Stratigraphic Framework of Cambrian and Ordovician Rocks in the Central Appalachian Basin from Medina County, Ohio, through Southwestern and South-Central Pennsylvania to Hampshire County, West Virginia

U.S. GEOLOGICAL SURVEY BULLETIN 1839–K

Chapter K

Stratigraphic Framework of Cambrian and Ordovician Rocks in the Central Appalachian Basin from Medina County, Ohio, through Southwestern and South-Central Pennsylvania to Hampshire County, West Virginia

By ROBERT T. RYDER, ANITA G. HARRIS, and JOHN E. REPETSKI

Stratigraphic framework of the Cambrian and Ordovician sequence in part of the central Appalachian basin and the structure of underlying block-faulted basement rocks

U.S. GEOLOGICAL SURVEY BULLETIN 1839

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Stratigraphic Framework of Cambrian and Ordovician Rocks in the Central Appalachian Basin from Medina County, Ohio, through Southwestern and South-Central Pennsylvania to Hampshire County, West Virginia

By Robert T. Ryder, Anita G. Harris, *and* John E. Repetski

Abstract

A 275-mi-long restored stratigraphic cross section from Medina County, Ohio, through southwestern and south-central Pennsylvania to Hampshire County, W. Va., provides new details on Cambrian and Ordovician stratigraphy in the central Appalachian basin and the structure of underlying Precambrian basement rocks. From west to east, the major structural elements of the block-faulted basement in this section are (1) the relatively stable, slightly extended craton, which includes the Wooster arch, (2) the fault-controlled Ohio-West Virginia hinge zone, which separates the craton from the adjoining Rome trough, (3) the Rome trough, which consists of an east-facing asymmetric graben and an overlying sag basin, and (4) a positive fault block, named here the South-central Pennsylvania arch, which borders the eastern margin of the graben part of the Rome trough. Pre-Middle Ordovician structural relief on Precambrian basement rocks across the down-to-the-west normal fault that separates the Rome trough and the adjoining South-central Pennsylvania arch amounted to between 6,000 and 7,000 ft.

The restored cross section shows eastward thickening of the Cambrian and Ordovician sequence from about 3,000 ft near the crest of the Wooster arch at the western end of the section to about 5,150 ft at the Ohio-West Virginia hinge zone adjoining the western margin of the Rome trough to about 19,800 ft near the depositional axis of the Rome trough. East of the Rome trough, at the adjoining western edge of the South-central Pennsylvania arch, the Cambrian and Ordovician sequence thins abruptly to about 13,500 ft and then thins gradually eastward across the arch to about 12,700 ft near the Allegheny structural front and to about 10,150 ft at the eastern end of the restored section.

In general, the Cambrian and Ordovician sequence along this section consists of four major lithofacies that are predominantly shallow marine to peritidal in origin. In ascending stratigraphic order, the lithofacies are identified by the following descriptive names: (1) sandstone, shale, limestone, and dolomite unit, (2) dolomite and sandstone unit, (3) limestone and black shale unit, and (4) shale and sandstone unit. Each of these units and their associated subunits thicken from west to east across the restored section to a maximum near the depositional axis of the Rome trough and then thin eastward to the end of the section.

The sandstone, shale, limestone, and dolomite unit is largely confined to the asymmetric graben that marks the initial phase of the Rome trough. This unit is Early and Middle Cambrian in age and consists, in ascending order, of a basal sandstone unit (undrilled but probably present), the Tomstown Dolomite (undrilled but probably present), the Waynesboro Formation, and the Pleasant Hill Limestone and its equivalent lower one-third of the Elbrook Formation at the eastern end of the section.

The dolomite and sandstone unit forms the core of the Cambrian and Ordovician sequence. In the Rome trough and on the adjoining South-central Pennsylvania arch, this unit consists, in ascending order, of the Middle and Upper Cambrian Warrior Formation and the equivalent upper two-thirds of the Elbrook Formation at the eastern end of the sec-

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tion, the Upper Cambrian Gatesburg Formation, and the Lower Ordovician and Middle Ordovician (Whiterockian and Chazyan) Beekmantown Group. West of the Ohio-West Virginia hinge zone, the dolomite and sandstone unit consists, in ascending order, of the Conasauga Formation of Janssens (1973), the Krysik sandstone of driller's usage, the B zone of Calvert (1964), the Knox Dolomite and the associated Rose Run Sandstone Member, and the Wells Creek Formation. The widespread Knox unconformity is located at the base of the Wells Creek Formation and at or near the top of the adjoining Beekmantown Group, except near the depositional axis of the Rome trough, where the unconformity seems to be absent.

The limestone and black shale unit is the thinnest of the four lithofacies. In ascending order, this unit consists of the Middle Ordovician (Chazyan) Loysburg Formation, the Middle Ordovician (Blackriveran and Rocklandian) Black River Group, and the Middle and Upper Ordovician (Rocklandian through lowermost Edenian) Trenton Group. West of the Ohio-West Virginia hinge zone, the Loysburg Formation and the Black River Group combine to form the Black River Limestone, and the Trenton Group is replaced by the Trenton Limestone and the overlying Utica Shale.

The shale and sandstone unit consists of (1) a lower shale unit, the Upper Ordovician (Edenian and Maysvillian) Reedsville Shale; (2) a middle argillaceous sandstone between the depositional axis of the Rome trough and the eastern end of the section, the Upper Ordovician (upper Maysvillian and lower Richmondian) Bald Eagle Formation and its equivalent Oswego Sandstone; and (3) an upper silty red shale containing local sandstone beds, the Upper Ordovician (Richmondian) Juniata Formation and its equivalent Queenston Shale.

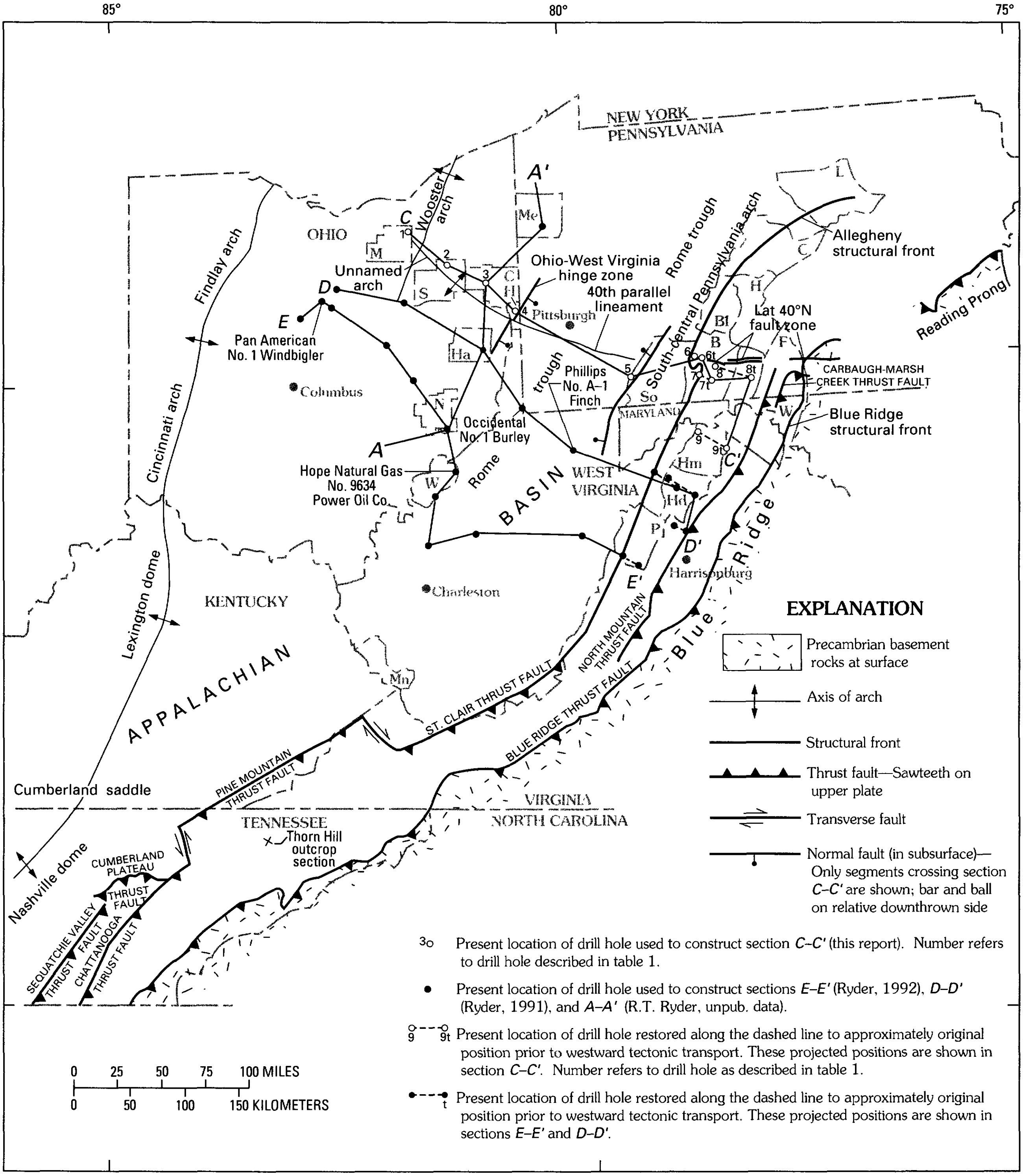
INTRODUCTION

Oil and gas exploration in the Ohio, Pennsylvania, and West Virginia parts of the Appalachian basin, from the late 1950's to the middle 1980's, resulted in the drilling of a modest number of holes into Cambrian strata and (or) Precambrian basement rocks (Calvert, 1963; Wagner, 1966, 1976; Oil and Gas Journal, 1973; Weaver and others, 1974; Cardwell, 1977; Maslowski, 1986). On the basis of geophysical and lithologic logs from these drill holes and paleontologic data from one of these holes, we have drawn a 275-mi-long restored stratigraphic cross section through the Cambrian and Ordovician sequence from Medina County, Ohio, through southwestern and south-central Pennsylvania to Hampshire County, W. Va. (section *C–C′*, fig. 1). The stratigraphic framework of the Cambrian and Ordovician sequence along this cross section and, to a lesser extent, the structure of the underlying block-faulted basement rocks are the main topics of this paper.

Cross section *C–C′* is the third in a series of restored stratigraphic cross sections drawn by the senior author to show the stratigraphic framework of Cambrian and Ordovician rocks across the Appalachian basin from Pennsylvania to Tennessee. Previously completed section *E–E′* (Ryder, 1992) and section *D–D′* (Ryder, 1991) are identified in figure 1. The stratigraphic framework of the Cambrian and Ordovician sequence presented in sections *C–C′*, *D–D′*, and *E–E′* is probably the most comprehensive to date, in terms of both its detail and its regional perspective. Much of what can be considered "new" information in section *C–C′* centers around (1) the lithology of little-studied Cambrian, Lower Ordovician, and lower Middle Ordovician strata in the deep subsurface of the Rome trough and adjoining thrust-faulted terrane east of the Allegheny structural front and (2) their correlation with previously described outcrop or subsurface sequences. Conodont species recovered from a 21,460-ft-deep drill hole in Somerset County, Pa. (No. 5, fig. 1), also constitute new data. They are used to constrain the position of the Lower Ordovician-Middle Ordovician boundary in the Rome trough. Implications of the sedimentary record concerning the early Paleozoic evolution of the Appalachian basin and the eastern continental margin of North America are not discussed here.

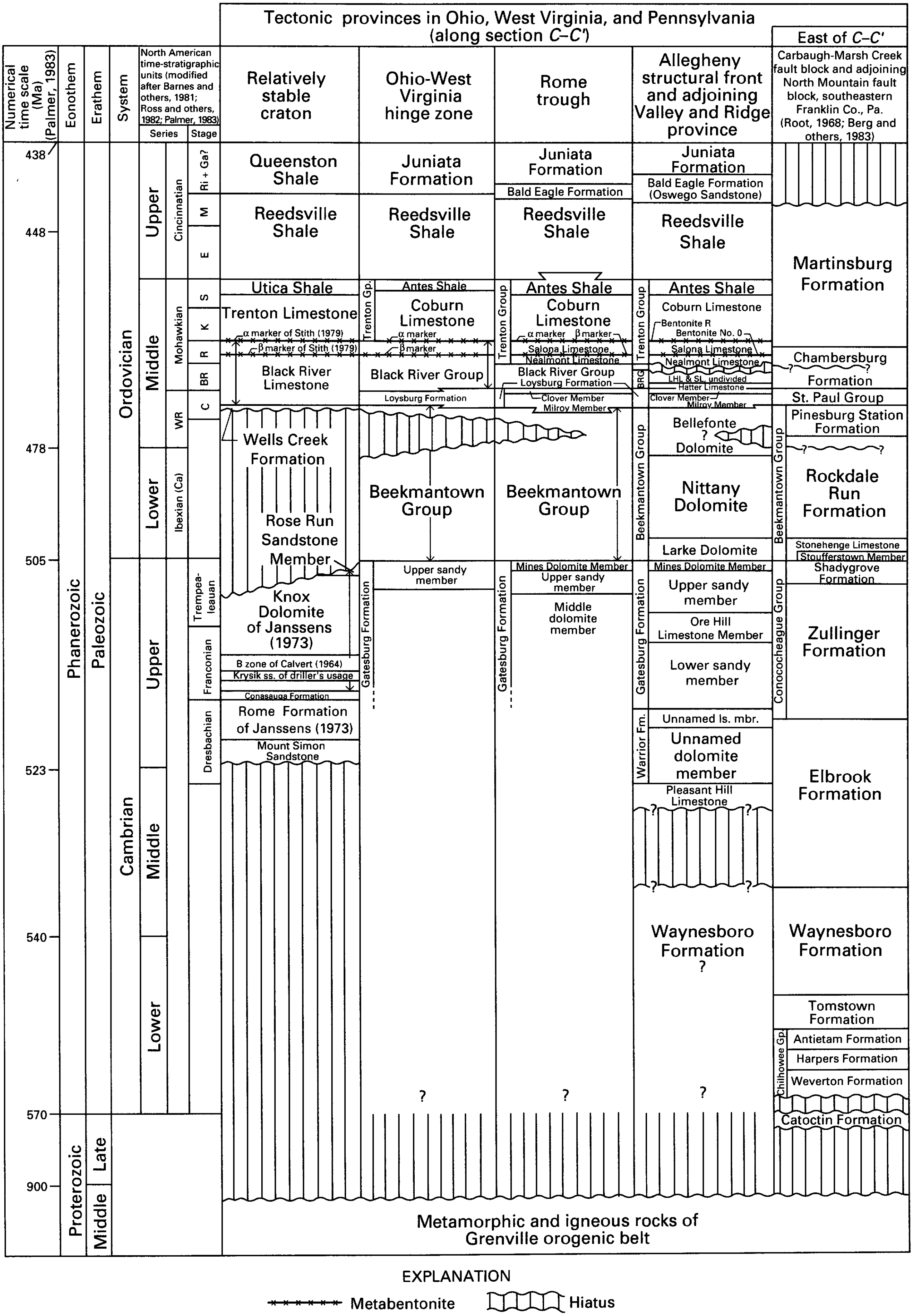
The stratigraphic nomenclature used in section *C–C′* follows existing nomenclature wherever possible, but, in certain places, modifications and additions are recommended. Stratigraphic investigations of the Cambrian and (or) Ordovician that were particularly applicable to this investigation include (1) Calvert (1963, 1964), Janssens (1973), Stith (1979, 1986), Wickstrom and others (1985), and Wickstrom and Gray (1988) in Ohio, (2) Knowles (1966), Wagner (1966, 1976), and Berg and others (1983) in Pennsylvania, and (3) Wagner (1966, 1976) in West Virginia. Information relating to compressional structures that cross section *C–C′* was provided by Jacobeen and

Figure 1. Tectonics of Ohio, Pennsylvania, West Virginia, and adjoining States showing the Appalachian basin, section *C–C′*, selected drill holes, and selected counties. Lines of sections *E–E′* and *D–D′* (Ryder, 1992, 1991) and *A–A′* (R.T. Ryder, unpub. data) are also identified on the map. Base from Wallace and de Witt (1975). Major tectonic and geologic features are from Cooper (1945), Calver and Hobbs (1963), Swingle and others (1966), Rodgers (1970), Wallace and de Witt (1975), Root and Hoskins (1977), Berg and others (1980), Shumaker and others (1985), and Coogan and Maki (1988a). Recent studies (for example, Wickstrom, 1990) indicate that the structure of the Cincinnati and Findlay arches is more complex than shown in this figure and by Wallace and de Witt (1975). Numbered drill holes in section *C–C′* are identified in table 1. Selected counties are identified as follows: Maryland—W, Washington. Ohio—C, Columbiana; Ha, Harrison; M, Medina; N, Noble; S, Stark. Pennsylvania—B, Bedford; Bl, Blair; C, Centre; F, Franklin; H, Huntingdon; L, Lycoming; Me, Mercer; So, Somerset. West Virginia—H, Hancock; Hd, Hardy; Hm, Hampshire; Mn, Mingo; P, Pendleton; W, Wood. ▶



Kanes (1975), Berg and others (1980), Shumaker and others (1985), and Kulander and Dean (1986).

European chronostratigraphic units (for example, Tremadocian through Ashgillian Series) commonly do not apply to the cratonal and platformal Ordovician rocks of North America (Ross and others, 1984). Therefore, in this paper, we apply North American chronostratigraphic units used by Barnes and others (1981) and Ross and others (1982) rather than the European chronostratigraphic units used by Palmer (1983), Berg and others (1983), and the COSUNA charts (for example, see Patchen and others, 1984). Our correlation chart (fig. 2) subdivides the Ordovician System into the Lower, Middle, and Upper North American Series of Barnes and others (1981) and the


Tectonic provinces in Ohio, West Virginia, and Pennsylvania (along section C–C′)
East of C–C′
Numerical time scale (Ma) (Palmer, 1983)
Eonothem
Erathem
System
North American time-stratigraphic units (modified after Barnes and others, 1981; Ross and others, 1982; Palmer, 1983)
Series
Stage
Relatively stable craton
Ohio-West Virginia hinge zone
Rome trough
Allegheny structural front and adjoining Valley and Ridge province
Carbaugh-Marsh Creek fault block and adjoining North Mountain fault block, southeastern Franklin Co., Pa. (Root, 1968; Berg and others, 1983)
438
448
478
505
523
540
570
900
Phanerozoic
Paleozoic
Proterozoic
Late
Middle
Ordovician
Cambrian
Upper
Middle
Lower
Cincinnatian
Mohawkian
Ibexian (Ca)
Ri + Ga?
M
E
S
K
R
BR
C
WR
Trempea-leauan
Franconian
Dresbachian
Queenston Shale
Juniata Formation
Bald Eagle Formation
Bald Eagle Formation (Oswego Sandstone)
Reedsville Shale
Martinsburg Formation
Utica Shale
Antes Shale
Trenton Limestone
Trenton Gp.
Trenton Group
Coburn Limestone
α marker of Stith (1979)
β marker of Stith (1979)
α marker
β marker
Bentonite R
Bentonite No. 0
Salona Limestone
Nealmont Limestone
Chambersburg Formation
Black River Limestone
Black River Group
Loysburg Formation
BRG
LHL & SL, undivided
Hatter Limestone
Clover Member
Milroy Member
St. Paul Group
Wells Creek Formation
Bellefonte Dolomite
Pinesburg Station Formation
Beekmantown Group
Nittany Dolomite
Rockdale Run Formation
Rose Run Sandstone Member
Larke Dolomite
Stonehenge Limestone
Stoufferstown Member
Mines Dolomite Member
Shadygrove Formation
Upper sandy member
Middle dolomite member
Knox Dolomite of Janssens (1973)
Gatesburg Formation
Ore Hill Limestone Member
Lower sandy member
Zullinger Formation
Conococheague Group
B zone of Calvert (1964)
Krysik ss. of driller's usage
Conasauga Formation
Rome Formation of Janssens (1973)
Mount Simon Sandstone
Unnamed ls. mbr.
Unnamed dolomite member
Warrior Fm.
Pleasant Hill Limestone
Elbrook Formation
Waynesboro Formation
Tomstown Formation
Antietam Formation
Harpers Formation
Weverton Formation
Chilhowee Gp.
Catoctin Formation
Metamorphic and igneous rocks of Grenville orogenic belt
EXPLANATION
Metabentonite
Hiatus

respective Ibexian, Whiterockian and Mohawkian combined, and Cincinnatian Series of Ross and others (1982). In addition, the Canadian Series of Barnes and others (1981)—because of its well-established usage in North America—is shown in our correlation chart as being equivalent to the Ibexian Series of Ross and others (1982). By equating the Ibexian (Canadian) Series with the Lower Ordovician Series, the Whiterockian and Mohawkian Series combined with the Middle Ordovician Series, and the Cincinnatian Series with the Upper Ordovician Series, we are in agreement with many Ordovician specialists in North America such as Miller (1984), Repetski (1985), Sweet and Bergström (1986), and Shaw and others (1990).

The Blackriveran through Gamachian Stages of the Ordovician listed in our correlation chart (fig. 2) follow those defined by Barnes and others (1981) and Ross and others (1982). The Chazyan as used by Barnes and others (1981) is retained in this paper as a formal stage because of its long-time usage in North America. In contrast, Ross and others (1982) recognized the Chazyan as a chronostratigraphic unit of historical interest rather than as a formal stage of the Ordovician System.

DRILL-HOLE CONTROL FOR SECTION

Section *C–C′*, the subject of this paper, is shown on plate 1. Nine drill holes ranging from 11 to 76 mi apart and from 6,676 to 21,460 ft in total depth constitute the control for the section (table 1). In the Ohio part of section *C–C′*, one drill hole and probably a second penetrated the entire sedimentary cover and bottomed in crystalline basement rocks of Proterozoic age. However, no drill holes reached basement rocks in the Pennsylvania and West Virginia parts of the section.

Stratigraphic correlations between drill holes are based primarily on geophysical logs, whereas lithofacies patterns between drill holes are based on lithologic logs described by the Geological Sample Log Company (Pittsburgh, Pa.) (table 1). Section *C–C′* has been restored to a horizontal datum located at the base of a widespread, 60- to 90-ft-thick, micritic limestone in the middle of the Loysburg Formation in Pennsylvania and adjoining northernmost West Virginia (pl. 1). In the Ohio part of the section, the micritic limestone datum is located at the base of the Black River Limestone or, in local oil industry terminology, the base of the Gull River Formation. At the eastern end of section *C–C′*, in Hampshire County, W. Va., the datum horizon has been removed by pre-Black River Group erosion. This micritic limestone was chosen as the datum horizon for section *C–C′* because it appears to be the most widespread and easily recognizable subsurface marker unit in the Cambrian-Ordovician sequence of the central Appalachian basin. Metabentonite beds in the Black River Limestone (Group) and Trenton Group are good marker units, but they cannot be traced with as much confidence as the micritic limestone unit. In addition, the shallow marine origin of the micritic limestone datum (Ryder, in press) and its proximity to the widespread Knox unconformity (pl. 1) permit the restoration of the pre-unconformity structural configuration of the Rome trough and adjoining structural elements. The Kerr-McGee No. 1 Schellsburg (KMS), Kerr-McGee No. 1 Martin (KMM), Arco No. 1 Steele (ARS), and Shell Oil No. 1 Duckworth (SD) drill holes (Nos. 6, 7, 8, and 9, fig. 1, pl. 1, table 1), located at or east of the Allegheny structural front, have been moved in this study southeastward of their present-day locations to account for westward tectonic transport along frontal imbricate thrust faults (Knowles, 1966; Wagner, 1966; Jacobeen and Kanes, 1975; Berg and others, 1983; Shumaker and others, 1985; Kulander and Dean, 1986). Southeastward palinspastic restoration of allochthonous strata in the KMS, KMM, ARS, and SD drill holes amounted to about 4, 10, 22, and 20 mi, respectively (pl. 1, fig. 1).

Of the nine drill holes used in section *C–C′*, drilled thicknesses of stratigraphic units were corrected for dip only in the ARS drill hole. In this drill hole, the drilled thicknesses of units were corrected for a 30° dip that approximates nearby surface dips recorded by Knowles (1966). In addition to the 30° dip correction, about 450 ft of duplication by a thrust fault was required to reconcile the drilled thickness of the upper sandy member of the Gatesburg Formation in the ARS drill hole with the nearby surface section measured by Knowles (1966). About 700 ft of thrust-fault duplication was removed from the Reedsville Shale in the SD drill hole. Thicknesses of Upper Ordovician and Lower Silurian strata that crop out near the KMM drill hole were taken from an unpublished section measured by Wallace de Witt, Jr. (unpub. data, 1969) (pl. 1). Lithology and thicknesses of Ordovician and Lower Silurian strata in the vicinity of the ARS drill hole were obtained from measured outcrop sections by Thompson (1963) and Knowles (1966) and from the geologic map by Knowles (1966).

Scattered macrofossils collected from outcrops near the KMM and ARS drill holes in Bedford County, Pa. (Thompson, 1963; Knowles, 1966; Spelman, 1966; Wal-

◄ **Figure 2.** Correlation of Middle Proterozoic, Cambrian, and Ordovician rocks along section *C-C′* and in adjoining Franklin County, Pa. Absolute age (in Ma) is taken from the geologic time scale compiled by Palmer (1983). The time scale is nonlinear. North American chronostratigraphic units are modified after Barnes and others (1981), Ross and others (1982), and Palmer (1983). Series and Stage names: BR, Blackriveran; Ca, Canadian; C, Chazyan; E, Edenian; Ga, Gamachian; K, Kirkfieldian; M, Maysvillian; R, Rocklandian; Ri, Richmondian; S, Shermanian; WR, Whiterockian. Group name: BRG, Black River Group. Formation names: LF, Loysburg Formation; LHL, Linden Hall Limestone; SL, Snyder Limestone.

Table 1. Drill holes used in section *C–C′*
[Locations shown on figure 1]

Identification no.	Name used in text (abbreviation)	Location	Permit no.	Lithologic log[1]	Cored intervals (ft) and formation	Total depth (ft)	Age of oldest rocks penetrated (formation)
1	Wiser Oil No. 1–A Smith (WS).	Hinckley Township, Medina County, Ohio.	1143	GSLC, J	5,700–5,714; Black River Limestone. 5,742–5,746; Wells Creek Formation. 5,759–5,890; Wells Creek Formation, Knox Dolomite of Janssens (1973). 7,028–7,040; basement rocks of Middle Proterozoic age.	7,040	Middle Proterozoic.
2	Belden and Blake and Company No. 9 Limited Partnership No. 1–381 Westfall (BBW).	Marlboro Township, Stark County, Ohio.	1080	GSLC, J		7,961	Late Cambrian (Rome Formation of Janssens, 1973).
3	Management Control No. 3 Murray (MM).	Hanover Township, Columbiana County, Ohio.	648	GSLC, J		10,242	Middle Proterozoic(?).
4	Humble No. 1 Minesinger (HM).	Clay District, Hancock County, W. Va.	80	GSLC		10,387	Late Ordovician (part of Beekmantown Group).
5	Amoco No. 1 Svetz (AS)	Middle Creek Township, Somerset County, Pa.	45	GSLC		21,460	Late Cambrian (Gatesburg Formation).
6	Kerr-McGee No. 1 Schellsburg (KMS).	Napier Township, Bedford County, Pa.	34	GSLC		11,850	Late Cambrian (Gatesburg Formation).
7	Kerr-McGee No. 1 Martin (KMM).	Harrison Township, Bedford County, Pa.	13	GSLC, W	3,000–3,027; Beekmantown Group. 5,002–5,025; Beekmantown Group. 6,671–6,676; Juniata Formation.	6,676	Early and Middle Ordovician (Beekmantown Group) thrust over Early Middle and Late Ordovician (Beekmantown Group, Reedsville Shale, Bald Eagle Formation, and Juniata Formation).
8	Arco No. 1 Steele (ARS)	Snake Spring Township, Bedford County, Pa.	009–20060	GSLC		15,500	Early(?) and Middle Cambrian (Waynesboro Formation) thrust over Middle and Late Cambrian and Early and Early Middle Ordovician (Warrior Formation, Gatesburg Formation, and Beekmantown Group).
9	Shell Oil No. 1 Duckworth (SD).	Springfield District, Hampshire County, W. Va.	12	GSLC, W	10,522–10,528; Beekmantown Group. 13,958–13,999; Elbrook Formation	13,999	Middle and Late Cambrian (Elbrook Formation).

[1] Lithologic logs from Geological Sample Log Company (GSLC) Pittsburgh, Pa., Janssens (1973) (J), and Wagner (1966) (W).

Table 2. Conodonts from the Amoco No. 1 Svetz drill hole, Somerset County, Pa.

[100- to 200-g cuttings taken at 100-ft intervals between 15,000 and 21,000 ft were processed for conodonts; only the productive samples are listed. Well collar at 2,480-ft elevation; total depth 21,460 ft. Conodont color alteration index (CAI) is a measure of organic maturation (Epstein and others, 1977)]

Sample interval (ft)	USGS collection no.	Conodonts	Age	CAI
		Coburn Limestone		
15,400–15,500.....	10750–CO	1 P (dichognathiform) element of *Phragmodus* sp. indet. or *Plectodina* sp. indet.	Middle Ordovician, no older than early Chazyan [no older than the *Phragmodus tangshanensis* Zone (=*P. preflexuosus* Zone of Sweet and Bergström (1986)]	5
		Trenton Group		
15,700–15,800.....	10751–CO	1 P (dichognathiform) element of *Phragmodus* sp. indet. or *Plectodina* sp. indet. 1 M element, unassigned.	do.	5
		Trenton and Black River Groups		
15,800–15,900.....	10752–CO	1 P (dichognathiform) element of *Phragmodus* sp. indet. or *Plectodina* sp. indet.	do.	5
		Loysburg Formation		
16,500–16,600.....	10753–CO	1 M element, unassigned. 1 indeterminate fragment.	do.	5
16,600–16,700.....	10754–CO	1 robust hyaline ramiform fragment.	do.	5
16,900–17,000.....	10755–CO	do.	do.	5
		Beekmantown Group		
17,000–17,100.....	10756–CO	1 Pb element of *Curtognathus* sp. indet.	do.	5
17,100–17,200.....	10757–CO	1 Pb element of *Curtognathus* sp. indet. 1 robust hyaline ramiform fragment.	do.	5
17,700–17,800.....	10758–CO	1 indeterminate fragment.	do.	5
17,800–17,900.....	10759–CO	1 M element of *Phragmodus* sp. indet. 1 fragment of *Multioistodus*? sp. 7 indeterminate fragments.	Middle Ordovician, interval of *P. tangshanensis* Zone-*Cahabagnathus friendsvillensis* Zone.	5
18,000–18,100.....	10759–CO	1 indeterminate fragment.	do.	5
18,100–18,200.....	10760–CO	1 P (dichognathiform) element of *Phragmodus* sp. indet.	do.	5
18,200–18,300.....	10760–CO	2 indeterminate fragments.	do.	5
18,400–18,500.....	10760–CO	1 indeterminate hyaline fragment.	do.	5
19,900–20,000.....	10760–CO	1 poorly preserved panderodontacean? element. 1 hyaline coniform fragment.	Middle(?) Ordovician, probably downhole contamination.	5

lace deWitt, Jr., unpub. data, 1969), and conodonts recovered from cuttings from the Amoco No. 1 Svetz (AS) drill hole (No. 5, fig. 1, pl. 1, tables 1, 2) provided specific ages for several stratigraphic units in section *C–C′*. Additional age assignments for units in section *C–C′* were determined by projecting paleontologically dated horizons from (1) adjoining drill holes, (2) thrust-faulted strata that crop out along the eastern margin of the basin, and (3) gently warped strata that crop out along the western margin of the basin.

BASEMENT STRUCTURE

Basement rocks in Pennsylvania and adjoining Ohio and West Virginia consist largely of metamorphic rocks of Grenville age (1.0 Ga; Grenvillian) (Bass, 1959, 1960; Lapham, 1975). We know from several published seismic lines showing basement faults having normal displacement (Beardsley and Cable, 1983; Henderson and Timm, 1985) and from isopach maps showing abrupt thickness changes in drilled Cambrian and Lower Ordovician rocks (Wagner, 1976; Harris, 1978) that the Middle Proterozoic basement rocks of western Pennsylvania have been disrupted by extensional tectonics. However, details of the basement structure here are poorly understood because (1) drill holes have not yet penetrated the sedimentary cover, (2) magnetic and gravity data have not been calibrated to known basement rock types and structures, and (3) very few seismic data have been published. Most interpretations cite the northeast-trending, fault-controlled Rome trough as the dominant tectonic element of western Pennsylvania basement structure (Wagner, 1976; Harris, 1978; Beardsley and Cable, 1983; Harper, 1989). One exception is the interpretation by Shumaker (1986), who suggested that the trend of the Rome trough changes abruptly in southwestern Pennsylvania from northeast to easterly, subparallel to and south of his 40th parallel lineament (fig. 1) and the colinear Lat 40°N fault zone of Root and Hoskins (1977) (fig. 1).

We favor the interpretations of Wagner (1976), Harris (1978), Beardsley and Cable (1983), and Harper (1989) and thus extend the Rome trough northeastward into southwestern Pennsylvania approximately normal to section *C–C′* (fig. 1, pl. 1). Our interpretations of the faults accompanying the Rome trough in the vicinity of section *C–C′* are based on limited data and, for this reason, are shown as 30- to 80-mi-long, incomplete segments on figure 1. Undoubtedly, these structures will be modified as multifold seismic records in the area are published and as holes in and adjacent to the Rome trough are drilled to Middle Proterozoic basement.

The abnormally wide Rome trough in southwestern Pennsylvania (fig. 1) probably resulted from the northeastward merger of the Rome trough in West Virginia with an adjoining unnamed graben between the Central and Eastern West Virginia arches (horst blocks) of Kulander and Dean (1976, 1986) (Ryder, 1992). The northwestern side of the Rome trough, where it intersects section *C–C′* (fig. 1), is bounded by a down-to-the-southeast normal fault (Harper, 1989). Harper (1989) suggested that this border fault is offset in a right-lateral sense by the northwest-trending Pittsburgh-Washington lineament (40th parallel lineament of Shumaker (1986)) (fig. 1). The border fault, described here, coincides with the Ohio-West Virginia hinge zone of Ryder (1992) and the Middle Cambrian hinge of Read (1989). Before the deposition of the datum horizon in Middle Ordovician time, the structural relief on Proterozoic basement rocks across this hinge zone is estimated to have been on the order of 2,000 ft (pl. 1).

The down-to-the-northwest normal fault that bounds the eastern side of the Rome trough, where it intersects section *C–C′* (fig. 1), is interpreted here to be the northward continuation of the western border fault of the Eastern West Virginia arch (horst) of Kulander and Dean (1976, 1986) (Ryder, 1992). Also, this down-to-the-northwest normal fault is closely aligned with the New York-Alabama lineament of King and Zietz (1978) that defines the down-to-the-southeast fault proposed by Ryder (1992) on the eastern side of the Central West Virginia arch (horst) of Kulander and Dean (1976, 1986). The AS drill hole (fig. 1, pl. 1), located on the downthrown northwestern side of the fault, drilled about 650 ft into Upper Cambrian rocks before reaching a total depth of 21,460 ft. Judging from the abnormally thick Ordovician sequence in the AS drill hole and from nearby proprietary seismic data, we estimate that an additional 8,000 to 10,000 ft of undrilled Cambrian strata underlie the AS drill hole (pl. 1). The drilling depth to Middle Proterozoic basement rocks may be greater here than anywhere else in the Rome trough. Before the deposition of the datum horizon in Middle Ordovician time, the structural relief on Proterozoic basement rocks between the eastern edge of the Rome trough and the adjoining positive fault block is estimated to have been 6,000 to 7,000 ft (pl. 1). At the same time, structural relief of 12,000 to 14,000 ft may have existed between the eastern edge of the Rome trough and the positive basement block west of the Ohio-West Virginia hinge zone (pl. 1).

Relatively thin Middle and Upper Cambrian strata encountered in the ARS and SD drill holes, in comparison with the estimated thickness of these strata in the Rome trough, suggest that the positive fault block adjoining the eastern edge of the Rome trough along section *C–C′* has not been broken by major basement-involved normal faults (pl. 1). This positive fault block, here named the South-central Pennsylvania arch (fig. 1, pl. 1), is contiguous with the Eastern West Virginia arch (horst) defined by Kulander and Dean (1976, 1986) (Ryder, 1992).

Neither the Rome trough nor the adjoining horst blocks along section *C–C′* stand out on the aeromagnetic maps of King and Zietz (1978) and Zietz and others (1980), as they seem to do along section *E–E′* (fig. 1), where positive and negative magnetic anomalies coincide with major positive and negative basement-involved fault blocks, respectively (Ryder, 1992). In contrast, the magnetic anomalies near section *C–C′* and near section *D–D′* about 50 mi to the south (fig. 1) seem to require structural interpretations that are opposite to those in section *E–E′*. That is, positive magnetic anomalies near sections *C–C′* and *D–D′* coincide with negative fault blocks, whereas negative anomalies coincide with positive fault blocks.

For example, the Rome trough in southwestern Pennsylvania and adjoining West Virginia—where the AS, Occidental No. 1 Burley, and Phillips No. A–1 Finch drill holes (fig. 1) suggest a minimum drilling depth of 20,000 ft to Proterozoic basement rocks—is characterized by moderate to high magnetic intensities (King and Zietz, 1978; Zietz and others, 1980). However, structurally higher blocks that adjoin the Rome trough, where the Humble No. 1 Minesinger (HM) (No. 4, fig. 1, pl. 1, table 1), KMS, KMM, and ARS holes have been drilled, are characterized by lower magnetic intensities. These interpretations suggest that major lithologic and (or) structural differences exist between the Middle Proterozoic basement rocks of central West Virginia and southwestern Pennsylvania. Mafic rocks that formed before or during the initial phases of Rome trough rifting may be one reason why higher magnetic intensities accompany the tectonically negative areas of southwestern Pennsylvania and adjoining West Virginia.

Near Pittsburgh, Pa. (fig. 1), the aeromagnetic maps of Popenoe and others (1964), King and Zietz (1978), and Zietz and others (1980) show a conspicuous narrowing of northwest-trending contours. The magnetic gradient normal to this magnetic trend slopes steeply to the northeast. This magnetic trend, first described by Beck and Mattick (1964), is nearly coincident with a line that marks the terminations of northeast-trending fold axes (Wagner and Lytle, 1976) and is aligned with the Lat 40°N fault zone of Root and Hoskins (1977) (fig. 1). Shumaker (1986) identified the magnetic trend as the 40th parallel lineament (fig. 1), which marks the southern end of a well-defined, northeast-trending, low-intensity magnetic anomaly that Culotta and others (1990) have defined as the Amish anomaly. They interpreted this low-intensity magnetic anomaly to be the result of Grenvillian compressional tectonics.

Rifting that created the Rome trough and associated basement-involved structures occurred largely in the Middle Cambrian (Read, 1989). Later tectonic events may have reactivated these Middle Cambrian structures, as Harper (1989) has proposed in western Pennsylvania, but the restoration of section *C–C′* to a horizontal datum in the lower part of the Middle Ordovician sequence has removed the later offsets. According to Beardsley and Cable (1983), block faulting of the basement beneath part of West Virginia may have been controlled by normal dip-slip motion along preexisting thrust faults of Middle Proterozoic (Grenvillian) age.

West of the Ohio-West Virginia hinge zone in eastern Ohio, the Middle Proterozoic basement rocks are undoubtedly broken by numerous normal faults (Sanford and others, 1985; Ahmad and Smith, 1988), but, in general, they have offset basement rocks far less than those faults east of the hinge zone. A northwest-trending basement arch called the Wooster arch by Coogan and Maki (1988a, b) crosses the western end of section *C–C′* (fig. 1). Moreover, Shumaker (1986) suggested that an unnamed, low-relief arch (monoclinal flexure), located several miles southwest of and subparallel to section *C–C′*, is underlain by a basement-involved normal fault (fig. 1).

THICKNESS CHANGES IN THE CAMBRIAN AND ORDOVICIAN SEQUENCE

Section *C–C′* shows a sixfold to sevenfold increase in thickness of the Cambrian and Ordovician sequence between the relatively stable craton of Ohio and the eastern side of the Rome trough in southwestern Pennsylvania (pl. 1). East of the Rome trough, on the adjoining South-central Pennsylvania arch, the Cambrian and Ordovician sequence along section *C–C′* decreases in thickness from about one-half to two-thirds of the thickness in the Rome trough (pl. 1). This magnitude of thickening and thinning is based on (1) the 3,000-ft-thick Cambrian and Ordovician sequence that was penetrated in the Wiser Oil No. A–1 Smith (WS) drill hole (No. 1, fig. 1, pl. 1, table 1) at the western end of the section, (2) the 9,500-ft-thick uppermost Cambrian and Ordovician sequence penetrated in the AS drill hole and the estimated 10,300 ft of undrilled Cambrian strata beneath it, (3) the 8,200-ft-thick uppermost Cambrian and Ordovician sequence penetrated in the KMS drill hole near the Allegheny structural front and the estimated 4,500 ft of undrilled Cambrian strata beneath it, and (4) the 10,500-ft-thick Cambrian and Ordovician sequence east of the Allegheny structural front that consists of 4,500 ft of dip- and fault-corrected drilled strata in the ARS drill hole, 5,100 ft of outcrop section stratigraphically above the ARS drill hole, and an estimated 900 ft of undrilled Lower and Middle Cambrian strata beneath the ARS drill hole (pl. 1).

In the Rome trough segment of section *C–C′*, the thickness of the Cambrian strata is estimated to represent about 55 percent of the total Cambrian and Ordovician sequence, whereas, on the positive fault blocks adjoining the Rome trough, the thickness of the Cambrian strata is estimated to represent 25 and 40 percent of the sequence (pl. 1). Although we have no corroborating drill-hole data, we speculate that most of the thickening of the Cambrian strata in the Rome trough segment of section *C–C′* occurred in the Middle Cambrian (pl. 1). The proposed down-to-the-east normal fault that marks the Ohio-West Virginia hinge zone is the approximate western limit of Lower and Middle Cambrian strata along section *C–C′*. In contrast, Lower and Middle Cambrian strata extend eastward beyond the eastern margin of the Rome trough to the eastern end of section *C–C′* (pl. 1). Documentation for the assigned ages in this section is presented in the following discussion of the stratigraphic framework.

Lower and Middle Ordovician strata also markedly increase in thickness in the Rome trough segment of section *C–C′*. However, this thickening is much better documented than the thickening of the Cambrian strata. Combined Lower and Middle Ordovician strata shown on section *C–C′* expand eastward from about 1,050 ft in the WS drill hole to about 5,800 ft in the AS drill hole and then thin to about 3,300 ft in the ARS drill hole (pl. 1).

Upper Ordovician strata in section *C–C′* show the same differential thickening as underlying strata, but the depocenter has shifted from the Rome trough to the Allegheny structural front (pl. 1). Drilled thicknesses of these strata increase from about 1,150 ft in the WS drill hole to a maximum of about 3,625 ft in the KMS drill hole (pl. 1). East and south of the KMS drill hole, the Upper Ordovician strata in section *C–C′* thin to between 2,500 and 3,000 ft in the KMM, ARS, and SD drill holes and contiguous outcrop sections.

Most of the observed thickness patterns in section *C–C′* are depositional, but they also have been influenced by several unconformities that truncate strata overlying the positive fault blocks adjoining the Rome trough. The most significant of these unconformities is the Knox unconformity (Beardsley and Cable, 1983; Coogan and Maki, 1988a; Mussman and others, 1988), which truncates progressively older lower Middle Ordovician, Lower Ordovician, and Upper Cambrian strata from about 40 mi east of the Ohio-West Virginia hinge zone to the western end of section *C–C′* (pl. 1). In Medina County, Ohio, at the western end of section *C–C′*, Lower Ordovician rocks have been completely truncated by the Knox unconformity, so that Middle Ordovician rocks rest directly on Upper Cambrian rocks (Calvert, 1963; Coogan and Maki, 1988a). The Knox unconformity is probably absent in the eastern part of the Rome trough in section *C–C′* but probably reappears east of the Rome trough, above the South-central Pennsylvania arch, where it is marked by the minor truncation of uppermost Lower Ordovician and lowermost Middle Ordovician strata (pl. 1). Additional unconformities that may have caused a thinning of the sequence on the South-central Pennsylvania arch are an unnamed Middle Cambrian unconformity and two unnamed Middle Ordovician unconformities (pl. 1).

STRATIGRAPHIC FRAMEWORK

Basal Sandstone Unit and Tomstown Dolomite (Lower Cambrian)

Although not penetrated by drill holes, strata equivalent to the basal sandstone unit and the Shady Dolomite, as recognized by Ryder (1992) in section *E–E′* (fig. 1), probably are present in section *C–C′* (pl. 1). We speculate that these strata are present in the Rome trough and the adjoining South-central Pennsylvania arch and attain a thickness of 500 to 600 ft. The proposed sequence rests unconformably on Middle Proterozoic basement rocks of Grenvillian age and probably consists of two parts: (1) a thin, basal, sandstone-dominated unit and (2) an overlying carbonate-dominated unit. The top of the carbonate unit is possibly an unconformity.

Following Ryder (1992), the name basal sandstone unit is applied to the postulated thin sandstone unit beneath the ARS and SD drill holes (pl. 1). This unit is correlated here with the uppermost part of the Lower Cambrian Chilhowee Group that crops out in (1) the North Mountain fault block of northern Virginia and the adjoining West Virginia panhandle (fig. 1) (Edmundson and Nunan, 1973; Gathright and Nystrom, 1974; Rader and Biggs, 1975; Dean and others, 1989, 1991) and (2) the Carbaugh-Marsh Creek fault block of south-central Pennsylvania and adjoining Maryland (fig. 1) (Cloos, 1951; Root, 1968; Fauth, 1978). The Early Cambrian age assigned to the undrilled basal sandstone unit (pl. 1) is based on trilobites collected from the upper part of the Chilhowee Group in Washington County, Md. (fig. 1) (Bassler, 1919).

The undrilled carbonate unit that probably overlies the basal sandstone unit beneath the ARS and SD drill holes correlates with (1) the Tomstown Formation (Limestone) in Franklin County, Pa. (Stose, 1906; Root, 1968; Fauth, 1978), (2) the Tomstown Formation (Dolomite) in Washington County, Md. (Cloos, 1951; Reinhardt and Wall, 1975; Edwards, 1978; Fauth, 1981), and (3) the Tomstown Dolomite in the easternmost part of the panhandle of West Virginia (Patchen and others, 1984; Dean and others, 1989, 1991) and in the subsurface of Hardy County, W. Va. (Ryder, 1991). The name Tomstown Dolomite is applied here to the carbonate unit to be consistent with nomenclature used by Ryder (1991). The Early Cambrian age assigned to the undrilled Tomstown Dolomite is based on the occurrence of *Salterella conulata* in Washington County, Md. (Reinhardt and Wall, 1975), and of *Salterella* sp. and trilobite fragments in Franklin County, Pa. (Stose, 1909).

The undrilled basal sandstone-Tomstown Dolomite interval was probably deposited as a transgressive unit before the rifting event that formed the Rome trough. Normal faults that bound the Rome trough and involve the postulated basal sandstone-Tomstown Dolomite interval are considered here to be latest Early Cambrian to early Middle Cambrian in age. Because of their probable transgressive nature, the proposed basal sandstone unit and Tomstown Dolomite may be as young as early Middle Cambrian in the Rome trough, but a late Early Cambrian age is more probable.

Waynesboro Formation (Lower and Middle Cambrian)

A 230-ft-thick, incomplete sequence of sandy dolomite and anhydritic red shale, penetrated at the base of the allochthonous Broadtop block (Shumaker and others, 1985) in the ARS drill hole, constitutes the oldest drilled sedimentary rocks shown in section *C–C′* (pl. 1). The top of the sandy dolomite and red shale sequence possibly is an unconformity. This sequence correlates with a lithologically similar unit that has been identified as the Waynesboro Formation in the thrust belt of south-central Pennsylvania and eastern West Virginia between the Allegheny structural front and the North Mountain thrust fault (fig. 1). Specific localities of the Waynesboro Formation that are relevant to this study are (1) local outcrops in Blair County, Pa., identified by Butts (1945), (2) drilled strata in the deep subsurface of Hardy County, W. Va., identified by Ryder (1991), and (3) undrilled strata along which major structural detachment has probably occurred in the subsurface of Hampshire County, W. Va. (Dean and others, 1985). On the basis of these correlations, the name Waynesboro Formation is assigned here to the sandy dolomite and red shale sequence in section *C–C′* (pl. 1). Following the drilled thickness of the Waynesboro Formation reported in Hardy County, W. Va., by Ryder (1991), the thickness of the Waynesboro Formation in section *C–C′*, east of the Allegheny structural front, is estimated to be about 500 ft.

The Waynesboro Formation crops out east of section *C–C′* in (1) the Carbaugh-Marsh Creek fault block of Franklin County, Pa. (Stose, 1906; Root, 1968; Fauth, 1978; Berg and others, 1980), and adjoining Washington County, Md. (Cloos, 1951; Edwards, 1978; Fauth, 1981), and (2) the North Mountain fault block of the panhandle of West Virginia (Patchen and others, 1984; Dean and others, 1989, 1991) and adjoining northern Virginia (Rader and Biggs, 1975, 1976; Rader, 1982) (figs. 1, 2).

The Waynesboro Formation in Blair County, Pa., was assigned an Early Cambrian age by Butts (1945) on the basis of a small collection of fossils that included the trilobite *Olenellus* sp. and the possible mollusk *Hyolithes* sp. Stose (1909) assigned a Middle Cambrian age to the Waynesboro Formation in Franklin County, Pa., on the basis of the presence of phosphatic brachiopods but admitted that these fossils do not permit a conclusive age designation. More recently, in Franklin County, Pa., Root (1968) assigned the Waynesboro Formation to the Lower Cambrian. Following Stose (1909), Bassler (1919) assigned a Middle Cambrian age to the Waynesboro Formation in Washington County, Md. We believe that the Early and Middle Cambrian age assigned to the Waynesboro Formation by Berg and others (1983) is reasonable in view of the scant fossil data and thus suggest that this age be adopted for the Waynesboro Formation east of the Allegheny front in section *C–C′* (fig. 2, pl. 1).

Although the Waynesboro Formation is most likely present in the Rome trough segment of section *C–C′*, it is not shown on plate 1 because its thickness, lithology, and lateral extent are unknown. The Ohio-West Virginia hinge zone is probably the western limit of the Waynesboro Formation in section *C–C′*. The Waynesboro Formation in the Rome trough segment of section *C–C′* correlates, at least in part, with the 1,000-ft-thick unnamed sandstone and shale member of the Rome Formation in the Rome trough segment of section *E–E′* (fig. 1). Ryder (1992) assigned a Middle Cambrian age to the unnamed sandstone and shale member of the Rome Formation on the basis of its probable correlation with trilobite-bearing drilled strata of Middle Cambrian age near the bottom of the middle one-third of the Rome Formation in Mingo County, W. Va. (Donaldson and others, 1975, 1988). However, the possibility remains that the lower one-third of the Rome Formation here, beneath the fossiliferous strata, is Early Cambrian in age (Patchen and others, 1984). We consider the Waynesboro Formation in the Rome trough segment of section *C–C′* to be Early and Middle Cambrian in age.

The sandstone unit that rests on Middle Proterozoic basement rocks west of the Ohio-West Virginia hinge zone is the Mount Simon Sandstone (Cohee, 1948). The Mount Simon Sandstone is a transgressive, basal sandstone that probably ranges in age from the latest Middle Cambrian near the Ohio-West Virginia hinge zone to early Late Cambrian at the western end of section *C–C′* (fig. 2, pl. 1). East of the Ohio-West Virginia hinge zone, the Mount Simon Sandstone may merge with the uppermost part of the Waynesboro Formation.

Pleasant Hill Limestone, Warrior Formation, and Elbrook Formation (Middle and Upper Cambrian)

A 1,680-ft-thick limestone and dolomite sequence overlies the Waynesboro Formation in the ARS drill hole (pl. 1). In ascending order, the sequence consists of (1) a 480-ft-thick limestone unit, (2) an 850-ft-thick oolitic, sandy dolomite unit, and (3) a 350-ft-thick sandy dolomitic limestone containing local chert and oolite beds. A partial section of the limestone and dolomite sequence, consisting of the upper 210 ft of the middle dolomite unit and an overlying 220-ft-thick upper dolomitic limestone unit, was penetrated at the bottom of the SD drill hole (pl. 1).

The lower limestone unit in the ARS drill hole correlates with (1) the Pleasant Hill Limestone as defined by Butts (1945) in outcrop in Blair County, Pa., (2) the Pleasant Hill Formation as defined by Wilson (1952) and Wagner (1966) in outcrop in Blair County, Pa., and by Wagner (1966) in the subsurface of Lycoming County, Pa., and (3) the lower part of the Elbrook Formation as defined by Ryder (1991) in the subsurface of Hardy County, W. Va. We assign the name Pleasant Hill Limestone to the lower limestone unit in the ARS drill hole (pl. 1) because the unit is near the type locality of the Pleasant Hill Limestone in Blair County, Pa., and consists predominantly of limestone.

The combined middle dolomite and upper dolomitic limestone units in the ARS and SD drill holes correlate with (1) the Warrior Limestone as defined by Butts (1918, 1945) in outcrop in Bedford, Blair, and Huntington Counties, Pa., (2) the Warrior Formation as defined by Wilson (1952), Wagner (1966), and Knowles (1966) in outcrop in Bedford, Blair, and Huntington Counties, Pa., and by Wagner (1966) in the subsurface of Lycoming County, Pa., and (3) the upper three-fourths of the Elbrook Formation as defined by Ryder (1991) in the subsurface of Hardy County, W. Va. We assign the name Warrior Formation to the combined middle dolomite and upper dolomitic limestone units in the ARS drill hole because of their proximity to the type locality of the Warrior Limestone in Huntington County. The name Warrior Formation as used by Wilson (1952), Wagner (1966), Knowles (1966), and Berg and others (1983) is favored over the name Warrior Limestone as used by Butts (1918, 1945) because it better represents the dolomite and limestone lithology of the unit. The dolomite and limestone parts of the Warrior Formation in the ARS drill hole are assigned here to the unnamed dolomite and unnamed limestone members, respectively, of the Warrior Formation (pl. 1). In the SD drill hole, the combined undrilled equivalent of the Pleasant Hill Limestone, the partly drilled middle dolomite unit, and the upper limestone unit are assigned here to the Elbrook Formation (pl. 1). We favor the name Elbrook Formation in the SD drill hole, rather than the name Warrior Formation used by Wagner (1966), because of the proximity of the drill hole to Hardy County, W. Va., where correlative strata are assigned by Ryder (1991) to the Elbrook Formation.

The combined Pleasant Hill Limestone and overlying Warrior Formation in Pennsylvania correlate with the Elbrook Formation (Limestone) in the Carbaugh-Marsh Creek fault block in Franklin County, Pa. (Stose, 1909; Root, 1968; Berg and others, 1983), and in adjoining Washington County, Md. (Bassler, 1919; Cloos, 1951; Fauth, 1981) (fig. 2). They also correlate with the Elbrook Formation in the North Mountain fault block of the West Virginia panhandle (Donaldson and Page, 1963; Dean and others, 1989, 1991; Patchen and others, 1984) and in adjoining northern Virginia (Rader and Biggs, 1975, 1976; Rader, 1982).

The 1,700-ft drilled thickness of the Pleasant Hill Limestone plus the Warrior Formation in section *C–C′*, the 1,500-ft estimated thickness of the Elbrook Formation in section *C–C′*, and the 1,600-ft drilled thickness of the Elbrook Formation in Hardy County, W. Va., along section *D–D′* are each about one-half the thickness of the Elbrook Dolomite as defined by Perry (1964) and Ryder (1992) in the subsurface of Pendleton County, W. Va. These three sequences are probably equivalent to the upper one-half of the Elbrook Dolomite in Pendleton County, W. Va. (section *E–E′* of Ryder, 1992). Apparently, strata equivalent to the lower one-half of the Elbrook Dolomite in the subsurface of Pendleton County, W. Va., are missing in sections *C–C′* and *D–D′* as a result of erosion and (or) nondeposition. This suggested hiatus is shown on section *C–C′* as an unconformity between the Waynesboro Formation and the overlying Pleasant Hill Limestone or Elbrook Formation (pl. 1, fig. 2). The unconformity may be absent in Franklin County, Pa., where Stose (1909) and Root (1968) estimated that the Elbrook Formation is about 3,000 ft thick (fig. 2).

The Pleasant Hill Limestone is assigned a Middle Cambrian age by Butts (1945) and Wilson (1952) on the basis of a collection of trilobites, hyolithids, and brachiopods from Blair County, Pa. East of the North Mountain fault in northernmost Virginia, Butts (1940) assigned a Middle Cambrian age to the lowermost part of the Elbrook Formation on the basis of the trilobite *Glossopleura* sp. This lower(?) Middle Cambrian part of the Elbrook Formation in the North Mountain fault block is probably older than the Pleasant Hill Limestone rather than equivalent to the Pleasant Hill Limestone, as Wilson (1952) and Berg and others (1983) suggested. In this study, the Pleasant Hill Limestone is assigned to the middle and upper parts of the Middle Cambrian (pl. 1, fig. 2).

Trilobites have been collected from approximately the upper two-thirds of the Warrior Formation in Bedford, Blair, Centre, and Huntington Counties, Pa. (Butts, 1945; Tasch, 1951; Wilson, 1952). All these trilobites are indicative of an early Late Cambrian (Dresbachian) age for the Warrior Formation. However, a late Middle Cambrian age is permissible for the lower part of the Warrior Formation, where fossils have not been collected (Wilson, 1952). Therefore, following Wilson (1952) and Berg and others (1983), we assign a Middle and Late Cambrian age to the Warrior Formation and to the correlative part of the Elbrook Formation (pl. 1, fig. 2).

Most certainly, strata equivalent to the Pleasant Hill Limestone and Warrior Formation combined and to the Elbrook Formation are present in the Rome trough segment of section *C–C′*. Although the Pleasant Hill, Warrior, and Elbrook are not shown in the Rome trough part of plate 1, they most likely correlate with the combined upper one-half of the Conasauga Group and the lowermost part of the Gatesburg Formation in the Rome trough segment of section *E–E′* (Ryder, 1992) (fig. 1). The Pleasant Hill Limestone that is present in the ARS drill hole (and that presumably is present in the Rome trough segment of section *C–C′*) is approximately equivalent to the unnamed limestone member of the Maryville Limestone of the Conasauga Group in the Rome trough segment of section *E–E′* (Ryder, 1992). This suggested correlative of the Pleasant Hill Limestone is slightly younger than the Rogersville Shale of the Conasauga Group that Resser (1938) suggested as being correlative with the Pleasant Hill Limestone. Very likely, the pre-Maryville Limestone part of the Conasauga Group (Pumpkin Valley Shale, Rutledge Limestone, Rogersville Shale) in the Rome trough segment of section *E–E′* is also present in the Rome trough segment of section *C–C′*. However, as previously implied, the pre-Maryville Limestone part of the Conasauga Group is absent east of the Rome trough in section *C–C′* owing to erosion and (or) nondeposition (fig. 2).

The Warrior Formation in the ARS drill hole, the strata equivalent to the Warrior Formation in the Elbrook Formation in the SD drill hole, and the Warrior Formation presumed to be present in the Rome trough segment of section *C–C′* are approximately equivalent to the combined unnamed dolomite member of the Maryville Limestone and the lowermost part of the lower sandy member of the Gatesburg Formation in the Rome trough segment of section *E–E′* (Ryder, 1992). The unnamed limestone member of the Warrior Formation in the ARS drill hole and equivalent strata in the SD drill hole probably correlate with the uppermost part of the unnamed dolomite member of the Maryville Limestone and the lowermost part of the lower sandy member of the Gatesburg Formation in the Rome trough segment of section *E–E′* (Ryder, 1992). Our proposed correlation of the Warrior is in general agreement with that of Wilson (1952), who correlated the Upper Cambrian part of the Warrior Formation with the Nolichucky Shale and the Maynardville Limestone of the Conasauga Group, the former of which Ryder (1992) considered to be a partial equivalent of the lower sandy member of the Gatesburg Formation. In addition, Wilson (1952) implied that the Middle Cambrian part of the Warrior Formation correlates with part of the Maryville Limestone. Resser (1938) correlated the entire Warrior Formation with the Upper Cambrian Nolichucky Shale of the Conasauga Group, a correlation that spans a chronostratigraphic interval that is smaller and slightly higher than the one proposed here.

The Pleasant Hill Limestone is not represented by equivalent strata west of the Ohio-West Virginia hinge zone, but the Warrior Formation is represented by a time-transgressive dolomite unit that Janssens (1973) identified as the Rome Formation (pl. 1). This unit thins westward from a thickness of about 590 ft in the Management Control No. 3 Murray (MM) drill hole (No. 3, fig. 1, pl. 1, table 1) to a thickness of about 390 ft in the WS drill hole at the western end of section *C–C′* (pl. 1). The Rome Formation of Janssens (1973) was assigned a Late Cambrian age, but, because of its transgressive nature, the lowermost part of the Rome, in the vicinity of the HM drill hole, may be latest Middle Cambrian in age (pl. 1, fig. 2).

Gatesburg Formation (Upper Cambrian)

A 1,650- to 1,790-ft-thick sequence of predominantly sandy dolomite conformably overlies the Warrior Formation and the equivalent Elbrook Formation in the ARS and SD drill holes (pl. 1). This sequence correlates with the Gatesburg Formation as defined by Butts (1918, 1945), Butts and Moore (1936), Wilson (1952), and Knowles (1966) in outcrop in central and south-central Pennsylvania and by Ryder (1991) in the subsurface of Hardy County, W. Va. Wagner (1966, 1976) assigned the name Gatesburg Formation to the sandy dolomite sequence in the SD drill hole, a practice that we accept for both the SD and the ARS drill holes in section *C–C′*. In ascending order, the Gatesburg Formation in the ARS and SD drill holes consists of (1) an approximately 790-ft-thick oolitic, sandy dolomite unit named the lower sandy member by Wilson (1952), (2) a 100-ft-thick limestone unit named the Ore Hill Limestone Member by Butts (1945), (3) a 550- to 700-ft-thick oolitic, sandy dolomite unit named the upper sandy member by Wilson (1952), and (4) an approximately 180-ft-thick, highly cherty, oolitic dolomite unit named the Mines Dolomite Member by Butts (1945) and Wilson (1952) (pl. 1) (Wagner, 1966). The members of the Gatesburg Formation used here are the same as those used in the outcrop of central and south-central Pennsylvania, except that the Stacy Dolomite Member—the basal unit of the Gatesburg recognized by Butts (1918, 1945), Wilson (1952), and Knowles (1966) in outcrop—is not identified. By using the Mines Dolomite as the upper member of the Gatesburg Formation, we follow the nomenclature suggested by Wilson (1952) and Berg and others (1983).

The sandstone and dolomite sequence in the bottom 650 ft of the AS drill hole, in the Rome trough segment of section *C–C′*, is correlated here with the upper part of the Gatesburg Formation (pl. 1, fig. 2). Following the terminology used by Ryder (1991) for the Gatesburg Formation in the Occidental No. 1 Burley drill hole (fig. 1), we name the incomplete 140-ft-thick dolomite unit at the base of the drilled sequence in the AS drill hole the middle dolomite member (pl. 1). The 430-ft-thick, sandstone-dominated middle part of the sandstone and dolomite sequence in the AS drill hole correlates with the upper sandy member in the ARS and SD drill holes and with the Olin Sandstone of Wagner (1976) in the Occidental No. 1 Burley drill hole (fig. 1). Wagner (1976) and Berg and others (1983) correlated the Olin Sandstone, an abnormally thick sandstone-dominated unit confined to the Rome trough in Pennsylvania and adjoining States, with the lower sandy member of the Gatesburg Formation. We disagree with the correlation by Wagner (1976) and Berg and others (1983) and, instead, correlate the Olin Sandstone with the upper sandy member of the Gatesburg Formation. Therefore, we assign the 430-ft-thick sandstone sequence in the AS drill hole to the upper sandy member of the Gatesburg Formation and abandon the name Olin Sandstone in this study (pl. 1). The 80-ft-thick cherty, oolitic dolomite unit that overlies the upper sandy member in the AS drill hole is assigned to the Mines Dolomite Member (pl. 1).

On the basis of trilobites from the Ore Hill Limestone Member in Bedford and Blair Counties, Pa., Butts (1945), Wilson (1951, 1952), and Taylor and Loch (1989) assigned a Late Cambrian (Franconian) age to the lower one-half of the Gatesburg Formation (fig. 2). Furthermore, Butts (1945) and Wilson (1952) assigned a Late Cambrian (Trempealeauan) age to the upper one-half of the Gatesburg Formation (fig. 2) by using local gastropods from the Mines Dolomite Member.

Approximately 25 mi east of the ARS drill hole, on the eastern side of the Carbaugh-Marsh Creek fault in Franklin County, Pa., the Gatesburg Formation correlates with an approximately 3,150-ft-thick limestone and subordinate dolomite sequence identified as the Conococheague Group (Root, 1968; Berg and others, 1983) (fig. 2). The name Conococheague Group of Root (1968) replaced the name Conococheague Formation (Limestone) of Stose (1909) and Wilson (1952). The lower 280 ft of the Conococheague Group in Franklin County, Pa., contains up to five thin beds of quartz sandstone (Root, 1968) that Wilson (1952) included with his Big Spring Station Member. Root (1968) subdivided the Conococheague Group in Franklin County, Pa., into (1) the Zullinger Formation (2,500 ft), which is approximately equivalent to the combined lower sandy member, the Ore Hill Limestone Member, and most of the upper sandy member, and (2) the Shadygrove

Formation (650 ft), which is approximately equivalent to the combined uppermost upper sandy member and the Mines Dolomite Member (fig. 2). The Conococheague in adjoining Washington County, Md., was assigned formation status by Bassler (1919), Cloos (1951), Wilson (1952), and Edwards (1978). The basal 200- to 300-ft-thick sandstone and dolomite unit at the base of the Conococheague Formation (Limestone) in Maryland was assigned to the Big Spring Station Member by Wilson (1952). The Conococheague Formation, including the Big Spring Station Member, is also identified in the North Mountain fault block of the West Virginia panhandle (Donaldson and Page, 1963; Dean and others, 1987) and adjoining northern Virginia (Young and Rader, 1973; Rader and Biggs, 1975, 1976).

Trilobites collected from the Conococheague Group (Limestone, Formation) in south-central Pennsylvania and adjoining Maryland and northern Virginia indicate that the Conococheague spans most of the Upper Cambrian (upper Dresbachian, Franconian, Trempealeauan) (Stose, 1909; Wilson, 1951, 1952; Sando, 1958) and therefore correlates with the majority of the Gatesburg Formation in section *C–C′* (fig. 2). Dresbachian-age trilobites in the lower part of the Big Spring Station Member suggest that the lowermost part of the Conococheague correlates with the uppermost part of the unnamed limestone member of the Warrior Formation (fig. 2).

Strata equivalent to the Gatesburg Formation west of the Ohio-West Virginia hinge zone, in section *C–C′*, consist of the upper part of the Rome Formation of Janssens (1973), the Conasauga Formation of Janssens (1973), the Krysik sandstone of driller's usage, the B zone of Calvert (1964), the lower part of the Knox Dolomite of Janssens (1973), and the Rose Run Sandstone Member (pl. 1). These units have a combined thickness of about 400 to 600 ft. The Krysik sandstone of driller's usage and the B zone of Calvert (1964) constitute the Steam Corners Member of Coogan and Maki (1988b). The upper Rome-Conasauga-Krysik-B zone interval correlates with the lower sandy member of the Gatesburg Formation, whereas the Rose Run Sandstone Member correlates with the upper sandy member of the Gatesburg Formation (pl. 1, fig. 2). The lower part of the Knox Dolomite of Janssens (1973) correlates approximately with the Ore Hill Limestone Member and the equivalent middle dolomite member and with the lower part of the upper sandy member of the Gatesburg Formation (pl. 1, fig. 2). These correlatives of the Gatesburg Formation in eastern Ohio—the Rome Formation (upper part), the Conasauga Formation, the Krysik sandstone, the B zone, the lower part of the Knox Dolomite, and the Rose Run Sandstone Member—are here assigned a Late Cambrian age (pl. 1, fig. 1).

The possibility exists that part or all of the upper sandy member, the Rose Run Sandstone Member, and the Mines Dolomite Member may be of Early Ordovician age. For example, McGuire and Howell (1963) assigned an Early Ordovician age to the Rose Run Sandstone in eastern Kentucky, consistent with the Early Ordovician age tentatively assigned by Repetski (1985), on the basis of conodonts, to sandstone beds equivalent to the Rose Run Sandstone in the basal part of the Chepultepec Dolomite in the Thorn Hill section of eastern Tennessee (fig. 1). Also, on the basis of conodonts, Orndorff (1988) assigned an Early Ordovician age to the upper 141 ft of the Conococheague Formation as recognized in northern Virginia by Young and Rader (1974) and Rader and Biggs (1975, 1976).

Beekmantown Group (Lower and Lower Middle Ordovician)

Near the depositional axis of the Rome trough in section *C–C′*, where the AS drill hole is located, a 3,800-ft-thick dolomite sequence conformably overlies the upper sandy member of the Gatesburg Formation (pl. 1). This dolomite sequence thins gradually east of the Rome trough, between the Allegheny structural front and the North Mountain fault, to about 3,000 ft in the KMS drill hole and to between 2,250 and 2,500 ft in the ARS (includes adjoining outcrop section) and SD drill holes (pl. 1). These thicknesses of the dolomite sequence in and around the KMS, ARS, and SD drill holes are comparable to the 2,400- to 2,650-ft measured outcrop thickness of the correlative Beekmantown Group in nearby Blair County, Pa. (Butts, 1945). West of the Rome trough, the dolomite sequence thins abruptly to about 550 ft in the HM drill hole astride the Ohio-West Virginia hinge zone down to about 60 ft in the WS drill hole at the western end of section *C–C′* (pl. 1).

Anhydrite and limestone are commonly found in the upper 1,410 ft of the dolomite sequence in the AS drill hole. The anhydrite is concentrated in the lower 480 and upper 320 ft of the 1,410-ft-thick sequence, whereas the limestone is concentrated in the upper 590 ft of the 1,410-ft-thick sequence (pl. 1). Native sulfur is associated with the lower zone of anhydritic dolomite. The anhydrite- and limestone-bearing zones in the AS drill hole are mainly confined to the Rome trough segment of section *C–C′*, except where the upper zone extends eastward beyond the margin of the trough to the KMS drill hole along the Allegheny structural front (pl. 1). Moreover, a 320-ft-thick zone of anhydritic dolomite containing native sulfur occurs in the lower one-half of the dolomite sequence in the KMS drill hole. This anhydritic dolomite apparently is confined to the area near the Allegheny structural front. In the SD drill hole, a 50-ft-thick limestone unit is present at the base of the dolomite sequence, and a 175-ft-thick calcareous dolomite is present near the top of the sequence.

Calvert (1963) identified the Knox unconformity at the base of the 60-ft-thick dolomite sequence in the WS drill hole at the western end of section *C–C′* (pl. 1). This well-known regional unconformity extends eastward into the Rome trough but probably disappears west of the AS drill hole. The unconformity probably reappears at the eastern end of section *C–C′* above the South-central Pennsylvania arch. More details regarding the stratigraphic position and extent of the Knox unconformity in section *C–C′* will be discussed in the following section.

Wagner (1966) assigned the dolomite sequence in the KMM and SD drill holes to formations of the Beekmantown Group but did not refer to the name Beekmantown Group. Likewise, Knowles (1966) assigned the dolomite sequence in the KMM drill hole and in the outcrop section adjoining the ARS drill hole to formations of the Beekmantown Group without using the name Beekmantown Group. In ascending order, the formations recognized by Wagner (1966) and Knowles (1966) are the Larke Dolomite (Formation) and the equivalent Stonehenge Limestone (Formation), the Nittany Dolomite (Formation), and the Bellefonte Dolomite (Formation). All of these formations crop out in Bedford, Blair, and Centre Counties, Pa. (Butts, 1918, 1945; Butts and Moore, 1936; Swartz and others, 1955; Spelman, 1966; Donaldson, 1969). Moreover, the 3,800-ft-thick dolomite sequence in the AS drill hole correlates with an estimated 3,100-ft-thick (drilled thickness is 2,600 ft) anhydritic and calcareous dolomite sequence in the Phillips No. A–1 Finch drill hole (fig. 1) that Wagner (1966) assigned to formations in the Beekmantown Group. Ryder (1991) assigned the name Beekmantown Group to the anhydritic and calcareous dolomite sequence in the Phillips No. A–1 Finch without identifying specific formations. Another correlative unit of the dolomite sequence in the AS drill hole, the 2,150-ft-thick anhydritic and calcareous dolomite sequence in the Occidental No. 1 Burley drill hole (fig. 1), also was assigned to the Beekmantown Group by Ryder (1991). Following Wagner (1966) and Ryder (1991), we assign the name Beekmantown Group to the 3,800-ft-thick dolomite sequence in the AS drill hole and to correlative dolomite sequences in the KMS, KMM, ARS, and SD drill holes (pl. 1). The Beekmantown Group in section *C–C′* is undivided, except for (1) the outcrop section near the ARS drill hole, where the Larke, Nittany, and Bellefonte Dolomites (Formations) have been identified by Knowles (1966), and (2) the drilled sequence in the SD drill hole, where Wagner (1966) assigned the basal limestone unit to the Stonehenge Limestone (Formation).

West of the Ohio-West Virginia hinge zone, the Beekmantown Group is replaced laterally by two formations. The lower formation, the lateral equivalent of the lower one-third of the Beekmantown Group in the AS drill hole, is assigned to the upper part of the Knox Dolomite of Janssens (1973). The upper formation, the lateral equivalent of the anhydritic and calcareous dolomite part of the Beekmantown Group in the AS drill hole, is assigned here to the Wells Creek Formation as used in Ohio by Janssens (1973), Stith (1979, 1986), Wickstrom and others (1985), and Wickstrom and Gray (1988). The Wells Creek Formation consists largely of grayish-green shale and dolomite. The conspicuous westward-tapering wedge formed by the Beekmantown Group in the Rome trough segment of section *C–C′* and the Knox-Wells Creek interval west of the Ohio-West Virginia hinge zone resulted from a combination of depositional thinning and truncation beneath the Middle Ordovician Knox unconformity (pl. 1).

The Beekmantown Group is also recognized in the Carbaugh-Marsh Creek fault block in Franklin County, Pa., where it has a measured thickness of approximately 4,000 ft. Following the names assigned by Sando (1957, 1958) to the Beekmantown Group in Franklin County and adjoining Washington County, Md., Root (1968) subdivided the Beekmantown Group in Franklin County into four formations (in ascending order): (1) the Stoufferstown Formation, a 260-ft-thick, coarse-grained, clastic limestone unit, (2) the Stonehenge Formation, a 775-ft-thick limestone unit, (3) the Rockdale Run Formation, an approximately 2,500-ft-thick limestone and subordinate dolomite unit, and (4) the Pinesburg Station Formation, an approximately 450-ft-thick dolomite and subordinate limestone unit. In this study, we follow Sando (1958) and Berg and others (1983) and treat the Stoufferstown as a member of the Stonehenge Formation (fig. 2). Similar nomenclature is applied to the approximately 4,000-ft-thick Beekmantown Group in the North Mountain fault block in the panhandle of West Virginia (Donaldson and Page, 1963; Dean and others, 1987) and to the 2,600- to 3,700-ft-thick Beekmantown Group in the North Mountain fault block in northern Virginia (Edmundson and Nunan, 1973; Young and Rader, 1974; Rader and Biggs, 1975, 1976).

An Early Ordovician age was assigned to the Beekmantown Group or to formations of the Beekmantown Group by Butts (1945), Knowles (1966), Spelman (1966), Lees (1967), and Donaldson (1969) where it crops out in Bedford, Blair, and Centre Counties, Pa. In addition, Sando (1957, 1958) assigned an Early Ordovician age to the Beekmantown Group in Franklin County, Pa., and adjoining Washington County, Md. This age designation was based on (1) the stratigraphic position of the Beekmantown between the Gatesburg Formation and the Conococheague Group of Late Cambrian [Orndorff (1988) recently assigned a Late Cambrian-earliest Early Ordovician age to the Conococheague] age and limestones of Middle Ordovician age and (2) local to common occurrences of probable age-diagnostic gastropods, conodonts, and trilobites. Macrofossils collected by Knowles (1966) and Spelman (1966) from the Beekmantown Group in the outcrop section near the ARS drill hole consist of (1) gastropods and chiton(?) plates from the Larke Dolomite (F_6 on pl. 1), (2) gastropods and orthocone cephalopods from the middle part of the Nittany Dolomite (F_5 on pl. 1), and (3) a coiled cephalopod from the lower part of the Bellefonte Dolomite (F_4 on pl. 1).

These fossils suggest an Early Ordovician age for at least the lower two-thirds of the Beekmantown Group near the ARS drill hole (pl. 1, fig. 2). Trilobites collected from the Stonehenge Formation in central Pennsylvania by Taylor (1986) do not support the Late Cambrian age assigned to the lowermost Stonehenge Limestone (Formation) and the Larke Dolomite (Formation) by Berg and others (1983).

Wagner (1966), on the basis of intertonguing strata of the uppermost Beekmantown Group and the lowermost St. Paul Group of early Middle Ordovician age (Neuman, 1951), tentatively assigned an early Middle Ordovician (Chazyan) age to the upper 200 ft of the Beekmantown Group in central and south-central Pennsylvania and adjoining Maryland and West Virginia. For the remainder of the Beekmantown Group in this area, Wagner (1966) agreed with the Early Ordovician age assigned by previous investigators. Conodont studies by Harris and Repetski (1982, 1983) confirmed the early Middle Ordovician age proposed by Wagner (1966) for the upper part of the Beekmantown Group. Their studies indicated that, from about Harrisonburg, Va. (fig. 1), northward into central Pennsylvania, the upper 350 to 900 ft of the Beekmantown Group contained strata ranging from earliest to early Middle Ordovician (Whiterockian) age. In Blair County, Pa., approximately the upper 700 ft of the Bellefonte Dolomite was assigned an early Middle Ordovician age by Harris and Repetski (1982, 1983). Berg and others (1983) have accepted the Early and Middle (Whiterockian and Chazyan) Ordovician age proposed by Harris and Repetski (1982, 1983) for the Beekmantown Group in Pennsylvania. However, the Whiterockian and Chazyan parts of the Middle Ordovician used by Berg and others (1983) (as defined in COSUNA charts) (see Patchen and others, 1984) occupy chronostratigraphic positions different from the Whiterockian and Chazyan defined by Barnes and others (1981) and Ross and others (1982) and adopted in this paper.

Conodonts were recovered (table 2) from three intervals in the Beekmantown Group in the AS drill hole: (1) 17,000 to 17,200 ft (f_4 on pl. 1), (2) 17,700 to 18,500 ft (f_5 on pl. 1), and (3) at about 19,900 to 20,000 ft (f_6 on pl. 1). Drill-hole cuttings from the f_4 interval yielded conodonts of Middle Ordovician age that are no older than the *Phragmodus tangshanensis* zone (*Phragmodus* pre-*flexuosus* zone of Sweet and Bergström, 1986) or the lower part of the Chazyan Stage as used in this paper. Cuttings from the f_5 interval exclusive of the top 100 ft in the AS drill hole yielded Middle Ordovician conodonts indicative of a two-zone interval—the *P. tangshanensis* zone and the succeeding *Cahabagnathus friendsvillensis* zone of Sweet and Bergström (1986) (lower to middle part of the Chazyan used in this paper). Conodonts from the f_6 interval are of Middle(?) Ordovician age and are no younger than the *P. tangshanensis* and *C. friendsvillensis* zones. These conodonts suggest that the upper 700 ft of the Middle Ordovician part of the Bellefonte Dolomite in Blair County, Pa., is represented by at least the upper 1,500 ft of the Beekmantown Group in the AS drill hole. If the conodonts in the f_6 interval are of Middle Ordovician age, at least 3,000 ft of the Beekmantown Group may be equivalent to the upper 700 ft of the Bellefonte Dolomite in Blair County. However, a 3,000-ft thickness for the Middle Ordovician part of the Beekmantown Group seems excessive, particularly because the remaining 800-ft-thick Lower Ordovician part would be about one-half the thickness of the Lower Ordovician sequence near the ARS drill hole. Possibly, the Middle(?) Ordovician conodonts in the f_6 interval resulted from downhole contamination. We tentatively place the Lower Ordovician-Middle Ordovician boundary at about 19,000 ft in the AS drill hole, which indicates that about 1,800 ft of the Beekmantown Group here is Early Ordovician in age and about 2,000 ft of the Beekmantown is of Middle Ordovician (Whiterockian) age (pl. 1).

In the KMS, KMM, ARS, and SD drill holes, east of the AS drill hole, the Lower Ordovician-Middle Ordovician boundary is placed in the upper one-half to one-third of the Beekmantown Group. In the ARS and SD drill holes, we suggest that the boundary coincides with the Knox unconformity (pl. 1). In eastern Ohio, the Lower Ordovician part of the Beekmantown Group is represented by the upper part of the Knox Dolomite of Janssens (1973), whereas the Middle Ordovician (Chazyan) part of the Beekmantown Group is represented by the Wells Creek Formation (pl. 1). From about 5 mi west of the Belden and Blake and Company No. 1–381 Westfall drill hole (BBW) (No. 2, fig. 1, pl. 1, table 1) to the western end of section *C–C′*, the Lower Ordovician part of the Knox Dolomite has been completely truncated by the Middle Ordovician Knox unconformity.

Knox Unconformity

Between the Ohio-West Virginia hinge zone and the western end of section *C–C′*, the Knox unconformity underlies the Wells Creek Formation and truncates, in succession, (1) the upper part of the Knox Dolomite of Janssens (1973) (equivalent to the Lower Ordovician part of the Beekmantown Group), (2) the Rose Run Sandstone (equivalent to the upper sandy member of the Gatesburg Formation), and (3) the top of the lower part of the Knox Dolomite of Janssens (1973) (equivalent to the middle dolomite member of the Gatesburg Formation). In eastern Ohio, the Knox unconformity is generally easy to recognize on geophysical and lithologic logs because of the abrupt lithologic change between the Wells Creek Formation (consisting of grayish-green shale, argillaceous, very finely crystalline dolomite, and, commonly, a thin basal sandstone) and the underlying Knox Dolomite (consisting of fine to medium crystalline dolomite). The Knox unconformity is more difficult to recognize in those drill holes where the

Wells Creek Formation contains a basal sandstone unit that overlies the Rose Run Sandstone or sandy dolomite of the Knox Dolomite.

The Knox unconformity continues east of the Ohio-West Virginia hinge zone into the Rome trough segment of section *C–C′*, where it is situated in the upper 500 to 600 ft of the Beekmantown Group and decreases in magnitude toward the axis of the trough. In the westernmost part of the Rome trough, the Knox unconformity probably separates Lower Ordovician strata from overlying lower Middle Ordovician strata, whereas, in the central part of the Rome trough, the Knox unconformity is located entirely within lower Middle Ordovician strata (pl. 1). Successively younger strata appear beneath the Knox unconformity, eastward of the Ohio-West Virginia hinge zone, until the unconformity probably disappears near the AS drill hole (pl. 1). Because the Knox unconformity is probably present in the subsurface of Hardy County, W. Va. (Ryder, 1991), we suggest that it reappears in the KMS, KMM, and SD drill holes in section *C–C′*. In the outcrop section near the ARS drill hole, the Knox unconformity may coincide with the top of the thick, cherty zone described by Knowles (1966) in the lower part of the Bellefonte Dolomite. Middle Ordovician strata probably are present beneath the proposed Knox unconformity in the KMS and KMM drill holes; however, in the SD drill hole and the outcrop section near the ARS drill hole, Middle Ordovician strata may have been eroded by the unconformity, so that Lower Ordovician strata are unconformably overlain by lower Middle Ordovician strata (pl. 1).

The Knox unconformity was not recognized by Root (1968) and Berg and others (1983) in Franklin County, Pa. (fig. 2), or by Sando (1957) in Washington County, Md., and Donaldson and Page (1963) in the West Virginia panhandle. The Knox unconformity has been identified in northern Virginia, at the top of the Beekmantown Group between the North Mountain fault and the Blue Ridge, by Young and Rader (1974), Rader and Biggs (1975, 1976), and Mussman and Read (1986). However, as Ryder (1991) suggested in section *D–D′* (fig. 1), this unconformity appears to be too high stratigraphically to be the Knox unconformity, which, in northern Virginia, should most likely appear within the middle part of the Beekmantown Group, not at the top of the Beekmantown. If the Knox unconformity is present in Franklin County, Pa., it probably resides near the top of the Rockdale Run Formation (fig. 2).

Conodont studies by Harris and Repetski (1982, 1983) show that, throughout most of southwestern and central Virginia, the Knox unconformity is defined in outcrop by limestone of early Middle Ordovician (Chazyan) age resting disconformably on the Beekmantown Group, which is of latest Early Ordovician age. Northward, from about Harrisonburg, Va. (fig. 1), to central Pennsylvania, the time span of the Knox unconformity is greatly diminished, as shown in outcrop by progressively younger Beekmantown strata (Whiterockian) appearing above and below the unconformity. The abnormally thick conodont-bearing (table 2) lower Middle Ordovician part of the Beekmantown Group in the AS drill hole suggests that continuous deposition occurred across the Lower Ordovician-Middle Ordovician boundary in south-central Pennsylvania.

The Knox unconformity at the eastern end of section *C–C′* probably represents a time span between 5 and 10 million years (pl. 1, fig. 2). Across section *C–C′*, the hiatus represented by the Knox unconformity is greatest near the Wooster arch. There, the lower part of the Knox Dolomite of Late Cambrian age overlain by the Wells Creek Formation of early Middle Ordovician (middle Chazyan) age implies that a time span of as much as 40 m.y. is represented by the Knox unconformity (fig. 2).

Loysburg Formation and Black River Group (Middle Ordovician)

The anhydritic and calcareous dolomite unit at the top of the Beekmantown Group in the AS drill hole and the laterally contiguous grayish-green shale and dolomite of the Wells Creek Formation in Ohio are overlain by a sequence of slightly to moderately dolomitic, locally fossiliferous, micritic limestone. Three to four metabentonite beds are located near the top of the micritic limestone in Ohio (pl. 1). The micritic limestone sequence is also present east of the AS drill hole between the Allegheny structural front and the eastern end of section *C–C′*. In the KMS and KMM drill holes, the micritic limestone sequence overlies the anhydritic and calcareous dolomite part of the Beekmantown Group, whereas, in the SD drill hole and the outcrop section near the ARS drill hole, the micritic limestone rests on nonanhydritic and noncalcareous dolomite of the Bellefonte Dolomite and equivalent strata. The contact between the micritic limestone sequence and the underlying Beekmantown Group appears to be conformable across section *C–C′*, except at the SD drill hole, where the contact is probably unconformable. From its maximum thickness of about 1,150 ft in the Rome trough, the micritic limestone sequence thins eastward to about 100 ft at the eastern end of section *C–C′* and westward to a thickness of about 580 ft at the western end of section *C–C′* (pl. 1). Thinning of this sequence between the Rome trough and the eastern end of section *C–C′* occurs in three ways: (1) by depositional thinning, (2) by the eastward stratigraphic rise of its basal contact with the underlying Beekmantown Group, and (3) by progressively eastward truncation beneath a widespread, postmicritic limestone unconformity and a local intramicritic limestone unconformity that is restricted to the area around the SD drill hole (pl. 1). Westward thinning of the micritic limestone sequence resulted from a combination of depositional thinning and the westward stratigraphic rise of its basal contact with the underlying Beekmantown Group and the Wells Creek Formation (pl. 1). From near the Ohio-West Virginia hinge zone to the western end of section *C–C′*, the upper part of the micritic limestone sequence increases in thickness by about 100 ft because of a slight stratigraphic rise of the contact between its top and the overlying highly argillaceous micritic limestone (pl. 1).

The micritic limestone sequence is subdivided here into (1) a lower part that is dolomitic in the Rome trough and on the adjoining South-central Pennsylvania arch and argillaceous west of the Ohio-West Virginia hinge zone and (2) an upper part that contains few, if any, dolomite beds and local thin gray shale beds. In addition, the lower part of the micritic limestone sequence contains micrite that, in general, is finer grained and has lighter shades of gray and brown than the micrite in the upper part of the sequence. From the MM drill hole westward to the western end of section *C–C′*, the shale beds in the lower part of the micritic limestone sequence are greenish gray to grayish green and thus are similar in color to the shale beds in the underlying Wells Creek Formation. In contrast, from the HM drill hole to an estimated 10 mi east of the Ohio-West Virginia hinge zone, the shale beds in the lower part of the micritic limestone are gray to dark gray.

Following Kay (1944a), Knowles (1966) and Chafetz (1969) assigned the name Loysburg Formation to the approximately 215-ft-thick lower part of the micritic limestone sequence in the outcrop section near the ARS drill hole (pl. 1). The Loysburg Formation here contains two members, the "tiger-striped" member of Kay (1944a) (Milroy Member of Rones, 1969) and the overlying Clover Member. In this area, the "tiger-striped" member (Milroy Member) is about 135 ft thick and consists of medium- to thick-bedded, predominantly laminated limestone and dolomitic limestone, whereas the Clover Member is about 80 ft thick and consists of thick-bedded, laminated micritic limestone. Furthermore, the Loysburg Formation and its constituent members were identified in the KMM and SD drill holes by Wagner (1966); however, the strata that he assigned to the Loysburg Formation are situated in the Beekmantown Group of this paper. We concur with Knowles (1966), Wagner (1966), and Chafetz (1969) that the Loysburg Formation is an appropriate name for the lower part of the micritic limestone sequence between the Allegheny structural front and the eastern end of section *C–C′* (pl. 1). Following Berg and others (1983), we use the Milroy Member of Rones (1969) instead of the "tiger-striped" member of Kay (1944a).

The Loysburg Formation is absent in the SD drill hole owing to erosion and nondeposition associated with an intra-Loysburg Formation unconformity (pl. 1). West of the Allegheny structural front, the Loysburg Formation thickens to a maximum of about 590 ft in the AS drill hole by westward stratigraphic downstepping of the dolomitic limestone facies of the Milroy Member at the expense of the underlying Beekmantown Group. In the Rome trough segment of section *C–C′*, the Loysburg Formation thins westward between the AS and HM drill holes (pl. 1). This thinning results from the westward stratigraphic rise of the base of the Loysburg Formation and the less pronounced westward stratigraphic downstepping of the top of the Loysburg Formation. Westward from about 10 to 15 mi east of the Ohio-West Virginia hinge zone, the Clover Member is replaced by the downstepping upper part of the micritic limestone sequence, and the Milroy Member changes facies from dolomitic limestone to argillaceous limestone. This argillaceous limestone is about 220 ft thick in the HM drill hole and is referred to here as the Loysburg Formation undivided (pl. 1, fig. 2). Berg and others (1983) also identified an undivided Loysburg Formation in southwestern Pennsylvania.

The Loysburg Formation as used in the AS, KMS, and KMM drill holes and in the outcrop section near the ARS drill hole correlates with a 450-ft-thick argillaceous limestone sequence in the Phillips No. A–1 Finch drill hole (fig. 1) and a 275-ft-thick argillaceous limestone sequence in the Occidental No. 1 Burley drill hole (fig. 1) that Wagner (1966) and Ryder (1991) assigned to the St. Paul Group. The equivalent of the Loysburg Formation in Franklin County, Pa., crops out near the Carbaugh-Marsh Creek fault as an approximately 1,000-ft-thick, predominantly light gray to brownish light gray, micritic limestone sequence that Neuman (1951), Root (1968), and Berg and others (1983) assigned to the St. Paul Group (fig. 2). Neuman (1951) originally defined the St. Paul Group and its constituent Row Park and New Market Limestones in outcrops east of the North Mountain fault in Washington County, Md., and adjoining West Virginia and Virginia. The St. Paul Group in Washington County is between 400 and 600 ft thick (Neuman, 1951).

In Ohio, the lower part of the micritic limestone sequence (Loysburg Formation in Pennsylvania) has been identified most commonly as (1) the Chazy Group or Limestone (Calvert, 1963, 1964; Dolly and Busch, 1972), (2) the Black River Group (lower part) (Stith, 1979, 1986), and (3) the Black River Limestone (lower part) (DeBrosse and Vohwinkel, 1974; Wickstrom and others, 1985; Wickstrom and Gray, 1988). All three names are acceptable, but we have retained the name Black River Limestone because it seems to be most favored by the Ohio Division of Geological Survey.

The upper part of the micritic limestone sequence that crops out near the ARS drill hole was assigned by Knowles (1966) to the Hatter and Benner Formations (Limestones) of Kay (1944a, b). In neighboring Blair and Huntington Counties, Rones (1969) recognized the Hatter Formation of Kay (1944a) but changed the Benner Formation of Kay (1944a, b) to the Snyder Formation (Snyder Member of Kay, 1944a, b) and the overlying Linden Hall Formation (Stover and Oak Hall Members of Kay, 1944a, b). Berg and others (1983) adopted the terminology suggested by Rones (1969). Likewise, we accept the terminology of Rones (1969) for the Hatter, Snyder, and Linden Hall, but we use the name Limestone instead of Formation and consider them to be subdivisions of the Black River Group (pl. 1, fig. 2).

Wagner (1966) identified the Hatter, Snyder, and Benner (Linden Hall of Rones, 1969) Formations in the KMM and SD drill holes; however, the strata to which he applied these names are either stratigraphically below or only partly coincident with the upper part of the micritic limestone sequence of this paper. Following Wagner (1966), we assign the name Black River Group to the upper part of the micritic limestone sequence in the KMM and SD drill holes (pl. 1). In the SD drill hole, the Black River Group is approximately 100 ft thick and bounded by unconformities, whereas, in the KMM drill hole, the Black River Group is approximately 130 ft thick, and an unconformity is present only at its top. The name Black River Group is also assigned here to the upper part of the micritic limestone sequence in the KMS and AS drill holes, where the sequence is 180 and 550 ft thick, respectively. Most of the eastward thinning of the Black River Group between the AS and SD drill holes is caused by the widespread post-Black River Group unconformity that has beveled successively older parts of the micritic limestone sequence toward the east (pl. 1). The 520-ft-thick Black River Group in the HM drill hole near the Ohio-West Virginia hinge zone is thicker than expected because of the westward stratigraphic rise of the top of the sequence and the slight stratigraphic downstepping of the base of the sequence (pl. 1). The top of the Black River Group in the HM drill hole is marked by a metabentonite that we identify as the α marker of Stith (1979) (pl. 1, fig. 2).

The Black River Group as defined in the AS drill hole also is present in the Phillips No. A–1 Finch and Occidental No. 1 Burley drill holes (fig. 1), where it attains a thickness of 575 and 660 ft, respectively. The thickness of the Black River Group is greater in the Occidental No. 1 Burley drill hole than it is in the Phillips No. A–1 Finch drill hole because of the approximately 150-ft stratigraphic rise of the top of the Black River Group between the Phillips No. A–1 Finch and Occidental No. 1 Burley drill holes (Ryder, 1991).

In Franklin County, Pa.—between the North Mountain and Carbaugh-Marsh Creek faults—the Black River Group and its constituent Hatter, Snyder, and Linden Hall Limestones are represented by strata in the lower part of the approximately 750-ft-thick Chambersburg Formation (Limestone) (Stose, 1906, 1909; Root, 1968; Berg and others, 1983) (fig. 2). The Chambersburg Formation (Shippensburg and Mercersburg Formations of Craig, 1949) thins to between 100 and 300 ft in western Franklin County (Clark, 1970; Okuma, 1970). Approximately the lower one-half of the Chambersburg Formation (Shippensburg Formation of Craig, 1949) in western Franklin County correlates with the Hatter-Snyder-Linden Hall interval in the outcrop section near the ARS drill hole (fig. 2). The widespread unconformity shown at the top of the Black River Group in the KMS, KMM, and SD drill holes and in the outcrop section near the ARS drill hole probably is a westward continuation of the intra-Chambersburg Formation unconformity (post-Shippensburg–pre-Mercersburg unconformity) recognized by Craig (1949) in Franklin County, Pa. (pl. 1, fig. 2).

The Chambersburg Formation (Limestone) continues southward into Washington County, Md., between the North Mountain and Carbaugh-Marsh Creek faults, where it is between 250 and 300 ft thick (Bassler, 1919; Craig, 1949; Edwards, 1978). As it does in adjoining Franklin County, the lower part of the Chambersburg Formation (Limestone) in Washington County, Md., correlates with the Hatter-Snyder-Linden Hall interval in section *C–C′*. In northern Virginia, a 300- to 500-ft-thick sequence consisting of the Lincolnshire Limestone and the overlying unnamed tongues of the Liberty Hall and Lantz Mills Formations (Read, 1980; Rader, 1982) is approximately equivalent to the Hatter-Snyder-Linden Hall interval in section *C–C′*. In the adjoining West Virginia panhandle, the names Black River Group (Limestone) (Cardwell and others, 1968; Patchen and others, 1984) or Chambersburg Limestone (Dean and others, 1987) are used in place of the unnamed tongues of the Liberty Hall and Lantz Mills Formations.

Following DeBrosse and Vohwinkel (1974), Wickstrom and others (1985), and Wickstrom and Gray (1988), we assign the upper part of the micritic limestone sequence in Ohio to the Black River Limestone (pl. 1, fig. 2). As previously mentioned, the Black River Limestone in Ohio also includes strata that are equivalent to the Loysburg Formation in Pennsylvania (pl. 1, fig. 2). The α marker of Stith (1979) marks the top of the Black River Limestone across the entire Ohio part of section *C–C′* (pl. 1, fig. 2). Another widespread metabentonite in the uppermost part of the Black River in Ohio and adjoining States underlies the α marker in section *C–C′*. This metabentonite is correlated here with the β marker of Stith (1979) (pl. 1, fig. 2). The α and β markers of Stith (1979) correlate with the Mud Cave and Pencil Cave bentonites, respectively, in Kentucky (Cressman and Noger, 1976; Cressman and Peterson, 1986). In south-central Pennsylvania, bentonite R and bentonite No. 0 (Thompson, 1963) correlate with the α and β markers of Stith (1979), respectively.

A Middle Ordovician (middle and late Chazyan and early Blackriveran) age is assigned here to the Loysburg Formation (fig. 2). This age is based on (1) the Chazyan age assigned to the Loysburg Formation in central and south-central Pennsylvania by Butts and Moore (1936) (included in their Carlim Limestone), Kay (1944a), and Chafetz (1969) on the basis of mollusk, brachiopod, primitive coral, ostracod, and trilobite faunas, (2) the Chazyan age assigned to the Row Park Limestone of the St. Paul Group (equivalent to the lower part of the Loysburg Formation) in Washington County, Md., by Neuman (1951) on the basis of brachiopods, and (3) the Chazyan age assigned to the Loysburg Formation (unnamed argillaceous limestone of the St. Paul Group of Ryder, 1992) in the Hope Natural Gas No. 9634 Power Oil Company drill hole in Wood County, W. Va. (fig. 1), by Prouty and others (1959) on the basis of brachiopod and primitive coral faunas. The upper part of the Loysburg Formation in the Rome trough and Allegheny front segments of section *C–C′* may be of early Blackriveran age (fig. 2). This additional age is based on (1) the eastward stratigraphic rise of the Loysburg Formation at the expense of the overlying Black River Group, (2) the Pamelian age (earliest Blackriveran age of this paper) that Neuman (1951) assigned to the New Market Limestone (equivalent to the upper part of the St. Paul Group) in Washington County, Md., on the basis of primitive coral faunas), and (3) the Marmor and Ashby Stages (lower Chazyan through middle Blackriveran Stages of Bergström, 1971) assigned to the Loysburg-equivalent St. Paul Group in Franklin County, Pa., by Cooper (1956) on the basis of brachiopods. Conodonts identified by A.G. Harris and J.E. Repetski (table 2) in the Loysburg Formation in the AS drill hole (f_3 and upper part of f_4 on pl. 1) are consistent with a middle Chazyan through early Blackriveran age.

We assign a Middle Ordovician (Blackriveran through Rocklandian) age to the Black River Group in section *C–C′* (fig. 2). This age is based on brachiopod, conodont, mollusk, primitive coral, stromatoporoid, and ostracod faunas reported by (1) Kay (1944a, b) and Swartz and others (1955) from outcrops of the Hatter and Benner Limestones (Snyder and Linden Hall Limestones of this paper) in central and south-central Pennsylvania, (2) Prouty and others (1959) from cores of the Hatter and Benner Limestones (Snyder and Linden Hall Limestones of this paper) of the Black River Group in the Hope Natural Gas No. 9634 Power Oil Company drill hole, (3) Craig (1949) from outcrops of the Shippensburg Formation (correlates with Black River Group of this paper) in Franklin County, Pa., and (4) Sweet and Bergström (1976) from strata between the α (Mud Cave bentonite) and β (Pencil Cave bentonite) markers in southern Ohio and adjoining Kentucky. Because the Black River Limestone, as used in Ohio by DeBrosse and Vohwinkle (1974), Wickstrom and others (1985), and Wickstrom and Gray (1988), includes strata equivalent to the Loysburg Formation, its age ranges from middle Chazyan through Rocklandian (fig. 2).

Trenton Group (Middle and Upper Ordovician)

The Black River Group (Limestone) is overlain in the AS drill hole by a 1,125-ft-thick sequence consisting of bioclastic limestone, argillaceous micritic limestone, and dark-gray and black shale (pl. 1). This sequence thins away from the AS drill hole to about 600 ft in the SD drill hole at the eastern end of section *C–C′* and to about 400 ft in the WS drill hole at the western end of section *C–C′*. Westward thinning of the limestone and gray and black shale sequence between the AS and WS drill holes occurs in three ways: (1) by depositional thinning, (2) by the westward stratigraphic rise of its basal contact with the underlying Black River Group, and (3) by the slight westward stratigraphic downstepping of the top of the sequence (pl. 1). Eastward thinning of the limestone and gray and black shale sequence from the AS drill hole resulted from a combination of depositional thinning and eastward stratigraphic downstepping of the top of the sequence.

The limestone and gray and black shale sequence is subdivided into a lower part dominated by bioclastic limestone and argillaceous micritic limestone and an upper part dominated by dark-gray and black shale (pl. 1). These two units are easily distinguishable from each other across the entire length of section *C–C′*, except that the lithologic change between them occurs across a 10- to 50-ft-thick transition zone and thus makes the contact somewhat arbitrary. In the SD drill hole, the dark-gray and black shale unit has been replaced through facies change by a predominantly argillaceous micritic limestone unit intercalated with gray and dark-gray shale (pl. 1). There, the lower and upper units are differentiated by the significantly higher percentage of shale in the upper unit. Metabentonite beds are common in the lower unit of the limestone and gray-to-black shale sequence across section *C–C′* (pl. 1).

Following Kay (1944b), Thompson (1963) and Knowles (1966) subdivided the approximately 380-ft-thick lower part of the limestone and gray and black shale sequence, which crops out near the ARS drill hole, into the Nealmont, Salona, and Coburn Limestones (Formations) (pl. 1). Moreover, Thompson (1963) applied the name Antes Shale of Kay (1944b) to the approximately 350-ft-thick upper part of the limestone and gray and black shale sequence that crops out near the ARS drill hole (pl. 1). Kay (1944b) and Thompson (1963) considered the Nealmont, Salona, and Coburn Limestones (Formations) and the overlying Antes Shale to be formations in the Trenton Group. Berg and others (1983) recognized the same formations in central and south-central Pennsylvania without referring to the Trenton Group of Kay (1944a, b). Wagner (1966), also following Kay (1944b), assigned (in ascending order) the names Nealmont, Salona, and Coburn Limestones (Formations) and Antes Shale to the limestone and gray-to-black shale sequence in the KMM drill hole (pl. 1).

We accept the terminology applied by Kay (1944a, b), Thompson (1963), Knowles (1966), Wagner (1966), and Berg and others (1983) to the limestone and gray and black shale sequence in the KMM drill hole and in the outcrop sections near the ARS drill hole. We also accept the widespread unconformity that Kay (1944a, b) recognized at the base of the Trenton Group. However, the Trenton Group of Kay (1944a, b) used in this study differs slightly from Kay's original definition. This difference results because we follow Rones (1969), who moved the base of the Trenton Group of Kay (1944a, b)—and the associated widespread unconformity—about 30 to 60 ft upsection from the base of the Oak Hall Member of the Nealmont Limestone of Kay (1944a, b) to the base of the overlying Centre Hall Member of the Nealmont Limestone of Kay (1944a, b). In addition, our log "picks" for the tops of the formations of the Trenton Group of Kay (1944a, b) in the KMM drill hole differ slightly from those of Wagner (1966). For example, the Nealmont Formation (Limestone) identified by Wagner (1966) in the KMM drill hole occupies the interval that we assign to the Black River Group in this study (pl. 1).

The Trenton Group of Kay (1944a, b) and its four constituent formations—the Nealmont, Salona, and Coburn Limestones and the Antes Shale—are also applied in this study to the limestone and gray and black shale sequence in the AS and KMS drill holes (pl. 1). Metabentonite beds No. 0 and R—which Thompson (1963) recognized at the base and top of the Salona Limestone, respectively, in outcrop near the ARS drill hole—are identified here in the KMS and KMM drill holes. Bentonite beds No. 0 and R at these localities correlate with the β and α markers of Stith (1979), respectively, in the AS drill hole (pl. 1).

The name Trenton Group of Perry (1972) is applied to the limestone sequence in the SD drill hole, where the Trenton is subdivided into the Nealmont Limestone and the overlying Dolly Ridge Formation (pl. 1). This nomenclature is based on units applied to the Trenton Group by Perry (1972) and Ryder (1992) in the outcrop and subsurface at the eastern end of section *E–E′* (fig. 1) and by Ryder (1991) in the subsurface of Hardy County, W. Va. The Nealmont Limestone in the SD drill hole correlates with the combined Nealmont, Salona, and Coburn Limestones in the AS, KMS, and KMM drill holes and the outcrop section near the ARS drill hole, whereas the Dolly Ridge Formation in the SD drill hole correlates with the Antes Shale in the AS, KMS, and KMM drill holes and the outcrop section near the ARS drill hole (pl. 1). The S_2 and S_3 metabentonites defined by Perry (1964) in the middle part of the Nealmont Limestone in the subsurface at the eastern end of section *E–E′* (fig. 1) are also recognized in the middle part of the Nealmont Limestone in the SD drill hole. We suggest that the S_2 metabentonite of Perry (1964) correlates with bentonite R of Thompson (1963) and the α marker of Stith (1979). The β marker of Stith (1979) in the AS drill hole and bentonite No. 0 of Thompson (1963) in the KMS and KMM drill holes and in the outcrop section near the ARS drill hole correlate with an unnamed metabentonite in the SD drill hole (pl. 1).

The Nealmont and Salona Limestones in the AS, KMS, and KMM drill holes and in the outcrop section near the ARS drill hole and the Nealmont Limestone (lower part) in the SD drill hole correlate approximately with the upper one-half of the Chambersburg Formation (Limestone) (Mercersburg and Oranda Formations of Craig, 1949) in Franklin County, Pa., and adjoining Washington County, Md., between the North Mountain and Carbaugh-Marsh Creek faults (Stose, 1906, 1909; Bassler, 1919; Cloos, 1951; Root, 1968; Edwards, 1978; Berg and others, 1983) (fig. 2). The Coburn Limestone and Antes Shale or the Nealmont Limestone (upper part) and Dolly Ridge Formation in the above-cited drill holes and outcrop section correlate approximately with the lower one-half of the Martinsburg Formation (Shale) in Franklin County, Pa., and adjoining Washington County, Md., between the North Mountain and Carbaugh-Marsh Creek faults (Stose, 1906, 1909; Bassler, 1919; Cloos, 1951; Root, 1968; Clark, 1970; Edwards, 1978; Berg and others, 1983) (fig. 2). The Salona Formation (Limestone) as mapped by Pierce (1966) and Okuma (1970) in western Franklin County, Pa., overlies the Chambersburg Formation and underlies the Martinsburg Formation (Reedsville Formation of Pierce, 1966 and Okuma, 1970). In this area, the upper one-half of the Chambersburg Formation as used by Pierce (1966) and Okuma (1970) correlates with the Nealmont Limestone in the Pennsylvania part of section *C–C′*. Also, approximately the lower one-half of the Martinsburg Formation in western Franklin County (Reedsville Formation of Pierce, 1966 and Okuma, 1970) correlates with the combined Coburn Limestone and Antes Shale in section *C–C′*.

In the panhandle of West Virginia and adjoining northern Virginia, between the North Mountain fault and the Blue Ridge, the Trenton Group in section *C–C′* correlates with the lower one-half to two-thirds of the Martinsburg Formation and the thin underlying Oranda Formation (Edmundson and Nunan, 1973; Young and Rader, 1974; Rader and Biggs, 1975, 1976; Rader, 1982; Patchen and others, 1984).

The name Trenton Group is applied in this study to the limestone and gray and black shale sequence between the AS and HM drill holes (pl. 1). In this segment of section *C–C′*, which consists of the western part of the Rome trough and the adjoining Ohio-West Virginia hinge zone, the Nealmont and Salona Limestones change facies westward and are replaced by the expanded upper part of the Black River Group. Consequently, the Coburn Limestone and the overlying Antes Shale are all that remain of the Trenton Group in the HM drill hole (pl. 1). The Trenton Group as defined in the Rome trough segment of section *C–C′* is also recognized in section *D–D′* (fig. 1). The Trenton Group in section *D–D′* is 630 and 320 ft thick in the Phillips No. A-1 Finch and Occidental No. 1 Burley drill holes, respectively, and consists of an unnamed limestone and the overlying Antes Shale (Ryder, 1991).

In the Ohio part of section *C–C′*, we assign the lower unit of the limestone and gray and black shale sequence to the Trenton Limestone as defined by Calvert (1963, 1964), DeBrosse and Vohwinkel (1974), Wickstrom and others (1985), and Wickstrom and Gray (1988) (pl. 1, fig. 2). In addition, we assign the upper unit of the limestone and gray and black shale sequence in Ohio to the Utica Shale, following Fettke (1960) and Calvert (1963, 1964). The Utica Shale as used here in the WS drill hole consists of the combined Utica Shale, Cynthiana Formation, and lower 100 ft of the Eden Shale (all of Calvert, 1963, 1964) in the Pan American No. 1 Windbigler (fig. 1) and WS drill holes. We prefer the name Utica Shale for the upper part of the limestone and gray and black shale sequence in the Ohio part of section *C–C′* rather than the name Point Pleasant Formation used by Wickstrom and Gray (1988) in northwestern and north-central Ohio, because the upper part of the sequence contains beds of black shale (pl. 1) (Wallace and Roen, 1989). This characteristic of the upper part of the sequence makes it more akin to the Utica Shale of northwestern Pennsylvania and adjoining New York (Fettke, 1960; Wagner, 1966) than to the Point Pleasant Formation of southern Ohio and adjoining Kentucky (Weiss and others, 1965).

The Trenton Group of Kay (1944a, b) is primarily Middle Ordovician (Rocklandian through Shermanian) on the basis of brachiopod, trilobite, conodont, and graptolite faunas reported by (1) Kay (1944b), Thompson (1963) (F_3 on pl. 1), Bergström (1971) and Sweet and Bergström (1976) from outcrops of the Trenton Group of Kay (1944a, b) in central and south-central Pennsylvania, (2) Prouty and others (1959) from cores of the Trenton Group in the Hope Natural Gas No. 9634 Power Oil Company drill hole, and (3) Sweet and Bergström (1976) from strata between the α (Mud Cave bentonite) and β (Pencil Cave bentonite) markers of Stith (1979) that crop out in southern Ohio and adjoining Kentucky. The conodonts (table 2) in the Nealmont, Salona, and Coburn Limestones in the AS drill hole (f_1 and f_2 on pl. 1) are consistent with a Rocklandian through Shermanian age for the Trenton Group.

Conodont biostratigraphy of the Salona and Coburn Limestones in central Pennsylvania by Valek (1982) indicates that the zonal index fossil *Amorphognathus tvaerensis* ranges to the top of the Coburn Limestone; thus, the Coburn is no younger than middle Shermanian (Sweet and Bergström, 1986). No conodonts have been found in the Antes Shale, but, given the middle Shermanian age of the uppermost Coburn Limestone and the gradational nature of the Coburn-Antes contact, the Antes Shale very likely occupies the upper part of the Shermanian (Sweet, 1984) (fig. 2). Following Sweet (1984; oral commun., 1990) we assign a late Shermanian age to most of the Antes Shale in section *C–C′*. In the Rome trough segment of section *C–C′*—where the Antes is thicker and occupies a higher stratigraphic position than it does in adjoining areas—we assign a late Shermanian to early Edenian age to the Antes Shale. Moreover, we assign a late Shermanian age to the Dolly Ridge Formation (equivalent to the Antes Shale in Pennsylvania) along the eastern West Virginia part of section *C–C′* and to the equivalent Utica Shale in the Ohio part of section *C–C′* (pl. 1).

The late Shermanian to earliest Edenian age assigned to the Antes Shale in this study refutes the early Edenian age assigned to the Antes Shale by Sweet and Bergström (1976) in central Pennsylvania and by Ryder (1991, 1992) in northern West Virginia. However, the Middle and Late Ordovician age assigned by Ryder (1991, 1992) to the Trenton Group of Kay (1944a, b) is still valid because of the probable Edenian age of the upper part of the Antes Shale in localities such as the AS drill hole.

The late Shermanian age assigned here to the Dolly Ridge Formation at the eastern end of section *C–C′* also refutes the Edenian age assigned to the Dolly Ridge Formation by Ryder (1991, 1992) in eastern West Virginia and adjoining Virginia. A late Shermanian age for the Dolly Ridge Formation accepted here is consistent with the Middle Ordovician age first proposed by Perry (1972) and supported by Diecchio (1985). Acceptance of a late Shermanian age for the Dolly Ridge Formation in this study requires a Middle Ordovician age—rather than a Middle and Late Ordovician age (Ryder, 1991, 1992)—for the Trenton Group of Perry (1972).

Unpublished correlations by the senior author (Ryder) along section *A–A′* (pl. 1) show that the Utica Shale rises stratigraphically to the north and northeast and thus is probably in part of early Edenian age in northeastern Ohio and northwestern Pennsylvania. These correlations suggest that, on a regional scale, the Utica Shale is Middle and Late Ordovician in age, although, in section *C–C′* of this study, the Utica Shale is probably confined to the Middle Ordovician. The Edenian age of the Utica Shale in southeastern Ohio (Ryder, 1991, 1992) is considered here to be invalid, and the age should be reassigned to the Shermanian.

Trenton Group strata of Rocklandian age in section *C–C′* are located in the Nealmont and Salona Limestones (below the α marker of Stith (1979), the bentonite R of Thompson (1963), and the S_2 metabentonite of Perry, (1964)) (pl. 1, fig. 2). These Trenton Group strata of Rocklandian age are replaced through facies change by Rocklandian-age strata of the Black River Group within about 20 mi east of the HM drill hole (pl. 1). In contrast, Trenton Group strata of Kirkfieldian and Shermanian age are distributed throughout section *C–C′* (fig. 2). A Kirkfieldian through Shermanian age is assigned to the following parts of the Trenton Group and Trenton Limestone: (1) all of the Trenton Group of Kay (1944a, b) except the Nealmont and Salona Limestones and the uppermost part of the Antes Shale in the Rome trough, (2) all of the Trenton Group of Perry (1972) except the lower part of the Nealmont Limestone, and (3) all of the Trenton Limestone (pl. 1). An Edenian age is assigned to the upper part of the

Antes Shale of the Trenton Group in the Rome trough (fig. 2). The Utica Shale in Ohio is assigned a Shermanian age (fig. 2).

Reedsville Shale and Bald Eagle Formation (Upper Ordovician)

The Trenton Group and the combined Trenton Limestone and Utica Shale in section *C–C′* are overlain by a silty and calcareous gray shale sequence (pl. 1). This sequence gradually thins westward from a thickness of about 1,850 ft in the KMS drill hole near the Allegheny structural front to about 790 ft in the WS drill hole at the western end of section *C–C′*. Eastward from the KMS drill hole, the silty and calcareous gray shale sequence thins to about 950 ft in the outcrop section near the ARS drill hole and 1,160 ft in the SD drill hole (pl. 1). In the AS, KMS, and KMM drill holes and the outcrop section near the ARS drill hole, the silty and calcareous gray shale sequence grades upward—through a 40- to 380-ft-thick sandy gray shale transition zone—into a 220- to 530-ft-thick sandstone containing thin beds of red, gray, and green shale (pl. 1). The sandstone and underlying transition zone pinch out into the upper part of the silty and calcareous gray shale sequence about 20 to 40 mi west of the AS drill hole (pl. 1). The silty and calcareous gray shale sequence in the SD drill hole is directly overlain by a 500-ft-thick sandstone unit without an intervening sandy shale transition zone (pl. 1).

Eastward from the Ohio-West Virginia hinge zone to the end of section *C–C′*, the silty and calcareous gray shale sequence combines with the overlying sandstone unit to record a net upward coarsening of grain size. In ascending order, this upward coarsening sequence consists of (1) a 180- to 550-ft-thick gray shale and local black shale beds, (2) a 720- to 900-ft-thick silty gray shale, (3) the previously described 40- to 380-ft-thick sandy gray shale transition zone, and (4) the previously described 220- to 530-ft-thick sandstone unit (pl. 1).

From the Ohio-West Virginia hinge zone to the western end of section *C–C′*, the silty and calcareous gray shale sequence becomes increasingly calcareous, and its upward-coarsening character is less distinct. For example, the lower gray shale unit identified east of the Ohio-West Virginia hinge zone also is identified west of the Ohio-West Virginia hinge zone, where it commonly contains thin micritic limestone beds in the BBW and WS drill holes. In addition, the silty gray shale unit identified east of the Ohio-West Virginia hinge zone is subdivided in the HM drill hole into (1) a lower calcareous, silty gray shale unit that continues at approximately the same thickness and lithologic character to the western end of section *C–C′* and (2) an upper silty gray shale unit that becomes more calcareous and, in general, less silty toward the western end of section *C–C′* (pl. 1). Near the BBW drill hole, the upper silty gray shale splits into two calcareous gray shale units: (1) a lower calcareous shale tongue that continues to the western end of section *C–C′* and (2) an upper calcareous shale tongue that overlies and then merges laterally with a silty, calcareous gray shale unit about 10 mi west of the BBW drill hole (pl. 1).

Following Butts and Moore (1936), Butts (1945), Perry (1972), de Witt (1974), Berg and others (1983), and Ryder (1991), the silty gray shale sequence in the Pennsylvania and West Virginia parts of section *C–C′* is assigned to the Reedsville Shale (pl. 1). The name Bald Eagle Formation as used by Knowles (1966), Pierce (1966), Thompson (1970), Horowitz (1971), de Witt (1974), and Berg and others (1983) is assigned to the predominantly greenish-gray sandstone overlying the Reedsville Shale in the Pennsylvania part of section *C–C′*, whereas the name Oswego Sandstone as used by Perry (1972), Patchen and others (1984), and Ryder (1991) is assigned to the predominantly greenish-gray sandstone overlying the Reedsville in the West Virginia part of section *C–C′* (pl. 1). Moreover, following Fettke (1960) and Calvert (1963, 1964), the name Reedsville Shale is applied to the silty and calcareous gray shale sequence in eastern Ohio. The Reedsville Formation of Calvert (1964) consists of both the Utica and the Reedsville Shales of this paper. Wickstrom and Gray (1988) applied the name Cincinnati Group (undifferentiated) to strata in northwestern and north-central Ohio that are referred to here as the Reedsville Shale.

The Reedsville Shale in section *C–C′* is also recognized in the Phillips No. A–1 Finch and Occidental No. 1 Burley drill holes, where it is 1,420 and 1,170 ft thick, respectively (Ryder, 1991). The Bald Eagle Formation in the Pennsylvania part of section *C–C′* correlates with a 100-ft-thick, predominantly greenish-gray sandstone unit in the Phillips No. A–1 Finch drill hole that Ryder (1991) identified as the Oswego Sandstone.

The Reedsville Shale in section *C–C′* correlates approximately with the upper one-half of the Martinsburg Formation (Shale) in Franklin County, Pa., and adjoining Washington County, Md., between the North Mountain and Carbaugh-Marsh Creek faults (Stose, 1906, 1909; Bassler, 1919; Cloos, 1951; Root, 1968; Clark, 1970; Edwards, 1978; Berg and others, 1983) (fig. 2). The Reedsville Shale in section *C–C′* also correlates approximately with the upper one-half of the Martinsburg Formation in the West Virginia panhandle and northern Virginia between the North Mountain fault and the Blue Ridge (Edmundson and Nunan, 1973; Young and Rader, 1974; Rader and Biggs, 1975, 1976; Rader, 1982; Patchen and others, 1984; Dean and others, 1987). Paleozoic strata younger than the Martinsburg Formation are missing in Franklin County, Pa., and adjoining Washington County, Md., between the North Mountain and Carbaugh-Marsh Creek faults (Root, 1968; Edwards, 1978) and in the West Virginia panhandle between the North Mountain fault and the Blue Ridge

(Cardwell and others, 1968). In northern Virginia, between the North Mountain fault and the Blue Ridge, outcrops of post-Martinsburg strata indicate that the Oswego Sandstone was removed by pre-Early Silurian erosion (Rader, 1982).

The Reedsville Shale and the Bald Eagle Formation (the Oswego Sandstone in West Virginia) are assigned a Late Ordovician age. The Reedsville Shale is approximately early Edenian through Maysvillian in age, and the Bald Eagle Formation (Oswego Sandstone) is approximately latest Maysvillian through earliest Richmondian in age (fig. 2). These ages are based on brachiopod, mollusk, and conodont faunas reported by (1) Knowles (1966) and Wallace de Witt, Jr. (unpub. data, 1969) (F_1 and F_2 on pl. 1), from outcrops of the Reedsville Shale in Bedford County, Pa., (2) Butts (1945) from outcrops of the Reedsville Shale in Blair County, Pa., (3) Butts and Moore (1936) from outcrops of the Reedsville Shale in Centre County, Pa., and (4) Sweet and Bergström (1976) and Sweet (1979) from Reedsville-equivalent outcrops in southern Ohio and adjoining Kentucky.

Juniata Formation and Queenston Shale (Upper Ordovician)

The Reedsville Shale-Bald Eagle Formation (Oswego Sandstone) interval in section *C–C′* is overlain by a silty and sandy red shale and red sandstone sequence (pl. 1). This sequence gradually thins westward from a thickness of 1,500 ft in the outcrop section adjoining the KMM drill hole (Wallace de Witt, Jr., unpub. data, 1969) to 360 ft near the crest of the Wooster arch at the western end of section *C–C′*. East of the KMM drill hole, the red shale and red sandstone sequence thins to a thickness of about 1,020 ft in the SD drill hole and a thickness of 1,000 ft in the outcrop section near the ARS drill hole. Red sandstone and local shale beds dominate the sequence in the SD drill hole (pl. 1). Northward in the outcrop section adjoining the ARS drill hole, the sequence consists of lower and upper red sandstone units and a middle sandy red shale unit (Knowles, 1966). The upper red sandstone unit pinches out about 13 mi west of the outcrop section near the ARS drill hole, but the lower red sandstone continues westward to the outcrop section adjoining the KMM drill hole and to the KMS drill hole before pinching out between the KMS and AS drill holes (pl. 1).

The name Juniata Formation has been applied to the exposed red shale and red sandstone sequence throughout central and south-central Pennsylvania (Butts and Moore, 1936; Butts, 1945; Knowles, 1966; Pierce, 1966; Okuma, 1970; Thompson, 1970; Horowitz, 1971; de Witt, 1974; Berg and others, 1983) and in adjoining Maryland and West Virginia (Cardwell and others, 1968; Cleaves and others, 1968; Patchen and others, 1984; Dean and others, 1985). Thompson (1970) and Horowitz (1971) showed that the boundary between the Juniata Formation and the underlying Bald Eagle Formation in central Pennsylvania is commonly controlled by diagenetic alteration rather than lithofacies. In the subsurface of eastern Ohio and adjoining western Pennsylvania, where the sequence is dominated by silty and sandy red shale, the name Queenston Shale has been applied by Fettke (1960), Calvert (1964), Wagner (1969), DeBrosse and Vohwinkel (1974), Piotrowski (1981), and Berg and others (1983). Following these studies, we assign the name Juniata Formation to the red sandstone and red shale sequence in the Pennsylvania and West Virginia parts of section *C–C′* and the name Queenston Shale to the equivalent red shale sequence in the Ohio part of section *C–C′* (pl. 1). The Juniata Formation in section *C–C′* is also recognized in the Phillips No. A–1 Finch and Occidental No. 1 Burley drill holes in section *D–D′* (fig. 1), where the formation is about 1,020 ft thick (Ryder, 1991).

No Paleozoic strata younger than the Martinsburg Formation are preserved in Franklin County, Pa., and adjoining Washington County, Md., between the North Mountain and Carbaugh-Marsh Creek faults (Root, 1968; Edwards, 1978) and in the West Virginia panhandle between the North Mountain fault and the Blue Ridge (Cardwell and others, 1968). In northern Virginia, between the North Mountain fault and the Blue Ridge, outcrops of post-Martinsburg strata indicate that the Juniata Formation was removed by pre-Lower Silurian erosion (Rader, 1982).

The Juniata Formation and the Queenston Shale are assigned a Late Ordovician (Richmondian and Gamachian?) age (fig. 2). This age is based on (1) the stratigraphic position of Juniata and Queenston strata between the underlying Reedsville Shale of probable early Edenian through Maysvillian age and overlying Lower Silurian strata and (2) conodonts from strata equivalent to the Juniata Formation and Queenston Shale that crop out in southern Ohio and adjoining Kentucky (Sweet and Bergström, 1976; Sweet, 1979).

Tuscarora Sandstone and "Clinton" Sandstone and Shale (Lower Silurian)

From about the HM drill hole to the eastern end of section *C–C′*, the Juniata Formation is overlain by a 170- to 420-ft-thick quartzose sandstone known as the Lower Silurian Tuscarora Sandstone or Tuscarora Quartzite (Darton and Taff, 1896; Butts and Moore, 1936; Butts, 1945; Cardwell and others, 1968; de Witt, 1974; Patchen and others, 1984; Dean and others, 1985) (pl. 1). In this study, we use the name Tuscarora Sandstone, whereas the Pennsylvania Geological Survey prefers the name Tuscarora Formation (Knowles, 1966; Pierce, 1966; Okuma, 1970; Berg and others, 1983). A 70- to 140-ft-thick transition zone consisting of quartzose sandstone and thin red shale beds is included with the Tuscarora Sandstone in section $C–C'$ (pl. 1). In northwestern Pennsylvania and adjoining western New York, the Tuscarora Sandstone interval is occupied by a sandstone and gray shale sequence known as the Medina Group (Fisher, 1954; Wagner, 1969; Piotrowski, 1981; Berg and others, 1983). In eastern Ohio, the Tuscarora Sandstone interval is occupied by a sandstone and gray shale sequence known informally as the "Clinton" sands of the drilling industry (Pepper and others, 1953) and the "Clinton" sandstone and shale (Janssens, 1977). The name "Clinton" sandstone and shale of Janssens (1977) is used in this paper. Pepper and others (1953) recognized that the "Clinton" sands are equivalent to the Albion Sandstone in western New York (now part of the Medina Group of Fisher (1954) and Piotrowski (1981) in northwestern Pennsylvania and western New York) rather than the stratigraphically younger Middle Silurian Clinton Formation in western New York (now the Middle Silurian Clinton Group of Fisher (1954) and Piotrowski (1981) in western New York and northwestern Pennsylvania). The "Clinton" sandstone and shale in the MM, BBW, and WS drill holes and the Tuscarora Sandstone in the HM drill hole are overlain by a continuous 15- to 60-ft-thick predominantly dolomite unit known in northwestern Pennsylvania as the Reynales Dolomite of the Clinton Group (Piotrowski, 1981; Berg and others, 1983) and in eastern Ohio as the Packer shell of driller's terminology (Pepper and others, 1953; DeBrosse and Vohwinkel, 1974). The Packer shell of driller's terminology and the Reynales Dolomite of Piotrowski (1981) and Berg and others (1983), on the basis of conodonts (Kleffner, 1985), are of late Early Silurian age.

SUMMARY AND CONCLUSIONS

A 275-mi-long restored section from Medina County, Ohio, through southwestern and south-central Pennsylvania to Hampshire County, W. Va., shows a Cambrian and Ordovician sequence that is thickest in an east-facing asymmetric graben and overlying sag basin that constitute the Rome trough, thinnest on the relatively stable craton that adjoins the western margin of the Rome trough, and moderately thick on the South-central Pennsylvania arch that adjoins the eastern margin of the Rome trough. The fault-controlled hinge between the relatively stable craton and the western margin of the Rome trough, identified here as the Ohio-West Virginia hinge zone, separates slightly extended Proterozoic basement rocks to the west from moderately to highly extended Proterozoic rocks to the east. The down-to-the-west normal fault that marks the eastern margin of the graben phase of the Rome trough had approximately 6,000 to 7,000 ft of pre-Middle Ordovician structural relief on Proterozoic basement between the trough and the adjoining South-central Pennsylvania arch. The Cambrian and Ordovician sedimentary cover in the study area thickens across the Ohio-West Virginia hinge zone from about 3,000 ft near the crest of the Wooster arch in northeastern Ohio to an estimated 19,800 ft near the depositional axis of the Rome trough in southwestern Pennsylvania. East of the Rome trough, the sedimentary cover thins across the South-central Pennsylvania arch from about 12,700 ft near the Allegheny structural front in south-central Pennsylvania to about 10,150 ft in northeastern West Virginia about 20 mi west of the North Mountain thrust fault.

In general, the Cambrian and Ordovician sequence described here consists of four major lithofacies that are predominantly shallow marine to peritidal in origin. In ascending order, the lithofacies are identified by the following descriptive names: (1) sandstone, shale, limestone, and dolomite unit, (2) dolomite and sandstone unit, (3) limestone and black shale unit, and (4) shale and sandstone unit. Each of these units and associated subunits thicken from west to east across restored section $C–C'$ to a maximum near the depositional axis of the Rome trough. The lower unit (sandstone, shale, limestone, and dolomite unit) abruptly reverses its eastward-thickening trend at the western edge of the positive fault block (South-central Pennsylvania arch) and from there thins gradually eastward and southeastward to the end of the restored section. The upper three units also begin to thin eastward from near the depositional axis of the Rome trough, but they have an overall convex-downward, lens-shaped geometry because of gradual eastward thinning in comparison with abrupt eastward thinning of the lower unit.

The sandstone, shale, limestone, and dolomite unit is largely confined to the asymmetric graben that marks the rifting phase of the Rome trough. Abrupt thickness changes in the unit across the border faults of the graben indicate that sedimentation was fault controlled. On the South-central Pennsylvania arch adjoining the eastern margin of the Rome trough, this unit consists, in ascending order, of an undrilled basal sandstone unit, the undrilled Tomstown Dolomite, the Waynesboro Formation, and the Pleasant Hill Limestone and the equivalent lower one-third of the Elbrook Formation in northeastern West Virginia. The undrilled basal sandstone unit, the undrilled Tomstown Dolomite, and the undrilled lower part of the Waynesboro Formation are probably of Early Cambrian age, whereas the upper part of the Waynesboro Formation, the Pleasant Hill Formation, and the strata equivalent to the Pleasant Hill Limestone in the Elbrook Formation are probably of Middle Cambrian age. The Tomstown Dolomite is probably overlain unconformably by the Waynesboro Formation, which in turn is probably overlain unconformably by the Pleasant Hill Limestone. The uppermost part of the sandstone, shale, limestone, and dolomite unit extends west of the Ohio-West Virginia hinge zone as a basal Cambrian sandstone known as the Mount Simon Sandstone. Although commonly assigned a Late Cambrian age in central and east-central

Ohio, the Mount Simon Sandstone, because of its transgressive nature, may very likely be of latest Middle Cambrian age in the vicinity of the Ohio-West Virginia hinge zone.

The sandstone, shale, limestone, and dolomite unit in the graben part of the Rome trough has not been drilled; however, proprietary seismic data suggest that it is present and has a thickness of about 7,500 ft. A basal sandstone and the Tomstown Dolomite probably occur at the base of the unit in the Rome trough and have a thickness that is probably similar to that suggested on the adjoining South-central Pennsylvania arch. The red shale- and sandstone-dominated Waynesboro Formation should also be present in the undrilled part of the Rome trough, but it probably has a much greater thickness than the partly drilled Waynesboro Formation on the adjoining South-central Pennsylvania arch. The Pleasant Hill Limestone probably also has thickened significantly in the undrilled part of the Rome trough. The thickened Pleasant Hill Limestone interval here may contain abundant gray shale beds in addition to limestone beds and therefore may be akin to the Conasauga Group identified in the Rome trough in central West Virginia (Ryder, 1992).

The lens-shaped dolomite and sandstone unit forms the core of the Cambrian and Ordovician sequence. Near the crest of the Wooster arch, this unit occupies about one-quarter of the total sequence. In contrast, between the depositional axis of the Rome trough and the eastern end of the restored section, the dolomite and sandstone unit occupies between one-third and one-half of the total Cambrian and Ordovician sequence. The Knox unconformity of regional extent is located in the upper part of the dolomite and sandstone sequence except near the depocenter of the Rome trough, where the unconformity is probably absent.

Three subunits constitute the dolomite and sandstone unit. The lower subunit consists of (1) the Middle(?) and Upper Cambrian Rome Formation of Janssens (1973) between the Ohio-West Virginia hinge zone and the Wooster arch, (2) the Middle and Upper Cambrian Warrior Formation in the Rome trough and on the adjoining South-central Pennsylvania arch, and (3) the strata equivalent to the Warrior Formation in the upper two-thirds of the Elbrook Formation at the eastern end of the restored section. The middle subunit of the dolomite and sandstone unit in the Rome trough and on the adjoining South-central Pennsylvania arch consists of the Upper Cambrian Gatesburg Formation and its four members: the lower sandy member, the middle dolomite member and the equivalent Ore Hill Limestone Member, the upper sandy member, and the Mines Dolomite Member. West of the Ohio-West Virginia hinge zone, the stratigraphic position of the Gatesburg Formation is occupied by (1) the Rome (upper part) and Conasauga Formations of Janssens (1973), the Krysik sandstone of driller's usage, and the B zone of Calvert (1964) (lower sandy member equivalents), (2) the lower part of the Knox Dolomite of Janssens (1973) (middle dolomite member-Ore Hill Limestone Member equivalent), and (3) the Rose Run Sandstone Member of the Knox Dolomite of Janssens (1973) (upper sandy member equivalent). The upper subunit of the dolomite and sandstone unit consists of (1) the Lower Ordovician and Middle Ordovician (Whiterockian) Beekmantown Group in the Rome trough and the adjoining South-central Pennsylvania arch and (2) the Lower Ordovician upper part of the Knox Dolomite of Janssens (1973) and the overlying Middle Ordovician (Chazyan) Wells Creek Formation between the Ohio-West Virginia hinge zone and the Wooster arch.

Between the Ohio-West Virginia hinge zone and the Wooster arch, the Knox unconformity is located at the base of the Wells Creek Formation (Chazyan) and truncates successively older parts of the Upper Cambrian and Lower Ordovician Knox Dolomite of Janssens (1973) and the associated Upper Cambrian Rose Run Sandstone. The Knox unconformity extends into the adjoining Rome trough, but the unconformity there is located approximately in the upper 600 ft of the Beekmantown Group, and its magnitude has diminished significantly. For example, on the western margin of the Rome trough, the Chazyan part of the Beekmantown Group rests unconformably on the Lower Ordovician (Ibexian) part of the Beekmantown Group. Yet farther eastward, the Chazyan part of the Beekmantown Group rests unconformably on older Whiterockian-age Beekmantown strata. Near the depositional axis of the Rome trough, the Knox unconformity seems to disappear, and Beekmantown Group deposition was more or less continuous across the Lower Ordovician-Middle Ordovician boundary. Conodonts recovered from the AS drill hole suggest that the Lower Ordovician-Middle Ordovician boundary near the depositional axis of the Rome trough is located approximately 2,000 ft below the top of the Beekmantown Group. The Knox unconformity probably reappears on the adjoining western flank of the South-central Pennsylvania arch, where Chazyan-age Beekmantown strata rest unconformably on older Whiterockian-age Beekmantown strata. From there, the Knox unconformity progressively increases in magnitude toward the eastern end of the restored section, where the Middle Ordovician (Chazyan) part of the Beekmantown Group probably overlies the Lower Ordovician part of the Beekmantown Group.

The lens-shaped limestone and black shale unit—which thickens eastward from about 980 ft at the crest of the Wooster arch to about 2,020 ft at the depositional axis of the Rome trough and then thins eastward to about 700 ft at the eastern end of the section—is the thinnest of the four major lithofacies. In the Rome trough and the adjoining Ohio-West Virginia hinge zone and South-central Pennsylvania arch, the limestone and black shale unit consists, in ascending order, of the Loysburg Formation, the Black River Group, and the Trenton Group. West of the Ohio-West Virginia hinge zone, the Loysburg Formation and the Black River Group combine to form the Black River

Limestone, and the Trenton Group is replaced by the Trenton Limestone and the overlying Utica Shale.

The Middle Ordovician Loysburg Formation in the Rome trough and on the adjoining South-central Pennsylvania arch consists of the Milroy Member (late Chazyan and earliest Blackriveran ages) and the overlying Clover Limestone Member (early Blackriveran age). The Loysburg Formation at the Ohio-West Virginia hinge zone is undivided and is significantly thinner than it is in the Rome trough. West of the Ohio-West Virginia hinge zone, the Loysburg Formation interval contains greenish-gray shale along with the limestone and is identified as the lower part of the Black River Limestone. At the eastern end of the restored section, the Loysburg Formation is absent because of erosion and nondeposition caused by an intra-Loysburg unconformity.

The Middle Ordovician Black River Group is undivided from the Ohio-West Virginia hinge zone to the eastern end of the restored section, except in outcrop east of the Allegheny structural front, where it consists, in ascending order, of the Hatter, Snyder, and Linden Hall Limestones. There and at the eastern end of the restored section, the 100- to 150-ft-thick Black River Group is thinner than it is elsewhere on the section, partly because of eastward depositional thinning and partly because of the truncation of progressively older Black River strata beneath a widespread pre-Trenton Group unconformity. The Black River Group beneath the unconformity is probably entirely of Blackriveran age and attains a maximum thickness of about 520 ft near the depositional axis of the Rome trough. Between the depositional axis of the Rome trough and the Ohio-West Virginia hinge zone, the Black River Group strata climb about 120 ft upsection, at the expense of the overlying Trenton Group, to include the α and β (metabentonite) markers of Stith (1979) and strata of Rocklandian age. The Black River Limestone west of the Ohio-West Virginia hinge zone, which correlates with the Loysburg Formation and the Black River Group combined, has a late Chazyan through Rocklandian age.

The Middle and Upper Ordovician Trenton Group of Kay (1944a, b) near the depositional axis of the Rome trough consists, in ascending order, of the Nealmont Limestone (Rocklandian age), the Salona Limestone (Rocklandian age), the Coburn Limestone (Kirkfieldian and Shermanian ages), and the Antes Shale (late Shermanian and earliest Edenian ages). The α and β markers of Stith (1979) are located at the top and base of the Salona Limestone, respectively. At the eastern end of the restored section, the combined Nealmont-Salona-Coburn limestone interval is represented by the Nealmont Limestone, whereas the Antes Shale interval is represented by the Dolly Ridge Formation. Here, the combined Nealmont Limestone and the Dolly Ridge Formation constitute the Trenton Group of Perry (1972). The S_2 metabentonite of Perry (1964), identified at the eastern end of the restored section in the middle part of the Nealmont Limestone, correlates with the α marker of Stith (1979) and the R bentonite of Thompson (1963). The Nealmont and Salona Limestones (Rocklandian age) near the depositional axis of the Rome trough grade westward into the upper part of the Black River Group near the Ohio-West Virginia hinge zone and the equivalent upper part of the Black River Limestone in eastern Ohio. The Coburn Limestone (Kirkfieldian and Shermanian ages) and the overlying Antes Shale (Shermanian and early Edenian ages) extend as far west as the Ohio-West Virginia hinge zone, beyond which their respective stratigraphic intervals are identified as the Trenton Limestone and the Utica Shale.

The shale and sandstone unit is lens shaped and thickens eastward from about 1,160 ft (m) near the crest of the Wooster arch to about 3,650 ft near the Allegheny structural front and then thins to about 2,700 ft at the eastern end of the section. The shale and sandstone unit at the eastern end of the restored section consists, in ascending order, of the Reedsville Shale, the Oswego Sandstone, and the Juniata Formation. The gray shale of the Reedsville Shale (Upper Ordovician; lower Edenian through Maysvillian Stages) extends across the entire section, whereas the argillaceous sandstone of the Oswego Sandstone and the equivalent Bald Eagle Formation in the Pennsylvania part of the section (Upper Ordovician; upper Maysvillian and lower Richmondian Stages) pinches out westward near the center of the Rome trough. The Juniata Formation (Upper Ordovician; Richmondian and Gamachian? Stages) and its correlative in Ohio, the Queenston Shale, extend across the entire section and consist of silty red shale and red sandstone beds.

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