ft)						
Formation top (relative to GL) (ft)						
Formation top (relative to SL) (ft)						
Formation 40						
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 *D–D′*.—Continued

[Abbreviations: AGL, above ground level; APD, above permanent datum; API no., American Petroleum Institute drill-hole identification number; equiv., equivalent; GL, ground level; KB, kelly bushing; SL, sea level]

Drill-hole no.	7	8	9	10	11	12	13
API no. (from State)	34–067–20737	34–067–20103	47–051–00539	47–049–00244	47–077–00119	47–023–00002	47–031–00021
Lease name	No. 1 Thomas Zechman	No. 1 Roy Birney	No. 1 John Burley	No. A–1 (A–1251) R.R. Finch	No. USA Q–1 GW–1466 [1]	No. 1 Greenland Lodge, Inc.	No. 1 Charles H. Bean, et al.
Permanent datum	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level
GL elevation (ft)	888	1,110.9	1,423	1,341	2,172	2,344	1,022
KB elevation (ft)	898	1,126.9	1,435	1,362	2,187	2,362	1,043
Measured from	KB (10 ft APD)	KB (16 ft APD)	KB (12 ft AGL)	KB (21 ft AGL)	KB (15 ft AGL)	KB (18 ft AGL)	KB (21 ft AGL)
Drill depth (ft)	10,625	10,181	16,512	17,111	9,910	13,000	16,075
KB elevation - GL elevation	10	16	12	21	15	18	21
Formation 36	Trenton Limestone	Cincinnati group	Salina Group (upper)	Rose Hill Formation (upper)			Waynesboro Formation
System or series	Upper Ordovician	Upper Ordovician	Silurian	Silurian			Lower and Middle Cambrian
Formation top (relative to KB) (ft)	-7,842	-7,455	-8,332	-9,495			-12,610
Formation top (relative to GL) (ft)	-7,832	-7,439	-8,320	-9,474			-12,589
Formation top (relative to SL) (ft)	-6,944	-6,328.1	-6,897	-8,133			-11,567
Formation 37	Black River Group	Utica Shale	Salina Group (upper halite zone)	Cacapon Sandstone Member of Rose Hill Formation			Elbrook Formation[2]
System or series	Middle and Upper Ordovician	Upper Ordovician	Silurian	Silurian			Middle Cambrian
Formation top (relative to KB) (ft)	-7,984	-8,350	-8,870	-9,850			-12,870
Formation top (relative to GL) (ft)	-7,974	-8,334	-8,858	-9,829			-12,849
Formation top (relative to SL) (ft)	-7,086	-7,223.1	-7,435	-8,488			-11,827
Formation 38	Wells Creek formation	Trenton Limestone	Salina Group (middle)	Tuscarora Sandstone			Waynesboro Formation
System or series	Middle Ordovician	Upper Ordovician	Silurian	Silurian			Lower and Middle Cambrian
Formation top (relative to KB) (ft)	-8,720	-8,610	-8,920	-10,060			-13,140
Formation top (relative to GL) (ft)	-8,710	-8,594	-8,908	-10,039			-13,119
Formation top (relative to SL) (ft)	-7,822	-7,483.1	-7,485	-8,698			-12,097
Formation 39	Unnamed sandstone (St. Peter Sandstone equiv.)	Black River Group	Salina Group (lower halite zone)	Juniata Formation			Elbrook Formation(?)
System or series	Middle Ordovician	Middle and Upper Ordovician	Silurian	Upper Ordovician			Middle and Upper Cambrian
Formation top (relative to KB) (ft)	-8,784	-8,762	-9,050	-10,370			-13,630
Formation top (relative to GL) (ft)	-8,774	-8,746	-9,038	-10,349			-13,609
Formation top (relative to SL) (ft)	-7,886	-7,635.1	-7,615	-9,008			-12,587
Formation 40	Beekmantown dolomite	Wells Creek formation	Salina Group (lower)	Oswego Sandstone			Elbrook Formation[2]
System or series	Lower Ordovician	Middle Ordovician	Silurian	Upper Ordovician			Middle Cambrian
Formation top (relative to KB) (ft)	-8,810	-9,540	-9,080	-11,364			-13,920
Formation top (relative to GL) (ft)	-8,800	-9,524	-9,068	-11,343			-13,899
Formation top (relative to SL) (ft)	-7,912	-8,413.1	-7,645	-10,002			-12,877

[1]Monongahela National Forest. [2]Rutledge Limestone equivalent(?) (Conasauga Group) (Pleasant Hill equivalent?).

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

[Abbreviations: AGL, above ground level; APD, above permanent datum; API no., American Petroleum Institute drill-hole identification number; equiv., equivalent; GL, ground level; KB, kelly bushing; SL, sea level]

Drill-hole no.	1	2	3	4	5	6
API no. (from State)	34–143–20077	34–077–20025	34–139–20448	34–169–21419	34–075–21283	34–157–21030
Lease name	No. 1–2171 V. and I. Haff	No. 1 I.M. Wheeler	No. D–1 Empire Reeves Steel Division	No. 1 Alonzo Drake, Jr.	No. 1 Dan E. Troyer	No. 2 (1–2669) Huebner
Permanent datum	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level
GL elevation (ft)	644	881	1,169	1,145	1,307	1,205
KB elevation (ft)	644	891	1,176	1,151	1,316	1,221
Measured from	KB	KB (10 ft APD)	KB (7 ft APD)	KB (6 ft APD)	KB	KB (16 ft APD)
Drill depth (ft)	3,123	3,865	5,085	6,897	7,369	8,227
KB elevation - GL elevation	0	10	7	6	9	16
Formation 41						
System or series						
Formation top (relative to KB) (ft)						
Formation top (relative to GL) (ft)						
Formation top (relative to SL) (ft)						
Formation 42						
System or series						
Formation top (relative to KB) (ft)						
Formation top (relative to GL) (ft)						
Formation top (relative to SL) (ft)						
Formation 43						
System or series						
Formation top (relative to KB) (ft)						
Formation top (relative to GL) (ft)						
Formation top (relative to SL) (ft)						
Formation 44						
System or series						
Formation top (relative to KB) (ft)						
Formation top (relative to GL) (ft)						
Formation top (relative to SL) (ft)						
Formation 45						
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 *D–D′*.—Continued

[Abbreviations: AGL, above ground level; APD, above permanent datum; API no., American Petroleum Institute drill-hole identification number; equiv., equivalent; GL, ground level; KB, kelly bushing; SL, sea level]

Drill-hole no.	7	8	9	10	11	12	13
API no. (from State)	34–067–20737	34–067–20103	47–051–00539	47–049–00244	47–077–00119	47–023–00002	47–031–00021
Lease name	No. 1 Thomas Zechman	No. 1 Roy Birney	No. 1 John Burley	No. A–1 (A–1251) R.R. Finch	No. USA Q–1 GW–1466 [1]	No. 1 Greenland Lodge, Inc.	No. 1 Charles H. Bean, et al.
Permanent datum	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level
GL elevation (ft)	888	1,110.9	1,423	1,341	2,172	2,344	1,022
KB elevation (ft)	898	1,126.9	1,435	1,362	2,187	2,362	1,043
Measured from	KB (10 ft APD)	KB (16 ft APD)	KB (12 ft AGL)	KB (21 ft AGL)	KB (15 ft AGL)	KB (18 ft AGL)	KB (21 ft AGL)
Drill depth (ft)	10,625	10,181	16,512	17,111	9,910	13,000	16,075
KB elevation - GL elevation	10	16	12	21	15	18	21
Formation 41	Rose Run sandstone	Beekmantown dolomite	Wills Creek Formation	Reedsville Shale			Waynesboro Formation
System or series	Upper Cambrian	Lower Ordovician	Silurian	Upper Ordovician			Lower and Middle Cambrian
Formation top (relative to KB) (ft)	-9,145	-9,648	-9,115	-11,468			-14,195
Formation top (relative to GL) (ft)	-9,135	-9,632	-9,103	-11,447			-14,174
Formation top (relative to SL) (ft)	-8,247	-8,521.1	-7,680	-10,106			-13,152
Formation 42	Copper Ridge dolomite (upper)	Rose Run sandstone	Lockport Dolomite (upper)	Utica Shale			Beekmantown Group (upper?)
System or series	Upper Cambrian	Upper Cambrian	Silurian	Upper Ordovician			Middle Ordovician
Formation top (relative to KB) (ft)	-9,260	-10,126	-9,390	-12,850			-14,753
Formation top (relative to GL) (ft)	-9,250	-10,110	-9,378	-12,829			-14,732
Formation top (relative to SL) (ft)	-8,362	-8,999.1	-7,955	-11,488			-13,710
Formation 43	B zone		Lockport Dolomite (limestone)	Trenton Limestone			
System or series	Upper Cambrian		Silurian	Upper Ordovician			
Formation top (relative to KB) (ft)	-9,430		-9,620	-13,111			
Formation top (relative to GL) (ft)	-9,420		-9,608	-13,090			
Formation top (relative to SL) (ft)	-8,532		-8,185	-11,749			
Formation 44	Copper Ridge dolomite (lower)		Keefer Sandstone	Trenton Limestone (Nealmont Formation equiv.)			
System or series	Upper Cambrian		Silurian	Upper Ordovician			
Formation top (relative to KB) (ft)	-9,500		-9,730	-13,520			
Formation top (relative to GL) (ft)	-9,490		-9,718	-13,499			
Formation top (relative to SL) (ft)	-8,602		-8,295	-12,158			
Formation 45	Nolichucky Shale of Conasauga Group		Rose Hill Formation (upper)	Black River Limestone			
System or series	Upper Cambrian		Silurian	Middle and Upper Ordovician			
Formation top (relative to KB) (ft)	-9,660		-9,778	-13,645			
Formation top (relative to GL) (ft)	-9,650		-9,766	-13,624			
Formation top (relative to SL) (ft)	-8,762		-8,343	-12,283			

[1]Monongahela National Forest.

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

[Abbreviations: AGL, above ground level; APD, above permanent datum; API no., American Petroleum Institute drill-hole identification number; equiv., equivalent; GL, ground level; KB, kelly bushing; SL, sea level]

Drill-hole no.	1	2	3	4	5	6
API no. (from State)	34–143–20077	34–077–20025	34–139–20448	34–169–21419	34–075–21283	34–157–21030
Lease name	No. 1–2171 V. and I. Haff	No. 1 I.M. Wheeler	No. D–1 Empire Reeves Steel Division	No. 1 Alonzo Drake, Jr.	No. 1 Dan E. Troyer	No. 2 (1–2669) Huebner
Permanent datum	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level
GL elevation (ft)	644	881	1,169	1,145	1,307	1,205
KB elevation (ft)	644	891	1,176	1,151	1,316	1,221
Measured from	KB	KB (10 ft APD)	KB (7 ft APD)	KB (6 ft APD)	KB	KB (16 ft APD)
Drill depth (ft)	3,123	3,865	5,085	6,897	7,369	8,227
KB elevation - GL elevation	0	10	7	6	9	16
Formation 46						
System or series						
Formation top (relative to KB) (ft)						
Formation top (relative to GL) (ft)						
Formation top (relative to SL) (ft)						
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)						

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

[Abbreviations: AGL, above ground level; APD, above permanent datum; API no., American Petroleum Institute drill-hole identification number; equiv., equivalent; GL, ground level; KB, kelly bushing; SL, sea level]

Drill-hole no.	**7**	**8**	**9**	**10**	**11**	**12**	**13**
API no. (from State)	**34–067–20737**	**34–067–20103**	**47–051–00539**	**47–049–00244**	**47–077–00119**	**47–023–00002**	**47–031–00021**
Lease name	**No. 1 Thomas Zechman**	**No. 1 Roy Birney**	**No. 1 John Burley**	**No. A–1 (A–1251) R.R. Finch**	**No. USA Q–1 GW–1466** [1]	**No. 1 Greenland Lodge, Inc.**	**No. 1 Charles H. Bean, et al.**
Permanent datum	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**	**Ground level**
GL elevation (ft)	**888**	**1,110.9**	**1,423**	**1,341**	**2,172**	**2,344**	**1,022**
KB elevation (ft)	**898**	**1,126.9**	**1,435**	**1,362**	**2,187**	**2,362**	**1,043**
Measured from	**KB (10 ft APD)**	**KB (16 ft APD)**	**KB (12 ft AGL)**	**KB (21 ft AGL)**	**KB (15 ft AGL)**	**KB (18 ft AGL)**	**KB (21 ft AGL)**
Drill depth (ft)	**10,625**	**10,181**	**16,512**	**17,111**	**9,910**	**13,000**	**16,075**
KB elevation - GL elevation	**10**	**16**	**12**	**21**	**15**	**18**	**21**
Formation 46	Maryville Limestone of Conasauga Group		Rose Hill Formation (lower)[2]	St. Paul Group (Loysburg Formation equiv.)			
System or series	Upper Cambrian		Silurian	Middle and Upper Ordovician			
Formation top (relative to KB) (ft)	-9,770		-10,041	-14,105			
Formation top (relative to GL) (ft)	-9,760		-10,029	-14,084			
Formation top (relative to SL) (ft)	-8,872		-8,606	-12,743			
Formation 47	Mount Simon Sandstone		Tuscarora Sandstone	Unnamed anhydritic dolomite			
System or series	Middle and Upper Cambrian		Silurian	Middle Ordovician			
Formation top (relative to KB) (ft)	-10,450		-10,218	-14,595			
Formation top (relative to GL) (ft)	-10,440		-10,206	-14,574			
Formation top (relative to SL) (ft)	-9,552		-8,783	-13,233			
Formation 48	Metamorphic and igneous rocks		Juniata Formation	Beekmantown Dolomite			
System or series	Mesoproterozoic		Upper Ordovician	Lower Ordovician			
Formation top (relative to KB) (ft)	-10,580		-10,500	-16,012			
Formation top (relative to GL) (ft)	-10,570		-10,488	-15,991			
Formation top (relative to SL) (ft)	-9,682		-9,065	-14,650			
Formation 49			Reedsville Shale				
System or series			Upper Ordovician				
Formation top (relative to KB) (ft)			-11,465				
Formation top (relative to GL) (ft)			-11,453				
Formation top (relative to SL) (ft)			-10,030				
Formation 50			Utica Shale				
System or series			Upper Ordovician				
Formation top (relative to KB) (ft)			-12,660				
Formation top (relative to GL) (ft)			-12,648				
Formation top (relative to SL) (ft)			-11,225				

[1]Monongahela National Forest. [2]Equivalent to Lower Silurian carbonates and shales, undivided.

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

[Abbreviations: AGL, above ground level; APD, above permanent datum; API no., American Petroleum Institute drill-hole identification number; equiv., equivalent; GL, ground level; KB, kelly bushing; SL, sea level]

Drill-hole no.	1	2	3	4	5	6
API no. (from State)	34–143–20077	34–077–20025	34–139–20448	34–169–21419	34–075–21283	34–157–21030
Lease name	No. 1–2171 V. and I. Haff	No. 1 I.M. Wheeler	No. D–1 Empire Reeves Steel Division	No. 1 Alonzo Drake, Jr.	No. 1 Dan E. Troyer	No. 2 (1–2669) Huebner
Permanent datum	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level
GL elevation (ft)	644	881	1,169	1,145	1,307	1,205
KB elevation (ft)	644	891	1,176	1,151	1,316	1,221
Measured from	KB	KB (10 ft APD)	KB (7 ft APD)	KB (6 ft APD)	KB	KB (16 ft APD)
Drill depth (ft)	3,123	3,865	5,085	6,897	7,369	8,227
KB elevation - GL elevation	0	10	7	6	9	16
Formation 51						
System or series						
Formation top (relative to KB) (ft)						
Formation top (relative to GL) (ft)						
Formation top (relative to SL) (ft)						
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 *D–D′*.—Continued

[Abbreviations: AGL, above ground level; APD, above permanent datum; API no., American Petroleum Institute drill-hole identification number; equiv., equivalent; GL, ground level; KB, kelly bushing; SL, sea level]

Drill-hole no.	7	8	9	10	11	12	13
API no. (from State)	34–067–20737	34–067–20103	47–051–00539	47–049–00244	47–077–00119	47–023–00002	47–031–00021
Lease name	No. 1 Thomas Zechman	No. 1 Roy Birney	No. 1 John Burley	No. A–1 (A–1251) R.R. Finch	No. USA Q–1 GW–1466 [1]	No. 1 Greenland Lodge, Inc.	No. 1 Charles H. Bean, et al.
Permanent datum	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level
GL elevation (ft)	888	1,110.9	1,423	1,341	2,172	2,344	1,022
KB elevation (ft)	898	1,126.9	1,435	1,362	2,187	2,362	1,043
Measured from	KB (10 ft APD)	KB (16 ft APD)	KB (12 ft AGL)	KB (21 ft AGL)	KB (15 ft AGL)	KB (18 ft AGL)	KB (21 ft AGL)
Drill depth (ft)	10,625	10,181	16,512	17,111	9,910	13,000	16,075
KB elevation - GL elevation	10	16	12	21	15	18	21
Formation 51			Trenton Limestone				
System or series			Upper Ordovician				
Formation top (relative to KB) (ft)			-12,780				
Formation top (relative to GL) (ft)			-12,768				
Formation top (relative to SL) (ft)			-11,345				
Formation 52			Trenton Limestone (Nealmont Formation equiv.)				
System or series			Upper Ordovician				
Formation top (relative to KB) (ft)			-13,135				
Formation top (relative to GL) (ft)			-13,123				
Formation top (relative to SL) (ft)			-11,700				
Formation 53			Black River Limestone				
System or series			Middle and Upper Ordovician				
Formation top (relative to KB) (ft)			-13,250				
Formation top (relative to GL) (ft)			-13,238				
Formation top (relative to SL) (ft)			-11,815				
Formation 54			St. Paul Group (Loysburg Formation equiv.)				
System or series			Middle and Upper Ordovician				
Formation top (relative to KB) (ft)			-13,640				
Formation top (relative to GL) (ft)			-13,628				
Formation top (relative to SL) (ft)			-12,205				
Formation 55			Unnamed anhydritic dolomite				
System or series			Middle Ordovician				
Formation top (relative to KB) (ft)			-13,955				
Formation top (relative to GL) (ft)			-13,943				
Formation top (relative to SL) (ft)			-12,520				

[1] Monongahela National Forest.

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

[Abbreviations: AGL, above ground level; APD, above permanent datum; API no., American Petroleum Institute drill-hole identification number; equiv., equivalent; GL, ground level; KB, kelly bushing; SL, sea level]

Drill-hole no.	1	2	3	4	5	6
API no. (from State)	34–143–20077	34–077–20025	34–139–20448	34–169–21419	34–075–21283	34–157–21030
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Permanent datum	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level
GL elevation (ft)	644	881	1,169	1,145	1,307	1,205
KB elevation (ft)	644	891	1,176	1,151	1,316	1,221
Measured from	KB	KB (10 ft APD)	KB (7 ft APD)	KB (6 ft APD)	KB	KB (16 ft APD)
Drill depth (ft)	3,123	3,865	5,085	6,897	7,369	8,227
KB elevation - GL elevation	0	10	7	6	9	16
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)						
Formation 60						
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 *D–D′*.—Continued

[Abbreviations: AGL, above ground level; APD, above permanent datum; API no., American Petroleum Institute drill-hole identification number; equiv., equivalent; GL, ground level; KB, kelly bushing; SL, sea level]

Drill-hole no.	7	8	9	10	11	12	13
API no. (from State)	34–067–20737	34–067–20103	47–051–00539	47–049–00244	47–077–00119	47–023–00002	47–031–00021
Lease name	No. 1 Thomas Zechman	No. 1 Roy Birney	No. 1 John Burley	No. A–1 (A–1251) R.R. Finch	No. USA Q–1 GW–1466 [1]	No. 1 Greenland Lodge, Inc.	No. 1 Charles H. Bean, et al.
Permanent datum	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level	Ground level
GL elevation (ft)	888	1,110.9	1,423	1,341	2,172	2,344	1,022
KB elevation (ft)	898	1,126.9	1,435	1,362	2,187	2,362	1,043
Measured from	KB (10 ft APD)	KB (16 ft APD)	KB (12 ft AGL)	KB (21 ft AGL)	KB (15 ft AGL)	KB (18 ft AGL)	KB (21 ft AGL)
Drill depth (ft)	10,625	10,181	16,512	17,111	9,910	13,000	16,075
KB elevation - GL elevation	10	16	12	21	15	18	21
Formation 56			Unnamed shale				
System or series			Middle Ordovician				
Formation top (relative to KB) (ft)			-14,200				
Formation top (relative to GL) (ft)			-14,188				
Formation top (relative to SL) (ft)			-12,765				
Formation 57			Beekmantown Dolomite				
System or series			Lower Ordovician				
Formation top (relative to KB) (ft)			-14,405				
Formation top (relative to GL) (ft)			-14,393				
Formation top (relative to SL) (ft)			-12,970				
Formation 58			Rose Run Sandstone				
System or series			Upper Cambrian				
Formation top (relative to KB) (ft)			-16,080				
Formation top (relative to GL) (ft)			-16,068				
Formation top (relative to SL) (ft)			-14,645				
Formation 59			Copper Ridge Dolomite				
System or series			Upper Cambrian				
Formation top (relative to KB) (ft)			-16,400				
Formation top (relative to GL) (ft)			-16,388				
Formation top (relative to SL) (ft)			-14,965				
Formation 60							
System or series							
Formation top (relative to KB) (ft)							
Formation top (relative to GL) (ft)							
Formation top (relative to SL) (ft)							

[1]Monongahela National Forest.

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

[Abbreviations: API, American Petroleum Institute; KB, kelly bushing; TD, total depth; µR/hr, micro Roentgen per hour]

Drill-hole no.	Scale and units	Depth of selected logged interval	Casing shoe location
1	0–12 µR/hr	10 ft below KB to TD	
2	0–200 API units	100 ft below KB to TD	473 ft below KB.
	200–400 backup scale		
3	0–200 API units	About 7 ft below KB to TD	
4	0–200 API units	100 ft below KB to TD	3,615 ft below KB.
	200–400 backup scale		
5	0–200 API units	100 ft below KB to TD	1,220 ft below KB.
	200–400 backup scale		
6	0–200 API units	100 ft below KB to TD	1,420 ft below KB.
	200–400 backup scale		
7	0–200 API units	828 ft below KB to TD	6,416 ft below KB.
8	0–200 API units	60 ft below KB to TD	1,590 ft below KB.
	200–400 backup scale		
9	0–250 API units	80 ft below KB to 3,870 ft	100 ft below KB.
	0–250 API units	3,870 ft below KB to 10,505 ft	3,903 ft below KB.
	0–250 API units	10,505 ft below KB to 14,475 ft	10,505 ft below KB.
	Units not listed (probably 0–250 API units)	10,505 ft below KB to TD	
10	0–150 API units	KB to 990 ft	993 ft below KB.
	0–200 API units	990 ft below KB to 7,455 ft	
	0–150 API units	7,455 ft below KB to 7,502 ft	
	0–200 API units	7,502 ft below KB to 12,075 ft	
	0–150 API units	12,075 ft below KB to TD	
11	0–150 API units	KB to 7,710 ft	1,215 ft below KB.
	150–300 backup scale		
	0–200 API units	7,710 ft below KB to TD	4,925 ft below KB.
12	0–200 API units	50 ft below KB to 480 ft	336 ft below KB.
	0–150 API units	480 ft below KB to 10,021 ft	5,255 ft below KB.
	0–200 API units	10,021 ft below KB to TD	
13	0–200 API units	100 ft below KB to 1,490 ft	
	Units not listed (probably 0–250 API units)	1,490 ft below KB to 5,920 ft	
	0–200 API units	5,920 ft below KB to TD	6,000 ft below KB.

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